System of Environmental-Economic Accounting

Ecosystem Accounting

United Nations
European Commission
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Preface

There is growing recognition that our economies are embedded within and dependent on nature and that nature itself, as our natural capital, should be recognized as an asset to the economy. Further, as the economic and social impacts of the climate and biodiversity crises become more evident, policymakers are increasingly seeking robust measurement that goes beyond gross domestic product (GDP) and integrates environmental and economic data. The System of Environmental-Economic Accounting (SEEA) is an international statistical standard that supports integrated decision-making by measuring the interdependence of the economy and the environment.

The System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) was adopted by the United Nations Statistical Commission in March 2021 as an international statistical standard for the ecosystem accounting framework and physical ecosystem accounts, and presents internationally recognized statistical principles and recommendations for the valuation of ecosystem services and assets. The adoption of SEEA EA is a historic step forward towards transforming how nature is viewed and valued. Importantly, environmental degradation will be reflected in balance sheets and can be recognized as a cost in the measurement of economic growth.

The new framework will inform national policies related to the environment-economy nexus, as well as provide crucial information to inform international initiatives and global reporting frameworks, including the Sustainable Development Goals, the Kunming-Montreal Global Biodiversity Framework, the United Nations Decade on Ecosystem Restoration, Beyond GDP, the measurement of land degradation under the United Nations Convention to Combat Desertification, and the measurement of GHG emissions and removals by land use, land use change and forestry (LULUCF) under the United Nations Framework Convention on Climate Change and associated Nationally Determined Contributions (NDC), just to name a few. It is worth noting that the monitoring framework for the Kunming-Montreal Global Biodiversity Framework draws directly on SEEA EA for several indicators, including the headline indicators under goals A and B.

The road to SEEA EA

SEEA EA is the culmination of a decade of work and builds upon the development of environmental accounting methodologies which have been undertaken in earnest since the 1990s. The first SEEA handbook was published as an interim report in 1993, in the wake of the 1992 United Nations Conference on Environment and Development, held in Rio de Janeiro, Brazil. A revised handbook with greatly expanded scope, based on a wide range of country experiences, was published in 2003. In 2012, the conceptual content of that handbook was standardized, and the Statistical Commission adopted the SEEA Central Framework, elevating it to an international statistical standard.

The SEEA Central Framework constitutes an agreed statistical framework for measuring stocks and flows of environmental assets, such as energy and water, as well as environmentally related transactions and activities, and monetary stocks of environmental assets. However, the scope of the SEEA Central Framework does not include ecosystem services nor does it take into account a range of valuation issues, such as the cost of degradation. In recent years, an important enabling factor towards the development of ecosystem accounting has been the technological advancement in the generation of Earth observation data, as well as in modelling of ecosystem services, made possible by increasing computational power and the move towards open data.

The initial response from the statistical community to the growing policy demands for an integrated approach to measuring ecosystems was the *System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting* (SEEA EEA), which was welcomed by the Statistical Commission in 2013 as an important first step in developing a statistical framework for ecosystem accounting. SEEA EEA was conceived as a complementary framework to the SEEA Central Framework, which viewed the environment through the lens of ecosystems. Thus, the various biophysical components of the environment (including individual environmental assets recorded in the SEEA Central Framework) are seen as operating together as a functional unit. Following the endorsement of SEEA EEA, many countries began testing and experimentation at the national and subnational levels. This work led to the release of *Technical Recommendations* in support of the SEEA EEA, recognizing the advancement in thinking and statistical practice with regard to the measurement of ecosystems and their integration into an accounting framework, as well as the increased demand for practical recommendations on how to implement the ecosystem accounting framework described in SEEA EEA. *Technical Recommendations* was designed to serve as an intermediate step in the transition from SEEA EEA to a statistical standard.

Between 2018 and 2021, SEEA EEA underwent a revision process. The revision process was undertaken under the auspices of the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA), as mandated by the Statistical Commission at its forty-eighth session in 2017. The revision was based on an open and inclusive approach, targeting not just the global statistical community but also the geospatial, scientific and environmental economics communities, from a wide range of countries, international organizations, academia and non-governmental organizations. The revision was closely informed by country experimentation and testing of SEEA EEA through a range of national and international projects in many different countries.

Together with the adoption of SEEA EA, the Statistical Commission recognized the need to resolve the outstanding methodological concerns related to chapters 8 to 11 on valuation, as well as the issues identified in the research agenda of SEEA EA. The SEEA EA research agenda identifies topics concerning conceptual issues and topics concerning methods and implementation issues. To ensure the ongoing relevance of SEEA EA and its application of best practice, the advancement of those topics will be undertaken under the auspices of the UNCEEA and with the involvement of experts in relevant substantive fields.

Linking SEEA EA to the System of National Accounts

SEEA EA adopts an accounting approach to organizing information on ecosystems to support coherence with economic information that is organized in accordance with the System of National Accounts (SNA). This approach supports the consistent evaluation of the impacts and dependencies of economic activities on ecosystems, the contribution of ecosystems to the economy and well-being, and the actions taken by the economy to restore and reduce impacts on ecosystems. Using an accounting approach necessitates the harmonization of environmental data from multiple sources, thereby creating integrated data that support the derivation of coherent and consistent indicators which are relevant to assessing the environment-economy nexus.

Thus, SEEA EA provides a mechanism for mainstreaming data on ecosystems and ecosystem services into economic and national development planning. The consistency that SEEA EA brings to organizing information on ecosystems and ecosystem services is essential to delivering a planning approach that reflects economic, environmental and social dimensions of sustainable development in an integrated way. As such, it is a powerful tool for central and line ministries, especially those concerned with sustainable national development and delivering better outcomes for the environment and society.

Implementation of SEEA EA

At the time of the adoption of SEEA EA in March 2021, more than 34 countries were compiling ecosystem accounts on an experimental basis. With the adoption of SEEA EA as an international statistical standard, many more countries have begun implementation and more are expected to commence, while it is of course recognized that a significant number of countries will require assistance and additional resources for statistical data collection. In March 2021, the Statistical Commission encouraged the implementation of SEEA EA in countries and requested UNCEEA to develop an implementation strategy that takes into account country priorities and data availability. Moreover, as part of the 2021 United Nations Common Agenda, the United Nations Secretary-General urged all Member States to begin implementing SEEA EA.

Acknowledgements

Background

The System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) is the outcome of a process notable for its transparency and the wide involvement of the international statistical community; economists; geographers; ecologists and other scientists; and policymakers. The process comprised five steps:

(a) Identifying and securing agreement on the issues to be considered in the drafting of SEEA EA;

(b) Research on those issues and presentation of proposals for addressing them;

(c) Consideration of the issues and proposals by experts and agreement on a provisional draft text;

(d) Consultation with countries and experts on specific issues as well as on the content of the completed chapters, incorporation of comments elicited through the consultation process, and preparation of a final draft of the text of SEEA EA;

(e) Presentation of the draft to the United Nations Statistical Commission at its fifty-second session, held in March 2021.

The revision process for the *System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting* (SEEA EEA) was launched officially in March 2018, at the forty-ninth session of the Statistical Commission. The process was centred around four research issues identified as priority areas for the revision: spatial areas, ecosystem condition, ecosystem services, and valuation and accounting treatments. Five working groups were established to address those issues and each group drafted a set of discussion papers that were reviewed and assessed by a large group of experts.

The revision of SEEA EEA was co-financed by the generous contributions of Australia, through the Australian Bureau of Statistics and the Department of the Environment and Energy; the United Kingdom of Great Britain and Northern Ireland, through the Office for National Statistics; the Department for Environment, Food and Rural Affairs; and the European Union, through Eurostat.

The revision process was led and managed by the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA) and its Technical Committee on SEEA EA. It involved experts from international, regional and non-governmental organizations; project staff; agencies of many countries responsible for compiling official statistics; city groups; other expert groups; and individual experts in the areas of economics, ecosystem science and related fields from various regions of the world. As was to be expected, the comprehensive and complex process in which those participants were engaged has yielded a product that incorporates a multiplicity of diverse contributions.

UNCEEA and its Bureau

At its thirty-sixth session, in March 2005, the Statistical Commission endorsed the establishment of the Committee with a mandate that includes overseeing and managing the revision of SEEA.[1] The Committee is composed of senior representatives of national statistical offices and international agencies. The Bureau of the Committee, whose representatives are elected from among the Committee's members, acts under the authority delegated by the Committee. The Bureau coordinates and manages the activities of the Committee conducted between its regular sessions.

During the revision of SEEA EEA, the Committee and its Bureau were chaired by Bert Kroese (Kingdom of the Netherlands), with secretariat services provided by the Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat.

1 See *Official Records of the Economic and Social Council, 2005, Supplement No. 4* (E/2005/24), chap. V, sect. A, para. 7.

Members of the Committee of Experts, and other contributors, representing national institutions

Amanda Clark and Jonathon Khoo (Australia); Norbu Ugyen (Bhutan); Rebecca Palis (Brazil); Carolyn Cahill and Greg Peterson (Canada); Shi Faqi and Zheng Xuegong (China); Paola Andrea Acevedo and Diego Andrés Cobaleda Martínez (Colombia); Kirsten Balling and Ole Pedersen (Denmark); Kaia Oras (Estonia); Jukka Muukkonen and Johanna Pakarinen (Finland); Françoise Nirascou (France); Sven Kaumanns (Germany); P. Bhanumati, Shailja Sharma and Pravin Srivastava (India); Etjih Tasriah (Indonesia); Aldo Femia and Angelica Tudini (Italy); Carol Coy (Jamaica); Asset Nakipbekov (Kazakhstan), Christine Magu, Hirum Mbatia and Mathew Collins Omondi (Kenya); Nazaria Baharudin and Siti Zakiah Muhamad Isa (Malaysia); Eduardo de la Torre, Enrique Ordaz and Graciela Marquez (Mexico); Ankhzaya Byamba and Erdenesan Eldevochir (Mongolia); Gerard Eding, Bert Kroese and Sjoerd Schenau (Kingdom of the Netherlands); Rachael Milichich and Stephen Oakley (New Zealand); Trine Braathu, Per Arild Garnåsjordet, Kristine Grimsrud and Peder Naes (Norway); Vivian Ilarina (Philippines); Andrey Tatarinov (Russian Federation); Aliielua Salani (Samoa); Gerhardt Bouwer and Joe de Beer (South Africa); Nils Brown and Viveka Palm (Sweden); Samuel Echoku and Aliziki Kaudha Lubega (Uganda); Rocky Harris, Liz McKeown, Nicola Shearman and Neil Wilson (United Kingdom); and Dennis Fixler (United States).

Representatives of international organizations

Jillian Campbell and Markus Lehmann (secretariat of the Convention on Biological Diversity); Rikke Munk Hansen and Gemma Van Halderen (Economic and Social Commission for Asia and the Pacific); Wafa Aboul Hosn (Economic and Social Commission for Western Asia); Oliver Chinganya and Xiaoning Gong (Economic Commission for Africa); Michael Nagy (Economic Commission for Europe); Rayen Quiroga (Economic Commission for Latin America and the Caribbean); Caitriona Maguire, Jock Martin and Jan-Erik Petersen (European Environment Agency); Anton Steurer (Eurostat); Francesco Tubiello (Food and Agriculture Organization of the United Nations); Gabriel Quiros and Jim Tebrake (International Monetary Fund); Daniel Clarke, Myriam Linster and Peter van de Ven (Organisation for Economic Co-operation and Development); Midori Paxton, Massimiliano Riva and Tim Scott (United Nations Development Programme); Ludgarde Coppens, Pushpam Kumar, Salman Hussain and William Speller (United Nations Environment Programme); Sofia Ahlroth, Juan Pablo Castañeda, Raffaello Cervigni and Catherine Van Rompaey (World Bank); and Hernan Epstein, Leandry Moreno and Clara van der Pol (World Tourism Organization).

Members of the Bureau of the Committee of Experts

Amanda Clark (Australia); Carolyn Cahill and Greg Peterson (Canada); Sven Kaumanns (Germany); P. Bhanumati (India); Eduardo de la Torre, Enrique Ordaz and Graciela Marquez (Mexico); Sjoerd Schenau (Kingdom of the Netherlands); Rachael Milichich (New Zealand); Vivian Ilarina (Philippines), Gerhardt Bouwer (South Africa); Liz McKeown and Neil Wilson (United Kingdom); Anton Steurer (Eurostat); Francesco Tubiello (Food and Agriculture Organization of the United Nations); Jim Tebrake (International Monetary Fund); Myriam Linster and Peter van de Ven (Organisation for Economic Co-operation and Development); and Sofia Ahlroth and Raffaello Cervigni (World Bank).

Staff of the Statistics Division (Environmental-Economic Accounts Section, Environmental Statistics and Geospatial Information Branch) providing secretariat services to the Committee and its Bureau

Elsa Begne, Jessica Ying Chan, Julian Chow, Bram Edens and Marko Javorsek, among others, under the overall supervision of Alessandra Alfieri.

Editorial board

The Technical Committee on SEEA EA, whose membership was extended by the Committee of Experts at its fourteenth meeting, in June 2019, served as the editorial board for the revision of SEEA EEA and provided both technical guidance on the drafting of the text of SEEA EA and expert advice on the resolution of technical issues. The Technical Committee held 30 meetings between June 2018 and the publication of the white-cover text of SEEA EA in July 2021.

The Technical Committee, chaired by Anton Steurer (Eurostat), was composed of the following members: Jonathon Khoo, Peter Meadows and Steven May (Australian Bureau of Statistics); François Soulard (Statistics Canada); P. Bhanumati (Ministry of Statistics and Programme Implementation, India); Sjoerd Schenau (Statistics Netherlands); Gerhardt Bouwer (Statistics South Africa); Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom); Rosimeiry Portela (Conservation International); Michael Bordt and Anthony Dvarskas (Economic and Social Commission for Asia and the Pacific; and Fisheries and Oceans Canada); Joachim Maes (European Commission, Joint Research Centre); Jan-Erik Petersen (European Environment Agency); Juha Siikamaki (International Union for Conservation of Nature); Francesco Tubiello (Food and Agriculture Organization of the United Nations); James Tebrake (International Monetary Fund); Peter van de Ven (Organisation for Economic Co-operation and Development); Alessandra Alfieri, Jessica Ying Chan, Julian Chow, Bram Edens, Elsa Begne and Marko Javorsek (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Carl Obst (consultant, Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Lars Hein (Wageningen University, Kingdom of the Netherlands); and Raffaello Cervigni and Catherine Van Rompaey (World Bank).

In his capacity as SEEA EA Editor, Carl Obst, under the guidance of the Technical Committee, undertook to synthesize the content of the discussion papers and draft the chapters of SEEA EA.

SEEA EEA revision working groups

The revision process was supported by five working groups. Listed below are the area leads and the experts who contributed to the work and outputs of the working groups.[2]

[2] All of the papers and materials related to the work of the working groups are available at https://seea.un.org/content/seea-eea-revision-research-areas.

Working group 1 on spatial units

Area lead: Sjoerd Schenau (Statistics Netherlands)

Experts: Daniel Juhn, Timothy (Max) Wright and Trond Larsen (Conservation International); David Keith (University of New South Wales, Australia); Doug Muchoney and Francesco Tubiello (Food and Agriculture Organization of the United Nations); Edwin Horlings and Patrick Bogaart (Statistics Netherlands); Emily Nicholson (Deakin University, Australia); François Soulard and Mark Henry (Statistics Canada); Jessica Ying Chan (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Keith Gaddis (National Aeronautics and Space Administration); Michael Bordt (Economic and Social Commission for Asia and the Pacific; and Fisheries and Oceans Canada); Roger Sayre (United States Geological Survey).

Working group 2 on ecosystem condition

Area lead: Joachim Maes (European Commission, Joint Research Centre)

Experts: Amanda Driver (South African National Biodiversity Institute); Bálint Czúcz (European Commission, Joint Research Centre); Bethanna Jackson (Victoria University of Wellington, New Zealand); Emily Nicholson (Deakin University, Australia); Heather Keith (Australian National University and Griffith University, Australia); Marko Javorsek (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Octavio Pérez Maqueo (Instituto de Ecología, Mexico); Simon Jakobsson (Norwegian Institute for Nature Research).

Working group 3 on ecosystem services

Area lead: Lars Hein (Wageningen University, Kingdom of the Netherlands)

Experts: Alessandra La Notte (European Commission, Joint Research Centre); Anthony Dvarskas (Stony Brook University and Economic and Social Commission for Asia and the Pacific); Becky Chaplin-Kramer (Stanford University, United States); Benjamin Burkhard (Leibniz Universität Hannover, Germany); Julian Chow and Bram Edens (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Charles Rhodes (United States Geological Survey); David Barton (Norwegian Institute for Nature Research); Dolf de Groot (Wageningen University, Kingdom of the Netherlands); Ilan Havinga (Wageningen University, Kindgom of the Netherlands); Jan-Erik Petersen (European Environment Agency); Luke Brander (Brander Environmental Economics); Mahbubul Alam, Maíra Ometto Bezerra and Rosimeiry Portela (Conservation International); Marc Russell (United States Environmental Protection Agency); Neville Crossman (University of Adelaide and Murray-Darling Basin Authority, Australia); Patricia Balvanera (Universidad Nacional Autónoma de México, Mexico); Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom); Roy Haines-Young (Fabis Consulting); Sander Jacobs (Research Institute for Nature and Forest (INBO), Belgium); Sjoerd Schenau (Statistics Netherlands); Steven King (United Nations Environment Programme World Conservation Monitoring Centre).

Working group 4 on individual ecosystem services

Area lead: Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom)

Lead authors: Alessandra La Notte (European Commission, Joint Research Centre); Anthony Dvarskas (Stony Brook University and Economic and Social Commission for Asia and the Pacific); Benjamin Burkhard (Leibniz Universität Hannover, Germany); Bram Edens (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Carl Obst (consultant, Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); David Barton (Norwegian Institute for Nature Research); Lars Hein (Wageningen University, Kingdom of the Netherlands); Neville Crossman (University of Adelaide and Murray-Darling Basin Authority, Australia); Rosimeiry Portela (Conservation International); Steven King (United Nations Environment Programme World Conservation Monitoring Centre).

Contributing authors: Alejandro Caparrós (Consejo Superior de Investigaciones Científicas, Spain); Simon Ferrier and Beth Fulton (Commonwealth Scientific and Industrial Research Organisation, Australia); Brett Day (University of Exeter, United Kingdom); Bruna Grizzetti and Grazia Zulian (European Commission, Joint Research Centre); Brynhildur Davíðsdóttir (University of Iceland); Carlos A.Guerra (German Centre for Integrative Biodiversity Research (iDiv)); David Nowak (Forest Service, United States Department of Agriculture); Eli Fenichel (Yale University, United States); Emil Ivanov (University of Nottingham, United Kingdom); Gem Castillo (Resource and Environmental Economics Foundation of the Philippines); Giles Atkinson (London School of Economics, United Kingdom); Ilan Havinga (Wageningen University, Kingdom of the Netherlands); Jane Turpie (University of Cape Town and Anchor Environmental Consultants, South Africa); Kashif Shaad (Conservation International); Kerry Turner (University of East Anglia, United Kingdom); Laurence Jones and Stefan Reis (United Kingdom Centre for Ecology and Hydrology, United Kingdom); Luke Brander (Vrije Universiteit Amsterdam, Kingdom of the Netherlands); Mahbubul Alam, Maíra Ometto Bezerra and Miroslav Honzák (Conservation International); Matthew Agarwala (Bennett Institute for Public Policy, University of Cambridge, United Kingdom); Onil Banerjee (Inter-American Development Bank); Payam Dadvand (ISGlobal, Spain); Peter Elsasser (Thünen Institute, Germany); Sergio Vallesi (Durham University, United Kingdom Silvia Cerilli (Food and Agriculture Organization of the United Nations); Silvia Ferrini (University of Siena, Italy; and University of East Anglia, United Kingdom); Stoyan Nedkov (Bulgarian Academy of Sciences, Bulgaria); Thomas Randrup (Swedish University of Agricultural Sciences); Timon McPhearson (The New School, United States); Tomas Badura (University of East Anglia, United Kingdom and CzechGlobe, Global Change Research Institute of the Czech Academy of Sciences, Czechia).

Working group 5 on valuation and accounting treatments

Area lead: Juha Siikamaki (International Union for Conservation of Nature)

Experts: Alejandro Caparrós (Consejo Superior de Investigaciones Científicas, Spain); Anil Markandya (Basque Centre for Climate Change, Spain); Bram Edens, Ivo Havinga and Herman Smith (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Burkhard Schweppe-Kraft (Federal Agency for Nature Conservation, Germany); David Barton (Norwegian Institute for Nature Research); Dennis Fixler (Bureau of Economic Analysis, United States); Eli Fenichel (Yale University, United States); Jane Turpie (University of Cape Town

and Anchor Environmental Consultants, South Africa); Jim Tebrake (International Monetary Fund); Joe St. Lawrence (Statistics Canada); Matias Piaggio (Tropical Agricultural Research and Higher Education Center, Costa Rica); Nicholas Conner (New South Wales Office for the Environment and Heritage, Australia); Peter Harper (independent expert); Peter van de Ven (Organisation for Economic Co-operation and Development); Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom); William Speller (United Nations Environment Programme).

Subgroup on Accounting for Biodiversity in SEEA EA

Co-chairs: Rosimeiry Portela and Trond Larsen (Conservation International)

Experts: Alessandra Alfieri and Marko Javorsek, Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Amanda Driver (South African National Biodiversity Institute), Anne-Sophie Pellier (Bird Life International); Carl Obst (consultant, Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Hedley Grantham (Wildlife Conservation Society); Jillian Campbell and Markus Lehman (secretariat of the Convention on Biological Diversity); Joel Houdet (University of Pretoria, South Africa); Juha Siikamaki and Thomas Brooks (International Union for Conservation of Nature); Ken Bagstad (United States Geological Survey); Neville Ash and Steven King (United Nations Environment Programme World Conservation Monitoring Centre); P. Bhanumati (Ministry of Statistics and Programme Implementation, India); Patrick Bogaart (Statistics Netherlands); Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom); Simon Ferrier (Commonwealth Scientific and Industrial Research Organisation, Australia).

Working Group on SEEA EA Indicators

Chair: P. Bhanumati (Ministry of Statistics and Programme Implementation, India)

Experts: Alessandra Alfieri, Jessica Ying Chan, Julian Chow, Bram Edens and Marko Javorsek (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Anton Steurer (Eurostat); Carl Obst (consultant, Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); François Soulard (Statistics Canada); Gerhardt Bouwer (Statistics South Africa); Mike Gill and HyeJin Kim (Group on Earth Observations Biodiversity Observation Network (GEO BON) Secretariat); Jillian Campbell and Kieran Noonan Mooney (secretariat of the Convention on Biological Diversity); Juan Pablo Castañeda (World Bank); Juha Siikamaki (International Union for Conservation of Nature); Katia Karousakis and Myriam Linster (Organisation for Economic Co-operation and Development); Ken Bagstad (United States Geological Survey); Nic Bax and Simon Ferrier (Commonwealth Scientific and Industrial Research Organisation, Australia); Ouyang Zhiyun (Chinese Academy of Sciences, China); Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom); Shi Faqi (National Bureau of Statistics, China); Sjoerd Schenau (Statistics Netherlands).

Other experts

Experts that drafted text of chapter 13: Anthony Dvarskas, Rikke Munk Hansen and Gemma Van Halderen (Economic and Social Commission for Asia and the Pacific); Jordan Gacutan Coulson Lantz and Ben Milligan (University of New South Wales, Australia); David Barton (Norwegian Institute for Nature Research); François Soulard and Jennie Wang (Statistics Canada); Thomas Brooks and Juha

Siikamaki (International Union for Conservation of Nature); Lars Hein (Wageningen University, Kingdom of the Netherlands); Michael Bordt (Economic and Social Commission for Asia and the Pacific; and Fisheries and Oceans Canada); Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom); Trond Larsen and Rosimeiry Portela (Conservation International); Simon Ferrier (Commonwealth Scientific and Industrial Research Organisation, Australia); Sjoerd Schenau (Statistics Netherlands); Steven King (United Nations Environment Programme World Conservation Monitoring Centre).

Experts that drafted text of chapter 14: Mike Gill and HyeJin Kim (GEO BON) Secretariat); Jillian Campbell (secretariat of the Convention on Biological Diversity); Nic Bax (Commonwealth Scientific and Industrial Research Organisation, Australia); P. Bhanumati (Ministry of Statistics and Programme Implementation, India); Rocky Harris (Department for Environment, Food and Rural Affairs, United Kingdom).

Designer of the figures in the publication: Katharine Strong (Statistics Canada).

Other groups

London Group on Environmental Accounting

The London Group on Environmental Accounting discussed issues related to SEEA EA at its meetings held between October 2018 and 2020 and provided comments on the draft chapters of SEEA EA in special webinars held between March and August 2020. The London Group was chaired by Nancy Steinbach (Statistics Sweden) until October 2020 and by Sven Kaumanns (Federal Statistical Office of Germany) thereafter.

The following experts prepared papers related to SEEA EA during the meetings of the London Group in 2018, 2019 and 2020: Aija Kosk (Estonian University of Life Sciences); Aldo Femia (Istat, Italy); Alessandra La Notte, Joachim Maes, Alexandra Marques, and Sara Vallecillo (European Commission, Joint Research Centre); Amanda Driver and Aimee Ginsburg (South African National Biodiversity Institute); Anton Steurer (Eurostat); Veiko Adermann, Kätlin Aun, Grete Luukas, Kaia Oras and Argo Ronk (Statistics Estonia); P. Bhanumati and Avneet Kaur (Ministry of Statistics and Programme Implementation, India); Ben Milligan (University of New South Wales, Australia); Heather Keith and Brendan Mackey (Griffith University, Australia); Carl Obst (IDEEA Group); Charles Rhodes (United States Environmental Protection Agency); David Barton, Zofie Cimburova and Megan Nowell (Norwegian Institute for Nature Research); David Keith (University of New South Wales, Australia); David Lindenmayer and Michael Vardon (Australian National University, Australia); Patrick Bogaart, Edwin Horlings and Sjoerd Schenau (Statistics Netherlands); Silvia Cerilli and Francesco Tubiello (Food and Agriculture Organization of the United Nations); François Soulard (Statistics Canada); Gerhardt Bouwer (Statistics South Africa); Irene Alvarado Quesada (Central Bank of Costa Rica); Iulie Aslaksen, Per Arild Garnåsjordet and Margrete Steinnes (Statistics Norway); Jane Turpie (University of Cape Town; and Anchor Environmental Consultants, South Africa); Jan-Erik Petersen and Jana Tafi (European Environment Agency); Jessica Ying Chan (Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat); Suzi Bond Jonathon Khoo, Steve May and Peter Meadows (Australian Bureau of Statistics); Sofia Ahlroth and Juan Pablo Castañeda (World Bank); Kaja Lotman (Estonian Environmental Board); Üllas Ehrlich and Katrin Vaher (Tallinn University of Technology, Estonia); Ken Bagstad (United States Geological Service); Rocky Harris and Laurence Jones (Department for Environment, Food and Rural Affairs, United Kingdom); Luis Miguel Galindo

Paliza (consultant, National Capital Accounting and Valuation of Ecosystem Services (NCAVES) project, Mexico); Masayuki Sato (Kobe University, Japan); Raúl Figueroa Díaz (National Institute of Statistics and Geography (INEGI), Mexico); Rikke Munk Hansen (Economic and Social Commission for Asia and the Pacific); Rintaro Yamaguchi (National Institute for Environmental Studies, Japan); Roger Sayre (United States Geological Survey); Steven King (United Nations Environment Programme World Conservation Monitoring Centre); Takashi Hayashi (Ministry of Agriculture, Forestry and Fisheries, Japan); Trond Larsen (Conservation International); Wafa Aboul Hosn (Economic and Social Commission for Western Asia).

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Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

Regular meetings with the values assessment experts associated with the IPBES were organized during the revision process. Engagement was secured mainly through the co-chairs of the IPBES values assessment, including Patricia Balvanera (Universidad Nacional Autónoma de México); Brigitte Baptiste (Universidad EAN, Colombia); Michael Christie (Aberystwyth University, United Kingdom); and Unai Pascual (Basque Centre for Climate Change, Spain).

Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project

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(Ministry of Statistics and Programme Implementation, India); Ouyang Zhiyun (Chinese Academy of Sciences); Qiu Qiong and Shi Faqi (National Bureau of Statistics, China).

The following experts were consulted on specific methodological and measurement issues: Gretchen Daily (Stanford University, United States); Ian Bateman (University of Exeter, United Kingdom); Stephen Polasky (University of Minnesota, United States).

Global consultations

Two formal global consultations were organized during the revision process. The first, on individual chapters, was held between March and August 2020,[3] and the second, on the completed draft of SEEA EA in its entirety, between October and November 2020.[4]

The following countries and State participated in the global consultations: Albania, Armenia, Australia, Azerbaijan, Belarus, Belgium, Bolivia (Plurinational State of), Botswana, Brazil, Bulgaria, Burundi, Cameroon, Canada, China, Colombia, Croatia, Czechia, Denmark, Ecuador, Estonia, Ethiopia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Iran (Islamic Republic of), Iraq, Ireland, Italy, Jordan, Kenya, Latvia, Lesotho, Lithuania, Malaysia, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Netherlands (Kingdom of the), New Zealand, Norway, Peru, Philippines, Poland, Qatar, Romania, Saudi Arabia, Senegal, Slovakia, Slovenia, South Africa, Spain, Sudan, Suriname, Sweden, Switzerland, Thailand, Tunisia, United Kingdom, United States, Uruguay, Venezuela (Bolivarian Republic of), Viet Nam, Zambia, Zimbabwe and State of Palestine. While in many cases, several national agencies contributed to the consolidated contribution or submitted separate contributions, they all adhered to a common national position on the global consultation.

The following organizations participated in the global consultations: Capitals Coalition; Conservation International; Convention on Biological Diversity secretariat; Ducks Unlimited Canada; Eastern Africa Statistical Training Centre; Ecological Accounting Chair (Chaire Comptabilité Écologique); Economic Commission for Latin America and the Caribbean; European Central Bank; European Commission (Directorate-General for Environment, Eurostat, Joint Research Centre); European Environment Agency; Food andAgriculture Organization of the United Nations; Gaborone Declaration for Sustainability in Africa; Global Footprint Network; GEO BON; Intemerate Working Group on Data, Statistics, and Valuation; International Monetary Fund; International Union for Conservation of Nature; Organisation for Economic Co-operation and Development; Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat; United Nations Development Programme; United Nations Environment Programme; United Nations Environment Programme World Conservation Monitoring Centre; World Bank; World Economic Forum Beijing Representative Office; World Tourism Organization.

The following individual experts participated in the global consultations: Adrien Comte (Centre international de recherche sur l'environnement et le développement (CIRED), France); Greti Lucaroni, Antonia Oriani, Karima Oustadi and Aldo Ravazzi Douvan (Sogesid TA – Ministry of Environment, Land and Sea of Italy – Technical Secretariat of the Italian Natural Capital Committee); Pablo Campos, Alejandro Caparrós and Jose L. Oviedo (Consejo Superior de Investigaciones Científicas, Spain); Alison Fairbrass and Paul Ekins (Institute for Sustainable Resources, University College London, United Kingdom); Simon Ferrier, Beth Fulton, Richard Mount, Suzanne Prober, Anna Richards, Gabriela Scheufele and

[3] For details, see https://seea.un.org/content/global-consultation-individual-chapters.

[4] For details, see https://seea.un.org/content/global-consultation-complete-draft.

Becky Schmidt (Commonwealth Scientific and Industrial Research Organisation, Australia); Ben Milligan (University of New South Wales, Australia); Christopher Martin (White Horse Training, United Kingdom); David MacDonald (Chair, Expert Group on Resource Management, Economic Commission for Europe); Eli Fenichel (Yale University, United States); T. Badura, S. Ferrini, G. Grilli and R.K. Turner (University of East Anglia, United Kingdom); Heather Keith and Michael Vardon (Australian National University and Griffith University, Australia); Jana Tafi, environmental accounting and assessments expert; Jane Turpie (University of Cape Town and Anchor Environmental Consultants, South Africa); John Finisdore (Sustainable Flows, Australia and United States); Mark Eigenraam, John Finisdore and Reiss McLeod (IDEEA Group, Australia); John Maughan (Green Growth Knowledge Platform); Julian Hilton (Aleff Group, United Kingdom and Chair, Sustainable Development Goals Delivery Working Group, Expert Group on Resource Management, Economic Commission for Europe); Laurence Jones (United Kingdom Centre for Ecology and Hydrology); Leon Braat (Editor-in-Chief, *Ecosystem Services*, published by Elsevier); Louise Willemen (University of Twente, Kingdom of the Netherlands); Melanie Kolb (Institute of Geography, Universidad Nacional Autónoma de México); Robert Johnston (Clark University, United States); Sara Ortiz (Universidad Rafael Landívar, Guatemala); Solen Le Clec'h (Wageningen University, Kingdom of the Netherlands); Steven Broekx (Flemish Institute for Technological Research (VITO), Belgium); Thomas Ochuodho (University of Kentucky, United States); Walter J. Radermacher (Sapienza University of Rome, Italy).

Meetings and workshops

The following meetings and workshops were held to encourage engagement, build on the expertise of different communities and allow for the detailed discussions on issues that were required to facilitate substantive progress on technical matters:

- Expert Workshop on Valuation for Ecosystem Accounting, Bonn, 24–26 April 2018
- Forum of Experts on SEEA Experimental Ecosystem Accounting, Glen Cove, New York, 18–20 June 2018
- Thirteenth meeting of the United Nations Committee of Experts on Environmental-Economic Accounting, New York, 21 and 22 June 2018
- Twenty-fourth meeting of the London Group on Environmental Accounting, Dublin, 1–4 October 2018
- Expert meeting on spatial areas and ecosystem condition, Paris, 28 and 29 November 2018
- Strategic meeting on accounting for biodiversity and ecosystems with International Union for Conservation of Nature (IUCN) and selected biodiversity experts, Paris, 30 November 2018
- Expert meeting on advancing the measurement of ecosystem services for ecosystem accounting, New York, 22–24 January 2019
- Fourteenth meeting of the United Nations Committee of Experts on Environmental-Economic Accounting, New York, 24 and 25 June 2019
- Forum of Experts on SEEA Experimental Ecosystem Accounting, Glen Cove, New York, 26 and 27 June 2019
- Technical Expert Meeting on advancing SEEA EEA revision, Glen Cove, New York, 28 and 29 June 2019

- Thirteenth meeting of the Advisory Expert Group on National Accounts, Washington, D.C., 1–3 October 2019
- Twenty-fifth meeting of the London Group on Environmental Accounting, Melbourne, Australia, 7–10 October 2019
- Meeting of the Organisation for Economic Co-operation and Development (OECD) Working Parties on Financial Statistics and National Accounts, Paris, 4–8 November 2019
- Meeting of the London Group on the general context of the revision (virtual), 13 March 2020
- Technical Meeting on Valuation and Accounting for the Revised SEEA EEA (virtual), 16–18 March 2020
- Meeting of the London Group on Environmental Accounting on draft chapters 3–5 (virtual), 21 April 2020
- Presentation of the revision process and engagement to African countries as part of the Africa Natural Capital Accounting Community of Practice (virtual), 4 June 2020
- Meeting of the London Group on Environmental Accounting on draft chapters 8–11 (virtual), 18 June 2020
- Virtual Expert Forum on SEEA Experimental Ecosystem Accounting – session 1: Ecosystem extent and condition, 23 and 24 June 2020
- Fifteenth meeting of the United Nations Committee of Experts on Environmental-Economic Accounting (virtual), 6, 8 and 9 July 2020
- Virtual Expert Forum on SEEA Experimental Ecosystem Accounting – session 2: Valuation and accounting treatments (virtual), 14 and 15 July 2020
- Meeting of the London Group on Environmental Accounting on draft chapters 6 and 7 (virtual), 18 August 2020
- Virtual Expert Forum on SEEA Experimental Ecosystem Accounting – session 3: Ecosystem services, 24 and 25 August 2020
- Twenty-sixth meeting of the London Group on Environmental Accounting (virtual), 5–8 and 12 October 2020
- Presentation of the revision process and engagement to Latin American countries as part of the Latin America Natural Capital Accounting Community of Practice (virtual), 28 October 2020
- Virtual Expert Forum on SEEA Experimental Ecosystem Accounting – session 4: Thematic accounts and indicators, 9 and 10 November 2020
- Extraordinary Meeting of the United Nations Committee of Experts on Environmental-Economic Accounting (virtual), 16–18 November 2020
- High-level webinar on the finalization of the revision of SEEA EEA for Latin American and Caribbean countries, co-organized by the Economic Commission for Latin America and the Caribbean and the Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 4 February 2021

Abbreviations and acronyms

AB	abiotic flow
BIOFIN	Biodiversity Finance Initiative
BOD	biological oxygen demand
BSU	basic spatial unit
CICES	Common International Classification of Ecosystem Services
COD	chemical oxygen demand
DIC	dissolved inorganic carbon
DPSIR	driving forces-pressure-state-impact-response
EAA	ecosystem accounting area
EBV	essential biodiversity variable
ECT	ecosystem condition typology
ECV	essential climate variable
EE-IOT	environmentally extended input-output table
EESV	essential ecosystem services variable
EEZ	exclusive economic zone
EFG	ecosystem functional group (IUCN GET)
EGSS	environmental goods and services sector
EOV	essential ocean variable
ET	ecosystem type
FDES	Framework for the Development of Environment Statistics
FTE	full-time equivalent
GDP	gross domestic product
GEO BON	Group on Earth Observations Biodiversity Observation Network
GEP	gross ecosystem product
GHG	greenhouse gas
GIS	geographic information system
GOOS	Global Ocean Observing System
GVA	gross value added
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IS	intermediate ecosystem service
ISIC	International Standard Industrial Classification of All Economic Activities
IUCN	International Union for Conservation of Nature

ICUN GET	International Union for Conservation of Nature Global Ecosystem Typology
LDN	land degradation neutrality
LULUCF	land use, land-use change and forestry
MAES	Mapping and Assessment of Ecosystems and their Services
NCAVES	National Capital Accounting and Valuation of Ecosystem Services
NDP	net domestic product
NDVI	normalized difference vegetation index
NDWI	normalized difference water index
NESCS	National Ecosystem Services Classification System (United States Environmental Protection Agency)
NPV	net present value
NSO	national statistical office
PM	particulate matter
PSUT	physical supply and use table
SBA	service benefiting area
SEEA	System of Environmental-Economic Accounting
SEEA AFF	System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries
SEEA EA	System of Environmental-Economic Accounting – Ecosystem Accounting
SEEA EEA	System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting
SNA	System of National Accounts
SPA	service providing area
SUT	supply and use table
TEEB	The Economics of Ecosystems and Biodiversity (initiative)
UNCEEA	United Nations Committee of Experts on Environmental-Economic Accounting
UNEP	United Nations Environment Programme
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
WTA	willingness to accept (a payment)
WTP	willingness (of a consumer) to pay

Contents

page

Tables

page

Figures

Section A
Introduction and overview

Section overview

The System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) is a spatially based, integrated statistical framework for organizing biophysical information on ecosystems, measuring ecosystem services, tracking changes in ecosystem extent and condition, valuing ecosystem services and assets and linking this information to measures of economic and human activity. SEEA EA was developed to respond to a range of policy demands and challenges, with a focus on making visible the contributions of nature to economic activities and people's lives.

At its fifty-second session, held from 1 to 3 and on 5 March 2021, the United Nations Statistical Commission adopted chapters 1 to 7 of SEEA EA, describing the accounting framework and the physical accounts as an international statistical standard; recognized that chapters 8 to 11 of SEEA EA describe internationally recognized statistical principles and recommendations for the valuation of ecosystem services and assets in a context that is coherent with the concepts of the System of National Accounts (SNA) for countries that are undertaking valuation of ecosystem services and/or assets; and noted that SEEA EA chapters 12 to 14 described the applications and extensions of ecosystem accounting.[5]

[5] See *Official Records of the Economic and Social Council, 2021, Supplement No. 4* (E/2021/24), chap. I, sect. B, decision 52/108, para. (c).

The SEEA EA complement the measurement of the relationship between the environment and the economy as described in the *System of Environmental-Economic Accounting 2012 – Central Framework* (SEEA Central Framework) (United Nations, European Commission, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank, 2014). SEEA, encompassing the SEEA Central Framework and SEEA EA, constitutes a system that complements SNA through the use of accounting principles to integrate physical and monetary measures related to the environment in such a way as to allow for comparison with data from national accounts.

Chapter 1 provides an overview of SEEA EA, with a focus on the context for its development, its connections with other measurement frameworks and initiatives and considerations for implementation. Chapter 2 summarizes the ecosystem accounting framework, placing information on ecosystem extent, ecosystem condition, ecosystem services and monetary values of ecosystem services and assets in context.

SEEA EA applies the accounting principles of the *System of National Accounts 2008* (2008 SNA) (United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank, 2009). In the context of monetary valuation, SEEA EA applies the SNA concept of exchange value. While estimates based on this value concept are useful in many contexts, there are some limitations. For one thing, such estimates do not include the monetary value of the wider social benefits of ecosystems, including their non-use values, which some users may find relevant.

More generally, monetary values will not fully reflect the importance of ecosystems for people and the economy. Assessing the importance of ecosystems therefore requires consideration of a wide range of information extending beyond data on their monetary value and their services, including data both on the biophysical characteristics of ecosystems and on the characteristics of the people, businesses and communities that are dependent on them.

SEEA EA is a system conceived and constructed as an integrated, internally consistent series of accounts. Its design is such that it can be implemented equally well in parts, that is to say, implementation can be flexible and modular. Indeed, the progressive, staged development of the range and detail of the ecosystem accounts is likely an appropriate implementation strategy. Generally, the compilation of ecosystem accounts in monetary terms requires the use of data in physical terms. It is therefore recommended that when monetary accounts are released, the associated data in physical terms – for example, concerning changes in ecosystem extent and condition – be released concurrently. This will aid interpretation of the monetary data and their application in policy- and decision-making. The interpretation and analysis of ecosystem accounting data are also supported through the use of other types of information, such as data on environmental protection expenditure, industry value added, employment and population.

Chapter 1
Introduction

1.1 Context for SEEA EA

1.1 It is well established that healthy ecosystems and biodiversity are fundamental to supporting and sustaining people's well-being, their communities and their economies. However, the environment is under pressure, and securing and improving livelihoods require facing consequential risks. These challenges have been recognized at the local, national and global levels, and the needed global responses have been clearly articulated in the 2030 Agenda for Sustainable Development, including the Sustainable Development Goals,[6] and other global instruments, such as the Paris Agreement.[7] The Paris Agreement, which is aimed at strengthening the global response to the threat of climate change, was adopted under the United Nations Framework Convention on Climate Change.[8] It is expected that a post-2020 global biodiversity framework, designed to bend the curve of biodiversity loss, will be finalized and adopted at the fifteenth meeting of the Conference of the Parties to the Convention on Biological Diversity.

1.2 There has been growing recognition that the degradation of nature is not a purely environmental issue requiring environmental policy responses and that economic and social policy responses are also needed. Decision makers across all sectors must therefore consider the particular environmental context in which decisions will be made and the associated dependencies and impacts. Establishing agreed ongoing measurement of changes in the state of the environment and their relationship to economic and other human activity is central to ensuring that ecosystems and biodiversity are mainstreamed in decision-making processes, including those related to economic and financial systems.

6 Adopted by the General Assembly, at its seventieth session, on 25 September 2015. See Assembly resolution 70/1.

7 Adopted by the Conference of the Parties to the United Nations Framework Convention on Climate Change at its twenty-first session, held in Paris from 30 November to 13 December 2015. See https://undocs.org/FCCC/CP/2015/10/Add.1.

8 United Nations, *Treaty Series*, vol. 1771, No. 30822.

1.2 What is SEEA EA?

1.2.1 Introduction

1.3 SEEA EA is a spatially based, integrated statistical framework for organizing biophysical information on ecosystems, measuring ecosystem services, tracking changes in ecosystem extent and condition, valuing ecosystem services and assets and linking this information to measures of economic and human activity. SEEA EA was developed by a multidisciplinary group of experts to respond to a range of policy demands and challenges, with a focus on making visible the contributions of nature to the economy and people and on better recording the impacts of economic and other human activity on the environment. To this end, ecosystem accounting incorporates a wider range of benefits that accrue to people than is captured in standard economic accounts and provides a structured approach to assessing the dependence and impacts of economic and human activity on the environment.

1.4 SEEA EA complements the measurement of the relationship between the environment and the economy described in the SEEA Central Framework. SEEA EA data on ecosystems can be combined with data on environmental pressures, individual resource stocks and environmental responses in the form of expenditures, taxes and subsidies, in the SEEA Central Framework accounts, to provide a comprehensive picture of environmental-economic relationships.

1.5 Through application of the national accounting principles of the 2008 SNA, the statistical framework for the measurement of the economy, the SEEA EA framework allows for a unique integration of environmental and economic data in support of decision-making. The harmonization of those data is intended to contribute both to mainstreaming the use of environmental data on ecosystems in economic decision-making and to supporting the use of economic data in environmental decision-making.

1.6 The use of an accounting approach takes advantage of the inherent structure of accounts in which both stocks and flows are part of a single recording system. In this context, the basic accounting principles are applied to the organization of data in both physical and monetary terms to provide an integrated, coherent and consistent data set. Further, the adoption of an accounting approach facilitates comparable, regular and ongoing measurement.

1.2.2 Coverage and interpretation of SEEA EA

1.7 SEEA EA reflects the integration of the latest knowledge, methods and techniques in the measurement of ecosystems. Nonetheless, it is recognized that there are challenges in implementation and interpretation that will require ongoing attention. It is expected that the body of knowledge associated with ecosystem accounting, as well as the level of understanding of the data sources and methods used to compile ecosystem accounts, will evolve over time as a result of the widespread implementation of those accounts. Consequently, as is the case for all statistical methodological documents, it will be necessary to refine and revise the content of SEEA EA in the future and to sustain the development of technical guidance and related material in support of implementation and interpretation.

1.8 SEEA EA is comprehensive in its coverage of ecosystems, encompassing all realms: terrestrial, freshwater, marine and subterranean ecosystem realms. Further, in describing the connections between ecosystems and economic and human activity, it places focus on ecosystem services, which reflect the many uses – direct and indirect – of ecosystems. However, such coverage does not include all of those connections with ecosystems. Specifically, the measurement scope of SEEA EA does not directly address the importance of ecosystems arising from their very existence and captures only a portion of the significant cultural and spiritual relationships between people and the environment.

1.9 Within the context of monetary valuation, SEEA EA applies the concept of exchange values in line with standard economic accounting principles. This supports comparison with standard economic and financial data. While those values are useful in many contexts, they will not be equivalent to monetary values that incorporate the wider social benefits of ecosystems. Measurement of the economic value of these social benefits, while important, exceeds the scope of SEEA EA. Chapter 12 discusses some aspects of the links between monetary values in ecosystem accounting and other monetary values.

1.10 More generally, it is emphasized that monetary values from the accounts and the wider economic values just described will not fully reflect the importance of ecosystems for people and the economy. Assessing the importance of ecosystems therefore requires consideration of a wider range of information that extends beyond data on the monetary value of ecosystems and their services. This includes data both on the biophysical characteristics of ecosystems and on the characteristics of the people, businesses and communities that are dependent on them.

1.11 While SEEA EA does not incorporate all the data that may be relevant in assessing the relationship between the environment and economic and human activity, it does provide a structured framework for organizing data that can support further analysis and place various perspectives in context.

1.2.3 Implementation of SEEA EA

1.12 SEEA EA is a system conceived and constructed as an integrated, internally consistent series of accounts. At the same time, its design is such that it can be implemented equally well as a whole or in parts, that is to say, implementation of the system can be flexible and modular. Indeed, the progressive, staged development of the range and detail of the ecosystem accounts is likely an appropriate implementation strategy. Depending on their specific environmental and economic context, countries may choose to implement only a selection of the accounts or to compile accounts only for selected regions. For example, a country may decide to compile accounts only in physical – not monetary – terms.

1.13 Particularly as related to the compilation of accounts in monetary terms, some compilers may express concern that the data requirements and methodological assumptions in this regard are too significant for the compilation of those accounts to be carried out within the context of official statistics. At the same time, there may be substantive demand for well-defined and comparable estimates in monetary terms for use in policy and analysis. Given these potentially competing considerations, it will be appropriate for work to be focused on compiling accounts that are highly relevant for decision-making and for which both suitable data and suitable estimation methods are available.

1.14 National statistical offices (NSOs) operate within different contexts and with different ranges of responsibility. Depending on the national context, there may be opportunities for collaborative approaches to compiling ecosystem accounts that take advantage of the strengths of NSOs together with the expertise of other agencies and research organizations. As ecosystem accounting is multidisciplinary in scope, multi-institutional approaches to implementation are appropriate.

1.15 In cases where accounts are being compiled in monetary terms, it is recommended that associated data in physical terms – for example, data related to changes in ecosystem extent and condition and flows of ecosystem services – be also released to facilitate the interpretation and application of the monetary data in policy- and decision-making. Further, the interpretation and analysis of ecosystem accounting data can be supported through the use of other information, such as data on environmental protection expenditure, industry value added, employment and population.

1.16 A range of technical guidance is available on the SEEA website[9] in support of the implementation, interpretation and application of the ecosystem accounts. This guidance will be expanded progressively in line with advancements of experience in compiling and using ecosystem accounts.

[9] See https://seea.un.org/ecosystem-accounting.

1.3 Statistical context for ecosystem accounting

1.3.1 Historical background of SEEA

1.17 Ecosystem accounting has arisen out of work on environmental accounting initiated by the international community of official statisticians under the direction of the Statistical Commission. Work on SEEA started in the 1980s in response to a demand for internalizing natural resource depletion and degradation into macroeconomic accounting and culminated with the issuance of the *Handbook of National Accounting: Integrated Environmental and Economic Accounting* (SEEA 1993)

(United Nations, 1993). The release of the publication responded to the policy demands of Agenda 21, the outcome document of the United Nations Conference on Environment and Development,[10] which included a call for countries to implement national systems of integrated environmental and economic accounting.[11]

1.18 On the basis of the experimentation of countries, SEEA 1993 was subsequently updated in 2003 through a process of expert meetings and wide consultation led by the London Group on Environmental Accounting, one of several city groups established to advance methodologies and practices by the Statistical Commission.[12] The resulting *Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003* (SEEA 2003) (United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank, 2007) presented a variety of different methodological approaches and a range of examples demonstrating diverse country practices. While SEEA 2003 was not formally adopted as an internationally agreed statistical framework, it nonetheless provided a well-accepted and robust set of approaches for the compilation of various environmental-economic accounts.

1.19 Recognizing the critical importance of information on the environment and its relationship with the economy, the Statistical Commission established the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA) in 2005 with the primary objective, the mainstreaming of environmental-economic accounting in official statistics. Subsequently, at its thirty-eighth session, held in February–March 2007, the Commission endorsed a second revision process,[13] which led to the development of the *System of Environmental-Economic Accounting 2012 – Central Framework* (SEEA Central Framework). At its forty-third session, in March 2012, the Commission adopted the SEEA Central Framework as the initial version of the international standard for environmental-economic accounts.[14] The SEEA Central Framework lays out a standardized approach to accounting for a variety of physical flows, physical and monetary measures of individual environmental assets and environmental transactions.

1.3.2 Development of SEEA EA

1.20 During the development of the SEEA Central Framework, a range of highly relevant topics were identified that called for further research or for further testing and experimentation in areas new to the statistical community. As accounting for ecosystems and their degradation was the primary focus of those topics, the Statistical Commission extended its support to the development of the *System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting* (SEEA EEA) (United Nations, European Commission, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development and World Bank, 2014) as a complement to the SEEA Central Framework.

1.21 At its forty-fourth session, in March 2013, the Statistical Commission endorsed SEEA EEA as an important step in the development of an integrated statistical framework for organizing biophysical information, measuring ecosystem services, tracking changes in ecosystem assets and linking this information to economic and other human activity; and encouraged its use by international and regional agencies and countries.[15] At that time, SEEA EEA was not adopted as an internationally agreed statistical standard and was given the label "experimental" because of the novelty of the conceptual framework from a statistical perspective and the lack of agreed measurement methods, including agreed methods of testing.

[10] *Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3–14 June 1992*, vol. I, *Resolutions Adopted by the Conference* (United Nations publication, Sales No. E.93.I.8 and corrigendum), resolution 1, annex II.

[11] Ibid., para. 8.41.

[12] For further information, see https://seea.un.org/content/london-group-environmental-accounting.

[13] See *Official Records of the Economic and Social Council, 2007, Supplement No. 4* (E/2007/24), chap. I, sect. B, decision 38/107.

[14] Ibid., *2012, Supplement No. 4* (E/2012/24), chap. I, sect. B, decision 43/105, para. (c).

[15] Ibid., *2013, Supplement No. 4* (E/2013/24), chap. I, sect. C, decision 44/104, decision 44/104, para. (e).

1.22 While the ecosystem accounting framework presented in SEEA EEA was novel, at the same time it reflected the integration of experience derived from many well-established areas of expertise, including statistics and national accounting, ecology and natural science, geography and geospatial measurement and environmental economics. By providing experts in those disciplines with a conceptual basis for the exchange and sharing of ideas, SEEA EEA facilitated a rapid growth in the development and testing of ecosystem accounting. In support of the activities being carried out at this level, in December 2017, the Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat released the *Technical Recommendations in support of the System of Environmental-Economic Accounting 2012 – Experimental Economic Accounting* (United Nations, 2019b). That publication summarized the current state of knowledge and practice on ecosystem accounting and supported for further development and testing of methods.

1.23 In June 2017, at its twelfth meeting, UNCEEA determined, given the level of interest, testing and experimentation, that a revision of SEEA EEA was appropriate and that the project should include the goal of elevating as many facets of ecosystem accounting as possible to the status of an international statistical standard to be established by 2021. The revision process was endorsed by the Statistical Commission at its forty-ninth session, in March 2018.[16]

1.24 The revision process was carried out under the auspices of the Committee of Experts with technical leadership provided by the SEEA Technical Committee on SEEA EEA. Four key areas of revision were established: (a) spatial units; (b) ecosystem condition; (c) ecosystem services; and (d) monetary valuation and accounting. Five working groups led research and discussion encompassing these research areas with activities commencing in early 2018. Twenty-three primary discussion papers, four background papers and numerous issue notes were drafted for review by various technical experts across the disciplines listed in paragraph 1.22 above. On the basis of the content of these materials and the feedback that they generated, chapters were drafted for consideration by the SEEA Technical Committee. The chapters were released for two rounds of global consultation through 2020. A novelty of this process was the active engagement with many expert communities and global environmental and sustainability initiatives, and the hosting of various in-person and virtual forums on ecosystem accounting. This breadth of engagement enriched the design and content of the ecosystem accounting framework and provided the basis for its ongoing development and implementation.[17]

1.4 Conceptual approach of SEEA EA

1.25 The general approach to ecosystem accounting in recording ecosystem stocks and flows has been described in a range of documents in various ways. SEEA-focused research (see, for example, Vanoli, 1995) and research focused on extensions to the SNA (see, for example, Nordhaus and Kokkelenberg, eds., 1999) have considered the type of accounting described in SEEA EA. Of particular note are the advances in the work on wealth accounting carried out by both the World Bank (2018) and the United Nations Environment Programme (2018). While the major focus in this work has been the measurement of the wealth of natural resources, the extension designed to capture a wider range of benefits derived from the environment, including ecosystem services, is well established in the wealth accounting literature.[18]

1.26 In addition to being connected with these economic and accounting approaches, the ecosystem accounting framework has adapted the concepts developed for ecosystem services measurement, such as the cascade model (Haines-Young and Potschin,

[16] Ibid., *2018, Supplement No. 4* (E/2018/24), chap. I, sect. B, decision 49/110, para. (d).

[17] The materials prepared and discussed over the course of the revision process are available at https://seea.un.org/content/seea-experimental-ecosystem-accounting-revision.

[18] The wealth accounting literature has been enriched by more recent work in this field including that of Arrow and others (2012); Barbier (2013); Dasgupta (2009); and Fenichel and Abbott (2014).

2010) and the conceptual framework produced by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz and others, 2015), within which the core ecosystem accounting model can be situated. In its spatial approach to considering ecosystems, the ecosystem accounting framework builds on extensive work carried out on the classification, mapping and delineation of ecosystems and their services.[19] The measurement of ecosystem condition makes evident its clear connections with long-standing ecological theory and measurement.[20] Overall, the underlying logic of, and conceptual basis for, ecosystem accounting should be considered to be well established.

1.27 The essence of ecosystem accounting lies in its representation of the biophysical environment in terms of distinct spatial areas, each representing a specific ecosystem type. Ecosystem types include forests, grasslands, wetlands, cultivated areas, urban areas, rivers, coastal dunes, coral reefs and deep-sea floors. Each spatial area of a specific ecosystem type is, for accounting purposes, treated as an ecosystem asset. Each ecosystem asset is accounted for in a manner that is broadly analogous to the SNA treatment of produced assets, such as dwellings, for which there is an underlying stock of capital (e.g. a house with specific characteristics such as a number of bedrooms and of a given condition) and an associated flow of services (e.g. owner-occupied housing services).

1.28 In practice, therefore, ecosystem accounting entails the recording over an accounting period of (a) the stock and change in stock of each ecosystem asset (encompassing entries for ecosystem enhancement and degradation); and (b) flows from that asset in the form of ecosystem services. The flows of ecosystem services in any accounting period are related to the ecosystem type, its size or extent and its condition or health and to factors determining levels of use such as population. While there are conceptual and definitional issues that require explanation, this general framing remains applicable throughout SEEA EA. Chapter 2 provides a more detailed overview of the ecosystem accounting framework.

1.29 The principles for recording stocks and flows that are applied in ecosystem accounting can be used to organize data expressed in both physical and monetary terms. The use of common principles encourages the combined use of physical and monetary data. For entries in monetary terms, SEEA EA applies the concept of exchange values under which ecosystem services and ecosystem assets are valued at the prices at which they are exchanged or would be exchanged if there were markets present. This approach supports comparison of ecosystem accounting monetary values with those recorded in conventional economic and financial accounts.

1.30 However, there is a range of other approaches to economic valuation of the environment that, in general, provide larger monetary values and are well suited to addressing different analytical questions and to being applied in different policy contexts. SEEA EA monetary values should therefore not be expected to provide, nor they are intended to provide an estimate of, a complete “value of nature”. Further, in many decision-making contexts, it is essential to use physical data, for example, on the changing condition of ecosystems, either directly or to support interpretation of monetary values. Physical data can also support discussion of non-monetary environmental values, which are significant in many contexts.

1.31 The ecosystem accounting framework is the basis for the compilation of various ecosystem accounts. Five types of ecosystem account are described: (a) ecosystem extent accounts; (b) ecosystem condition accounts; (c) ecosystem services flow accounts in physical terms; (d) ecosystem services flow accounts in monetary terms; and (e) monetary ecosystem asset accounts. There is also a range of related accounts,

[19] See, for example, Burkhard and Maes, eds. (2017); David A. Keith and others, eds. (2020); and Sayre and others (2020).

[20] See, for example, Andreasen and others (2001); Holling (1973); Karr (1981); Leopold (1949); and Wheeler (2002).

complementary presentations and applications, including thematic accounts and indicators. All of these accounts and related outputs are introduced in chapter 2 and described in detail in the appropriate chapters.

1.32 The framework presented in SEEA EA refines the original conceptual framework for ecosystem accounting set out in SEEA EEA. In many areas, the revisions provide additional explanations and clarifications. In some areas, reinterpretation or reformulation of the original framework reflects the outcomes of ongoing discussions and conversations with a wider range of experts. This is evident particularly in the application of concepts specific to ecology and biodiversity and in the discussion on the monetary valuation of ecosystem services and assets. The main areas where conceptual improvements were introduced are described in appendix A1.1.

1.5 Connections to other measurement frameworks and initiatives

1.5.1 Introduction

1.33 Ecosystem accounting has a number of key features that allow it to support, complement and extend other measurement frameworks and initiatives. Ecosystem accounting, in particular:

(a) Is designed to facilitate comparison and integration with the economic data prepared in accordance with the principles of the SNA. This leads to the adoption of certain measurement boundaries and valuation concepts that are not systematically applied in other forms of ecosystem measurement;

(b) Encompasses accounting for ecosystem assets in terms of both ecosystem extent and condition, and ecosystem services. Commonly, the measurement of ecosystem extent and condition is a wholly separate undertaking from the measurement of ecosystem services;

(c) Enables coherent accounting in both physical terms (e.g. hectares or tons) and monetary terms. Through coherent recording in physical and monetary terms and coverage of stocks and flows, the ecosystem accounting framework is well suited to deriving a wide range of indicators from a single information base and to supporting integrated environmental-economic analyses;

(d) Is designed to provide a broad, cross-cutting perspective on ecosystems at the country and/or the subnational level. Since many ecosystem measurements are carried out at a detailed local level, ecosystem accounting enables the utilization of granular data to produce a richly textured picture of the condition of ecosystems and the services they supply;

(e) Supports the consistent and comparable recording of data over time and thus provides information on trends in condition indicators (e.g. for grasslands or lakes), trends in the composition of ecosystem types (as measured by, e.g. the rates of conversion from natural to intensively managed ecosystem types) and trends in relationships between changes in the stock of ecosystems and flows of ecosystem services.

1.5.2 Connection to the SEEA Central Framework

1.34 As noted in section 1.2, collectively, SEEA EA and the SEEA Central Framework constitute a rich comprehensive framework for the organization of data on the relationship between the environment and the economy. They have been designed to complement each other and both reflect the application of the accounting principles of the SNA.

1.35 The SEEA Central Framework provides the concepts, definitions and classifications needed to support integrated accounting for physical flows (natural inputs from, and residual flows to, the environment including water, energy, air emissions and solid waste); environmental transactions and transfers (e.g. environmental taxes, environmental subsidies and environmental protection expenditure); and individual environmental assets (e.g. mineral and energy resources, timber, fish, land, soil and water).

1.36 Connections to ecosystem accounting can be identified in a number of areas covered by the Central Framework. In the context of accounting for physical flows, measures of natural inputs from the environment (e.g. uncultivated timber resources) will be aligned with measures of ecosystem services, while measures of residual flows (e.g. flows of particulate matter and excess nitrogen) will be related to flows of ecosystem services such as air filtration and water purification. Often, residual flows indicate environmental pressures that can be related to changes in ecosystem condition. Connections can also be identified among environmental taxes and subsidies, expenditures on environmental protection and change in ecosystem condition and between the monetary value of natural resources, such as timber resources and fish stocks, and the monetary value of ecosystem assets.

1.37 A long-standing ambition of environmental-economic accounting has been to derive adjusted measures of value added and wealth that take into account the cost of using up environmental assets. In ecosystem accounting, realization of that ambition is being achieved through measurement of ecosystem degradation so as to reflect the loss of future flows of ecosystem services. This complements the measurement of depletion as defined in the SEEA Central Framework, which focuses on the costs of using up stocks of natural resources. The range of connections among the accounts of the SEEA Central Framework and those of SEEA EA are described in more detail in appendix A1.2.

1.5.3 Connection to SNA

1.38 In broad terms, the connection between SEEA EA and the SNA lies in the application and adaptation of national accounting concepts and principles for the purpose of accounting for ecosystem assets and their services. A summary of the most relevant concepts and principles is provided in chapter 2. SEEA, encompassing the SEEA Central Framework and SEEA EA, constitutes a system that complements the SNA through the use of the same accounting principles to integrate environmental measures in physical and monetary terms and in such a way as to allow for comparison with data from the national accounts.

1.39 SEEA EA encompasses a broader asset boundary in physical terms than that of the SNA, reflecting the definition of environmental assets in paragraph 2.17 of the SEEA Central Framework. According to that definition, ***environmental assets are "the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity".*** Another key difference between SEEA EA and the SNA lies in the treatment of ecosystem services. In the SNA, these flows remain outside the production boundary that establishes the set of goods and services that are the focus of measures of output, value added and gross domestic product (GDP). Measurement of ecosystem services, in both physical and monetary terms, through ecosystem accounting complements the estimates of output based on the SNA production boundary.

1.40 Further, the consistency with SNA concepts and principles of the SEEA EA approach to valuing the contribution of ecosystems is such that the monetary values can be used to provide complementary aggregates, such as of value added and wealth, which take into account the supply and use of ecosystem services and are adjusted for ecosystem degradation and enhancement.

1.41 The derivation of complementary aggregates can be presented through the compilation of a sequence of institutional sector accounts and balance sheets that build on the similarly labelled accounts in the SNA. Chapter 11 describes how these derivations can be undertaken. Two of their key features are: (a) the allocation of degradation to the economic unit that suffers the loss of ecosystem services rather than to the economic unit that causes the degradation;[21] and (b) the introduction of a non-SNA quasi-sector referred to as the ecosystem trustee that holds stewardship over the ecosystem services that do not directly benefit an individual or private economic actor.

21 Alternative presentations that apply the "polluter pays" principle for the allocation of degradation are described in chapter 12.

1.42 Other connections to standard economic accounts can be developed including extended supply and use tables (SUTs). In this case, there is particular interest in recording the use of ecosystem services by different economic units to better reflect the contribution of environmental assets to production and consumption patterns.

1.43 Like all other statistical methodology frameworks, the SNA is subject to revision on a periodic basis. Given the aim of ensuring alignment between SEEA accounting principles and treatments and those of the SNA, it will be necessary for the treatments discussed in SEEA EA to be revisited from time to time.

1.5.4 Connections to other statistical methodology outputs and guidance

1.44 SEEA EA incorporates the findings presented in a range of technical outputs on ecosystem accounting, as developed in the period from 2013 to 2020,[22] as well as those derived from a large number of projects and initiatives on the subject. Those materials, projects and initiatives, which were the products of different agencies in different contexts, played an important role in the testing of the framework rolled out in SEEA EEA (2012). That testing enabled the evaluation of technical and methodological options and an assessment of the relevance of a national accounting approach to ecosystem measurement for research, policy analysis and decision-making. A range of these findings were collected and incorporated in the Technical Recommendations in support of SEEA EEA.

22 These include Cropper and Khanna (2014); Maes and others (2013); United Nations Environment Programme (2014); and Weber (2014).

1.45 In addition to research focused specifically on ecosystem accounting there are a number of statistical methodological -related publications, handbooks and technical guidance documents that are of relevance for both the organization of data for the compilation of ecosystem accounts and the application of ecosystem accounting to thematic accounting and the derivation of indicators, among other endeavours. These documents include:

- SEEA methodological publications: *System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries* (Food and Agriculture Organization of the United Nations and United Nations, 2020); *System of Environmental-Economic Accounting for Energy* (SEEA-Energy)

(United Nations, 2019); and *System of Environmental-Economic Accounting for Water* (SEEA-Water) (United Nations, 2012), which provide guidance on accounting for stocks and flows in these areas

- Framework for the Development of Environment Statistics (FDES 2013) (United Nations, 2017) including the Basic Set of Environment Statistics (annex A), which provides guidance on the collection and presentation of environmental statistics and covers, inter alia, a number of themes related to ecosystem accounting, including measures related to ecosystem condition
- Global Statistical Geospatial Framework (United Nations, Department of Economic and Social Affairs, Statistics Division, 2019), which provides guidance from a statistical perspective on geospatial information-related concepts and terminology
- "Measuring the Sustainability of Tourism" website under the World Tourism Organization (ww.unwto.org/tourism-statistics/measuring-sustainability-tourism), which provides guidance on linking ecosystem accounting to measures of tourism activity
- Ocean accounts,[23] which provide a broad framework for connecting relevant elements of the SNA, the SEEA Central Framework and SEEA EA in order to harmonize priority ocean data covering economic, ecological, governance and social dimensions
- *Exploring Approaches for Constructing Species Accounts in the Context of SEEA EEA* (United Nations Environment Programme World Conservation Monitoring Centre, 2016), which provides guidance on how to apply an accounting approach to the compilation of information on species of special concern, such as those species of social, economic or conservation importance

1.5.5 Relationship to other global environmental measurement and assessment initiatives

1.46 In its broad coverage of all types of ecosystems, SEEA EA incorporates a wide range of ecological and biophysical data, including data on ecosystem extent and condition, as well as data on flows of ecosystem services that commonly need to be derived from hydrological or other biophysical models. In accordance with its aims, ecosystem accounting provides a robust framework and associated data in support of a variety of global environmental and sustainability initiatives involving comparable measurement and reporting activities carried out over time and across countries. In many cases, the information collected through the implementation of those initiatives can provide source data for the compilation of ecosystem accounts.

1.47 Some key initiatives are listed directly below, reflecting the wide range of programmes of work being implemented at the global, regional and national levels and within the corporate, academic and environmental non-governmental organization communities. These initiatives may be connected to work on ecosystem accounting and on the System of Environmental-Economic Accounting more broadly. They include:

- Monitoring of the Sustainable Development Goals and, in particular, monitoring of progress towards achieving Goals 6, 14 and 15
- Post-2020 global biodiversity framework under the Convention on Biological Diversity[24] and its monitoring framework

23 See the background document entitled *Technical Guidance on Ocean Accounting for Sustainable Development*, prepared by the Economic and Social Commission for Asia and the Pacific for the fifty-first session of the Statistical Commission, held from 3 to 6 March 2020. Available at https://unstats.un.org/unsd/statcom/51st-session/documents/BG-item-3h-TG_Ocean%20accounting_ESCAP-E.pdf.

24 United Nations, *Treaty Series*, vol. 1760, No. 30619.

- Measurement of land degradation under the United Nations Convention to Combat Desertification [25]
- Measurement of greenhouse gas (GHG) emissions and removals through activities in the land use, land-use chain and forestry (LULUCF) sector under the United Nations Framework Convention on Climate Change and associated nationally determined contributions
- IPBES regional and global assessments, including the IPBES values assessment
- Development of the area of wealth accounting, encompassing measures of the value of natural capital (United Nations Environment Programme and World Bank)
- International Union for Conservation of Nature (IUCN) assessment frameworks, including the Red List of Threatened Species, the Red List of Ecosystems and A Global Standard for the Identification of Key Biodiversity Areas: Version 1.0 (Gland, Switzerland, 2016); and knowledge products such as the World Database on Protected Areas (a joint project of the IUCN and the United Nations Environment Programme, and managed by the World Conservation Monitoring Centre (UNEP-WCMC)
- Group on Earth Observations Biodiversity Observation Network (GEO BON) programmes of work on biodiversity, including the listing of essential biodiversity variables (EBVs) and essential ecosystem services variables (EESVs); and the Group on Earth Observations Earth Observations for Ecosystem Accounting (EO4EA) initiative

[25] Ibid., vol. 1954, No. 33480.

1.48 The relevant measurement and reporting frameworks across these initiatives are currently not aligned at the level of data items and definitions, although all reflect the commitment to achieving a common broad and ambitious goal, which is to ensure that environmental stocks and flows become a standard feature of decision-making. There is consequently an opportunity for the statistical community to support improved alignment of data and indicators and to further enhance wider collaboration and engagement.

1.49 Given the range of environment-related measurement and reporting work under way, there is considerable opportunity for compilers of ecosystem accounts to assess the potential of the data derived from that work to be used or adapted for the purpose of compiling ecosystem accounts in their country. Based on the same rationale, consideration could be given to how data used in, for example, state of environment reports or environmental impact assessments might become sources of relevant information for accounting.

1.6 Measurement, implementation and application

1.6.1 Introduction

1.50 The roles of different agencies in the implementation of ecosystem accounting and the adoption of alternative compilation pathways are summarized in the present section. As users of the accounts will include policymakers and analysts, ecosystem and natural resource managers, private sector businesses, local communities and other stakeholders, implementation requires ongoing engagement with those users to ensure that the ecosystem accounts are fit for purpose.

1.6.2 Role of NSOs and other agencies

1.51 NSOs have traditionally focused on producing official statistics independently, often in relative isolation from other data producers. However, the role of NSOs began to change over the past several years, as new technologies have allowed for unparalleled levels of data collection from a variety of new sources and as official statistics have become one source of information among many. Increasingly, this has prompted NSOs to undertake the role of data stewards. In assuming that role, NSOs have shifted from functioning solely as statistics producers to acting also as service providers, which entails both facilitating a collaborative approach to data and statistics across different data and statistics communities and providing oversight and governance.

1.52 There is arguably no statistical domain that demonstrates the potential of NSOs to serve as data stewards more than ecosystem accounting. SEEA EA implementation has often been led by the official statistics community and NSOs, but given the high degree to which ecosystem accounting is cross-cutting and spatial in nature, implementation necessitates a highly collaborative approach and the active participation of representatives of many different agencies and disciplines, including geography, ecology, economics and statistics. There is also a need in many countries for coordination with agencies and experts at subnational administrative levels. Work is needed to fulfil a key objective, namely, the appropriate institutionalization of the processes (including data sharing), roles and responsibilities underpinning the compilation of ecosystem accounts.

1.53 Of particular significance for the collaborative process of ecosystem accounting is the role of environmental policy agencies and associated technical research agencies whose work focuses on managing data in the areas of, for example, geographical and remote sensing data, climate, water resources, biodiversity and environmental monitoring. These agencies, together with associated networks of scientists and researchers, often play a critical role in collecting and validating local environmental data and knowledge. Since, traditionally, NSOs have less experience working with those types of environmental data, collaboration with environmental policy and associated technical research agencies in the development of ecosystem accounts should be expected.

1.54 To ensure trust and quality, NSOs, in collaboration with relevant agencies, should provide oversight and governance through provision of an independent and expert opinion on data. Given the widespread interest in ecosystem accounting shown by multiple stakeholder groups (e.g. academia, government, the private sector), the role of NSOs in promoting high-quality ecosystem accounts is especially important. Moreover, the voice of NSOs can be recognized as authoritative by virtue of their independence and their particular and unique role within government.

1.55 The SEEA website[26] provides a range of materials designed to support implementation, including general advice on the establishment of programmes of work, compilation guidance documents and a knowledge base containing examples of SEEA work.[27] Two publications of the Statistics Division, *Guidelines on Biophysical Modelling for Ecosystem Accounting* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022a) and *Monetary Valuation of Ecosystem Services and Assets for Ecosystem Accounting. Interim version* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022b), provide advice specific to the implementation of ecosystem accounts. In addition, compilers of ecosystem accounts are encouraged to learn from experiences of other countries and regions.

[26] See https://seea.un.org/.

[27] See https://seea.un.org/content/knowledge-base for many examples of the application of ecosystem accounting in the SEEA knowledge base.

1.6.3 Approaches to the compilation of ecosystem accounts

1.56 Ecosystem accounts are most informative when they are not compiled as one-off, irregular or short-term studies of specific areas or environmental themes. Generally, the data generated from such studies do not support ongoing long-term measurement of trends or, by extension, the design and monitoring of policy responses. Aligned with the expectations associated with the preparation of common socioeconomic data – including national accounts, employment and population census data – is the expectation that, progressively, long time series of ecosystem accounting data can be established. This would provide the opportunity to strengthen and improve institutional arrangements and measurement approaches over time and would contribute to the compilation of enduring data sets. Those data sets could, in turn, underpin further research and analysis, which would, ideally, generate a virtuous circle of improved data supply.

1.57 The several alternative approaches to the compilation of ecosystem accounts lie along a spectrum. At one end are "spatially explicit" approaches, which entail comprehensive and detailed spatial measurement of ecosystem services and rigorous delineation of ecosystem assets. At the other end are "minimum spatial" approaches, which seek to provide a broad overview of trends among key ecosystem types and services. While the content of accounts compiled using an approach located at one end of the spectrum will be aligned conceptually with the content of accounts compiled using the approach situated at the opposite end, there will still be differences in the level of detail shown in the accounts (as reflected, for example, by the number of ecosystem types included). Under the minimum spatial approach, there is limited capacity to disseminate outputs in the form of maps (and other spatially referenced outputs) that display the location and configuration of ecosystem assets and the services supplied by those assets.

1.58 In practice, the approach to compilation of ecosystem accounts lies between these two ends of the spectrum, with implementation being dependent on (a) policy focus; (b) availability of source data; and (c) resources available for compilation. While increasing the level of spatial detail has the potential to increase the accounts' robustness and possibly open up a wider range of applications, it generally also increases the level of complexity of the compilation process. In practice, it is likely that the spatial resolution of the accounts will increase over time as more and better data become available and as methods and technologies improve.

1.59 A common starting point for ecosystem accounting is the compilation of ecosystem extent accounts, which provide a statistical frame for ecosystem accounts. Where national-level data are not available, global data sets can serve as the basis for a suitable first step. Beyond the extent account, depending on the data available and the issues that are of particular interest, efforts may be directed towards the compilation of ecosystem condition accounts for different ecosystem types and towards the quantification of ecosystem services flows. While not a mandatory component, monetary valuation, which commonly relies on the organization of a wide array of data in physical terms, could be undertaken as the final part of a compilation process.

1.6.4 Uses and applications of ecosystem accounting

1.60 In support of ongoing reporting requirements and discussion of emerging issues, the ecosystem accounts provide information that is:

- Comprehensive, that is, it encompasses accounting for all ecosystem types across the terrestrial, freshwater, marine and subterranean realms and for a wide range of ecosystem services

- Structured, that is, it follows an internationally agreed accounting framework coherent with agreed rules aligned with those of the SNA
- Consistent, that is, it presents data that are consistent over time and with respect to concepts and classifications
- Coherent, that is, it integrates a broad range of data sets in order to provide information on ecosystem services and assets
- Spatially referenced, that is, it links data spatially to the scale of ecosystems and enables the integration of data across different accounts
- Adaptable, that is, it allows for the use of targeted measurement scopes, which are appropriate to the context and can be increased over time (e.g. in the case of ecosystem services and ecosystem types)

1.61 The range of features of the information that ecosystem accounts are capable of providing facilitates support of economic and environmental policy- and decision-making. Consequently, ecosystem accounting can be applied, inter alia, to highlighting ecosystems and ecosystem services of particular concern to policymakers; supporting the design of policy responses and instruments; assisting in the ongoing management of ecosystems; monitoring the effectiveness of various policies through the use of performance indicators; providing detailed spatial information on ecosystem services supply; supporting assessments of biodiversity; and mainstreaming environmental data in economic and financial decision-making.

1.62 The features of the information organized according to SEEA EA are set out in a statistical methodology framework and data compiled and published under this framework have the potential to encourage increased use of common classifications and definitions. This should assist in reducing the costs associated with deriving and using data, widening opportunities for development of shared technologies and data management solutions and increasing the possibilities for sharing methods and undertaking collaborative research.

1.63 SEEA EA is intended primarily to support national-level decision-making, with a focus on connecting information on multiple ecosystem types and multiple ecosystem services to macro-level economic information (e.g. measures of national income, output, value added, consumption and wealth). At the same time, ecosystem accounting theory and practice is applicable at subnational scales as well. For example, ecosystem accounts can be used to support decision-making at the level of both individual administrative areas such as provinces and urban areas and environmentally defined areas such as water catchments, protected areas, biodiversity priority areas and coastal zones.

1.64 The compilation of ecosystem accounts often entails the use of spatially explicit data to analyse differences across locations and regions within a country, which can lead to a richer understanding of national-level information. Moreover, the use of spatially explicit data within the ecosystem accounting framework can support the coordination of local- and national-scale policies by enabling the establishment of an agreed common set of data and a common framing of the relationship between the environment and economic and human activity.

1.65 Through the utilization of a set of coherent data, ecosystem accounts can support the consistent application of a wide variety of approaches, including cost-benefit analysis, risk assessments, system-based modelling, scenario analysis and scenario-based forecasting, and trade-off analysis. The incorporation of available coherent environmental data into the decision-making processes carried out in the business and finance sectors complements the wide range of initiatives under way in those sectors, which reflect their recognition of the importance of ecosystems and biodiversity.[28] The incorporation of ecosystem account data can be used in conjunction with other methods and tools applied to policy- and decision-making. [29]

1.66 Ideally, accounts should be updated regularly (e.g. annually) on the basis of source data availability and user needs, so as to ensure that a structured, comprehensive and up-to-date database is in place to allow for a quick response to demands for specific policy-related information. Although an assessment of specific policies or investments would likely require information additional to that presented in the ecosystem accounts, data from the accounts should be capable of defining relevant structures and trends and, in many cases, will support the modelling of a wide range of environmental and economic impacts. Further, basing different assessments on a common underlying data set can result in improved comparison of policy alternatives.

1.67 Notwithstanding their many potential applications, ecosystem accounts do not provide exhaustive coverage of all relevant environmental data. Indeed, SEEA EA data complement the data collated using the SEEA Central Framework, which, as described in appendix A1.2, contains a wide variety of other types of data on the links between the environment and the economy, including data on flows of pollutants and residuals and measures of expenditure on environmental protection and restoration. Moreover, it is likely that the coverage of ecosystem accounts will not be complete, particularly in the initial stages of implementation: they may be focused, for example, on specific subnational areas or on a limited set of ecosystem services. Further, as outlined in section 1.2 above, within the context of monetary valuation, SEEA EA does not include all potential economic values, in particular consumer surplus and non-use values. Depending on user requirements, additional measurement and analysis may therefore be needed.

1.7 Structure of SEEA EA

1.68 SEEA EA comprises five sections A to E. Sections A to C comprise the international statistical standard describing the accounting framework and physical accounts. Section D describes internationally recognized statistical principles and recommendations for the monetary valuation of ecosystem services and assets. Section E describes applications and extensions of ecosystem accounting.[30]

1.69 SEEA EA is introduced in chapter 1 of section A, and the overview of the ecosystem accounting framework and associated relevant national accounting principles are considered in chapter 2. Together, these chapters cover the background of and rationale for ecosystem accounting, placing this work within the broader context of work on the measurement of the relationship between the environment and the economy. The various components of the ecosystem accounting framework introduced in chapter 2 are examined in greater depth in subsequent chapters.

1.70 Accounting for ecosystem extent and condition is covered in section B. The definition and delineation of spatial units for ecosystem accounting are the subject of chapter 3. Those units, referred to as ecosystem assets, serve as the building blocks of the accounting framework and provide the structure for the organization of data about ecosystems. Included in the chapter is a description of the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET), a reference classification for ecosystem types. Chapter 4 outlines the process through which data on the size of an ecosystem asset, referred to as ecosystem extent and usually measured in terms of area, can be organized and presented in an ecosystem extent account. Chapter 5 presents a three-stage approach to accounting for the condition of ecosystem assets, where ecosystem condition is measured in relation to ecosystem integrity and where

28 Such initiatives include the work of the Capitals Coalition, the Global Reporting Initiative (GRI), the International Integrated Reporting Council (IIRC), the Sustainability Accounting Standards Board (SASB) and the World Business Council for Sustainable Development (WBCSD), among many other organizations.

29 For a summary of potential applications, see the reports associated with the sessions of the Policy Forum on Natural Capital Accounting for Better Decision Making, available at www.wavespartnership.org/en/policy-forum-natural-capital-accounting-better-decision-making; and the SEEA policy guides issued by the Statistics Division, available at https://seea.un.org/content/enhanca-enhance-natural-capital-accounting-policy-uptake-and-relevance.

30 United Nations Statistical Commission, report on the fifty-second session, E/2021/24, decision 8g, https://unstats.un.org/unsd/statcom/52nd-session/documents/2021-30-FinalReport-E.pdf.

data on ecosystem characteristics are structured using the SEEA ecosystem condition typology (ECT) and are referenced to a condition appropriate for the ecosystem type.

1.71 Section C presents accounting for ecosystem services in physical terms. The focus of chapter 6 is on a wide range of conceptual issues including the link between ecosystem services and benefits, the defining characteristics of final and intermediate services, accounting treatments for selected ecosystem services and other flows, and the definition of ecosystem capacity. Also presented in the chapter is the SEEA ecosystem services reference list that provides descriptions for 33 ecosystem services. Building on SUTs, chapter 7 displays accounting entries for the ecosystem services flow account in physical terms and discusses specific measurement issues, such as defining measurement baselines for the quantification of ecosystem services flows for accounting purposes.

1.72 The monetary valuation of ecosystem services and ecosystem assets is considered in section D. Chapter 8 outlines the principles of monetary valuation for accounting purposes, highlighting the application of the concept of exchange value as described in the SNA. Chapter 9 outlines how accounting entries are obtained for the ecosystem services flow account in monetary terms, building on the same account in physical terms, and summarizes the appropriate valuation techniques for estimating flows of ecosystem services in monetary terms for accounting purposes. Chapter 10 describes the monetary ecosystem asset account, which incorporates entries for the opening and closing value of ecosystem assets and for changes in their value due to degradation, enhancement and other changes in value. Chapter 10 also describes the net present value (NPV) approach to the valuation of ecosystem assets. Chapter 11 demonstrates how the monetary values from the ecosystem services flow account in monetary terms and the monetary ecosystem asset account can be combined with the standard SNA accounts to compile extended economic accounts, including extended SUTs, extended balance sheets and extended sequence of institutional sector accounts.

1.73 Section E introduces a variety of applications and extensions of the ecosystem accounts. Chapter 12, recognizing the range of methods for valuation of ecosystems and related flows in monetary terms, considers complementary approaches to valuation, thereby placing ecosystem accounting values in a wider environmental-economic valuation context. Chapter 13 describes thematic accounting, that is, accounting developed to support discussion and analysis of specific environmental themes, including the themes of biodiversity, climate change, oceans and urban areas as examples. Chapter 14 examines the links between ecosystem accounts and indicators and indicator frameworks, including those associated with the monitoring of global agreements, such as those proposed for Convention on Biological Diversity and the 2030 Agenda for Sustainable Development.

1.74 Several chapters, including the present one, include appendices containing classifications, examples and other illustrative material designed to support the explanation of concepts and the compilation of accounts. Annex I to the publication presents a stylized example of accounting for a limited set of ecosystem types and ecosystem services. A research and development agenda is presented in annex II, which is followed by a glossary of key terms and a list of references.

Appendix A1.1
From SEEA EEA to SEEA EA: main conceptual changes

A1.1 SEEA EEA presented initial efforts to define a measurement framework for integrating biophysical data, tracking changes in ecosystems and linking those changes to economic and other human activity. At its forty-fourth session, in 2013, the Statistical Commission welcomed SEEA EEA as an important step forward in the development of a statistical framework for ecosystem accounting. The definitions and accounting treatments provided in SEEA EA build on the measurement framework elaborated in SEEA EEA.

A1.2 Research and testing of the concepts, definitions, classifications and treatments outlined in SEEA EEA have resulted in substantial refinement and clarification of the ecosystem accounting framework. The key areas of progress are noted in the present appendix. The endorsement of SEEA EEA led not only to technical advances but also to a substantial increase, as well in testing and experimentation of, awareness of, and involvement in, ecosystem accounting across many countries, disciplines and sectors. This broad engagement, particularly the engagement beyond the community of official statisticians, added considerable richness to the economic, ecological, geographical, accounting and statistical basis for ecosystem accounting.

A1.3 There has been a steady refinement of the choice of labels for and description of the types of spatial units. In SEEA EEA, the relationship among the three types of units – basic spatial units (BSUs), land-cover/ecosystem functional units and ecosystem accounting units – was framed as a hierarchy. In SEEA EA, the land-cover/ecosystem functional unit, which has now been relabelled as an ecosystem asset, is the key conceptual unit. While ecosystem accounting units (EAUs) have been relabelled as ecosystem accounting areas (EAAs), their role, as conceptualized within the ecosystem accounting framework, remains unchanged. BSUs have retained their place within SEEA EA but are now regarded as a means of implementing the ecosystem accounting approach rather than as elements in a nested hierarchy.

A1.4 SEEA EA provides an agreed classification of ecosystem types based on IUCN GET. This represents a significant advance over the classification, comprising broad classes of land-cover/ecosystem functional units set out in SEEA EEA. Associated with the SEEA EA classification are principles for the delineation of ecosystem assets by ecosystem type. Those principles now support the delineation of spatial units for ecosystem accounting based on the consistent application of data from various sources. Use of these principles has facilitated a more coherent description of accounting for ecosystem extent.

A1.5 SEEA EEA provided a basic description of accounting for ecosystem condition using a reference condition-based measurement approach. While SEEA EA has retained the use of that approach, it has considerably expanded the description of measurement. In particular, SEEA EA has determined the focus of measurement to be ecosystem integrity. It covers SEEA ECT for the organization of characteristics, variables and indicators of condition and outlines a three-stage approach to accounting for ecosystem condition entailing selection of variables, referencing of indicators and derivation of aggregate ecosystem condition indices. SEEA EA also describes the application of the approach to natural and anthropogenic ecosystems and focuses on its linkages to both biodiversity assessment and use of indicators of environmental pressures.

A1.6 The definition of ecosystem services in SEEA EA remains the same as that found in SEEA EEA and, in broad terms, the conceptual intent in the measurement of ecosystem services has not been changed. There have, however, been substantive improvements in the discussion of the links to benefits and well-being, the description of the boundary with abiotic flows and the definition of intermediate services, which were not defined explicitly in SEEA EEA. While a classification of ecosystem services has not been established, a comprehensive reference list of ecosystem services has been developed in consultation with the custodians of the leading international ecosystem services classifications and typologies. Moreover, the descriptions of accounting treatments for a number of ecosystem services, including biomass provisioning services, global climate regulation services and water supply-related services, have undergone significant refinement. Those refinements in the description of accounting treatments were reflected in the description of a complete SUT for ecosystem services in physical terms, which was introduced only in general terms in SEEA EEA.

A1.7 SEEA EEA introduced the concept of ecosystem capacity but without providing a specific definition. While SEEA EA does provide a definition of ecosystem capacity as well as descriptions of associated concepts such as potential supply and ecosystem capability, it does not present an example of an ecosystem capacity account.

A1.8 The challenges associated with the monetary valuation of ecosystem services and ecosystem assets are recognized in both SEEA EEA and SEEA EA. The use of the concept of exchange value has been retained, and an improved description has been provided on links to alternative valuation concepts, such as the concept of welfare value. Determining which valuation techniques can be applied to measurement of exchange values has been a focus of deliberation, and those techniques have been ranked in order of preference. The use of the NPV technique to value ecosystem assets in monetary terms has been retained, and discussion of its application in an ecosystem accounting context has been considerably expanded. Further, definitions of a range of entries in the monetary ecosystem asset account, including the terms *ecosystem degradation* and *ecosystem enhancement*, have been developed.

A1.9 The design of extended monetary accounts in which data from the ecosystem accounts are combined with data from the standard SNA accounts has been clarified. In annex A6 of SEEA EEA, two potential models for the sequence of institutional sector accounts had been presented. Research undertaken as part of the SEEA EA revision process identified a third alternative entailing the introduction of an ecosystem trustee. This alternative, presented in chapter 11, has been agreed upon as the appropriate approach for generating such a sequence of accounts.

A1.10 Apart from an introduction to accounting for biodiversity and for carbon stocks, the content of SEEA EEA does not extend beyond the presentation of ecosystem accounts and descriptions of their links to SNA sector accounts. In contrast, SEEA EA, in its last three chapters, covers a wide range of applications and extensions of ecosystem accounting, encompassing complementary approaches to valuation and derivation of indicators and design of combined presentations, as well as thematic accounting, which includes accounting for biodiversity and accounting for carbon stocks.

Appendix A1.2
Linking SEEA EA and the SEEA Central Framework

Introduction

A1.11 SEEA EA is designed to complement the SEEA Central Framework and thereby provide, together with the Central Framework, a complete description of the relationship between the environment and the economy through the application of the same accounting principles used by the SEEA Central Framework. The complementarity of the two frameworks can be considered both in the context of the definition of environmental assets and from the perspective of data coverage within a basic driving forces-pressure-state-impact-response (DPSIR) framework (European Environment Agency, 1999).

A1.12 The definition of environmental assets provided in the SEEA Central Framework encompasses the measurement of individual environmental assets (such as land, soil, water and timber) and ecosystem assets. This definition supports accounting in both the SEEA Central Framework and SEEA EA. The asset boundary established by this definition is broader than the asset boundary of the SNA since, unlike the SNA definition, it establishes a physical boundary for assets and does not require that flows of benefits must accrue to owners of environmental assets.

A1.13 Under the SEEA Central Framework, the focus of accounting within this broader asset boundary is on the types of individual resources such as minerals, timber, water, land and soil that are the components of the environment and are used in economic activity. The focus of accounting for environmental assets in SEEA EA is not only ecosystems per se but also in many senses, how their individual components function together. Consequently, there are often strong connections between accounting for individual environmental assets, as described in the SEEA Central Framework, and SEEA EA measures of ecosystem assets such as timber resources and forest ecosystems and measures of ecosystem services, for example, wood provisioning.

A1.14 With its focus on individual resources, accounting under the SEEA Central Framework considers only the benefits accruing from the use of those resources in production as defined by the SNA production boundary. Thus, the monetary value of the resources is linked to the values of minerals, energy, timber, fish and other resources extracted or harvested from the environment. In SEEA EA, the set of benefits within scope is broadened to include a wide range of ecosystem services. This covers both contributions to production as defined under the SNA and other services, such as air filtration, water regulation and recreation-related activities.

A1.15 The DPSIR framework is a common framing for measurement and analysis of the connection between the environment and the economy. The focus of SEEA EA is on the *state* and *impact* components of this framework. Thus, measures of changes in the mix of ecosystem types, changes in the condition of ecosystem assets and changes in the basket of ecosystem services provide a more complete picture of environmental state and the impacts of economic and human activity than that provided by the SEEA Central Framework accounts.

A1.16 On the other hand, through the SEEA Central Framework – in particular the measurement of physical flows (associated, for example, with water use, energy use, air emissions and solid waste), as well as the derivation of data on the stocks and use of natural resources – a richly informative perspective on the *pressure* exerted by economic activity on the environment and ecosystems can be developed. Moreover, the SEEA Central Framework supports the organization of data on the *response* to environmental issues through establishment of accounts for environmental taxes and subsidies, environmental protection expenditure and activities of the environmental goods and services sector (EGSS).

A1.17 While the potential exists for identifying features common to the measurement approach of the SEEA Central Framework and that of ecosystem accounting, a basic difference is that accounting under the Central Framework is focused on the national level, whereas ecosystem accounting has also a subnational-level focus, with measurement often entailing use of detailed spatial data and models. The integration of data from the SEEA Central Framework, for example, on pressures arising from residual flows, may require the spatial disaggregation of data on residual flows to locations within a country, so that the link between the residual flows and changes in ecosystem condition can be clearly established. A broad national-level comparison of residual flows and changes in condition is likely to miss important variations across locations within a country.

A1.18 In the area of monetary valuation, both SEEA EA and the SEEA Central Framework apply the exchange value concept and use the NPV approach for the valuation of environmental assets. The range of the flows that are within scope of valuation is the factor responsible for the primary difference between the two frameworks with respect to estimates of the monetary value of environmental assets. As noted above, in the SEEA Central Framework, flows are limited to those within scope of the SNA and are associated primarily with natural resource extraction and harvest. In ecosystem accounting, the scope of valuation is extended to capture all relevant ecosystem services. The inclusion in SEEA EA of a broad range of ecosystem services leads to an expansion of the scope of wealth since the underlying environmental assets are recognized as providing a wider set of benefits.

A1.19 These connections are addressed in greater detail below. While neither the Central Framework nor the SEEA EA framework on its own provides a complete body of information for analysing the relationship between the environment and the economy, when combined, however, they present a rich and coherent data set.

Recording environmental assets and related stocks

A1.20 As noted above, the SEEA Central Framework focuses on individual assets, that is to say, without consideration of the broader context or system in which those assets, commonly natural resources, are located. The SEEA Central Framework focuses, for example, on timber resources, whereas the focus of SEEA EA is the forest, which supplies not only wood biomass but also a range of other ecosystem services. The same kind of comparison can be drawn within the context of fish resources and marine or freshwater ecosystems.

A1.21 There should be coherence between recording of physical changes in the stock of ecosystem assets and related recording of changes in individual environmental assets. In other words, for the same accounting period and the same location, the changes in the stock of natural resources should correspond to the changes in the stock of ecosystem assets. For example, a change in ecosystem type from forest to cultivated land as recorded in the ecosystem accounts should be reflected in a reduction in timber resources as measured in the asset account for those resources.

A1.22 The link between data on ecosystem extent and data on land cover and land use needs to be highlighted in this context. For terrestrial areas there should be a reasonable concordance between data on land cover and ecosystem extent since land cover is a key variable in the delineation of ecosystem types. Further, for cultivated areas, data on land use may be considered in delineating ecosystem types.

A1.23 As a result of the coherence in the measurement of physical stocks, there are important advantages for ecosystem accounting in compilation since it becomes possible to use the range of materials, including documentation, that have been developed for the measurement of water resources, including *SEEA-Water* (United Nations, 2012), and for agriculture, forestry and fisheries, including the *System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries (SEEA AFF)* (Food and Agriculture Organization of the United Nations and United Nations, 2020). While these materials, generally speaking, have not been developed for ecosystem accounting purposes, they can support, especially in the context of methods and data sources, the development of relevant estimates and accounts.

A1.24 SEEA EA considers two areas, namely, accounting for carbon and accounting for species populations, where the asset accounting approaches based on measurement of stocks and changes in stocks as described in the SEEA Central Framework are applied. Moreover, the range of measurement-related materials emerging in these two areas can be used to support the measurement of ecosystem assets and ecosystem services and should be coherent with the individual environmental asset accounts of the Central Framework.

A1.25 The SEEA Central Framework defines the concept of natural resource depletion and introduces the concept of ecosystem degradation. These concepts are distinguished on the basis primarily of scope of measurement, mirroring the distinction between a focus on individual environmental assets and a focus on ecosystem assets. That is to say, depletion is defined in relation to the using up of the stock of resources relative to rates of regeneration, while degradation is defined in relation to changes in condition and future flows of ecosystem services.

A1.26 Since measurement of depletion centres on an individual resource with a single benefit stream, a direct connection can be made between changes in the stock of the resource and changes in future benefit streams. For degradation, the relationship is more complex since in this case a bundle of ecosystem services is generally supplied by a single ecosystem asset and the relationships between each service, and the changes in ecosystem condition will vary. Nonetheless, for a given ecosystem asset, there should be a reasonably close relationship between measures of depletion and measures of degradation as they pertain to provisioning services such as for wood or fish biomass.

Environmental flows

A1.27 The SEEA Central Framework discusses accounting for environmental flows – such as flows of water, energy, GHG emissions and solid waste – which are recorded in physical terms. The defining characteristics of three types of flows – natural inputs, products and residuals – are set out in detail. In the Central Framework, ***natural inputs are defined as "all physical inputs that are moved from their location in the environment as a part of economic production processes or are directly used in production"*** (para. 3.45). In general terms, this definition encompasses the set of provisioning services that contribute to the production of agricultural, forestry, fisheries and similar outputs.

A1.28 A number of differences in scope between the SEEA Central Framework and SEEA EA should be noted. As defined in the Central Framework:

- Natural inputs include inputs of mineral and energy resources, inputs from soil resources (excavated) and energy inputs from renewable sources (e.g. solar, wind). These inputs are excluded from the scope of ecosystem services but may be recorded as abiotic flows within the SEEA EA framework.
- Natural inputs include inputs of timber, aquatic resources (e.g. fish) and other biological resources but only in cases where the production process does not entail cultivation or is unmanaged since cultivated biological resources are produced within the economy. In SEEA EA, provisioning services are recorded in contexts both of cultivation and of non-cultivation.
- Natural inputs include inputs of water resources. In SEEA EA, following the treatment presented in chapter 6, these flows may be recorded as a proxy for the ecosystem services underpinning the supply of water, such as water regulation and water purification but should otherwise be recorded as abiotic flows.
- Natural inputs include inputs of nutrients and carbon, nitrogen and other elements. These flows are not commonly recorded in an ecosystem accounting context but may be relevant for measurement of some regulating and maintenance services, for example, in the context of recording global climate regulation services and water purification services.
- Natural resource residuals represent those flows of natural resources that are extracted or harvested and immediately returned to the environment. Examples include discarded catch in fishing and felling residues in forestry. In SEEA EA, flows of provisioning services are recorded in gross terms before natural resources residuals are recorded. Recording is thereby aligned with the gross recording of natural inputs used in the SEEA Central Framework.

A1.29 Physical flows of products occur within the economy and are therefore not recorded within SEEA EA. Nonetheless, it should be possible, in concept, to link flows of final ecosystem services that contribute to SNA benefits to physical flows of products. For example, biomass provisioning services could be linked to flows of food and other products to which they are inputs. This may be of particular relevance to the development of "footprints" and the understanding of the extent to which ecosystem services are embodied in traded goods and services.

A1.30 As defined in the SEEA Central Framework, ***residuals are "flows of solid, liquid and gaseous materials, and energy that are discarded, discharged or emitted by establishments and households through processes of production, consumption or accumulation"*** (Central Framework, para. 3.73). In general, these physical flows are not recorded directly in the ecosystem accounts. Instead, they are reflected either in measures of environmental pressures that may be used as proxies in the assessment of ecosystem condition; or in measures of the flow of ecosystem services provided by the ecosystem assets that receive, store or process the relevant residual. For example, data concerning particulate matter less than 2.5 micrometres in diameter (PM2.5) absorbed by trees would be used in the measurement of air filtration services.

A1.31 While SEEA EA is not directly aligned with the SEEA Central Framework with respect to recording of residual flows, the quantities of residual substances that are not broken down or absorbed are of particular interest in the context of ecosystem accounting. Indeed, since flows of residuals are likely to affect the capacity of ecosystem assets to supply ecosystem services, developing the potential to quantify this type of feedback loop is an important motivation for clarifying the links between ecosystem accounting and accounts under the Central Framework. Moreover, information on residual flows is relevant to the assessment and valuation of ecosystem disservices and externalities, a topic discussed in chapter 12 of the present publication.

A1.32 The basic structure of the ecosystem services flow accounts is derived, with three main alterations described directly below, from the design of the physical supply and use tables (PSUTs) introduced in the SEEA Central Framework. First, unlike the PSUT, which contain just one column for the environment as a whole, the ecosystem services flow accounts contain multiple columns, each encompassing a different ecosystem type.

A1.33 As noted above, the PSUT covers three types of flows: natural inputs, products and residuals. While the concept of ecosystem services is in general linked to that of natural inputs as defined in the Central Framework, the Framework's coverage of natural inputs is limited to provisioning services (as discussed above). Flows of regulating and maintenance services and cultural services are covered by SEEA EA but are not included in the SEEA Central Framework.

A1.34 Lastly, the SEEA Central Framework does not consider the ways in which different stocks and flows may be connected spatially (i.e. it adopts an individual resource perspective) and rather than enable the location of ecosystems and their services to be reflected in the accounts, the Central Framework focuses on accounting at national scale. In contrast, the ecosystem services flow account has the capacity to record intermediate services, which reflect the dependencies among ecosystem assets. Further, it has the added potential to present results from accounting in the form of maps.

Environmental transactions

A1.35 The focus of chapter IV of the SEEA Central Framework is the recording of environmental transactions, including environmental taxes and subsidies and other environment-related payments, as well as environmental activity accounts. Information on environmental activities, particularly those related to the restoration of ecosystems, may be of particular relevance for both the compilation of ecosystem accounts and the provision of a more comprehensive description of policy responses, for example, to changes in ecosystem condition. To support the assessment of the effectiveness of any ecosystem-related expenditure, measures of expenditure on, say, ecosystem restoration, for example, may be compared with changes in ecosystem condition and changes in flows of ecosystem services.

A1.36 Of the greatest relevance in this regard are 4 of the 16 classes of environmental protection activities described under the Classification of Environmental Activities (SEEA Central Framework, annex I, sect. A): protection of ambient air and climate (class 1); protection of biodiversity and landscapes (class 6); management of other biological resources (excluding timber and aquatic resources) (class 13); and management of water resources (class 14).

A1.37 Environmental taxes and subsidies and other environment-related payments commonly reflect the direct connection between a specific activity and its effect on specific ecosystems and the services that they provide. For example, taxes may be imposed to reduce pollution, which, if unaddressed, would otherwise reduce the condition of river systems; and payments may be made to ecosystem managers for their efforts to conserve certain areas of land or to maintain the population of certain species (e.g. pollinator species). In this context, data on taxes and subsidies derived from accounting under the SEEA Central Framework, when available at a sufficient level of granularity, can be compared with the ecosystem changes recorded in the ecosystem accounts in order to support assessment of the effectiveness of policy instruments.

Chapter 2
Principles of ecosystem accounting

2.1 Introduction

2.1 The present chapter provides a summary of the ecosystem accounting framework, its core conceptual components, the main accounts and relevant national accounting principles. It demonstrates the nature of the connections between the different accounts and explains the integration of ecological and economic approaches to describing the relationship between the environment and the economy.

2.2 Overview of the ecosystem accounting framework

2.2.1 An accounting approach

2.2 The essence of an accounting approach lies in the systematic recording of data on relevant stocks and flows. In corporate accounting, the focus of accounting is business units and in national accounting the focus is a range of different economic units[31] (including businesses, households, governments) located in a geographical area, which is usually a country. Accounting can also be undertaken for an individual asset such as a house.

[31] Referred to in the SNA as institutional units.

2.3 The focus of ecosystem accounting is ecosystems. Ecosystem accounting therefore aims at recording data on the stocks and flows of selected ecosystems in a systematic manner. While ecosystems are the initial focus, the accounting approach applied in SEEA EA also encompasses documenting the relationships among ecosystems, people and economic units. This provides a basis for analysing the role played by ecosystems in supporting economic and other human activity and for understanding the impact of economic and human activity on ecosystems.

2.4 Ecosystems can be attributed to specific locations. Indeed, the measurement of ecosystems is most commonly undertaken with an understanding of where different ecosystems are located, how they are arranged in relation to other ecosystems and how they are changing over time. Ecosystem accounting therefore focuses considerable attention on recording data on stocks and flows in a spatially explicit manner.

2.5 The approach described in SEEA EA has two particular features. First, it presents accounting concepts and structures in both physical and monetary terms. Second, it applies the accounting principles for the national accounts described in the 2008 SNA. This facilitates comparison of data from ecosystem accounts with data from conventional economic accounts, for example, measures of GDP.

2.2.2 Measurement perspectives on ecosystems

2.6 As defined in the Convention on Biological Diversity, an ***ecosystem is a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.***[32] Ecosystems change as a result of natural processes (e.g. succession, natural disturbances such as storms), wider environmental

[32] See article 2 of the Convention, entitled "Use of terms", available at www.cbd.int/convention/articles/?a=cbd-02.

dynamics such as climate change, and direct human actions involving deliberate management or disturbance, such as conversion of ecosystems to other uses, extraction of natural resources, and restoration and conservation activity.

2.7 While ecosystems are the clear focus for accounting, the functional ecological unit that constitutes an ecosystem can be viewed in a number of different ways that are all relevant in different measurement contexts and for different purposes. The statistical framework of SEEA EA integrates these various perspectives. Five distinct measurement perspectives – spatial, ecological, societal benefit, asset value and institutional ownership – are relevant:

- **Spatial**: a comprehensive measurement base of statistical units is formed through use of the ecosystem concept to establish the number of occurrences of ecosystems within a defined territory that can be classified in mutually exclusive ways.
- **Ecological**: the ecosystem concept is the focus for measurement of ecosystem integrity, health and condition and serves to underpin concepts such as ecosystem resilience and the assessment of ecological thresholds.
- **Societal benefit**: ecosystems are viewed as a source of benefits for people, the economy and society, potentially in terms of a relational connection or in the more economic sense of supplying services and benefits.
- **Asset value**: ecosystems are viewed as assets that provide services and benefits into the future depending on their ecological status and the social demands for ecosystem services. Issues of ecosystem degradation and enhancement are considered from this perspective.
- **Institutional ownership**: ecosystems are considered in relation both to existing economic and legal entities and to issues of stewardship and allocation of degradation costs.

2.8 While these perspectives involve different measurement considerations, they are all fundamentally interconnected, since they have the same underlying measurement focus, namely, the ecosystem.

2.9 Under each of these perspectives, various labels are used to reflect specific understandings or interpretations of the ecosystem being measured. In SEEA EA, the label "ecosystem asset" is applied to avoid the confusion stemming from use of different labels under different perspectives within the ecosystem accounting framework and to support the integration of perspectives. The label "ecosystem asset" is therefore used to refer to the individual spatially defined statistical units that compose the set of ecosystems that determine the scope of the accounts (under the spatial perspective); to the ecological functional units that are the focus of biophysical measurement and assessment (under the ecological perspective); to the supply or producing units that deliver ecosystem services and associated benefits (under the societal benefit perspective); to the assets that are stores of future value (under the asset value perspective); and to the entities that have a status in their own right or may be linked to existing legal, social and institutional units (under the institutional ownership perspective).

2.10 A unique feature of ecosystem accounting is its use of the same statistical unit across all accounts, building on the measurement base established through the spatial perspective. While this may represent a measurement compromise for any single perspective, it has the significant advantage of facilitating the coordination and integration of data in a manner that supports informed discussion across perspectives.

2.11 It is the spatial perspective that supports the linkage of the components of the accounting framework and the definition of *ecosystem assets*. Thus, ***ecosystem assets***

are contiguous spaces covered by a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions speaks directly to that perspective. This definition is a statistical representation of the scientific l concept of ecosystem as defined under the Convention on Biological Diversity. The definition is therefore not bound to other measurement perspectives and should not be regarded as being specifically linked to an ecological, economic or institutional interpretation of ecosystems. Defined in this way, ecosystem assets remain nested within the broader concept of environmental assets as defined in the SEEA Central Framework, in which are defined as components of the biophysical environment and are not linked to such considerations as ecological status, benefit flows or ownership.

2.2.3 Logic of the ecosystem accounting framework

2.12 The central logic of the ecosystem accounting framework builds from the definition of an ecosystem asset. A set of ecosystem accounts encompasses those ecosystem assets within a defined EAA. The ***EAA is the geographical territory for which an ecosystem account is compiled.*** An EAA may be defined by, for example, the boundary of a country, a subnational administrative area, a water catchment or a protected area. Within an EAA, the ecosystem assets reflect different ecosystem types, each with its own structure, function, composition and associated ecological processes.

2.13 Information on the ecosystem types will be reflected in measures of ecosystem extent and ecosystem condition. ***Ecosystem extent is the size of an ecosystem asset.*** It is most commonly measured in terms of spatial area. ***Ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics.***

2.14 Ecosystem assets supply a bundle of ecosystem services that reflect various ecosystem characteristics and processes as well as the ecosystem type; the extent, condition and location of the asset; and the patterns of use by economic units (including households, businesses and governments). ***Ecosystem services are the contributions of ecosystems to the benefits that are used in economic and other human activity.*** In this definition, use incorporates direct physical consumption, passive enjoyment and indirect use. Further, economic and other human activity encompasses all forms of interactions between ecosystems and people, including both in situ and remote interactions.

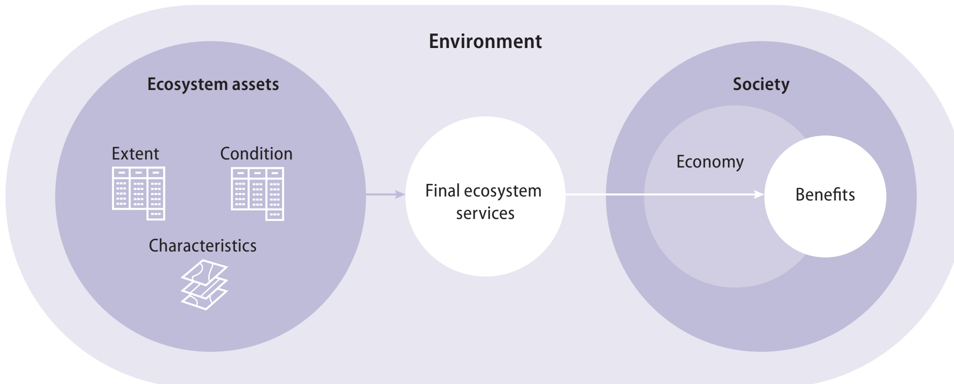
2.15 ***Benefits are the goods and services that are ultimately used and enjoyed by people and society.*** The benefits to which ecosystem services contribute may be captured in current measures of production (e.g. food, water, energy, recreation) or may be outside such measures (e.g. clean water, clean air, flood protection).

2.16 In an accounting context, flows of ecosystem services are observable interactions between economic units, people and ecosystems. While many of these interactions will not be reflected in exchanges in monetary terms, some of the value of those interactions can nonetheless be represented in those terms.

2.17 The relationships among these key components of ecosystem accounting are displayed in figure 2.1.

2.18 The connection between the stock and flow components of the ecosystem accounting framework can be embodied in the concept of ecosystem capacity, which, in broad terms, refers to the ability of an ecosystem asset to provide services into the future. Measures of ecosystem capacity with respect to ecological limits are therefore relevant, and, in accounting terms, an ecosystem's capacity will underpin a store of future value.

Figure 2.1
General ecosystem accounting framework



2.2.4 Ecosystem accounting framework: ecological considerations

2.19 Often ecosystems are perceived as more or less "natural" systems that are subject to human influence to only a limited extent. However, a wider perspective is necessary based on the understanding that human activity is embedded within and influences ecosystems across the world. Different degrees of human influence can be observed. For instance, in a natural forest or wetland, ecosystem processes exert the dominant effect on the dynamics of the ecosystem and there are likely to be fewer impacts from human management of the ecosystem or from human disturbances. At the other end of the spectrum – for example, in intensively cultivated fields or in ponds where there is intensive aquaculture – ecosystem processes are heavily influenced by human management. Ecosystems close to, or within, areas of human settlement may be significantly affected by human activity and disturbances, such as pollution, but may nonetheless retain some characteristics of functioning ecosystems. Ecosystem accounting encompasses ecosystem types across this entire spectrum in line with the broad scope of environmental assets as defined in the SEEA Central Framework.

2.20 When ecosystems are assessed, their location and how they function should be considered. Key spatial properties of an ecosystem's location are its extent, size or area; its spatial configuration (the way in which its various components are arranged and organized); the landscape or seascape forms[33] (e.g. mountain regions, coastal areas) within which the ecosystem is situated; and climate and associated seasonal patterns. Key properties of an ecosystem's functioning are its abiotic components (e.g. mineral soil, air, sunshine, water); its biotic components (e.g. flora, fauna, microorganisms); its structure (e.g. the trophic layers within the ecosystem); its processes (e.g. photosynthesis, decomposition); and its functions (e.g. recycling of nutrients, primary productivity).

2.21 Ecosystems can be identified at different spatial scales; for instance, a small pond and a tundra stretching over millions of hectares may both be considered an ecosystem. In addition, ecosystems are interconnected and are commonly nested and overlapping. They are also subject to processes that operate over varying timescales. Consequently, the scale of analysis will depend on whether the focus is on the internal interactions within ecosystems or, more broadly, on ecosystem types.

33 A landscape or seascape (including those involving freshwater) is defined for accounting purposes as a group of contiguous, interconnected ecosystem assets representing a range of different ecosystem types.

2.22 It is widely recognized that ecosystems are subject to complex dynamics. The propensity of ecosystems to withstand pressures to change, or to return to their initial condition following natural or human impact, is called ecosystem resilience. Ecosystem resilience is not a fixed, given property and may change over time, owing, for example, to ecosystem degradation (e.g. through removal of timber from a forest), ecosystem enhancement (e.g. through restoration of wetlands) or external effects (e.g. climate change). Other aspects of the complex dynamics of ecosystems are reflected in the presence of thresholds, tipping points and irreversibilities that are breached when ecosystem processes break down.

2.23 These complex dynamics and the associated non-linear relationships, which are evident over multiple and intersecting time frames, between the different ecosystem characteristics make the behaviour of ecosystems as a function of human and natural impacts difficult to predict, although there have been significant improvements in the understanding of those dynamics. The dynamics and relationships can be revealed through a time series of accounts that record measures of ecosystem extent and ecosystem condition. Further, the ecosystem services flow account can record the effects of changes in ecosystem dynamics over time in terms of changes in the supply and use of ecosystem services. Expected future flows of ecosystem services will be affected by expected ecosystem dynamics, which should in turn affect assessments of ecosystem capacity and monetary values of ecosystem assets.

2.24 Understanding biodiversity is integral to assessment of the composition, structure and function of ecosystems. According to the definition provided in the Convention on Biological Diversity, ***biodiversity is the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.***[34] SEEA EA incorporates data on aspects of ecosystem diversity and between-species diversity (commonly referred to as species diversity). The effects of levels of, and changes in, within-species diversity (commonly referred to as genetic diversity) are implicit but not separately identified in ecosystem accounts.

2.25 While the processes contributing to changes in biodiversity are many and varied, some generic types of processes leading to such changes at the ecosystem and species levels can nonetheless be identified. At the ecosystem level, biodiversity loss is caused by the conversion, reduction or degradation of ecosystems (or habitats). Generally, as the level of human use of ecosystems increases or intensifies above critical thresholds, biodiversity loss increases and the capacity to maintain ecosystem function is reduced. The corollary is that increases in biodiversity, for example, through habitat restoration or natural succession, are shown to lead to improvements in maintaining function of ecosystems and increases in their resilience. The implications of these changes for flows of ecosystem services depend on the context and vary from service to service.

2.26 At the species level, biodiversity loss is characterized by a decrease in abundance of many endemic species existing in a particular area; at the same time, some species, in particular those that benefit from disturbed habitats, increase in abundance. The extinction of the endemic species is often the final step in a long process of gradual reductions in abundance. In many cases, there is an initial increase in local or national species richness (i.e. the total number of species, regardless of origin or abundance) because of the introduction or favouring of exotic species by humans.[35] However, owing to these changes, ecosystems lose their regional endemic species and become more and more alike through a process described as homogenization.[36]

34 See Convention on Biological Diversity, art. 2, entitled "Use of terms", available at www.cbd.int/convention/articles/?a=cbd-02.

35 This is the so-called intermediate disturbance diversity peak (see Lockwood and McKinney (2001)).

36 See Lockwood and McKinney (2001); and Millennium Ecosystem Assessment (2005).

2.2.5 Ecosystem accounting framework: economic considerations

2.27 Ecosystem services are supplied by ecosystem assets, either by a single ecosystem asset or by multiple ecosystem assets operating collectively. In this framing, ecosystem assets may be characterized as producing units. For accounting purposes, it is assumed to be possible to attribute the supply of each ecosystem service to a single ecosystem type (e.g. to attribute wild fish provisioning services to a lake) or, where the supply of a service involves a combination of different types of ecosystem assets (e.g. flood control services across a catchment), to estimate the contribution of each associated ecosystem type to the total supply.

2.28 Ecosystem services encompass a wide range. They may be categorized as provisioning services (i.e. those related to the supply of food, fibre, fuel and water); regulating and maintenance services (i.e. those related to filtration, purification, regulation and maintenance activities for air, water, soil, habitat and climate); and cultural services (i.e. experiential and non-material services reflecting the perceived or realized qualities of ecosystems whose existence and functioning enable individuals to derive a variety of cultural benefits). A reference list of ecosystem services designed for ecosystem accounting purposes is presented in chapter 6.

2.29 In many instances, the receipt of benefits by economic units entails a joint production process involving inputs from an ecosystem (i.e. ecosystem services) and human inputs including combinations of labour, produced assets, intermediate inputs (e.g. fuel or fertilizer) and individuals' leisure time. For example, the contribution of an ecosystem (e.g. a lake) to the growth of wild fish, which is supplied by that ecosystem and used by an economic unit (e.g. a fisherman), must be distinguished from benefits that, in this case, are the fish sold by the fisherman to other economic units. Further, ecosystem accounting recognizes that the combination of inputs will vary. Thus, for example, where fish are sourced from aquaculture facilities, the ecosystem contribution is significantly lower, since much of the ecosystem contribution will have been substituted by produced inputs.

2.30 All ecosystem services reflect underlying ecosystem characteristics and processes, such as nutrient cycling, photosynthesis and canopy cover, but SEEA EA does not undertake to systematically record those characteristics and processes. Rather, the focus of ecosystem accounting is on the resulting supply of ecosystem services to economic units, including businesses and households (for example, the supply of recreation-related services by local parks to households). The supply is recorded as transactions between ecosystem assets (the suppliers) and economic units (the users) and is treated as final ecosystem services since this represents the final output of an ecosystem before interaction with the economy. In order for a supply of final ecosystem services to be recorded, there must be a corresponding use by an economic unit.

2.31 The ecosystem accounting framework also supports the recording of flows of intermediate services, which are flows of services between and within ecosystem assets and, like all other ecosystem services, and reflect underlying ecosystem characteristics and processes. Recording these flows supports an understanding of the dependencies among ecosystem assets, for example, within a water catchment.

2.32 The definition of ecosystem services and the approach to their recording are designed to support integration of ecosystem accounting data with data on the production of goods and services that are currently recorded in the standard national accounts. In effect, ecosystem accounting recognizes a set of flows that are not recorded within the current production boundary of the SNA. The approach taken provides the opportunity to compile broader measures of output, income and consumption.

2.33 Recognition of ecosystems as stores of value related to future flows of ecosystem services has three implications. First, it allows the connection to be made between the extent and condition of ecosystem assets and the potential of those assets to supply services and associated benefits into the future and for future generations. That connection can be embodied in the concept of ecosystem capacity and is also related to the concepts of option value and insurance value as applied to ecosystems. These topics are discussed in greater detail in chapter 6.

2.34 Second, recognition of ecosystems as a store of value serves to highlight the importance of investment in and management of ecosystem assets as a means of supporting the future supply of ecosystem services. There may be a wide range of motivations for investment in ecosystem assets and there is a range of ways in which accounts can present data to demonstrate the connection between those assets and the economic units undertaking such an investment.

2.35 Third, recognition of ecosystems as a store of value facilitates a discussion on the scope of the value or values that should be considered in relation to ecosystems, based on the understanding that no single perspective is all-encompassing. Ecosystem accounting accommodates a perspective founded on accounting and economic principles, according to which ecosystem value is embodied in the expected future flows of services. While this perspective is useful in some contexts, it does not, and cannot, provide a complete representation of the value of an ecosystem to society. In section 2.4 on the framing of values for ecosystem accounting, this topic is discussed in greater depth.

2.3 Set of ecosystem accounts

2.3.1 Ecosystem accounts

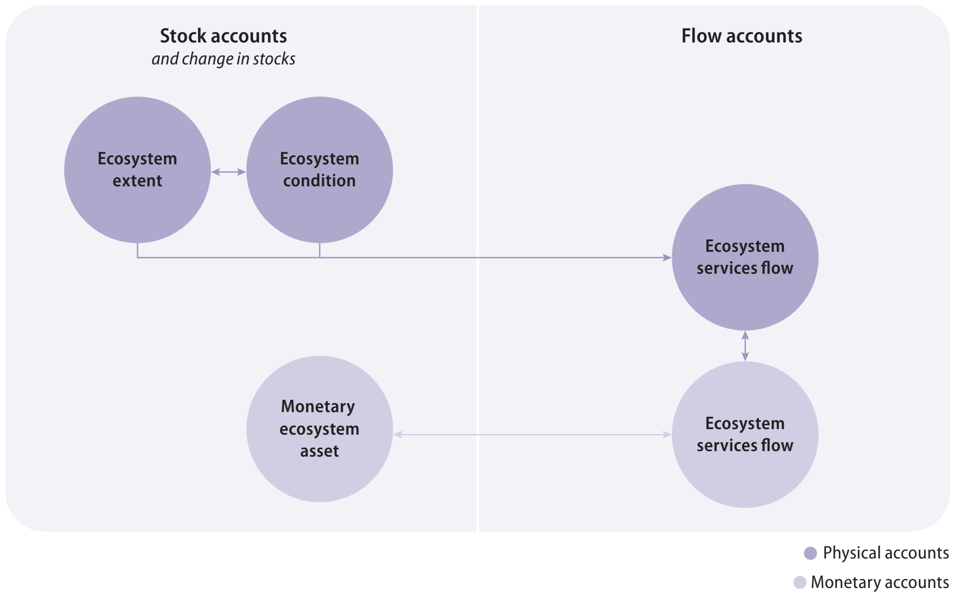
2.36 SEEA EA presents a system of integrated *ecosystem accounts*. SEEA EA also describes *related accounts and presentations*, which provide for complementary presentations, connections to the SNA and the SEEA Central Framework, and accounting information for policy-relevant themes. These various accounts and presentations are summarized in the present section.

2.37 The five ecosystem accounts within the SEEA EA accounting system, listed in table 2.1, are strongly interconnected and provide a comprehensive and coherent view of ecosystems. There is no single, all-encompassing ecosystem account, and, while SEEA EA has been designed as a system of *integrated accounts*, each account has merit in its own right and is a source of valuable information.

Table 2.1
Ecosystem accounts

1	Ecosystem extent account – physical terms
2	Ecosystem condition account – physical terms
3	Ecosystem services flow account – physical terms
4	Ecosystem services flow account – monetary terms
5	Monetary ecosystem asset account – monetary terms

Figure 2.2
Connections between ecosystem accounts



2.38 The logic underpinning the connections between the various ecosystem accounts is articulated in figure 2.2. As regards compilation, there are particular connections (a) between the ecosystem extent account and the ecosystem condition account with respect to their focus on the description of ecosystem characteristics; (b) between those two accounts and the ecosystem services flow account in physical terms, since the characteristics of an ecosystem will influence the supply of ecosystem services; (c) between the ecosystem services flow accounts in physical and monetary terms stemming from the use of data on the prices of ecosystem services; and (d) between the ecosystem services flow account in monetary terms and the monetary ecosystem asset account since the latter requires estimation of future flows of ecosystem services. Given all of these connections, supporting the coherence of various ecological and economic data is understandably a core feature of ecosystem accounting.

2.39 **Ecosystem extent accounts** organize data on the extent or area of different ecosystem types. Data from extent accounts can support the derivation of indicators of composition and change in ecosystem types and thereby provide a common basis for discussion among stakeholders, including discussions related to conversions between different ecosystem types within a country. Compilation of these accounts is also relevant in determining the set of ecosystem types appropriate for underpinning the structure of other accounts. Chapter 3 describes how ecosystem assets are delineated,

Table 2.2
Stylized ecosystem extent account (area)

Accounting entries	Stylized ecosystem types						Total
	Forests	Lakes	Crop-land	Urban areas	Wet-lands	Seagrass	
Opening extent							
Additions to extent							
Reduction to extent							
Closing extent							

including the classification of the various ecosystem types. Ecosystem extent accounts are discussed in chapter 4. A stylized ecosystem extent account is presented in table 2.2.

2.40 **Ecosystem condition accounts.** A central feature of ecosystem accounting is its organization of biophysical information on the condition of different ecosystem types. The ecosystem condition account organizes data on selected ecosystem characteristics in relation to a reference condition in order to provide insight into the integrity of ecosystems. It can also organize data relevant to the measurement of the capacity of an ecosystem to supply different ecosystem services. A stylized ecosystem condition account that records opening and closing condition indices for different ecosystem types and changes in those indices by type of condition characteristic is presented in table 2.3. The compilation of the ecosystem condition account and the derivation of indices are described in chapter 5.

2.41 **Ecosystem services flow accounts – physical terms.** The supply of final ecosystem services by ecosystem assets and the use of those services by economic units, including households, enterprises and government, constitute one of the central features of ecosystem accounting. Using an SUT structure, the ecosystem service flow accounts record the flows of final ecosystem services supplied by ecosystem assets and used by economic units during an accounting period and also allow for the recording of intermediate services flows between ecosystem assets. Chapter 6 provides a discussion of the concepts related to ecosystem services and presents a reference list of ecosystem services. The ecosystem services flow account in physical terms is described in chapter 7.

Table 2.3
Stylized ecosystem condition account (condition indices)

	Stylized ecosystem types					
Accounting entries	Forests	Lakes	Cropland	Urban areas	Wetlands	Seagrass
Opening condition value						
Change in abiotic ecosystem characteristics (physical and chemical state)						
Change in biotic ecosystem characteristics (composition, structure and function)						
Change in landscape/seascape characteristics						
Net change in condition						
Closing condition value						

2.42 **Ecosystem services flow accounts – monetary terms.** Estimates of ecosystem services in monetary terms are commonly based on estimations of prices for individual ecosystem services multiplied by the physical quantities recorded in the ecosystem services flow account in physical terms. Concepts, definitions, treatments and measurement techniques for the monetary valuation of ecosystem services are discussed in chapters 8 and 9. A stylized ecosystem services flow account structure is presented in table 2.4.

2.43 **Monetary ecosystem asset accounts.** Asset accounts are designed to record information on stocks and changes in stocks (additions and reductions) of assets. The ecosystem monetary asset account records this information in monetary terms for ecosystem assets based on the monetary valuation of ecosystem services and application of the NPV approach to obtain values in monetary terms for those assets at the beginning and end of each accounting period. The measurement of changes in asset values due, for example, to ecosystem enhancement, ecosystem degradation and ecosystem conversion are also included in this account. Asset accounts are described in chapter 10. A stylized monetary ecosystem asset account is presented in table 2.5.

Table 2.4
Stylized ecosystem services flow account (physical units or currency)

Accounting entries	Types of economic units				Stylized ecosystem types						
	Industries	Government	Households	Rest of the world	Forests	Lakes	Cropland	Urban areas	Wetlands	Seagrass	Total
Supply of ecosystem services											
Provisioning services											
Regulating and maintenance services											
Cultural services											
Use of ecosystem services	Final ecosystem services (used by economic units)				Intermediate services (used by ecosystem assets)						
Provisioning services											
Regulating and maintenance services											
Cultural services											

2.3.2 Related accounts and presentations

2.44 The ecosystem accounts provide an integrated and comprehensive perspective on ecosystems in both physical and monetary terms. Nonetheless, for both compilation and analytical purposes, there are a number of related accounts and presentations that may be appropriate for purposes of monitoring and analysis in different circumstances. These accounts and presentations are grouped broadly into four types: (a) extended economic accounts; (b) complementary valuations; (c) thematic accounts; and (d) combined presentations and indicators.

2.45 **Extended economic accounts.** Using national accounting principles, data from the ecosystem accounts can be used to complement the standard economic accounts of the SNA concerning measurement of economic production, generation of income, capital formation and wealth. Extended SUTs, extended balance sheets and extended sequence of institutional sector accounts can therefore all be compiled, including associated aggregate measures of income and wealth adjusted for the enhancement and degradation of ecosystem assets. These accounts are described in chapter 11.

2.46 **Complementary valuations.** In serving as the basis for the integration of ecosystem data with the accounts of the SNA, the ecosystem accounting framework incorporates a range of measurement choices, particularly as regards the scope of ecosystem services, the use of the exchange value concept for monetary valuation and the attribution of degradation to the economic unit that suffers from the loss of ecosystem condition. It is possible to design complementary valuations using different valuation concepts, measurement scopes and assumptions (e.g. concerning institutional arrangements) to support different policy and analytical purposes. Possible complementary valuations are discussed in chapter 12.

Table 2.5
Stylized monetary ecosystem asset account (currency)

Accounting entries	Stylized ecosystem types						Total
	Forests	Lakes	Cropland	Urban areas	Wet-lands	Seagrass	
Opening value							
Ecosystem enhancement							
Ecosystem degradation							
Ecosystem conversions							
Other changes							
Net change in value							
Closing value							

2.47 **Thematic accounts.** These accounts organize data on themes of specific policy relevance. Examples of relevant themes include biodiversity, climate change, oceans and urban areas. In all of these areas, relevant data can be obtained from the ecosystem accounts. Further, additional data – for example, concerning GHG and resource management expenditure – can be sourced from the SEEA Central Framework and SNA accounts. Sometimes, data that have not been incorporated in accounts can also be used to support thematic accounting. For the themes of biodiversity and climate change, additional accounts – namely, species accounts and carbon accounts – are also relevant. The principles of thematic accounting and the design of thematic accounts are considered in chapter 13.

2.48 **Combined presentations and indicators** offer a way to collate and tabulate data on a selected set of variables from the ecosystem accounts or other sources so as to enable users to grasp relationships of analytical significance quickly. Within a standard account structure, there are often only a relatively limited set of key measures, and these presentations supply a means of highlighting relevant variables, particularly for the derivation of indicators. Indicators can be designed and selected in many different ways and accounting frameworks provide a strong basis for their derivation and coherence. These topics are discussed in chapter 14.

2.4 Framing of values in ecosystem accounting

2.4.1 Introduction

2.49 The concepts and methods applied in SEEA EA reflect specific and well-defined objectives in recording values related to ecosystems and ecosystem services. The primary objective is to consider ecosystems and ecosystem services within the context of economic measures of production, consumption and accumulation (wealth). In monetary terms, SEEA EA records stocks and flows based on exchange values, which are narrower in scope than other monetary values for the environment that often encompass measures of consumer surplus and non-use values.

2.50 At the same time, integration of both physical and monetary data by SEEA EA allows it to provide data that are relevant in supporting assessments based on other value perspectives. Further, SEEA EA demonstrates how physical data, for example, on ecosystem extent and condition, can be used in macroeconomic policy- and decision-making. Thus, beyond the context associated with the primary objective noted above, data from the accounts are relevant in a range of other contexts such as sustainability and environmental reporting, spatial planning and environmental management, and assessment of financial risks, particularly where it concerns the integration of environmental and economic considerations.

2.51 It is recognized that the concepts and methods of ecosystem accounting cannot encompass all of the value perspectives concerning ecosystems. Hence, the data from ecosystem accounts should not be regarded as providing a holistic, complete or full societal value of nature or as reflecting all of the multiple value perspectives on ecosystems.

2.52 The aim of the present section is not to provide a definitive summary of the literature or to establish an SEEA EA values perspective but rather to place ecosystem accounting within a broader values context. This can support an understanding of the different ways in which ecosystems may be valued; support appropriate interpretation and application of ecosystem accounting data; and indicate the types of analysis that ecosystem accounting supports but does not incorporate, for example, cost-benefit analysis and assessment of non-use values.

2.4.2 Summary of the multiple value perspectives on nature

2.53 Section 2.2 described five measurement perspectives for ecosystems. Similarly, multiple perspectives exist on the value of ecosystems, with each perspective recognized as focusing on the same concept of what an ecosystem is. The purpose of value frameworks is to place the various perspectives in a common context and thereby enable analysts and decision makers to determine how their views may align or differ.

2.54 Two continuums are commonly used to reflect value perspectives: (a) the continuum from anthropocentric to non-anthropocentric values; and (b) the continuum from instrumental to intrinsic and relational values. Definitions taken from Pascual and others (2017) are used to support the present discussion. According to those definitions:

- **Anthropocentric values** are those that are centred on human beings
- **Non-anthropocentric values** are those that are centred on the environment
- **Instrumental value** is the value attributed to something as a means of achieving a particular end
- **Intrinsic value** signifies inherent value, that is, the value that an entity (e.g. an organism) possesses independent of any human experience or evaluation. Such a value is viewed as an inherent property of the entity and not ascribed or generated by external valuing agents (such as human beings)
- **Relational values** are values relative to the meaningfulness of relationships, including the relationships between individuals or societies and other animals and aspects of the living world, as well as those among individuals articulated by formal and informal institutions

2.55 Various researchers have posited different combinations of these values to describe various frameworks of values. Particular examples include the total economic value framework (Pearce and Turner, 1990; TEEB, 2010); the IPBES values framework (Díaz and others, 2015; Pascual and others, 2017); the life framework of values (O’Connor and Kenter, 2019; O’Neill, Holland and Light, 2008); the lessons learned in valuing nature (Turner and others, 2003); and the framework for integrating economics and ecology (Polasky and Segerson, 2009). A comprehensive assessment of these and other value frameworks and perspectives is being conducted by IPBES.[37]

2.56 Significantly, these different value perspectives are not in some manner additive, that is, it should not be concluded that through recognition of all types of value, an aggregate value of nature could be obtained. Rather, it is more appropriate to consider that, for a given ecosystem, each value perspective will provide a different value, in other words, there are multiple, potentially incommensurate values to be compared and contrasted in decision-making. Importantly, all of these values and associated frameworks recognize that the environment has value beyond monetary values.

2.57 Even though these value concepts are overlapping and nested, a statistical framing of data on ecosystems could play an important role in incorporating at least some parts of these wider value perspectives on ecosystems as a regular component of decision-making. Indeed, an advantage of standardizing ecosystem accounting value concepts is that there is an agreed definition of measurement that is stable over time. This can, in turn, be used as a common basis for policy design and decision-making.

2.4.3 Linking the ecosystem accounts and multiple value perspectives

2.58 In broad terms, the commonly understood focus of SEEA EA is on values of anthropocentric origin, that is, values that are centred on human beings. Further, the measurement focus is commonly on instrumental or use values, in part because those values reflect interactions between people and the environment that are most readily observable and also because, from a monetary valuation perspective, these values are most readily reflected in monetary terms. The focus on anthropocentric instrumental values may also be considered of high relevance from a policy perspective, since these values are related to the types of human interactions with the environment that can place the most pressure on ecosystems.

2.59 Ecosystem accounting data in monetary terms are valued using the concept of exchange values. Under this concept, ecosystem services and ecosystem assets are valued at the prices at which they are, or would be, exchanged on a market. This approach to monetary valuation facilitates comparison with the monetary values recorded in the national accounts. Chapter 8 describes the exchange value concept in more detail.

2.60 The scope of the monetary values in ecosystem accounting is limited to the range of ecosystem services that are included in a given ecosystem account. As the use of exchange values does not provide a broader monetary value that incorporates the direct and indirect benefits received from ecosystems including their non-use values, monetary data from the ecosystem accounts, in line with the valuation basis used in the SNA, do not provide a comprehensive monetary value of well-being associated with ecosystems. Complementary approaches to monetary valuation are discussed in chapter 12, and the relationship between exchange values and other economic valuation concepts is described in appendix A12.1.

2.61 It is common for the discussion of values and valuation in accounting to place a particular focus on instrumental values expressed in monetary terms. However, since ecosystem accounting encompasses data in both physical and monetary terms and provides data that are spatially explicit, there is the potential for ecosystem accounting data to support discussion of a wider range of value perspectives.

2.62 Specifically, it is noted that data on ecosystem extent and ecosystem condition in physical terms support discussion of a number of the aspects of intrinsic and non-

[37] For more information on the IPBES values assessment, see https://ipbes.net/values-assessment.

anthropocentric perspectives on the value of nature. Further, data on flows of ecosystem services in physical terms support discussion of instrumental values and some aspects of relational values. Data from accounts such as species accounts, carbon stock accounts and water resources accounts also support these discussions.

2.63 Lastly, the assessment of multiple values often requires consideration of local contexts and a wide variety of users. Generally, ecosystem accounts are described for relatively large areas with multiple ecosystem types and for broad categories of users, including households, businesses and governments. However, in principle, the application of ecosystem accounting concepts can be undertaken at smaller scales (using higher resolutions of data for local administrative areas) and/or for particular social groups. For example, measurement may focus on the use of specific ecosystem services in individual locations or may be elaborated to highlight the uses of ecosystem services by households at different income levels. The potential to undertake such measurement will necessarily be subject to the availability of data.

2.64 Overall, while the primary focus is on anthropocentric instrumental values, data from a set of ecosystem accounts would also be relevant in supporting assessments based on other value perspectives.

2.5 General national accounting principles

2.5.1 Introduction

2.65 Recording entries in the ecosystem accounts follows the general principles of national accounting as described in chapter 3 of the 2008 SNA. A summary of some of the rules and principles of most relevance to SEEA EA – double- and quadruple-entry accounting, time of recording, units of measurement and valuation rules and principles – is provided in chapter II of the SEEA Central Framework.

2.66 The present section examines the accounting principles that require particular consideration within the context of ecosystem accounting but does not discuss valuation principles. Chapters 8 and 9 provide greater detail on the range of the non-market valuation considerations that arise in ecosystem accounting.

2.5.2 Length of the accounting period and frequency of accounts

2.67 In economic accounting, there are clear standards concerning the time at which transactions and other flows should be recorded and the length of the accounting period. The standard accounting period in economic accounts is one year. This length of time satisfies many analytical requirements although, often, quarterly accounts are also compiled.

2.68 While one year may be suitable for analysis of economic trends, analysis of trends in ecosystems may require information for varying lengths of time, depending on the processes being considered. Even in situations where ecosystem processes can be analysed on an annual basis, the beginning and end of the year may well differ from the beginning and end of the year that is used for economic analysis.[38]

[38] For example, hydrological years may not align with calendar or financial years.

2.69 Although considerable variation in the cycles of ecosystem processes exists, it is suggested that ecosystem accounting apply the standard economic accounting period length of one year. Most significantly, this aligns with the length of time for common analytical frameworks for economic and social data and the general integration of information is thus best supported through the use of this time frame.

2.70 Consequently, for the purposes of ecosystem accounting, it may be necessary to convert or adjust available environmental information so as to align it with a common annual basis using appropriate factors or assumptions (by applying interpolation or extrapolation techniques, for example), while recognizing that data may be collected irregularly over time intervals longer than one year.

2.71 Ideally, annual accounts would be compiled each year to provide a consistent time series of data. However, it is acknowledged that compiling ecosystem accounts with this level of regularity may not be possible during initial phases of implementation. Nonetheless, the general ambition should remain for there to be regular reporting of accounts, for example, every three to five years. A key factor that may limit the more frequent compilation of accounts is availability of source data, for example, concerning detailed maps of ecosystem types. In addition to considering the availability of alternative data sources, compilers may also consider the application of interpolation and extrapolation techniques that support infilling of accounting periods not covered in benchmark or baseline data sets.

2.5.3 Time of recording

2.72 The general national accounting requirement is that transactions and other flows must be recorded as occurring at the same point in time in the various accounts for both units involved. In respect of ecosystem services, this implies that the supply of ecosystem services must be recorded in the same accounting period as that in which the use of those services is recorded. It is to be noted that the timing of the transaction may be different from timing with respect to when an ultimate benefit is received. For example, the benefits of global climate regulation services occur well after the associated carbon sequestration has itself taken place. In this regard, it should be recalled that the focus of ecosystem accounting is recording the supply and use of ecosystem services rather than the well-being or outcomes that eventuate.

2.73 Measures of ecosystem assets should be related to the opening and closing dates of the accounting period. If information available for the purposes of compiling accounts for ecosystem assets does not pertain directly to those dates, then adjustments to the available data may be required and in making such adjustments, an understanding of relevant shorter seasonal and longer natural cycles would be required.

2.5.4 Units of measurement

2.74 In the measurement of stocks, entries relate to a measurement unit (e.g. total area or total volume) at a point in time. In the measurement of flows, entries relate to a measurement unit per unit of time (e.g. cubic metres per year). The unit of time that is appropriate will depend on the selected length of the accounting period.

2.75 For accounts compiled in monetary terms, all entries in the accounts must be measured in currency units.

2.76 For accounts compiled in physical terms, the units of measurement will vary and will depend on the account and the relevant variable. In ecosystem extent accounts, a common unit of area, such as the hectare, is recommended to allow for assessment of the relative size and composition of ecosystem types within an EAA. Using a common unit of area also ensures that accounting balances and aggregations can be applied for the account.

2.77 In ecosystem condition accounts, the use of different measurement units for each characteristic and associated variable is likely. Through normalization using reference levels and reference conditions, the variables can be compared with each other. However, there is no natural aggregation across characteristics without the use of appropriate weighting or aggregation approaches.

2.78 In ecosystem services flow accounts in physical terms, different ecosystem services are recorded in different measurement units. Given the structure of these flow accounts, it is possible to aggregate across columns for a single service to provide an estimate of total supply or total use of that service. However, it is not possible to aggregate across different ecosystem services, that is over rows, to present total supply or use of ecosystem services for an ecosystem type or type of economic unit. Depending on the analytical purpose, this would be one motivation for the use of a standard money metric.

2.79 In measuring supply and use, it is fundamental that the same measurement unit be applied for both supply and use of a single ecosystem service in physical terms. Thus, if the supply of a service is measured in tons per year, then the use of that service must also be measured in tons per year. This permits the balancing of supply and use for individual ecosystem services and the related reconciliation.

2.5.5 Gross and net recording

2.80 The terms "gross" and "net" are used in a number of accounting situations. In ecosystem accounting, the recording of ecosystem services is undertaken so that all flows between ecosystem assets and economic units are identified explicitly, that is, the recording is in gross terms for both physical and monetary measures. For example, final ecosystem services are recorded as the output of ecosystem assets and as inputs to an economic unit (e.g. biomass provisioning services are recorded as inputs to agricultural units). In the case of SNA benefits, there is a related transaction between two economic units (e.g. sale of agricultural outputs from the agricultural unit to a manufacturer). No double counting is implied in this treatment since the recording of the final ecosystem service is offset by the recording of the input to the economic unit. For non-SNA benefits where there is no corresponding output, the recording entails showing a flow of final ecosystem services from an ecosystem asset (e.g. flows of air filtration services) and use by an economic unit. These recording principles can be demonstrated using SUT presentations, which are elaborated in chapter 7.

2.81 In the monetary valuation of ecosystem services, the relevant values should be calculated so that the costs incurred by economic units of using or accessing the ecosystem services are deducted, that is, so that the values are "net" of costs. This issue arises when the valuation method being applied entails use of an observed market price and deducting these costs is therefore required to ensure that the monetary valuation is focused on the contribution of the ecosystem. These valuation issues are discussed further in chapter 9.

2.82 In other situations, the term "gross" is used to indicate that an accounting aggregate (e.g. GDP) has not been adjusted for the costs of using capital, that is, to indicate that measures of depreciation, depletion and degradation have not been deducted. In these situations, the term "net" indicates that the aggregate has been adjusted for the costs of capital. Finally, there are situations in which the term "net" is used to refer to the difference between two accounting items (as in the case, for example, of net lending, which is the difference between a sector's transactions in financial assets and the incurrence of liabilities).

2.5.6 Scale of application

2.83 The ecosystem accounting framework and associated accounts have been designed with the intent of their being applied at national (or large subnational) scale, that is, in the context of multiple ecosystem assets (across the variety of ecosystem types within an EAA) and for multiple ecosystem services. This is analogous to the general application of the national accounts, which covers the activities of all industries resident within an economic territory.

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

- A single ecosystem asset or ecosystem type (e.g. a wetland or wetlands) and/or a single ecosystem service (e.g. water regulation). For individual provisioning services, there may be a direct connection to natural resource accounting, as described in chapter V of the SEEA Central Framework.
- 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 a single ecosystem service. Accounting of this type may be of interest for monitoring and understanding the dynamics of the supply of a specific service across a broad spatial area (e.g. water regulation or global climate regulation).
- Areas of land within a country that have common land-use or land management arrangements or are the focus of integrated land management practices (e.g. watersheds, national parks)

2.85 The logic of the ecosystem accounting framework described above can be applied in all of these reduced or tailored cases, since the accounting principles themselves are scale- independent. Moreover, to the extent that individual projects focus on these more tailored accounts, it should be possible to integrate the findings within a broader project covering multiple ecosystem assets and services. The potential for integration is heavily dependent on the adoption of consistent measurement boundaries and classifications, which would then become a prime motivation for application of a common ecosystem accounting framework.

2.5.7 Data quality and scientific accreditation

2.86 The concept of data quality for official statistics is a broad-ranging one, encompassing factors of relevance, timeliness, accuracy, coherence, interpretability, accessibility and quality of the institutional environment in which the data are compiled. The development of statistical frameworks, such as the ecosystem accounting framework presented here, is designed to assist in the advancement of quality, particularly in the areas of relevance, coherence and interpretability.

2.87 In ecosystem accounting, it is likely that a reasonable proportion of the information used will be drawn from disparate data sources, possibly developed to provide information for various scientific, research, management and administrative purposes rather than primarily for statistical purposes. Administrative data sets are often produced and analysed with a focus on smaller or borderline cases rather than on those cases that may be the most statistically significant. Some ecological data are treated similarly. For example, data on the quality of water may be collected for areas where there is a known pollution problem rather than to provide broad coverage and a representative sample of water quality. Care must therefore be taken to ensure that, as far as possible, the data used are representative of all contexts within the scope of accounting.

2.88 It is also likely that information for ecosystem accounting will be drawn from various independent studies in the biophysical sciences and economics literature. This being the case, appropriate review and validation of the data will be required, including, for example, consideration of the various measurement concepts and scopes that have been applied, to ensure that the data are suitable for the purposes of ecosystem accounting and that coherence across the accounts can be achieved.

2.89 Compilers are encouraged to work at national and international levels to develop relevant accreditation processes for scientific and other information relevant for ecosystem accounting. In this context, it is noted that general statistical quality frameworks, such as the International Monetary Fund Data Quality Assessment Framework (DQAF),[39] are applicable to biophysical data as well as socioeconomic data. These frameworks are tools designed to assure that data are collected and compiled according to international standards and are subject to appropriate quality assessment procedures.

[39] See https://dsbb.imf.org/dqrs/DQAF.

2.5.8 Uncertainty in measurement

2.90 There are a number of sources of uncertainty in ecosystem accounting. These can be grouped in four main categories: (a) uncertainty related to physical measurement of ecosystem services and ecosystem assets; (b) uncertainty in the valuation of ecosystem services and ecosystem assets; (c) uncertainty related to the dynamics of ecosystems and changes in flows of ecosystem services; and (d) uncertainty regarding future prices and values of ecosystem services.

2.91 **Uncertainty related to physical measurement of ecosystem services and ecosystem assets**. It is clear that, given the scarcity of data for many ecosystem services, physical measurement of the flow of ecosystem services, in particular at aggregated levels, is prone to uncertainty. Most countries do not consistently measure flows of ecosystem services at an aggregated (national or even subnational) scale, and service flows often need to be estimated on the basis of point-based observations in combination with spatial data layers and non-spatial statistics. At the same time, it is to be noted that aggregated information related to flows of provisioning services are generally readily available.

2.92 **Uncertainty in the valuation of ecosystem services and ecosystem assets**. A second source of uncertainty is related to the monetary value of ecosystem services. For provisioning services, a key factor is that attributing a resource rent to ecosystems involves a number of assumptions regarding rent generated by other factors of production. For non-market ecosystem services, it is often difficult both to establish the demand for these services and to determine the supply of these services by ecosystems, in particular at an aggregated scale.

2.93 **Uncertainty related to the dynamics of ecosystems and changes in flows of ecosystem services**. Establishing the value of ecosystem assets requires making assumptions regarding the supply of ecosystem services over time, which in turn depends on the dynamics of the ecosystem. Changes in ecosystem assets are often reflected in a changed capacity to supply ecosystem services. It is now recognized that ecosystem changes are often sudden, involving thresholds at which rapid and sometimes irreversible changes to a new ecosystem state occur. Predicting the threshold level at which such changes occur is a complex undertaking and prone to substantial uncertainty.

2.94 **Uncertainty regarding future prices and values of ecosystem services**. Pricing benefits and costs that may accrue in the future is a complex endeavour because it is extremely difficult to predict future circumstances. The implications of humanity's continuing modification of the climate and ecosystems are uncertain, and those implications are likely both to affect and to depend on how the future evolves. Uncertainties concerning values are even greater inasmuch as the methods of non-market valuation compound errors in estimation.

2.95 The strategies for dealing with the various sources of uncertainty will vary by country as a function of data availability and the relevant services selected for ecosystem accounting. The approaches to limiting uncertainties and maximizing the robustness of the data in ecosystem accounts will need to be further developed once more practical experience with ecosystem accounting has been acquired and evaluated. The experiences gathered at both national and subnational levels will be relevant in this context, and it is therefore important that all accounting work document the scope of measurement, the definitions applied, the methods used and the assumptions made.

Section B

Accounting for ecosystem extent and condition

Section overview

Ecosystem assets are at the heart of the ecosystem accounting framework described in chapter 2. Section B of SEEA EA, encompassing chapters 3, 4 and 5, describes the framework's approach to structuring data on ecosystem assets. In the first instance, this involves delineating ecosystem assets, which are represented as spatial units. This step allows accounting for the extent of ecosystems and for how their size and configuration are changing over time. In a second step, the condition of ecosystem assets is assessed through a focus on their integrity.

Measurement of the extent and condition of ecosystems is a common focus of environmental data collection. Generally speaking, there is a wealth of data in this domain. Unfortunately, a common feature of those data is that they are not coordinated and are difficult to use to convey an integrated picture of changes, especially across multiple ecosystem types and at the national level. The intent in ecosystem accounting is to provide a common structure and approach for the integration of the relevant information on the size and condition of ecosystems.

The approach to delineating ecosystem assets described in chapter 3 provides the underlying statistical basis for the organization of data on ecosystems in a comprehensive and mutually exclusive manner. In this respect, the spatial units that are delineated are analogous to the economic units that are delineated for the purpose of compiling economic statistics, usually in the form of a business register. Much of the underlying data coordination work carried out in ecosystem accounting is focused on attributing data on different characteristics to ecosystem assets and ecosystem types.

The coordination of data on ecological characteristics using statistical and accounting principles is an important extension of the wider SEEA approach, which recognizes the significance of non-monetary data in describing the relationship between the environment and the economy. While accounting for extent and condition does support the measurement of ecosystems in monetary terms, as described in section D, data from the ecosystem extent and ecosystem condition accounts is of direct relevance, particularly in understanding the effects of human activities on ecosystems and in assessing distance from ecological thresholds. Further, data on ecosystem extent and condition are a means of considering the intrinsic value of ecosystems, since data on ecosystem extent and condition do not require consideration of the relative importance of ecosystems to people.

Taken together, these various facets indicate that ecosystem extent and condition accounts are a central feature of ecosystem accounting and should be a core component of SEEA EA implementation in all contexts.

Chapter 3
Spatial units for ecosystem accounting

3.1 Introduction

3.1 A key feature of ecosystem accounting is its ability to integrate spatially referenced data, that is, data on the location, size and condition of ecosystems within a given area, and how those characteristics are changing over time. Recording stocks of ecosystems and changes in stocks in a coherent and mutually exclusive manner supports the derivation of indicators (for example, rate of change in forest or grassland areas relative to rate of change in cultivated areas).

3.2 For accounting purposes, different ecosystems are treated as spatial units. The delineation of ecosystems into spatial units requires careful consideration of various ecosystem characteristics across the various ecological realms, including terrestrial, freshwater, marine and subterranean ecosystems. The present chapter outlines the approach adopted in SEEA EA to define, classify and delineate spatial units. Section 3.2 describes the different types of spatial units used in ecosystem accounting and sections 3.3 and 3.4 set out the general principles and identify practical considerations for the delineation and classification of those units for ecosystem accounting purposes.

3.3 The availability of spatial data to describe ecosystems and their economic uses and associated beneficiaries is an important consideration in the compilation of ecosystem accounts. The spatial and thematic detail of those data, as well as their geospatial comparability and integration into a shared spatial data infrastructure, influences the richness of the ecosystem accounts that can be compiled. This topic is discussed in section 3.5.

3.4 Data on the size and changes in size of ecosystems are recorded in ecosystem extent accounts, and their location and configuration can be presented in maps. Understanding the size and location of ecosystems supports the measurement of ecosystem condition and the measurement and valuation of many ecosystem services, the flows of which will vary from ecosystem to ecosystem. These matters are discussed in later chapters.

3.2 Types of spatial units

3.2.1 Ecosystem assets

3.5 The primary spatial units for ecosystem accounting are labelled ecosystem assets. ***Ecosystem assets are contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions.*** The definition of ecosystem assets is a statistical representation of the general definition of ecosystems found in the Convention on Biological Diversity (see para. 2.6).

3.6 Ecosystem assets play a key role in ecosystem accounting. They are the statistical units for ecosystem accounting, that is, the ecological entities about which information is sought and for which statistics are ultimately compiled. This includes information concerning their extent, condition, the ecosystem services they provide and their monetary value. Each ecosystem asset is classified to an ecosystem type. ***An ecosystem type reflects a distinct set of abiotic and biotic components and their interactions.*** Such components include, for example, the animals, plants, fungi, water, soil and minerals present in ecosystems. Appendix A3.1 provides an introduction to a range of ecological concepts and terms, including *ecosystem*, *habitat*, *biome* and *ecoregion*, and the various general drivers and characteristics of ecosystems.

3.7 The statistical outputs from ecosystem accounting are most commonly presented either in tabular form, where data on ecosystem assets are grouped according to their ecosystem type, or in the form of maps, where individual ecosystem assets are reflected and the configuration and location of different ecosystem types can be displayed.

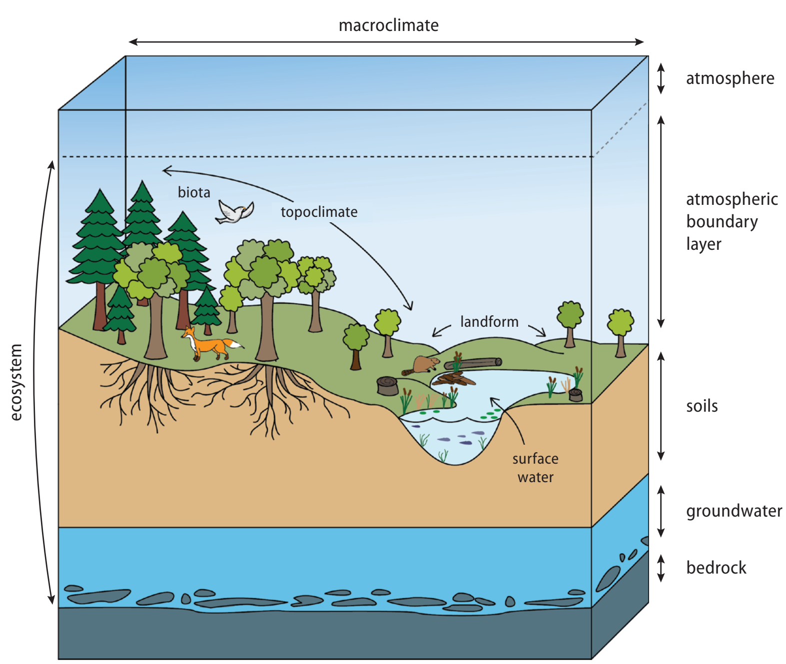
3.8 The SEEA Central Framework defines environmental assets as ***the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity*** (Central Framework, para. 2.17). This definition encompasses ecosystems. Like environmental assets, ecosystem assets are considered assets on the basis of their biophysical existence and their status as assets is not dependent on establishment of flows of benefits or ownership, which is a requirement for economic assets in the SNA.[40]

[40] As discussed in chapter 11, establishing the economic ownership of ecosystem assets and the attribution of benefits is required for the integration of ecosystem accounting data with economic accounts, although ecosystem accounts can be compiled in the absence of that information.

3.9 Conceptually, ecosystem assets are envisaged as three-dimensional spaces (see figures 3.1 and 3.2). While many ecosystems in the terrestrial, freshwater and marine realms are located close to the Earth's surface, they all have three-dimensional characteristics.

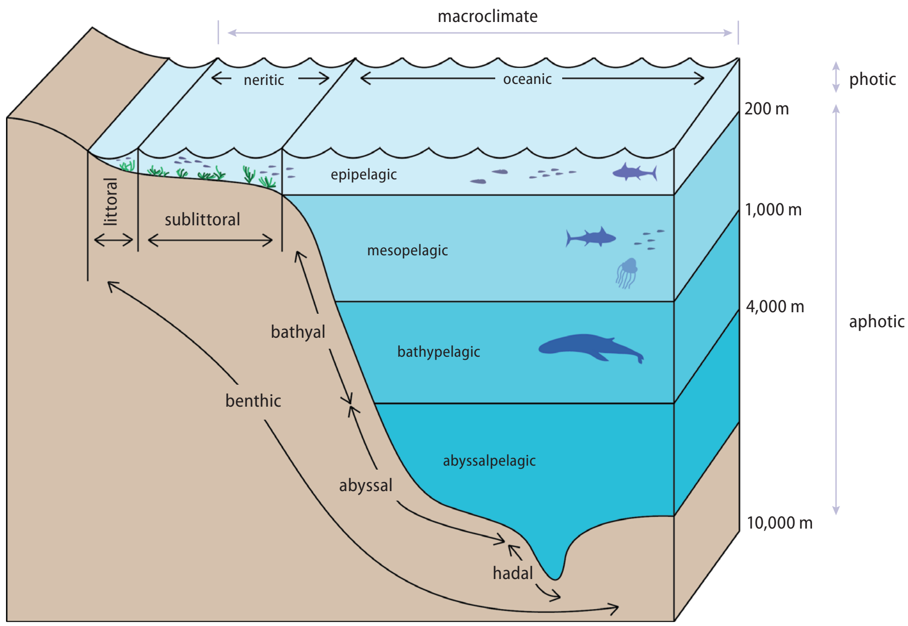
3.10 For example, for terrestrial systems, the biotic components usually extend from the roots of plants below the surface to the vegetation growing above the surface. The abiotic components – soil, surface water, soil water and air from the atmosphere – interact directly with those living components.

Figure 3.1
Vertical structure of a terrestrial ecosystem



Source: Adapted from Bailey (1996).

Figure 3.2
Vertical structure of marine ecosystems



Source: Adapted from Kingsford (2018).

3.11 **Marine ecosystems.** Marine ecosystems are not concentrated near one surface (i.e. the air-land/water interface) but extend throughout the water column and include the underlying sediment and seabed, which provide a natural boundary for ecosystem assets (see figure 3.2). In concept, ecosystem assets for marine ecosystems could be delineated by taking into account various ecological differences with respect to, for example, salinity, temperature, nutrients and both location and depth within the water column, and distinguishing the seabed from the overlying water column.

3.12 However, since it may be difficult to delineate ecosystem assets in a vertically stratified manner, delineation based on surface area is likely the most practical measurement pathway for accounting purposes. In particular, for marine ecosystems within the continental shelf,[41] it is recommended that ecosystem assets be delineated based on the areas of the different ecosystem types associated with the seabed, for example, seagrass meadows, subtidal sandy bottoms and coral reefs.

3.13 **Atmospheric boundary.** Several important ecological processes are based on interaction with the atmosphere, including respiration, nitrogen fixation and those processes, such as air filtration, associated with the impact of air pollution on vegetation and fauna. To establish a clear boundary for accounting, the atmosphere directly above and within an ecosystem is considered part of the ecosystem asset as one of the abiotic components within the spatial unit.

3.14 The interaction between the Earth's surface and its ecology, and the atmosphere is limited to the atmospheric boundary layer. For accounting purposes, this forms the natural upper boundary of ecosystem assets. The atmospheric boundary layer is defined as the bottom layer of the troposphere that is in contact with the surface of the Earth (American Meteorological Society, 2020). Parts of the atmosphere above this layer are not considered ecosystem assets.

41 The continental shelf is that part of the continental margin that lies between the shoreline and the shelf break or, where there is no noticeable slope, between the shoreline and the point where the depth of the superadjacent water is approximately between 100 and 200 metres.

3.15 While the atmosphere satisfies the general definition of an environmental asset as given in the SEEA Central Framework and flows of emissions to the atmosphere can be recorded in PSUTs, the volume of air in the atmosphere is not included in the measurement scope of environmental assets in the Central Framework (para. 5.16). Further discussion on a more complete accounting treatment for the atmosphere is part of the SEEA EA research and development agenda, including the consideration of the atmosphere as a separate environmental asset (see annex II to the present publication).

3.16 **Subsoil boundary.** The subsoil that is directly involved with ecosystem processes is considered part of the ecosystem asset. This holds for terrestrial (soil), freshwater and marine ecosystems (sediments). These ecosystem processes include water flows between soil layers and aquifers, bioturbation, carbon cycling, cycling of nutrients and other diagenetic processes. The precise subsoil boundary layer for an ecosystem asset is dependent on the structure of the soil, sediment and bedrock.

3.17 **Aquifers.** All aquifers, both confined and unconfined, contain some biotic components and are treated as ecosystems. Confined aquifers should be treated as ecosystem assets distinct from the ecosystem assets located above them. Depending on the context, unconfined aquifers may be treated as distinct or integrated with the surface ecosystem asset.

3.18 **Subterranean ecosystems.** There are a variety of subterranean ecosystems, including caves and underground streams. These ecosystems satisfy the general conceptual definition of an ecosystem asset in having a distinct set of biotic and abiotic components.

3.19 **Subsoil abiotic resources.** Resources located in the deeper substrate within the lithosphere, such as natural gas, oil, coal and mineral ores, that have no direct interaction with surrounding ecosystems are not considered ecosystem assets, but are included under the broader definition of environmental assets.

3.2.2 Applying the conceptual boundary for ecosystem assets

3.20 Although ecosystem assets are conceptually three-dimensional, they have a two-dimensional boundary or footprint. This footprint is defined by the intersection of the three-dimensional bounding envelope of the ecosystem asset with the Earth's surface. The sides of this envelope are assumed to be vertical so that the resulting footprints of adjacent ecosystem assets do not overlap. In practice, therefore, for most accounting purposes, ecosystem assets are represented in two dimensions, that is, by their area.

3.21 It is also possible to define the footprint of those ecosystem assets that are located below surface-level terrestrial and freshwater ecosystems, such as subterranean ecosystems and aquifers, in two-dimensional terms. However, since these areas coexist with the areas of other ecosystem assets closer to the Earth's surface, their extent should be accounted for separately, depending on analytical requirements.

3.2.3 EAAs

3.22 The second type of spatial unit for ecosystem accounting is the EAA. ***EAA is the geographical territory for which an ecosystem account is compiled.*** The EAA therefore determines which ecosystem assets are included in an ecosystem account.

3.23 An EAA is a two-dimensional construct providing an accounting boundary around a set of ecosystem assets represented by their two-dimensional footprints, such that the sum of the areas of the ecosystem assets is equal to the total area delineated by the EAA.

3.24 The relationships between the spatial units are presented in mapped form in figure 3.3 within a stylized context. In this figure, a combination of six different ecosystem assets (EA1–EA6) are shown as located within an EAA. Each ecosystem asset is classified to a different ecosystem type (ET1–ET4). A single ecosystem asset can be assigned to only a single ecosystem type (ET) but there can be multiple occurrences of a single ET within an EAA.

3.25 The same relationships can also be presented in tabular form where, at a given point in time, the sum of the areas of different ETs will be equal to the total EAA. This is shown in table 3.1, which provides the basic entry point into accounting for ecosystem extent as discussed in chapter 4.

3.26 Common forms of EAAs include:

(a) National jurisdictions and groups of countries (e.g. member countries of the European Union);

(b) Subnational administrative areas (e.g. States, provinces);

(c) Environmentally defined areas within a country (e.g. water catchments, ecoregions) or across countries (e.g. regions defined by river systems such as the Amazon, the Mekong and the Nile);

(d) Other areas of policy or analytical interest such as protected areas; areas owned by specific industries or sectors (e.g. government-owned land); and areas outside national jurisdiction (e.g. open oceans and high seas).[42]

[42] These areas may be the focus of regional or international accounting work.

Figure 3.3
Relationships between spatial units in ecosystem accounting

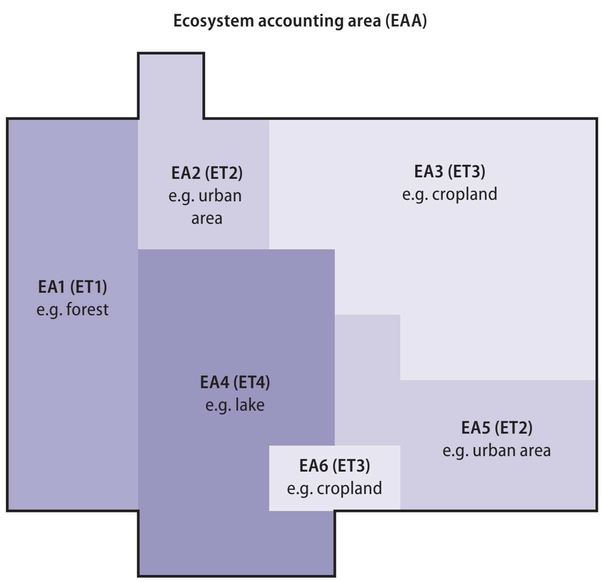


Table 3.1
Tabular presentation of spatial units

Spatial unit	Size[a]
Ecosystem type 1 (EA1)	12
Ecosystem type 2 (EA2 and EA5)	13
Ecosystem type 3 (EA3 and EA6)	15
Ecosystem type 4 (EA4)	14
EAA	**54**

[a] Any measurement unit for area may be used, for example, hectares or square kilometres.

3.27 Consistent with the scope of the SEEA Central Framework, the scope of national jurisdictions for ecosystem accounting should include all ecosystems across the terrestrial, freshwater and marine realms to the boundary of the exclusive economic zone (EEZ). In practice, the initial scope may be more limited, for example, covering only terrestrial and freshwater ecosystems; but it is important that there be an aim to extend the coverage to incorporate all ecosystems under national jurisdiction.

3.28 Where countries share an administrative boundary, it is most common for a distinct EAA to be applied, one for each country. Delineation of an EAA using an administrative boundary may also imply that a contiguous area of the same ecosystem type is partitioned between two or more countries. Such partitioning is appropriate for the purposes of accounting within an individual EAA. However, in these contexts there may be advantages in (a) seeking alignment on the approach to defining and delineating the relevant ecosystem assets so as to ensure that all areas are accounted for and are classified consistently; and (b) considering the development of complementary accounts for transboundary areas that are of joint management interest. This may be appropriate in particular cases involving large river basins and associated ecosystems.

3.29 Generally, the measurement objective of SEEA EA is to provide information on the changes in ecosystem-related stocks and flows in relatively large and diverse areas encompassing different ecosystem types, as suggested through the EAA-related examples provided above. Conceptually, it is possible to compile ecosystem accounts for an individual ecosystem asset such as a single forest, wetland or cultivated area, but this is not the focus of SEEA EA.

3.30 Usually, an EAA reflects contiguous areas, but this is not a requirement for accounting purposes. For example, accounts may be developed for all protected areas within a country or for a specific ecosystem type (e.g. all of a country's natural grasslands).

3.31 Within an EAA, ecosystem assets are grouped into different ecosystem types (e.g. forests, wetlands and cultivated land). The resulting accounting structures are generally such that measures of ecosystem extent, ecosystem condition and ecosystem services are presented for aggregations of ecosystem assets, that is, by ecosystem types, based on data commonly compiled for ecosystem assets. For example, for a given EAA, an ecosystem extent account shows the changing total area of each ecosystem type (e.g. forest, wetland, coastal habitat or cultivated land), but does not present the changing area of each individual ecosystem asset. However, the same underlying data can be mapped to show the changing size, configuration and distribution of individual ecosystem assets within an EAA. Approaches to accounting for ecosystem extent are discussed in chapter 4.

3.32 Since an EAA is a two-dimensional construct, the area of subterranean ecosystems cannot be incorporated in addition to those ecosystem assets that are closer to the Earth's surface. Therefore, for the purposes of accounting for ecosystem extent in which the area of the EAA and the sum of the areas of individual ecosystem assets should be equivalent, the area of subterranean ecosystems should be excluded. Where relevant for policy and analysis, complementary extent accounts for subterranean ecosystems can be compiled (see sect. 4.3.3).

3.33 Complementary extent accounts for marine ecosystems beyond the continental shelf or EEZ that encompass the full range of relevant ecosystem assets, including those associated with pelagic ocean waters and deep-sea floors, can also be compiled.

3.34 Where complementary extent accounts are compiled, other data concerning, for example, the condition of those ecosystem assets and the supply and use of ecosystem services can be incorporated alongside similar data for other ecosystem types, at least in tabular form.

3.3 Delineating ecosystem assets

3.3.1 General principles

3.35 In concept, an ecosystem asset is differentiated from neighbouring ecosystem assets on the basis of the extent to which the interactions between biotic and abiotic components within that ecosystem asset are stronger than the interactions with components outside the ecosystem asset. The differences will be reflected in variations in composition, structure and function. Hence, ecosystem assets should be delineated and classified to distinct ecosystem types, based on various ecosystem characteristics such as physical structure and type (including vegetation structure and type), species composition, ecological processes, climate, hydrology, soil characteristics, currents and topography.

3.36 It is expected that, allowing for a normal degree of natural variation, there will be a general persistence of the characteristics of an ecosystem asset. For example, the loss of vegetation as a result of disturbances such as fire and flood does not necessarily imply a change in ecosystem type. With respect to the delineation of an ecosystem asset, it is also expected that, based on the approach to the measurement of ecosystem condition described in chapter 5, the condition of that asset will be relatively homogeneous.

3.37 In delineating ecosystem assets for the purpose of ecosystem accounting, the following principles should apply:

(a) **Ecosystem assets should represent ecosystems.** The spatial units should align with the definition of ecosystems under the Convention on Biological Diversity reflecting a consideration of organisms, their environmental setting and ecosystem processes. It is accepted that the delineations cannot be perfect representations of a complex ecological reality;

(b) **Ecosystem assets should be capable of being mapped.** Since ecosystem accounting is commonly implemented using a spatially based approach, it is necessary for ecosystem assets to be capable of being identified and mapped in a specific location;

(c) **Ecosystem assets should be geographically and conceptually exhaustive across ecological realms.** The "exhaustive" criterion is understood as reflecting comprehensiveness, both spatially and conceptually, including built environments. The set of ecosystem assets should allow for an EAA to be fully tessellated, that is, filled;

(d) **Ecosystem assets should be mutually exclusive, both conceptually and geographically.** This means that ecosystem assets should not overlap, either conceptually or geographically and that any area on land or the sea floor, or any horizontal depth layer in the ocean, should be occupied by one and only one ecosystem asset. As long as ecosystem assets are mutually exclusive, there can be no double counting of the same space. This principle is applied within a single dimensionality, that is, within one, two or three dimensions.

3.38 The occurrence and extent of ecosystem assets delineated using these principles can change over time. Indeed, the expectation is that, over time, through the use of consistent principles and classifications, different boundaries will be delineated to reflect the changing sizes and configuration of ecosystem assets (e.g. due to expansion of urban areas or restoration of wetlands). Recording these changes, labelled in SEEA EA as ecosystem conversions, is the focus of accounting for ecosystem extent described in chapter 4.

3.39 Where the boundary of an EAA, for example, a country's national border, passes through a delineated ecosystem asset, only the area of the ecosystem asset inside the EAA boundary should be included in the account. While this effectively partitions the ecosystem asset, it ensures that the sum of the areas of all ecosystem assets is equal to the total area of the EAA.

3.40 An EAA will contain a range of ecosystem types. In broad terms, there exists a gradient extending from pristine natural areas to intensively managed ecosystems, including production plantation forests, croplands and meadows, and built environments. While natural areas are governed mainly by natural ecological processes, intensively managed areas are defined primarily (and semi-natural areas partly) by land uses determined by human activity. However, since all of these types of areas may be within an EAA, all of its ecosystem types should be accounted for.

3.41 The composition of ecosystem types within an EAA are rarely reflected in neat boundaries between easily identified areas of, for example, croplands and wetlands. In reality, there is a mixture of different features and ecosystem types throughout an EAA. In this context, two specific factors influence delineation in practice.

3.42 One factor is the number of different ecosystem types for which delineation is undertaken. The greater the number of ecosystem types to be delineated, the more challenging the task, but, at the same time, the greater the richness of the picture that is drawn and the more homogeneous the ecosystem assets.

3.43 The other factor is the spatial scale at which delineation is undertaken. In cases where delineation is undertaken at a low resolution, for example, for 5 x 5 km grid cells, it is less likely that specific ecosystem assets, such as small wetlands, will be identified. On the other hand, when delineation is undertaken at a high resolution, for example, for 30 x 30 m grid cells, many distinct ecosystem assets may be identified.

3.44 In practice, a balance must be struck between the resolution at which delineation is undertaken (and the related rules by which ecosystem types are identified) and the number of ecosystem types to be delineated. That balance will depend on data availability and analytical requirements. The general recommendation is that, for a given ecosystem account, a single spatial resolution of analysis should be selected and, consequently, an ecosystem asset will not be delineated unless its area is sufficiently large to render it identifiable at that resolution.

3.3.2 Approaches to identifying specific features

3.45 In addition to considering the number of ecosystem types and the resolution at which delineation is to be undertaken, it is also necessary to assess whether there are specific features that need to be distinctly identified in the accounts. The present section considers two contexts in which specific guidance is particularly appropriate: the context of linear features and that of complex mosaics.

3.46 **Linear features.** In all EAAs, there are a variety of linear features. Typical examples are streams, rivers and road verges. If the resolution of delineation is sufficiently high, those features may be readily identified, but they are commonly missed. For ecosystem accounting purposes, it is relevant to make a distinction between "narrow" linear features, whose width is small enough to be treated as zero when accounting for the total area of an EAA (which must be equal to the sum of the areas of individual ecosystem assets), and "wide" linear features, whose width is large enough to warrant the separate recording of the associated area.

3.47 The recommended treatments, using the distinction between narrow and wide linear features and considering rivers and streams separately from other linear features, are described directly below:

(a) For rivers and streams, width changes downstream along a river system, so that there is a transition from narrow upstream headwater reaches to wide downstream trunk rivers. Ideally, the area of sufficiently wide rivers and streams should be separately recorded. The treatment of this transition in the accounts would depend on the nature of the source data involved (e.g. on whether those data are raster data or vector data). If delineating the area of rivers is not possible, they may be delineated in terms of length;

(b) For other linear features that are ecologically linked to the surrounding landscape, such as ditches or hedgerows in a pasture landscape, it is recommended that they should not be separately identified, and any associated area should be attributed to the ecosystem type of the surrounding ecosystem;

(c) For any linear features that are not ecologically linked to the surrounding landscape, such as forest access roads, the choice is either to treat them as if they were streams and rivers if they are sufficiently wide (i.e. as a distinct ecosystem type with an associated area) or to include them with the surrounding ecosystem types (i.e. without an associated area). The choice should be guided by the added value that a separate ecosystem type would contribute to the account or its applications.

3.48 These treatments are applied in the context of compiling a standard two-dimensional extent account for an EAA. In some cases, there may be linear features that are of particular significance, economically, ecologically or culturally. To account for these features, it may be necessary to delineate ecosystem assets at higher resolutions so that the area of the relevant linear features can be separately identified alongside neighbouring ecosystem assets and so that the linear features can be separately accounted for, for example, in terms of condition and ecosystem service flows. Further, in some instances, there may be interest in a separate recording of linear features in terms of their length. A complementary set of one-dimensional extent accounts for such a purpose is described in chapter 4.

3.49 It is to be noted that where a linear feature is attributed to the surrounding ecosystem, the condition of that ecosystem should take the presence of the linear feature into account. Thus, changes in the extent of linear features, for example, through increases in the number of kilometres of hedgerows, should be reflected in changes in the measure of condition. Incorporating linear features may have positive or negative effects on a measure of condition depending on the context.

3.50 **Complex mosaics**. Some spatial areas are characterized by a complex mix of different ecosystem types. Examples include urban areas and cultivated areas with small farm holdings. In concept, all of the different ecosystem types can be delineated following the general principles discussed above provided that the resolution is appropriately high. In a second step, distinct EAA boundaries can be determined where there is interest in specific spatial areas, for example, urban areas or cultivated areas. This process supports a consistency in delineation across wider EAAs, for example, across a country, notwithstanding that some of the ecosystem assets delineated, such as green and blue spaces in urban areas, may be small relative to similar ecosystem types outside the complex mosaics.

3.51 Where there is interest in accounting specifically for complex mosaics, applying complementary classifications of ecosystem types (e.g. types of urban areas such as parks, lawns and ponds and types of crops in cultivated areas) would be relevant in supporting analysis and decision-making. A discussion on the broader issues of delineation associated with accounting for urban areas is presented in chapter 13 on thematic accounting.

3.4 Classifying ecosystem assets

3.4.1 General principles

3.52 Ecosystem assets are classified into ecosystem types. Given the variety of ecosystem types and contexts around the world, there are many examples of ecosystem-related classifications. For SEEA EA purposes, any ecosystem classification to be used for ecosystem accounting should ideally satisfy the definition of an ecosystem type (i.e. as representing a distinct set of abiotic and biotic components and their interactions) and should enable application of the principles for delineating ecosystem assets listed in section 3.3.1.

3.53 Depending on the data available, the compilation of accounts at the national or subnational level may involve the use of a large number of ecosystem types so as to ensure that the accounts are suitable for the context. For the purpose of reporting and comparison among countries, a smaller number of higher-level classes is appropriate so as to facilitate the use of the ecosystem data by a wide range of users.

3.54 It is recommended that existing national ecosystem classification schemes be used for ecosystem accounting wherever possible. Generally, such classification schemes provide detailed descriptions and classes that incorporate specific local ecological knowledge. Cross-referencing of spatial units to the SEEA EA reference classification, IUCN GET, enables national-level accounts to be scaled up and compared by countries (see sect. 3.4.2). Where specific national ecosystem types have been identified that do not translate directly into the SEEA EA reference classification, local ecological expertise should be applied to determine the most appropriate cross-referencing.

3.55 Where a national classification of ecosystems is not available, IUCN GET may be used to develop one through a scaling down to locally derived and locally relevant ecosystem types.

3.56 For the purposes of international reporting and comparison, the SEEA ecosystem type reference classification, reflecting IUCN GET ecosystem functional groups, (EFGs) should be applied. Generally, at this level of reporting there will be fewer classes than ideal for national-level account compilation and hence some aggregation of national classes will be required.

3.4.2 SEEA ecosystem type reference classification

3.57 The SEEA ecosystem type reference classification has been established to ensure that the compilation of ecosystem accounts in different locations can be compared against a commonly agreed set of ecosystem types that were established on the basis of agreed principles. There are a variety of ways in which ecosystems can be classified and compilers are encouraged to use classes relevant to their local context. The availability of a reference classification that provides a common baseline, which can be used to evaluate the appropriateness of a given classification and to supply a structure for comparability of data and accounting methods, is therefore desirable.

3.58 The SEEA ecosystem type reference classification reflects IUCN GET, which was developed to support implementation of the IUCN Red List of Ecosystems. IUCN GET is a global typological framework that applies an ecosystem process-based approach to ecosystem classification for all ecosystems around the world. In this approach, ecological assembly theory is used to identify key properties that distinguish functionally related ecosystems and to synthesize traditionally disparate classification approaches across terrestrial, freshwater, subterranean and marine ecological realms. Application of a focus on functionally related ecosystems at the higher levels of the classification allows ecosystem types that are similar but different at the local level to be grouped in an ecologically meaningful way. This is particularly important for purposes of international comparison, a context where the variety of ecosystem types is very large.

3.59 IUCN GET has a structure comprising six levels. The three upper levels (1 to 3) differentiate the functional properties of ecosystems. Levels 4 to 6 offer finer levels of detail on ecosystem types that are relevant in national and subnational contexts. Existing national ecosystem type classes would be expected to be described at a level of detail corresponding conceptually to GET levels 5 or 6. David A. Keith and others, eds. (2020) provide a full description of IUCN GET and its approach to classification.

3.60 The SEEA ecosystem type reference classification corresponds to IUCN GET levels 1 to 3. The focus on these levels allows: (a) national variations in the description of local ecosystem types to be developed while recognizing the importance of locally relevant classes; and (b) ecologically meaningful groupings of locally relevant ecosystem types to be formed for the purposes of integrating national-level data from different sources (e.g. agriculture, environment, forestry and marine data).

3.61 The top level defines four realms: marine (M); freshwater (F); terrestrial (T); and subterranean (S). ***A realm is a major component of the biosphere that differs fundamentally in ecosystem organization and function.*** The subterranean realm is included in the reference classification with the understanding that for a standard two-dimensional extent account its ecosystem types will be out of scope. The top level also provides for the classification of atmospheric units to an atmospheric realm at a future date, which would provide complete coverage of the biosphere. As noted in section 3.2.1, that part of the atmosphere above the atmospheric boundary layer is not included in the scope of ecosystem assets.

3.62 The second level of the classification broadly follows the modern functional biome concept under which ***a biome is "a biotic community finding its expression at large geographic scales, shaped by climatic factors and characterized by physiognomy and functional aspects, rather than by species or life-form composition"*** (Mucina, 2019). IUCN GET defines 24 biomes: 4 exclusively in the marine realm; 3 exclusively in the freshwater realm; 7 exclusively in the terrestrial realm; 4 exclusively in the subterranean realm; and 6 in transitional areas between different realms. These transitional areas represent interfaces between various combinations of the marine, freshwater, subterranean and terrestrial realms.

3.63 Levels 1 and 2 of the SEEA ecosystem type reference classification are presented in table 3.2. Many of the ecosystem types described at level 2 are familiar as naturally occurring biomes, including tropical forests, shrublands, deserts, freshwater lakes and pelagic ocean waters. Six biomes are defined by anthropogenic processes,[43] where human activity is pivotal to ecosystem assembly and maintenance of ecosystem components and processes.

3.64 The third level of the classification describes EFGs. ***An EFG, which is a functionally distinctive group of ecosystems within a biome,*** is defined in a manner consist-

[43] Also referred to as "anthromes" (see Ellis (2011); and Ellis and others (2010)).

ent with the definition of ecosystems under the Convention on Biological Diversity, which underpins the SEEA EA concept of ecosystem assets. Ecosystem types within the same EFG share common ecological drivers that promote the convergence of the biotic traits that characterize the group. There are 100 EFGs in IUCN GET, although it would be highly unlikely for a country to have ecosystem assets representative of all EFGs. More commonly, less than 40 EFGs would be present in a single EAA. A full listing of the EFG classes is provided in appendi 3.2.

3.65 For the compilation of ecosystem accounts at the national or subnational level, it is expected that the delineation of ecosystem types would occur at fine levels of detail using national classifications. The compilation of ecosystem accounts may occur at this same fine level of classification. For the presentation of ecosystem accounting outputs, either in tabular or in map format, it may be appropriate to combine fine-level classes. For example, there may be presentation at the equivalent of the EFG level. It is expected that for the purposes of international comparison, the reporting of data at the EFG level (level 3) would be appropriate.

3.66 Specific note should be taken at this point in the text of the six anthropogenic biomes: T7 (intensive land-use systems), which includes croplands, pastures, plantations and urban areas; F3 (artificial wetlands); M4 (anthropogenic marine ecosystems); S2 (anthropogenic subterranean voids); MT3 (anthropogenic shorelines); and SF2 (anthropogenic subterranean freshwaters); and their composite EFGs. For a range of ecosystem accounting purposes, there will be interest in accounting at a finer level of detail than that of the EFGs that are within these biomes. For example, urban ecosystems (T7.4) are often structurally complex and highly heterogeneous; and annual croplands (T7.1) consist of fields of varying crop types and fallow land. To delineate and report on spatial units within the above-mentioned anthropogenic biomes and their corresponding EFGs, various ecosystem subtypes may be identified. To define those spatial units, it is recommended that national land-use classes be used or, as needed, the classes of the SEEA Central Framework Classification of Land Use (Central Framework, annex I, sect. B) (at the three-digit level).

3.67 The use of IUCN GET as the reference classification of ecosystem types reflects the need for a globally applicable classification of ecosystem types covering all realms. There is a range of existing global classifications of ecosystem types, habitats, land cover and land use, as well as regional or realm-specific classifications of ecosystem types that may be used in other contexts. Examples include World Terrestrial Ecosystems (Sayre and others, 2020); the European Nature Information System and Mapping and Assessment of Ecosystems and their Services (MAES); the Food and Agriculture Organization of the United Nations (FAO) Global Agro-Ecological Zones; the SEEA Central Framework Classification of Land Use and Land Cover Basic Rules and Classifications (annex I, sects. B and C); the Moderate Resolution Imaging Spectroradiometer (MODIS); and classifications used under global conventions such as the United Nations Framework Convention on Climate Change and the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention).[44] To support the integration of data and the compilation of accounts, correspondences among these classifications will be developed, building on work, for example, of Bordt and Saner (2019) and under the United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (2017).

[44] United Nations, *Treaty Series*, vol. 996, No. 14583.

Table 3.2
SEEA ecosystem type reference classification based on IUCN GET

Realms	Biomes
Terrestrial	T1 Tropical – subtropical forests
	T2 Temperate – boreal forests and woodlands
	T3 Shrublands and shrubby woodlands
	T4 Savannas and grasslands
	T5 Deserts and semi-deserts
	T6 Polar-alpine
	T7 Intensive land-use systems
Freshwater	F1 Rivers and streams
	F2 Lakes
	F3 Artificial fresh waters
Marine	M1 Marine shelves
	M2 Pelagic ocean waters
	M3 Deep-sea floors
	M4 Anthropogenic marine systems
Subterranean	S1 Subterranean lithic
	S2 Anthropogenic subterranean voids
Transitional	TF1 Palustrine wetlands
	FM1 Semi-confined transitional waters
	MT1 Shoreline systems
	MT2 Supralittoral coastal systems
	MT3 Anthropogenic shorelines
	MFT1 Brackish tidal systems
	SF1 Subterranean freshwaters
	SF2 Anthropogenic subterranean freshwaters
	SM1 Subterranean tidal

Source: David A. Keith and others, eds. (2020).

3.5 Considerations with respect to delineation of spatial units

3.5.1 Delineation of ecosystem assets in practice

3.68 The distinction between ecosystem assets of different types is ecological. This reflects an understanding of the differing composition, structure and function of the various biotic and abiotic components and their interactions. In principle, then, delineating the boundaries between ecosystem assets is statistically observable and can be undertaken through comprehensive and regular assessments by ecologists on the ground, including assessments of changes over time.

3.69 In practice, the high resource costs of ground assessments signify that the delineation of ecosystem assets would likely involve the mapping of different ecosystem types within an EAA using remote sensing data from satellites where possible. At the same time, it would be necessary to develop regular programmes of ground assessments to support the calibration of remote sensing data.

3.70 Irrespective of the data-collection approach, the data should be collated and analysed by applying geographic information system (GIS) platforms and techniques. This offers the benefits of supporting the integration and manipulation of spatial data from various sources and unleashing the potential to organize and compare those data reliably and sustainably. While such work is specialized, there is nonetheless extensive practical and theoretical understanding of the use of GISs to support the delineation of ecosystem assets for ecosystem accounting purposes. The use of GIS platforms and techniques is relevant in other areas of ecosystem accounting. Accompanying technical guidance on the use of GIS techniques and tools for ecosystem accounting is outlined in the *Guidelines on Biophysical Modelling for Ecosystem Accounting* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022a).

3.71 While the use of GIS is standard, it becomes necessary to incorporate ecological expertise so as to ensure that the boundaries drawn between ecosystem assets are appropriate in ecological terms with regard to the ecosystem type classification that is adopted and that the changes through time are meaningful. In addition, where ground assessments are carried out, this information should be integrated appropriately to provide the most accurate measures or used as part of data validation work.

3.72 To operationalize the delineation of ecosystem assets within GISs, it may be appropriate to use a BSU. ***A BSU is a geometrical construct representing a small spatial area.*** The purpose of BSUs is to provide a fine-level data framework within which data on a range of characteristics can be incorporated. A grid cell is one example of a BSU but other BSU shapes – for example, reflecting polygons – may be used. Figure 3.4 shows how a grid-based BSU can be overlaid on an EAA to assist in delineating the ecosystem assets included in the example presented in figure 3.3.

3.73 In the application of a BSU technique, each BSU is attributed with data on characteristics that are relevant in distinguishing between ecosystem assets of different types. One way of conceiving this is to imagine that over the entire EAA, data on each characteristic is mapped at the BSU level to establish a data layer for that characteristic.

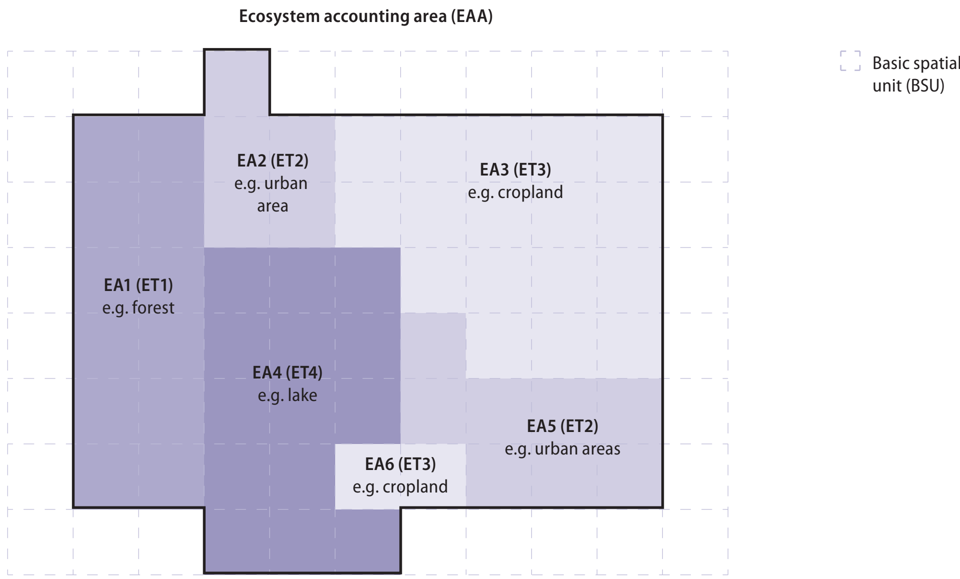
3.74 As noted above, different ecosystem types can be distinguished through combinations of a number of characteristics. At a basic level, it is necessary to combine data on land cover, climate (e.g. temperature regime, precipitation regime, potential evapotranspiration) and landforms (e.g. soil type, lithography, geomorphology). From this starting point, a range of other characteristics may be added, related, for example, to water, carbon or nutrients.

3.75 The extent to which it is possible to combine multiple data sets to delineate ecosystem assets depends on data availability. Where available, existing maps that delineate ecosystem assets may be used. As a second option, ecosystem asset maps may be generated using national-level information on land cover, climate, landforms or other characteristics, as relevant, following the descriptions above.

3.76 Where national-level data on basic characteristics are not available, global data sets may be used. This approach has been applied in a number of contexts. An example is the map of World Terrestrial Ecosystems (Sayre and others, 2020), which was derived from the objective development and integration of global temperature domains, global moisture domains, global landforms and 2015 global vegetation and land-use data. As a final option, it may be necessary to use data on the single characteristic of land cover to provide an initial delineation of ecosystem assets.

3.77 For those biomes that are subject to direct human management (particularly biome T7: Intensive land-use systems), it is appropriate to incorporate data on land and ecosystem use in the delineation of ecosystem assets in addition to data on other variables such as land cover. In this context, data on land and ecosystem use can provide

Figure 3.4
Application of a grid-based BSU to delineate ecosystem assets



an indicator of differing ecological composition, structure and function. The potential for identifying separate ecosystem assets within these biomes is discussed in section 3.4.2.

3.78 While the focus of the description in section 3.5.1 is on the use of spatial approaches to delineating ecosystem assets, data on the extent of ecosystem assets or of specific ecosystem types may be collected through other means, for example, surveys of landholders. For certain ecosystem types, for example, cultivated areas and forests, the collection of data through these other means will provide input into the accounts. However, data from these sources do not support the derivation of maps since the precise location and boundaries of the ecosystem assets will not be recorded. Consequently, alignment with data on other ecosystem types may be challenging and the risks are increased of double counting or missing areas of ecosystems. On the other hand, non-spatial data may be valuable in supporting data quality assurance and estimation of ecosystem condition and ecosystem services.

3.5.2 Use of data on characteristics of land

3.79 In ecosystem accounting, there is commonly an interest in accounting for terrestrial ecosystems and hence the use of data associated with the various characteristics of land is of immediate relevance and interest. Demonstrated rapid and significant changes in terrestrial ecosystems, for example, due to urban and agricultural expansion are one reason for this interest. As described above, while land-cover and land-use data are not sufficient to delineate ecosystem assets, they do provide much relevant information for the measurement of ecosystem extent of terrestrial ecosystem types. Those data may also be of direct use in the measurement of ecosystem service flows and in the monetary valuation of ecosystem services and ecosystem assets.

3.80 Both land-cover and land-use data should be organized following the concepts and definitions outlined in the SEEA Central Framework. Land cover refers to the observed physical and biological cover of the Earth's surface and includes natural vegetation and abiotic (non-living) surfaces. At its most basic level, land cover comprises all of the individual features that cover the area within a country. For the purposes of land-cover statistics, the relevant country area includes only land and inland waters.

3.81 Several international land-cover classifications, providing well-documented and tested metadata, may be used. The standard classification of land cover in the SEEA Central Framework is based on the FAO Land Cover Classification System.[45]

3.82 Land use reflects both (a) the activities undertaken and (b) the institutional arrangements put in place for a given area for the purposes of economic production, or the maintenance and restoration of environmental functions. In effect, "use" of an area implies the existence of some human intervention or management. Land in use therefore includes areas (e.g. protected areas) that are under the active management of institutional units of a country for the primary purpose of conserving biodiversity and other environmental values (SEEA Central Framework, para. 5.246).

3.83 Land management is the process of managing the use and development of land resources. There may be differences in the degree to which areas of land or water are managed by humans, ranging from more intensively (in the case, for example, of built-up areas and cropland) to less intensively (in the case, for example, of polar regions and oceans). The level of land management can have positive or negative effects on ecosystems and monitoring changes in the degree of management may be of interest in the context of monitoring the links among changes in ecosystem assets, their condition and land management policies and decisions.

3.84 Landownership is a key characteristic that constitutes a direct link between ecosystems, their management and economic statistics. Economic assets, including land, can be assigned and classified to institutional units (i.e. corporations, government, households, non-profit organizations) based on ownership. As not all ecosystems are owned (e.g. some remote natural areas and the high seas beyond the EEZ), various accounting conventions have been established. Moreover, in many countries there are communally owned areas, for example, areas used for the rearing of livestock. Relevant conventions for the allocation of ownership are discussed in chapter 11 in the context of integrating ecosystem accounts with the SNA sequence of accounts. Data on landownership for terrestrial ecosystems are available in many countries in the form of cadastres, which are registers of areas defined administratively and delineated on the basis of ownership.

3.85 Data on each of these characteristics of land – cover, use, management and ownership – can be overlaid (where spatial data are available) or presented in conjunction with data on the extent of ecosystem assets and associated measures of condition and ecosystem services. For example, data derived from cadastres showing the sector of ownership or the nature of tenure can be linked to data on ecosystem assets and hence provide a basis for monitoring the effects of land management policies within a given region (e.g. a water catchment).

3.5.3 Organizing data on socioeconomic and other characteristics

3.86 The delineation of ecosystem assets generally requires the use of data besides land-related data, namely, a variety of data on several ecosystem characteristics, as noted above. The organization of those data may create the opportunity to establish a richer database of spatial information. This would include data on land management and landownership, as described above, as well as data on, for example, stocks and flows of water and carbon; the presence of particular species (either endemic or invasive); measures of soil and water quality; temperature, slope and elevation; pollution

45 For the FAO Land Cover Classification System, see www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036361/.

and other residual flows; the production of agricultural, forestry and fisheries outputs; and indicators for recreational activities and cultural sites.

3.87 One motivation for organizing these additional data emerges from the particular needs of ecosystem accounting. While data on only certain characteristics are required for the delineation of ecosystem assets, there are many other characteristics that are relevant for accounting for ecosystem condition, estimating flows of ecosystem services and determining monetary values for ecosystem services and ecosystem assets. Data on ecosystem extent, condition and services may be further enriched by the integration of spatially detailed socioeconomic data, for example, demographic data.

3.88 In this regard, particular attention should be directed to the measurement of ecosystem services where both their supply and their use must be recorded. In the case of some services (e.g. biomass provisioning services), their supply and their use occurs in the same location in a single ecosystem asset. In the case of other services (e.g. air filtration services), the supply of the service may take place in a location different from the location of its use; and in the case of still other services (e.g. flood mitigation services), it is necessary to allocate the supply of the service to a combination of ecosystem assets. Spatial attribution of the supply and use of ecosystem services is therefore a task that is important for ensuring appropriate recognition of the role of different ecosystems and the mix of different users. These issues are discussed further in chapter 7.

3.89 Spatial data on additional characteristics should be attributed to ecosystem assets in order to support coherence in accounting terms. Operationally, this attribution may be applied using a BSU-based structure to align and integrate spatial data on different characteristics and hence account for varying spatial coverage, scales and projections. Since the extent and configuration of ecosystem assets change over time, the nature of the attribution of data also change. Thus, use of an agreed BSU structure, or master layer, would likely provide considerable computational advantages.

3.90 It is envisaged that, ideally, a country would use the principles of the Integrated Geospatial Information Framework[46] to underpin the collation and organization of spatial data. The organized data could in turn provide a coherent "one map" for a country, including its marine ecosystems, across many ecological, social and economic characteristics. Countries are therefore encouraged to use the implementation of ecosystem accounting as an opportunity to integrate spatial data and techniques.

[46] See https://ggim.un.org/igif.

Appendix A3.1
Ecological concepts underpinning spatial units for ecosystem accounting

Introduction

A3.1 The present appendix provides a short introduction to ecological concepts so that compilers of accounts with a non-ecological background can gain an appreciation of some of the complexities associated with delineating and measuring ecosystem assets. By providing a basic framework for ecological concepts and a summary of key ecosystem characteristics, the discussion should support a more informed discussion with experts in ecology.

Key ecological concepts

A3.2 A range of different but related characteristics of areas are used in ecology, each reflecting different ecological concepts. The present section summarizes the key concepts of relevance in the context of ecosystem accounting.

Ecosystems

A3.3 The central concept of interest for ecosystem accounting and classification is that of the ecosystem itself. The most important element of this definition is the final phrase, "interacting as a functional unit". The phrase signifies that, from an ecosystem functioning perspective, the abiotic environment (climate, lithology, hydrology, etc.) is relevant in relation to biota (if only in a one-directional way) rather than on its own. Ecosystem function concerns processes related to fluxes of resources such as energy and water; to photosynthesis; and to decomposition, which underpin the interactions among ecosystem components (Ågren and Andersson, 2011).

A3.4 David A. Keith and others, eds. (2020), building upon assembly theory (which focuses on the selection of ecological communities through environmental filtering of available traits within a species pool (Keddy, 1992)), distinguish five groups of processes that govern ecosystem functioning. Those processes concern:

- **Resources** (energy, nutrients, water, carbon, oxygen, etc.). One or more of these resources will often be limited, inducing an ecosystem functional response such as competition.
- **Ambient environmental conditions** (temperature, salinity, geomorphology, etc.). These factors regulate the availability of and access to resources, as well as ecological processes (temperature controls biochemical reaction kinetics, geomorphology controls soil moisture conditions, etc.).
- **Disturbance regimes** (fire, floods, mass movements, etc.). These factors episodically destroy existing ecosystem structures and/or introduce or release new resources and niches.
- **Biotic interactions** (competition, predation, ecosystem engineering, etc.). While these are largely endogenous processes that shape ecosystem

structure and function, they include organisms that act as mobile links between different ecosystems and regulate transfers of matter and energy among them.

- **Human activity**. Anthropogenic processes are special kinds of biotic interactions that influence structure and function of ecosystems either directly (e.g. through land-cover change, movement of biota) or indirectly (e.g. through harvest of biomass and other forms of resource use, climate change)

A3.5 Together, those processes, factors and conditions give rise to a variety of ecosystem traits, such as productivity, diversity, trophic structure, physiognomy, types of life forms and phenology. Assembly processes and ecosystem traits both influence stocks of assets and flows of services by shaping ecosystem structure and function. The same processes that determine the "identity" of an ecosystem also determine its integrity. Accordingly, variables that describe these processes and characterize the state of an ecosystem with respect to them are within the focus of ecosystem condition accounts (see chap. 5).

Habitat and biotope

A3.6 The concept of habitat is closely related but not identical to the concept of ecosystem. ***Habitat is defined as "a location (area) in which a particular organism is able to conduct activities which contribute to survival and/or reproduction"*** (Stamps, 2019). Thus, the concept of habitat is organism-specific, focuses on both biotic and abiotic factors and has a geographical component. Habitats are therefore provided by ecosystems for individual species. For example, a closed cover of larix trees may define a taiga forest ecosystem that provides a habitat for woodpeckers.

A3.7 While the term *biotope* is frequently used interchangeably with the term *habitat*, it is often assigned to the community concept and habitat to the species concept. Thus, a species has a certain habitat, but the group of species that share an ecosystem with that species in a geographical region share a biotope (Dimitrakopoulos and Troumbis, 2019). A biotope is a topographic unit and can be considered to be equivalent to an ecosystem asset.

Realm

A3.8 A realm is a major component of the biosphere that is fundamentally distinct in ecosystem organization and function. The four core realms are terrestrial, freshwater, marine and subterranean. Each realm consists of different biomes (see directly below). There are also a number of transitional realms related to ecosystems that are found between the core realms, for example, the marine-terrestrial realm, which contains shoreline and coastal ecosystems.

Biome

A3.9 ***A biome is "a biotic community finding its expression at large geographic scales, shaped by climatic factors, and perhaps better characterized by physiognomy and functional aspects [of vegetation], rather than by species or life-form composition. Biomes are frequently used as tools to provide large-scale (regional to global) backgrounds in a range of ecological and biogeographical studies"*** (Mucina, 2019). Biomes are the largest geographical biotic communities that are convenient to recognize. Most of them broadly correspond with climatic regions (zonobiomes), although other environmental factors are sometimes important, for example, soils (pedobiomes) or topography (orobiomes).

A3.10 There is no single authoritative list of biomes. While some biomes (e.g. tropical rainforest, taiga) are recognized by all specialists in the field, many other different biomes are proposed for less well-defined ecosystems, especially those on ecotones, such as savannas and woodlands. Use of the IUCN GET list of biomes as a reference serves the purposes of SEEA EA.

Ecoregions

A3.11 ***An ecoregion is "a geographic group of landscape mosaics", "resulting from large-scale predictable patterns of solar radiation and moisture, which in turn affect the kinds of local ecosystems and animals and plants found there"*** (Bailey, 2009; 2014). Individual ecosystems (i.e. ecosystem assets) within an ecoregion may have a strong functional relationship with each other (e.g. when upstream ecosystems regulate water and nutrient resources for downstream ecosystems) or they may be functionally unconnected (e.g. when two ecosystem assets of the same ecosystem type, but in adjacent subcatchments, simply reflect the same abiotic conditions, such as soil, climate and topography). Ecoregions are often used within a mapping context and are described using a hierarchical structure. Terrestrial ecoregions are often grouped into different higher-order biogeographic regions, where the biogeographic regions (e.g. Nearctic for Northern America, Indomalaya for India and South-East Asia) reflect global differences in species distributions due to geographical separation and evolutionary history. On a smaller scale, ecoregions may be spatially contiguous units of a single biome or subdivisions thereof (e.g. West Siberian Taiga and East Siberian Taiga) (Olson and others, 2001).

Ecotones

A3.12 ***Ecotones are areas of transition between two ecosystems along a gradient of one or more resources or environmental controls.*** A typical example is the area of transition from forest to grassland along a gradient of moisture availability. Determination of the precise location of ecosystem types, and hence the location of the ecotones between them, is ultimately subjective. Where the gradients are very gentle, ecotones can occupy areas that are quite extensive. The translation of ecotone gradients into a basis for ecosystem classification will depend on the nature and "sharpness" of the transition and the scale of application.

Key characteristics of ecosystems

A3.13 In each of the three core environmental realms – terrestrial, freshwater and marine – ecosystems are commonly understood as occupying space and comprising an abiotic complex, a biotic complex and the interactions between the two complexes. The present section describes the key characteristics of terrestrial, freshwater and marine ecosystems. Those characteristics are linked to ecosystem structure and functioning and play a key role in the classification of ecosystems within each realm, as well as in the measurement of their condition. Reflecting the intention of the appendix as a whole, the present section does not offer an exhaustive listing of ecosystem characteristics. It is intended primarily to provide a sense of the level of richness of ecosystems, which should be considered in their delineation and measurement.

Terrestrial ecosystems

A3.14 Terrestrial ecosystems are found on land and are limited by the presence and availability of water and nutrients. The key drivers for the presence of different ecosystem types are climate, topography and geomorphology, lithology and human activities. In summary:

- **Climate**, pragmatically defined as the statistics of weather, is an important driver of many ecosystems, because of its strong links to resources (e.g. water, energy) and constraints (e.g. droughts). From an ecological point of view, the most relevant climatic parameters are (a) temperature (mean annual temperature; seasonality; temperature of the coldest month; accumulated growing degree days); (b) precipitation (total annual precipitation; seasonality); and (c) potential evapotranspiration (annual total; seasonality).
- **Topography and geomorphology** affect climate (on the global and local scales), moisture conditions (on the regional and local scales) and nutrient redistribution. Differences in topography and geomorphology are exemplified by (a) hillslopes and plains (hillslopes have improved drainage compared with plains); (b) gentle and steep slopes (steeper slopes will have shallower soils, faster drainage and possibly more disturbances owing to mass movements); (c) low and high topography (adiabatic expansion of rising air results in a cooler and wetter (micro)climate on high plains and mountains); and (d) profile and planform convexity (topographic controls on hillslope hydrology promote relatively dry conditions on convex divergent hillslopes and relatively wet conditions in concave hollows and the convergent channel network).
- **Lithology** determines the parent material for soil formation and consequently controls vegetation primarily through resource processes (especially nutrient availability), through mineral composition and through the formation of weathering products, such as clay minerals.
- **Human activities** can exert an impact on ecosystems either directly (e.g. through land-cover change, movement of biota) or indirectly (e.g. through resource use, climate change).

A3.15 The key characteristics of terrestrial ecosystems are shaped by these drivers. The distribution, composition and significance of those characteristics will vary significantly over ranges extending, for example, from tropical rainforests to alpine ecosystems. Key abiotic characteristics of terrestrial ecosystems are soil and moisture regime. Key biotic characteristics include vegetation, animals and biota (such as fungi and bacteria). Collectively, the biotic characteristics are reflected in variations in the structure, composition and function of ecosystems.

A3.16 Concerning key characteristics of soil and vegetation, the following points are relevant:

- **Soil** controls vegetation primarily through a number of resource processes and is formed partially through local current processes and partially through past ecosystem processes. Relevant soil characteristics include:
  - Soil chemical properties such as cation exchange capacity, which determine the capacity of the soil to retain nutrients
  - Soil physical properties, such as texture, porosity, drainage and permeability, which determine the characteristics and availability of moisture during dry periods
  - Soil organic matter, an important biota-controlled soil characteristic that contributes to the above-mentioned chemical and physical properties

- **Vegetation** may be used as a proxy for all biota. While the terms vegetation and ecosystems are often used interchangeably (e.g. with respect to tropical rainforests), vegetation is a biotic element of an ecosystem and exists in a physical environmental context that defines it. For many ecosystems, and for terrestrial ecosystems in particular, vegetation is an important element of the classification and labelling process. Vegetation is generally characterized by species assemblages that have a strong spatial expression and whose occurrences are therefore recognizable on the landscape. Vegetation can also be characterized by a set of more generic plant functional traits (see, for example, Pérez-Harguindeguy and others (2013)), including:
  - Growth form, for example, trees, shrubs, grass and the corresponding canopy architecture
  - Raunkiær life form, for example, phanerophytes (woody, buds > 25 cm above the ground) and geophytes (buds in dry ground)
  - Life history, for example, annuals versus perennials
  - Leaf type and phenology, for example, broad-leaved, needle-leaved, deciduous, evergreen
  - Adaptation to moisture stress (xerophytes) or salt stress (halophytes)

Freshwater ecosystems and wetlands

A3.17 Freshwater ecosystems are characterized by the presence of surface waters whose surface extent can vary spatially over time and whose vegetation consists of largely aquatic species. The main distinction among freshwater ecosystems is between flowing water systems (e.g. rivers and streams) and low- or non-flowing systems (e.g. lakes, ponds and wetlands). Many of the drivers and characteristics are correlated with each other and vary quite predictably along a downstream gradient.

A3.18 The key drivers and abiotic characteristics of *rivers* and *streams* include:

- **Morphology.** By definition, rivers and streams are geomorphological features and can be distinguished in terms of (a) stream order, that is, position from source (lowest order) to outlet (highest order), as a proxy for classification of drainage area; (b) fluvial zone (erosional, transfer, depositional); (c) sediment size (bedrock, boulders, gravel, sand, clay) and mobility (bedload, suspended); (d) channel pattern[47] (straight, meandering, wandering, braided, anastomosing); and (e) bedform (planar, ripples, pool-riffle, bars)
- **Hydrology,** which can be ephemeral, intermittent, perennial or interrupted
- **Chemistry** involving, for example, oxygen and nutrient concentration

A3.19 The key drivers and abiotic characteristics of *lakes and pools* include:

- **Origin**: for example, tectonic, volcanic, glacial, karstic, fluvial, artificial
- **Stratification**: for example, meromictic (never mixes), monomictic (mixes once a year), dimictic (mixes twice a year) and polymictic (often mixes)
- **Trophic status**: oligotrophic (nutrient-poor) and eutrophic (nutrient-rich)
- **Salinity**: freshwater lakes and salt lakes
- **Permanency**: for example, episodic, seasonal and permanent lakes

A3.20 The key biotic characteristics of rivers, streams, lakes and pools include fish, macroinvertebrates and vegetation.

[47] It should be noted that channel pattern is strongly controlled by bank strength, which itself is partly controlled by vegetation. On longer timescales, channel pattern can therefore be regarded as an ecosystem characteristic, rather than a driver.

A3.21 ***Wetlands can be broadly defined as ecosystems that arise when inundation by water produces soils dominated by anaerobic processes, which, in turn, forces the biota, particularly rooted plants, to adapt to flooding (***Keddy, 2010).

A3.22 Some key drivers and abiotic characteristics of *wetlands* are:

- **Morphology**: terrain-conforming versus self-emergent
- **Hydrological system**: permanence/seasonality of water levels (water availability); minerotrophic (groundwater, surface water) versus ombrotrophic (precipitation)
- **Trophic status**: oligotrophic (nutrient-poor) versus eutrophic (nutrient-rich)
- **Landscape position**: along streams (riverine), lakes (lacustrine), estuarine or disconnected/upstream (palustrine)

A3.23 The key biotic characteristics of wetlands concern the *dominant vegetation type*. This may be bryophytes or graminoids (bog and fen or peatland); graminoids, shrubs, forbs or emergent plants (marsh); trees, shrubs or forbs (swamp); or submerged or floating aquatic plants (shallow water).

A3.24 As for terrestrial ecosystems, human activities can be a significant driver of freshwater and wetland ecosystems, for example, through the fragmentation of river systems with dams and the draining of wetlands.

Marine ecosystems

A3.25 Marine ecosystems consist of all saltwater ecosystems that are directly connected to the world's oceans. From a broader ocean perspective, this also includes coastal transitional and intertidal ecosystems (estuaries, deltas, coastal salt marshes and other shorelines).

A3.26 **Bathymetry** is the marine equivalent of topography for terrestrial ecosystems. It is a measure of the depths and shapes of the marine environment when viewed at the transition from coastal landscapes to the deeper open ocean environment. In the context of this transition, *benthic* refers to those habitats or organisms associated with the ocean floor as it extends from the shoreline to increasing depths, while *pelagic* refers to habitats or organisms existing in the marine water column.

A3.27 The key drivers of *marine ecosystems* are:

- **Bathymetric profile**, which influences the characteristics of marine ecosystems since the depth from the water surface will determine exposure of the underlying water layer and/or ocean bottom to air/wind, precipitation, currents, light and nutrients. This driver can be considered in two primary ways. First, *intertidal or littoral zones* create requirements for biota using these areas that are different from the requirements created by *open ocean zones*. For example, as the intertidal zone is affected by tides and is above water for part of the day, biota living within this area will need to have strategies for adapting to potential exposure to air and precipitation. Second, zones are designated as *photic* (receiving light), *disphotic* (receiving insufficient light for photosynthesis) or *aphotic* (receiving no light) based on the ability of light to penetrate the water column, which limits photosynthesis. For example, the continental shelf is relatively shallow and its photic zone is home to light-dependent ecosystems such as corals, seagrasses and kelp; the continental margin begins the slope towards deeper aphotic ecosystems on the abyssal plain where virtually no light penetrates.

- **Climate**, which affects and is affected by the ocean. There are four key aspects to consider. First, *wind* generates surface currents, and waves support the ocean circulation system, which moves water, nutrients and biota globally. The strength of surface winds also plays an important role in the depth of the mixed layer and in upwelling of nutrient-rich deeper waters in coastal locations. Second, the pH (acidity) of the oceans, which currently averages on the somewhat basic or alkaline side of the pH scale (approximately 8), determines the types of biota that can survive in the marine ecosystem. Decreases of *pH* because of increases in atmospheric carbon dioxide (CO_2), also known as ocean acidification, can negatively impact certain biota, such as corals and shellfish. Third, the *temperature* of the oceans depends on atmospheric warming and water temperature will determine the ability of aquatic biota to tolerate certain coastal and marine environments. This can result in changes in the distribution of marine biota. Changing global air temperatures can also exert an impact on the ocean ecosystem through inputs of freshwater from melting glaciers. Fourth, precipitation exerts an impact on the flow of freshwater into coastal and marine systems, thereby influencing the salinity and density of the water layers.
- **Lithology** (underlying rock material), which determines the substrate present on the ocean floor or sea bottom. This can consist of a variety of materials of various origins, for example, rock, sand, mud or biogenic materials (corals, oyster/mussel beds), that shape marine ecosystems.
- **Ocean circulation** patterns, which bring warmer water to cooler continents and vice versa, regulating the temperatures observed in different parts of the globe. The Earth's climatic zones (arctic, temperate, tropical and Antarctic) are very much affected by these ocean processes. *Currents and thermohaline circulation* (which moves surface waters deep into the ocean) also move nutrients and oxygen globally, shaping coastal and marine ecosystems. Equatorial currents moving in opposite directions (clockwise north of the equator and counterclockwise south of the equator) create productive areas with upwelling of nutrient-rich deeper waters. The local impact on deep ocean circulation by bathymetry, as occurs when nutrient-rich currents meet seamounts, creates highly productive upwelling areas for marine biota.
- **Salinity** differences between estuarine (mix of salt- and freshwater) and open ocean (saltwater) environments, which determine the biota that thrive in these settings
- **Stratification** of coastal and marine water layers based on temperature, salinity and density, as well as factors such as surface winds, which plays an important role in driving marine ecosystem structure and function. Stratification varies seasonally and by location on the globe. The *surface mixed layer* is the area of greatest turbulence and circulation of water because of its proximity to surface winds, which results in relatively uniform temperature and salinity. As a result of temperature and salinity differences between the surface and deeper waters, density differences create a boundary between the relatively nutrient-poor waters at the surface and the relatively nutrient-rich deeper waters.
- **Human activities**, which exert an impact on marine ecosystems through both direct and indirect effects. Direct effects include harvesting of

marine species, ecosystem modification, noise and release of nutrients, litter and invasive species into marine and coastal waters. Indirect effects include impacts on climate that then drive changes in marine ecosystem characteristics.

A3.28 The key abiotic and biotic characteristics are:

- **Biota**: biota in the sea column (pelagic biota) may actively propel themselves through the water (nekton: including some bacteria, algae, invertebrates, fishes, birds and mammals) or may be carried passively by currents and winds (plankton). Biota associated with the sea floor (benthic biota) – such as aphotic coral, sponges and bivalves, plants such as seagrasses and kelp, invertebrates and bacteria – can consist of complex three-dimensional structures formed by sessile (stationary) suspension feeders.
- **Sediment chemical and physical properties**, which can indicate the potential for sediments to support biota and associated biological and chemical processes as well as their status as a carbon sink
- **Water column characteristics**, which are important in evaluating the condition of the marine ecosystem. Relevant characteristics include (a) water temperature, which influences the suitability of a marine ecosystem as habitat for biota; and (b) water quality, which is influenced by natural and anthropogenic inputs and processes, including contaminants, nutrients, litter (including plastics) and sediment and freshwater inputs from land. These inputs, as well as broader climatic drivers, can exert an impact on dissolved oxygen, salinity and turbidity (cloudiness) as well as the health of marine biota in the system. Water quality can be an important marker of marine ecosystem condition; for example, low dissolved oxygen levels may indicate an ecosystem impacted by excess anthropogenic nutrient inputs.
- **Vegetation**: Coastal and marine vegetation, including mangroves, seagrasses and seaweeds, are important elements of marine ecosystems. That vegetation provides a habitat and food for biota and plays a role in nutrient and gas cycling and coastal protection. Vegetation in marine systems takes various forms (as regards, for example, size or shape) and may be relatively fixed or immobile (e.g. mangroves) or may float along with ocean currents (e.g. sargassum).

Appendix A3.2

International Union for Conservation of Nature Global Ecosystem Typology

A3.29 The upper three levels of IUCN GET (David A. Keith and others, eds., 2020) are set out below. The realms presented are the terrestrial (T), freshwater (F), marine (M) and subterranean (S) and six transitional realms.

Realm	Biome	Ecosystem functional group
Terrestrial	T1 Tropical/subtropical forests	T1.1 Tropical-subtropical lowland rainforests
		T1.2 Tropical-subtropical dry forests and thickets
		T1.3 Tropical-subtropical montane rainforests
		T1.4 Tropical heath forests
	T2 Temperate-boreal forests and woodlands	T2.1 Boreal and temperate montane forests and woodlands
		T2.2 Deciduous temperate forests
		T2.3 Oceanic cool temperate rainforests
		T2.4 Warm temperate laurophyll forests
		T2.5 Temperate pyric humid forests
		T2.6 Temperate pyric sclerophyll forests and woodlands
	T3 Shrublands and shrubby woodlands	T3.1 Seasonally dry tropical shrublands
		T3.2 Seasonally dry temperate heaths and shrublands
		T3.3 Cool temperate heathlands
		T3.4 Young rocky pavements, lava flows and screes
	T4 Savannas and grasslands	T4.1 Trophic savannas
		T4.2 Pyric tussock savannas
		T4.3 Hummock savannas
		T4.4 Temperate woodlands
		T4.5 Temperate subhumid grasslands
	T5 Deserts and semi-deserts	T5.1 Semi-desert steppes
		T5.2 Succulent or thorny deserts and semi-deserts
		T5.3 Sclerophyll hot deserts and semi-deserts
		T5.4 Cool deserts and semi-deserts
		T5.5 Hyper-arid deserts
	T6 Polar-alpine (cryogenic)	T6.1 Ice sheets, glaciers and perennial snowfields
		T6.2 Polar-alpine cliffs, screes, outcrops and lava flows
		T6.3 Polar tundra and deserts
		T6.4 Temperate alpine grasslands and shrublands
		T6.5 Tropical alpine grasslands and herbfields

(*Continued*)

Realm	Biome	Ecosystem functional group
Terrestrial (*continued*)	T7 Intensive land-use systems	T7.1 Annual croplands
		T7.2 Sown pastures and fields
		T7.3 Plantations
		T7.4 Urban and industrial ecosystems
		T7.5 Derived semi-natural pastures and old fields
Freshwater	F1 Rivers and streams	F1.1 Permanent upland streams
		F1.2 Permanent lowland rivers
		F1.3 Freeze-thaw rivers and streams
		F1.4 Seasonal upland streams
		F1.5 Seasonal lowland rivers
		F1.6 Episodic arid rivers
		F1.7 Large lowland rivers
	F2 Lakes	F2.1 Large permanent freshwater lakes
		F2.2 Small permanent freshwater lakes
		F2.3 Seasonal freshwater lakes
		F2.4 Freeze-thaw freshwater lakes
		F2.5 Ephemeral freshwater lakes
		F2.6 Permanent salt and soda lakes
		F2.7 Ephemeral salt lakes
		F2.8 Artesian springs and oases
		F2.9 Geothermal pools and wetlands
		F2.10 Subglacial lakes
	F3 Artificial wetlands	F3.1 Large reservoirs
		F3.2 Constructed lacustrine wetlands
		F3.3 Rice paddies
		F3.4 Freshwater aquafarms
		F3.5 Canals, ditches and drains
Terrestrial-freshwater	TF1 Palustrine wetlands	TF1.1 Tropical flooded forests and peat forests
		TF1.2 Subtropical/temperate forested wetlands
		TF1.3 Permanent marshes
		TF1.4 Seasonal floodplain marshes
		TF1.5 Episodic arid floodplains
		TF1.6 Boreal, temperate and montane peat bogs
		TF1.7 Boreal and temperate fens
Freshwater-marine	FM1 Semi-confined transitional waters	FM1.1 Deepwater coastal inlets
		FM1.2 Permanently open riverine estuaries and bays
		FM1.3 Intermittently closed and open lakes and lagoons
Marine	M1 Marine shelves	M1.1 Seagrass meadows
		M1.2 Kelp forests
		M1.3 Photic coral reefs
		M1.4 Shellfish beds and reefs
		M1.5 Photo-limited marine animal forests
		M1.6 Subtidal rocky reefs

(*Continued*)

Realm	Biome	Ecosystem functional group
Marine (*continued*)	M1 Marine shelves (*continued*)	M1.7 Subtidal sand beds
		M1.8 Subtidal mud plains
		M1.9 Upwelling zones
		M1.10 Rhodolith/maërl beds
	M2 Pelagic ocean waters	M2.1 Epipelagic ocean waters
		M2.2 Mesopelagic ocean waters
		M2.3 Bathypelagic ocean waters
		M2.4 Abyssopelagic ocean waters
		M2.5 Sea ice
	M3 Deep-sea floors	M3.1 Continental and island slopes
		M3.2 Submarine canyons
		M3.3 Abyssal plains
		M3.4 Seamounts, ridges and plateaus
		M3.5 Deepwater biogenic beds
		M3.6 Hadal trenches and troughs
		M3.7 Chemosynthetic-based ecosystems
	M4 Anthropogenic marine systems	M4.1 Submerged artificial structures
		M4.2 Marine aquafarms
Marine-terrestrial	MT1 Shorelines	MT 1.1 Rocky shorelines
		MT 1.2 Muddy shorelines
		MT 1.3 Sandy shorelines
		MT 1.4 Boulder and cobble shores
	MT2 Supralittoral coastal	MT 2.1 Coastal shrublands and grasslands
		MT 2.2 Large seabird and pinniped colonies
	MT3 Anthropogenic shorelines	MT 3.1 Artificial shorelines
Marine-freshwater-terrestrial	MFT1 Brackish tidal	MFT1.1 Coastal river deltas
		MFT1.2 Intertidal forests and shrublands
		MFT1.3 Coastal salt marshes and reed beds
Subterranean	S1 Subterranean lithic	S1.1 Aerobic caves
		S1.2 Endolithic systems
	S2 Anthropogenic subterranean voids	S2.1 Anthropogenic subterranean voids
Subterranean-freshwater	SF1 Subterranean freshwaters	SF1.1 Underground streams and pools
		SF1.2 Groundwater ecosystems
	SF2 Anthropogenic subterranean freshwaters	SF2.1 Water pipes and subterranean canals
		SF2.2 Flooded mines and other voids
Subterranean-marine	SM1 Subterranean tidal	SM1.1 Anchialine caves
		SM1.2 Anchialine pools
		SM1.3 Sea caves

Source: David A. Keith and others, eds. (2020).

Chapter 4
Accounting for ecosystem extent

4.1 Purpose of accounting for ecosystem extent

4.1 A common starting point for ecosystem accounting is the organization of information on the extent of different ecosystem types within a country or other EAA and how that extent is changing over time. ***Ecosystem extent is the size of an ecosystem asset.*** It is usually measured in terms of spatial area but may also be measured in terms of length or volume. Extent data are summarized in an ecosystem extent account.

4.2 Accounting for ecosystem extent is relevant for four reasons. First, an ecosystem extent account provides a common basis for discussion of the composition (mix/combination) of and changes in ecosystem types within a country. This information supports (a) the derivation of coherent indicators of deforestation, desertification, agricultural conversion, urban expansion and other forms of ecosystem change; (b) the measurement of ecosystem diversity and the derivation of indicators of changes in biodiversity; and (c) an understanding, when information underpinning an extent account is mapped, of the locations and configuration of ecosystem types within an EAA and how this is changing over time (e.g. with respect to fragmentation of the landscape or proximity of cultivated areas to natural ecosystems).

4.3 Second, given that a core intent of ecosystem accounting is to mainstream ecological data in economic planning and decision-making, the organization of data on ecosystem extent provides both a straightforward and a meaningful entry point into the discussion of ecosystems for those less familiar with ecological concepts and data. In particular, extent accounts provide a common framing through which other data on ecosystems can be presented. For example, where relevant data are available, mapped data on ecosystem condition and ecosystem service flows can be tabulated using a common classification of ecosystem types.

4.4 Third, the structure of the ecosystem extent account, as set out below, demonstrates in a manner that is accessible and readily interpretable, the capability of accounting to provide a time-series narrative, in this case through the estimation of opening and closing balances over an accounting period. Recording a time series is particularly important for revealing the degree to which the extent and composition of ecosystem types have changed and the nature of conversions among ecosystem types.

4.5 Fourth, the spatial data most commonly used to compile an ecosystem extent account provide an underlying infrastructure for the measurement of ecosystem condition and for the measurement and modelling of many ecosystem services. In both cases, the relevant indicators of condition and services commonly vary by ecosystem type and depend on the location and configuration (spatial arrangement) of ecosystem types within an EAA. Further, the ecosystem extent account and the ecosystem condition account provide the most information when viewed and interpreted jointly.

4.2 Ecosystem extent accounts

4.2.1 Scope of extent accounts

4.6 Following the principles described in chapter 3, an ecosystem extent account is compiled for the total area of an EAA. Thus, an ecosystem extent account records the areas and changes in areas of all of the ecosystem assets within an EAA, classified by ecosystem type, that is to say the areas of all ecosystem assets of the same ecosystem type are aggregated. Since input data are commonly spatial data available in the form of maps, mapped outputs, where all of the ecosystem assets of the same ecosystem type are coded equivalently, can also be produced. Further, in this case, extent accounts reflect tabulated outputs of the mapped input data.

4.7 In concept, at the national level, the EAA extends to cover all terrestrial, freshwater and marine ecosystems with a boundary set by the country's border with other countries and its EEZ.[48]

4.8 Compilers may choose to use an EAA of smaller geographical scope, by focusing, for example, on the terrestrial or marine realm or on a subnational region. Also, it is possible to compile accounts covering areas outside national jurisdiction, for example, ocean areas including the high seas. These accounts could be compiled as part of regional or international accounting efforts.

4.9 Complementary extent accounts can be compiled for ecosystem types that are outside the scope of the standard two-dimensional extent account, such as subterranean ecosystems and aquifers. Complementary accounts can be compiled also for linear features reflecting a one-dimensional perspective, with the understanding that the area associated with linear features will be included in scope of the standard two-dimensional extent accounts following the treatments outlined in section 3.3. Potential structures for complementary extent accounts are described in section 4.2.4.

4.2.2 Structure of extent accounts and accounting entries

4.10 The structure of an ecosystem extent account is presented in table 4.1. The structure of the rows reflects the general logic of asset accounts as described in the SEEA Central Framework, with an opening extent, closing extent, and additions and reductions in extent. Measurement units for entries are units of area appropriate for the scale of analysis, for example, hectares or square kilometres.

4.11 The column headings correspond to the classes under the selected ecosystem type classification. In table 4.1, these classes are examples of ecosystem types at the EFG level 3 of the SEEA ecosystem type reference classification based on IUCN GET, as described in chapter 3 and presented in appendix A3.2. Table 4.1 includes ecosystem types from the terrestrial, freshwater and marine realms. It may be appropriate to compile accounts separately for each of these realms, particularly if the available units of measurement are different.

4.12 At the national or subnational level, it will be most appropriate to compile accounts using an existing ecosystem type classification and to establish a correspondence to the SEEA ecosystem type reference classification for the purpose of international comparison.

4.13 From an accounting perspective, there is no specific limit placed on the number of ecosystem types or the level of detail that is included. The choice will depend on the relevance of different ecosystem types and data availability. The overall constraint is that the sum of the areas of all ecosystem types must be equal to the total area of the EAA.

[48] Subsurface ecosystems, such as subterranean ecosystems and aquifers, are excluded from the primary extent account, as their area cannot be added together with the area of ecosystems in other realms without double counting.

Table 4.1
Ecosystem extent account (units of area)

	Ecosystem types (based on the EFG level 3 of IUCN GET)																		
	Terrestrial												Freshwater			Marine			
	T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1	
	Tropical/subtropical lowland rainforests	Tropical/subtropical dry forests and scrubs	Tropical/subtropical montane rainforests	Tropical heath forests	Boreal and temperate montane forests and woodlands	Deciduous temperate forests	…	Temperate pyric sclerophyll forests and woodlands	…	…	…	Derived semi-natural pastures and old fields	Permanent upland streams	…	Intermittently closed and open lakes and lagoons	Seagrass meadows	…	Coastal saltmarshes and reedbeds	
	T1.1	T1.2	T1.3	T1.4	T2.1	T2.2	…	T2.6	…	…	…	T7.5	F1.1	…	FM1.3	M1.1	…	MFT1.3	TOTAL
Opening extent																			
Additions to extent																			
Managed expansion																			
Unmanaged expansion																			
Reduction in extent																			
Managed reductions																			
Unmanaged reductions																			
Net change in extent																			
Closing extent																			

Note: The present table provides an indicative structure with respect to the set of ecosystem types. Compilation requires the use of nationally selected ecosystem types.

4.14 The accounting entries encompass opening and closing extent, additions to extent and reductions in extent. The definitions provided in paragraph 4.15 below should be applied, with the understanding that, depending on data availability, it may not be possible to record all accounting entries that distinguish the different types of additions and reductions. In this case, it is sufficient to record the opening and closing extents and the net change in different ecosystem types. This level of detail can still provide important information on trends in ecosystem extent.

4.15 Relevant accounting entries are:

- **Opening extent and closing extent**, which represent the total area of ecosystem assets for a given ecosystem type at the beginning and end of an accounting period, generally one year
- **Additions to extent**, which represent increases in the area of an ecosystem type. Where possible, to support understanding of the nature of the additions and possible policy responses, additions to extent should be separated into managed expansions and unmanaged expansions. Specifically:
  - **Managed expansions** represent an increase in the area of an ecosystem type due to direct human activity in the ecosystem, including the unplanned effects of such activity. Examples include the conversion of forests to cultivated land and land reclamation work in coastal areas. Human activity may also create new areas of more natural ecosystem types, for example, through the reforestation of cultivated areas
  - **Unmanaged expansions** represent an increase in area of an ecosystem type resulting from natural processes, including seeding, sprouting, suckering or layering. Unmanaged expansion can be influenced by human activity, for example, the expansion of deserts due to the effects of climate change, or can result from abandonment of land by people
- **Reductions in extent** represent decreases in the area of an ecosystem type. Where possible, to support understanding of the nature of the reductions and possible policy responses, reductions in extent should be separated into managed reductions and unmanaged reductions. Specifically:
  - **Managed reductions** represent a decrease in the area of an ecosystem type due to direct human activity in the ecosystem, including the unplanned effects of such activity, or cases where the activity may be illegal. Examples include deforestation and increases in urban areas.
  - **Unmanaged reductions** represent a decrease in area of an ecosystem type associated with natural processes. Unmanaged reductions can be influenced by human activity, for example, the loss of coral reefs due to the effects of climate change, or can result from abandonment of land by people.

4.16 All additions and reductions in extent are considered ecosystem conversions and imply a change in ecosystem type. However, a change in the condition of an ecosystem is not sufficient grounds for declaring that an ecosystem conversion has occurred, since this does not necessarily entail a change in ecosystem type. In particular, it is to be noted that the effects of extreme events, for example, bushfires or hurricanes, where there may be considerable loss of vegetation, soil or other ecosystem components, need not imply a change of ecosystem type. Indeed, most commonly, these events are followed by a period of regeneration and, generally speaking, patterns of disturbance should be expected. Section 4.2.3 provides further discussion of ecosystem conversions. In practice, it may be useful to compile ecosystem type change matrices (see sect. 4.3.2) to support compilation of measures of managed and unmanaged changes.

4.17 The availability of updated input data and/or changed methods, for example, resulting from new or reinterpreted satellite imagery, may permit a reassessment of the size of the area of different ecosystem types. Where such changed data and/or methods are used, it will likely require the revision of previous estimates to ensure a continuity of time series. Time series may also be revised when updated classifications are applied. No distinct entry for revisions is recorded in the accounts. Rather, the individual entries for opening and closing extent and additions and reductions are altered. For analytical and dissemination purposes, it may be appropriate to show the size of the revisions by calculating the difference between estimates from historical and revised accounts for the same accounting period.

4.18 Generally, additions to one ecosystem type will be matched by an entry for reductions in another ecosystem type, for example, an increase in cultivated land may be matched by a reduction in woodlands. If there is a change in the total area of the EAA, a matching entry is not recorded.

4.19 Changes in the total area of an EAA due to political factors (e.g. changes following a realignment of borders) should be recorded as managed expansions or reductions for the relevant ecosystem types. These changes do not require revisions to past accounts although it may be of analytical interest to compile historical information pertaining to ecosystem assets within the changed boundaries.

4.20 The area of an EAA for a national jurisdiction including marine, terrestrial and freshwater realms is unlikely to change significantly over the period from the opening to the closing stock. Hence, the total area recorded in the right-hand column of table 4.1 will generally be the same for the opening and closing extents and total additions will therefore equal total reductions.

4.21 However, changes at the edges of the realms and associated transition areas, particularly between the marine and terrestrial realms, are likely to occur, for example, through coastal erosion, sediment deposition and aggradation and sea level rise or owing to land reclamation work. The associated changes in ecosystem type need to be accounted for.

4.22 For the ecosystem extent account presented in table 4.1, there is no requirement that the areas recorded for each ecosystem type be contiguous. That is, the total area of, for example, trophic savannas (T4.1) is likely to be spread out across an EAA in distinct ecosystem assets. The locations of the ecosystem types will be apparent when extent data are presented in maps.

4.2.3 Recording ecosystem conversions

4.23 The ecosystem extent account records changes in ecosystem type. These changes are collectively referred to as ecosystem conversions. ***Ecosystem conversions are situations in which, for a given location, there is a change in ecosystem type involving a distinct and persistent change in ecological structure, composition and function, which, in turn, is reflected in the supply of a different set of ecosystem services.***

4.24 Ecosystem conversions are of particular relevance in understanding trends in and impacts on biodiversity and flows of ecosystem services. Identification of ecosystem conversions relies on determining the time at which the opening extent has been recorded and the length of the accounting period and on identification of the differences between ecosystem types. These issues are discussed in the present section.

4.25 Generally, the length of the accounting period is one year, which is an appropriate reporting period for recording managed expansions and reductions, since the change from one ecosystem type to another can be readily determined as having occurred during the accounting period. Time frames for unmanaged expansions and reductions may vary considerably, however, and determining the appropriate accounting period in which the conversion should be recorded may therefore be more difficult.

4.26 When extreme events occur and it is expected that the ecosystem will recover from the effects, it is appropriate to record no change in ecosystem type, that is, the change may be considered to be part of normal patterns of disturbance. In this case, changes in patterns of disturbance (e.g. greater frequency of fires) are likely to be better represented as changes in condition. A similar treatment should apply in the case of seasonal changes in extent (e.g. of sea ice), since those changes may be considered part of normal ecosystem dynamics. Where appropriate, seasonal changes may be recorded in subannual extent accounts.

4.27 Where changes are gradual and longer-term (for example, changes in coral reefs due to ocean acidification), initial changes may be most appropriately recorded as changes in the condition of the ecosystem asset. However, at some point in time, the ecosystem may be considered to have changed sufficiently in terms of its ecological structure, composition and function to be considered a different ecosystem type. Information collected in the measurement of ecosystem condition and relevant limits and thresholds may be considered in this assessment. Such changes in ecosystem type for a given location should be recorded as an expansion or reduction in the extent account in the accounting period in which it is determined that the change took place.

4.28 Although determining the precise time at which an ecosystem conversion takes place may involve ecological uncertainty, through the adoption of an annual reporting approach, there will be a clear recording structure in place that ensures the consideration of changes on a regular basis and allows the changes to be recorded at appropriate points in time.

4.29 Owing to data and resource limitations, it may not be possible to compile annual extent accounts. This outcome should not be interpreted as meaning that changes in ecosystem extent over time are necessarily slow or are insignificant on an annual basis. While this may be the case in some instances, the significance of recording changes in the composition and configuration of ecosystem types in a timely fashion cannot be underestimated. It is to be noted as well that the increasing availability of remote sensing and similar data sets is reducing the barriers to regular compilation. These data may also support the use of benchmarking and interpolation techniques to provide up-to-date information on ecosystem extent for policy and analysis.

4.30 A common aim in ecosystem extent accounting is to record differences between the current composition of ecosystem types and a reference or baseline composition. Depending on the purpose of analysis, this may entail estimation over long periods of time, for example, comparison of current measures of extent with a pre-Industrial Revolution composition. Conceptually, it is straightforward to compile extent accounts to compare two or more points in time that are a considerable distance apart. For instance, using the same structure as shown in table 4.1, the opening extent could be estimated for 1970 and the closing extent estimated for 2015.

4.31 The structure of table 4.1 allows for recording changes that are managed and unmanaged. Depending on the availability of data and policy interest, an extension to the ecosystem extent account may be developed to enable classification of ecosystem conversions by the reasons for change (e.g. urban expansion, salinization or afforestation).[49]

[49] Proposals for classifying conversions are described in United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (2017) in relation to the measurement of Sustainable Development Goal indicator 15.3.1 concerning land degradation. Those proposals were recently updated in Sims and others (2021).

4.3 Complementary presentations of ecosystem extent data

4.3.1 Mapping ecosystem extent

4.32 Significant analytical benefits are likely to accrue from presenting maps of ecosystem extent that display the configuration of ecosystem assets by different ecosystem types across an EAA. Analysis of a time series of extent maps also enables analysis of the location of changes in ecosystem types. In particular, mapping ecosystem extent can reveal patterns of changing fragmentation of ecosystem assets. These types of changes are not evident when data are presented in tabular form.

4.33 Spatially detailed data on the area of ecosystem assets can also be used to derive a range of supporting indicators, some of which may be relevant in assessing the condition of ecosystems, in particular concerning characteristics related to their fragmentation and connectivity. Example of such indicators include measures of the number of occurrences of an ecosystem type (number of patches), average patch size and edge length.

4.3.2 Ecosystem type change matrix

4.34 Through use of spatially detailed data and by comparing maps from two periods to compile an ecosystem type change matrix, additional details on the nature of ecosystem conversions may be obtained. The ecosystem type change matrix set out in table 4.2 shows the area of different ecosystem types at the beginning of the accounting period (opening extent); the increases and decreases in this area according to the ecosystem type it was converted from (in the case of increases) or the ecosystem type it was converted to (in the case of decreases); and, finally, the area covered by different ecosystem types at the end of the accounting period (closing extent). It is assumed here that the total area of the EAA is unchanged between the two points in time. Where the EAA has changed in size, a choice will need to be made regarding which point in time should be used to define the total area for comparison. The default option is to choose the EAA with the smaller area since only this EAA will include areas present in both time periods and will therefore provide complete data coverage for two points in time.

4.35 For example, the opening extent for ecosystem type T1.1 (Tropical-subtropical lowland rainforests) is recorded in the right-hand column of the first row and the closing extent is recorded in the bottom row of the left-hand column. Where the ecosystem type in a particular location does not change (i.e. where there is no ecosystem conversion), the total unchanged area is recorded along the diagonal from top left to bottom right. Where there is a change in ecosystem type (in other words, an ecosystem conversion), an entry is made at the intersection of the row related to the original ecosystem type (i.e. the ecosystem type whose area has decreased) and the column related to the new ecosystem type (i.e. the ecosystem type whose area has increased). The conversion of ecosystem type T1.1 to ecosystem type T7.5 (Derived semi-natural pastures and old fields) would be recorded in the cell at the intersection of the row for T1.1 and the column for T7.5. Recording in this way for each ecosystem type ensures that (a) the sum of all cell entries in a row will equal the opening extent (i.e. unchanged areas plus the reduction in area); and (b) the sum of all cell entries in a column will equal the closing extent (i.e. unchanged areas plus the addition to area).[50]

[50] An alternative presentation of a change matrix (for land cover) is provided in figure 5.14 of the SEEA Central Framework.

Table 4.2
Ecosystem type change matrix (units of area)

					Ecosystem types (based on the EFG level 3 of IUCN GET) Closing extent																		
					Terrestrial												Freshwater			Marine			
					T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1	
					Tropical/subtropical lowland rainforests	Tropical/subtropical dry forests and scrubs	Tropical/subtropical montane rainforests	Tropical heath forests	Boreal and temperate high montane forests and woodlands	Deciduous temperate forests	…	Temperate pyric sclerophyll forests and woodlands	…	…	…	Derived semi-natural pastures and old fields	Permanent upland streams	…	Intermittently closed and open lakes and lagoons	Seagrass meadows	…	Coastal saltmarshes and reedbeds	
					T1.1	T1.2	T1.3	T1.4	T2.1	T2.2	…	T2.6	…	…	…	T7.5	F1.1	…	FM1.3	M1.1	…	MFT1.3	Opening
Ecosystem types (based on the ecosystem functional group EFG level 3 of IUCN GET) Opening extent	Terrestrial	T1 Tropical-subtropical forests	Tropical-subtropical lowland rainforests	T1.1																			
			Tropical-subtropical dry forests and scrubs	T1.2																			
			Tropical-subtropical montane rainforests	T1.3																			
			Tropical heath forests	T1.4																			
		T2 Temperate-boreal forests and woodlands	Boreal and temperate high montane forests and woodlands	T2.1																			
			Deciduous temperate forests	T2.2																			
			…	…																			
			Temperate pyric sclerophyll forests and woodlands	T2.6																			
		…	…	…																			
			…	…																			

Table 4.2
Ecosystem type change matrix (units of area) (*continued*)

				Ecosystem types (based on the EFG level 3 of IUCN GET) Closing extent																		
				Terrestrial												Freshwater			Marine			
				T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1	
				Tropical/subtropical lowland rainforests	Tropical/subtropical dry forests and scrubs	Tropical/subtropical montane rainforests	Tropical heath forests	Boreal and temperate high montane forests and woodlands	Deciduous temperate forests	…	Temperate pyric sclerophyll forests and woodlands	…	…	…	Derived semi-natural pastures and old fields	Permanent upland streams	…	Intermittently closed and open lakes and lagoons	Seagrass meadows	…	Coastal saltmarshes and reedbeds	
				T1.1	T1.2	T1.3	T1.4	T2.1	T2.2	…	T2.6	…	…	…	T7.5	F1.1	…	FM1.3	M1.1	…	MFT1.3	Opening
Selected ecosystem types (based on the EFG level 3 of IUCN GET) Opening extent	Terrestrial	T7	…	…																		
			Derived semi-natural pastures and old fields	T7.5																		
	Freshwater	F1	Permanent upland streams	F1.1																		
		…	…	…																		
		FM1	Intermittently closed and open lakes and lagoons	FM1.3																		
	Marine	M1	Seagrass meadows	M1.1																		
		…	…	…																		
		MFT1	Coastal saltmarshes and reedbeds	MFT1.3																		
				Closing																		

4.3.3 Extent accounts for linear features and subsurface ecosystems

4.36 Conceptually, most ecosystem assets have a two-dimensional footprint geometry, allowing their extent to be measured by their area. However, for some ecosystem assets this approach is not appropriate because their length far exceeds their width, with the result that their footprint geometry is effectively one-dimensional. Typical examples are streams, smaller rivers and road verges. Such assets are referred to as linear features.

4.37 A complementary extent account for linear features can be compiled by recording the length of each individual linear feature (with each being treated as an ecosystem asset). Each linear feature can also be assigned to an ecosystem type, allowing aggregation by linear feature type. It is of relevance to distinguish clearly between linear features dominated by produced assets (e.g. roads) and those that are more natural in character (e.g. streams). Classification along the lines of IUCN GET would be appropriate in this regard. This type of accounting reflects the same logic that underpins a two-dimensional extent account (as described above) but uses units of length instead of units of area. The resulting one-dimensional extent account can complement a two-dimensional extent account, with the understanding that total one-dimensional length cannot be aggregated with total two-dimensional area owing to the difference in dimensionality.

4.38 The presentation in table 4.3 exhibits the distinction between larger rivers, recorded as having both area and length, and smaller rivers and streams, recorded as having length only. The fact that narrow linear features have an assumed area of zero does not disqualify them from being ecosystem assets with an associated condition or from having the potential to supply ecosystem services.

4.39 Complementary extent accounts can also be compiled for subsurface ecosystem assets, including subterranean ecosystems and aquifers. Following the classification of ecosystem types, accounts could be compiled showing the number of occurrences, the area or footprint of these ecosystems and, potentially, their volume. As appropriate, these indicators of ecosystem extent may be complemented by data on ecosystem condition and ecosystem services.

Table 4.3
Presentation of closing balances including both one-dimensional (1D) and two-dimensional (2D) ecosystem types

Ecosystem type		Extent	
		Area (km^2)	Length (km)
2D	Forest	345	
	Lakes	50	
1D	Rivers	5	50
	Streams		200
Total		**400**	**250**

4.3.4 Linking extent accounts and economic data

4.40 There is a general ambition to link environmental data to measures of economic activity across all SEEA accounts. In the context of the ecosystem extent accounts, a primary means of achieving this aim is through linkage of data on ecosystem extent by ecosystem type with data on the economic owners or managers of the ecosystem assets. Data on economic owners may be categorized by institutional sector following the classes in the 2008 SNA such as non-financial corporations, general government and households. Such a classification is most relevant for understanding the ownership and financing context. In some cases, there may be particular interest in identifying ecosystem areas (and the different ecosystem types) that are under common ownership or under the control of indigenous peoples.

4.41 Data concerning economic managers or types of economic activity may be classified by groupings under the International Standard Industrial Classification of All Economic Activities (ISIC), such as agriculture, forestry and water supply, and then aligned to the structure of SUTs. This classification of data is most relevant for understanding the links between ecosystem types and economic activity and for understanding to which ecosystems those industries have rights of access and use. The distinction between ownership and type of activity is important since the same ecosystem type may be linked to a range of different ownership contexts and uses.

4.42 The set of ownership and type-of-activity classes that is developed will depend on the data available and the purpose of analysis. Tables that display the connection between ecosystem types and economic ownership and management can provide a range of information. For example, they may describe the mix of ecosystem types that are managed by government, as distinct from the household sector, or the various ecosystem types managed by the agricultural industry.

4.43 Table 4.4 presents a cross-classification of ecosystem assets. The columns display data on ecosystem types (in this case EFG classes) and the rows display data on types of economic units for a single point in time, for example, the closing of the accounting period. The classes of economic units shown in the table reflect a production or management perspective and industrial categories are prominent. An alternative set of categories reflecting economic ownership by institutional sector (e.g. non-financial corporations, financial corporations, general government, households) may also be developed. Extent data classified by economic use and ownership should be maintained as distinct data layers and cross-tabulated or mapped when required.

4.44 Information linking ecosystem extent to economic units is of particular importance in the design and implementation of policy since the outcomes with respect to specific ecosystem types are likely to be highly influenced by the characteristics of the owning or managing economic units. It is likely that this type of analysis is of most relevance for terrestrial ecosystems, but types of ownership and access rights will be of relevance in certain other contexts as well, for example, that of marine spatial planning.

4.45 The structural information on the links between ecosystem assets and economic units such as presented in table 4.4 also provides the basis for creating links between economic units and data from other ecosystem accounts, in particular ecosystem services flow accounts.

Table 4.4
Ecosystem extent by type of economic unit (units of area)

		Ecosystem types (based on the EFG level 3 of IUCN GET)																		
		Terrestrial												Freshwater			Marine			
		T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1	
		Tropical/subtropical lowland rainforests	Tropical/subtropical dry forests and scrubs	Tropical/subtropical montane rainforests	Tropical heath forests	Boreal and temperate high montane forests and woodlands	Deciduous temperate forests	…	Temperate pyric sclerophyll forests and woodlands	…	…	…	Derived semi-natural pastures and old fields	Permanent upland streams	…	Intermittently closed and open lakes and lagoons	Seagrass meadows	…	Coastal saltmarshes and reedbeds	
		T1.1	T1.2	T1.3	T1.4	T2.1	T2.2	…	T2.6	…	…	…	T7.5	F1.1	…	FM1.3	M1.1	…	MFT1.3	TOTAL
Closing extent by economic unit																				
Agriculture, forestry and fishing	ISIC A																			
Agriculture																				
Forestry																				
Fishing																				
Mining and quarrying	ISIC B																			
Manufacturing	ISIC C																			
Electricity, gas, steam and air conditioning supply	ISIC D																			
Water supply, sewerage, waste management and remediation activities	ISIC E																			
Services																				
Other industries																				
Government																				
Households																				
TOTAL																				

Abbreviations: ISIC, International Standard Industrial Classification of All Economic Activities.

Chapter 5
Accounting for ecosystem condition

5.1 Introduction

5.1.1 Measurement focus in accounting for ecosystem condition

5.1 A central feature of ecosystem accounting is its organization of biophysical information on the condition of different ecosystem assets and ecosystem types within an EAA. Ecosystem condition accounts provide a structured approach to recording and aggregating data describing the characteristics of ecosystem assets and how they have changed.

5.2 ***Ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics.*** Condition is assessed with respect to an ecosystem's composition, structure and function, which, in turn, underpin the ecosystem integrity of the ecosystem, and support its capacity to supply ecosystem services on an ongoing basis. Measures of ecosystem condition may reflect multiple values and may be undertaken across a range of temporal and spatial scales.

5.3 Measurement of ecosystem condition is of significant interest within the context of supporting environmental policy and decision-making, which are often focused on identifying ecosystems of particular concern and protecting, maintaining and restoring their condition. Comprehensive and comparable measures of ecosystem condition that are compiled regularly are therefore of direct relevance.

5.4 Ecosystem condition accounts complement environmental monitoring systems by using data from those systems, focusing, for example, on biodiversity, water quality or soil properties. The intention of the ecosystem condition account is therefore to build upon and synthesize, rather than replace, data from existing monitoring systems. Further, as described in more detail in section 5.6, ecosystem condition accounts provide a means to mainstream a wide range of ecological concepts and data into economic and development planning processes and the regular production of ecosystem condition accounts may in turn help to systematize and strengthen existing monitoring systems.

5.5 Ecosystem condition accounts are not intended to directly assess climate patterns, although climate is a determining factor in the types of ecosystems that are observed. However, in some cases, climate-related variables, such as temperature and precipitation, are relevant in the assessment of the condition of local ecosystems; and other variables, such as species richness, may be affected by broader patterns of climate change. Consequently, analysis of climate patterns can support measurement of ecosystem condition.

5.6 Although the recording of the condition of assets is not a standard output within economic accounts, measurement of and assumptions regarding asset condition are inherent in accounting for assets. For example, in estimating rates of deterioration in the measurement of depreciation of produced assets, it is generally assumed that the condition of an asset is embodied in its current market price. Since ecosystem assets do not usually have a market price, explicit recording of ecosystem condition in physical terms plays an important role in completing the accounting picture.

5.7 A primary benefit of compiling ecosystem condition accounts stems from the use of an approach to compiling data on different aspects of ecosystem condition that supports alignment with other data on ecosystems, for example, data on ecosystem extent and ecosystem services. This structured approach – based on a common understanding of the size, composition, function, location and types of ecosystem assets – offers insight into changes that is more comprehensive than that provided by individual data sets.

5.1.2 Ecological concepts underpinning measurement of ecosystem condition

5.8 The concept of ecosystem condition used in SEEA EA is based on long-standing ecological knowledge and is related to several other terms that are used in the scientific literature or in legislation that aims towards assessing and protecting ecosystems (Heather Keith and others, 2020). Although these terms may appear different, the underlying concepts are overlapping, with differences reflecting the fact that they have been developed and used by different research communities for different ecosystem types.

5.9 Ecosystem condition is often defined by measuring a current ecosystem's similarity to or distance from a reference state, such as one minimally impacted by people or a historical state (Costanza, 1992; Palmer and Febria, 2012). Ecosystem condition can be described through assessment of combinations of physical, chemical and biological indicators and their changes over time, an approach commonly used by water managers to assess the state of wetlands, rivers and lakes and subsequently adapted to marine and terrestrial ecosystems. "Naturalness" and "intactness", or the term *hemeroby*, which is opposite in meaning, are sometimes used to describe the distance of an ecosystem from an (undisturbed) reference. It must be recognized that humans have modified or replaced natural ecosystems over large parts of the globe and consequently the measurement of ecosystem condition needs to be suitable also for semi-natural and anthropogenic ecosystems.

5.10 In ecology, the description of ecosystem condition is strongly rooted in the concept of ecosystem integrity, which implies the state of being unimpaired, complete or undivided (Karr, 1993). ***Ecosystem integrity is defined as the ecosystem's capacity to maintain its characteristic composition, structure, functioning and self-organization over time within a natural range of variability*** (Pimentel and Edwards, 2000). Ecosystems with high integrity or condition are typically more resilient, in other words, more able to recover from disturbances or to adapt to environmental changes (Holling, 1973).

5.11 Regardless of their condition, all ecosystems are not equally resilient. Shoreline systems or estuaries, for instance, are often exposed to a highly dynamic environment and have evolved so as to be able to absorb or recover from disturbances. In contrast, fragile ecosystems that are often subject to extreme resource limitations related to water, nutrients or temperature – for example, sphagnum bogs and alpine herb fields – can be in good condition but have a low level of resilience, as they may quickly collapse into a degraded state even under light pressure.

5.12 Biodiversity (diversity within and between species and of ecosystems), which contributes to the composition, structure and function of ecosystems, is integral in measuring ecosystem condition. For example, commonly used biodiversity metrics such as species abundance, species richness and species-based indices are often used to measure aspects of ecosystem condition, in particular composition (Rendon and others, 2019). The functional diversity of species gives support to ecosystem function (Cadotte, Carscadden and Mirotchnick, 2011), while fine-scale diversity of ecological communities contributes to biodiversity within an ecosystem.

5.13 Ecosystem condition and ecosystem services are linked, but the relationship varies among different services and often it is not linear. The fact that ecosystems in better condition can support a greater quantity and better quality of many relevant ecosystem services (see Smith and others (2017) for a meta-analysis) provides an argument for sustainable ecosystem management. The relationship between ecosystem condition and service provision is central to the concept of ecosystem capacity (see chap. 6).

5.14 Measures of ecosystem condition are more comprehensive and integrative than measures of the capacity to supply specific ecosystem services. The range of characteristics of ecosystem condition, and their associated measured variables and indicators, should include more than those relevant to provision of final ecosystem services used by humans.

5.15 These related concepts provide SEEA EA with a strong scientific and statistical foundation for defining ecosystem condition and proposing practical methods for implementation of ecosystem condition accounts using commonly applied variables and indicators. A key feature of the accounting approach described here is that it encompasses consideration of both ecosystem conservation and sustainable use of ecosystem services by humans.

5.1.3 General approach to compiling ecosystem condition accounts

5.16 SEEA EA uses a three-stage approach to accounting for ecosystem condition. The move from one stage to the next requires a progressive building of data and the use of additional assumptions.[51] Outputs at each stage are relevant for policy- and decision-making.

5.17 Outputs from stages one and two comprise the ecosystem condition accounts and correspond to the presentation of data on condition variables and condition indicators, respectively. Overall measures of ecosystem condition for multiple ecosystem types and multiple indicators can be undertaken in the optional third stage through the derivation of composite indices and application of appropriate aggregation approaches.

5.18 In ecosystem accounting, the condition of an ecosystem asset is interpreted as the ensemble of multiple relevant ecosystem characteristics, which are measured by sets of variables and indicators that are used in turn to compile the accounts. Variables and indicators are selected in relation to the context and purpose of assessment and different considerations will be relevant across natural and anthropogenic ecosystems. Individual indicators can be aggregated into composite indices that provide a synthesis of the integrity, health or naturalness of an ecosystem asset.

5.19 Ecosystem condition accounts record data on the state and functioning of ecosystem assets within an EAA using a combination of relevant variables and indicators. The selected variables and indicators reflect changes over time in the key characteristics of each ecosystem asset. Ecosystem condition accounts are compiled in biophysical terms and the accounting structure provides the basis for organizing the data, aggregating across ecosystem assets of the same ecosystem type and measuring change over time between the opening and closing points of accounting periods. The accounting approach described here builds from the level of ecosystem assets and, as described,

[51] This description of the approaches to accounting for ecosystem condition reflects the body of research summarized in Heather Keith and others (2020).

may imply the need for direct field measurements for every ecosystem asset. Since in practice, this is not possible, condition accounts are most commonly compiled using remote sensing, modelling and other techniques in combination with available direct field measures.

5.20 The precise structure of ecosystem condition accounts depends on the characteristics selected, data availability, uses of the accounts and policy applications. Ecosystem condition accounts are commonly compiled by ecosystem type because each type has distinct characteristics. For example, characteristics of forests may include tree density and age, while characteristics concerning water flow and quality are relevant for rivers. However, some characteristics may be common across a number of ecosystem types. For example, species richness or functional diversity is relevant across all ecosystems and other characteristics (e.g. diversity among different ecosystem types) are relevant for a combination of ecosystem types within a landscape or seascape.[52]

[52] A landscape or seascape (including those involving freshwater) is defined for accounting purposes as a group of contiguous, interconnected ecosystem assets representing a range of different ecosystem types.

5.21 The approach to accounting for ecosystem condition is spatially explicit. Aggregate measures, for example, for an ecosystem type within an EAA, therefore reflect a measure of the average condition of the constituent ecosystem assets. This is appropriate for a range of policy and analytical contexts. However, particularly with respect to aggregate measures of biodiversity, it is necessary to incorporate data on characteristics that are not attributable to individual ecosystem assets. For example, information on the total number of species across an EAA (a measure of gamma diversity), should be incorporated in an aggregate measure of biodiversity for an EAA. These issues are discussed further on in this chapter and in chapter 13 within the context of accounting for biodiversity.

5.22 A difference between scientific and policy aims in the development and use of condition indicators lies in the fact that scientists aim to understand the complexity of ecosystems and encapsulating that reality, whereas policymakers often need headline indicators for ecosystems that can be readily evaluated together with indicators representing economic, social, political and other realities. Accounting aims towards demonstrating the connection between these perspectives, and individual variables, indicators and ecosystem condition indices therefore all have a role to play in applying ecosystem condition accounts in decision-making.

5.2 Defining and selecting ecosystem condition characteristics and variables

5.2.1 Introduction

5.23 The first stage of measurement of ecosystem condition involves setting the measurement focus and defining and selecting ecosystem characteristics and associated variables. This stage is important in underpinning compilation at the second stage, which involves ecosystem condition indicators, and derivation of aggregate measures of condition across multiple ecosystem types at the optional third stage.

5.24 The primary spatial units are ecosystem assets. It is expected that they will be delineated so as to be reasonably homogeneous with respect to their main characteristics (see chap. 3), a feature that would extend to their condition too. Subject to data availability, it is recommended that the condition variables be recorded, ideally, for each ecosystem asset so as to ensure the full reliability and transparency of the ecosystem condition accounts. Where data are available, measures of ecosystem condition may be mapped to highlight variations in condition across ecosystem assets.

5.25 Conceptually, it is possible to compile accounting tables for an individual ecosystem asset, such as a single wetland or cultivated area. Nevertheless, the measurement objective of SEEA EA is to provide information on the changes in ecosystem-related stocks and flows in relatively large and diverse areas and therefore there is no expectation that all individual assets will be represented in tabular form in the accounts.

5.26 The accounts shown here include entries for opening and closing condition, that is, they pertain to observations on the state of the ecosystems at the beginning and end of an accounting period. If required, accounts can incorporate entries to show a more complete time series although in this case alternative configurations for the account tables would likely be required. Ecosystem condition accounts should also present important pieces of additional information (e.g. concerning measurement units and reference levels) that clearly document the transformation of information from raw data to high-level indices.

5.27 For clarity of presentation, the accounts shown here include entries only for a single ecosystem type. Extensions of the accounting structure to include additional ecosystem types (or the compilation of a separate account for each ecosystem type) should follow the same broad structure for each ecosystem type, with the understanding that there will be a need to record different variables and indicators.

5.2.2 Ecosystem condition characteristics

5.28 ***Ecosystem characteristics are the system properties of an ecosystem and its major abiotic and biotic components (water, soil, topography, vegetation, biomass, habitat and species).*** Examples of such characteristics include vegetation type, water quality and soil type. The term ecosystem characteristics is intended to encompass all of the perspectives required to describe the long-term, "typical" behaviour of an ecosystem. Characteristics include the attributes of an ecosystem asset including components, structure, processes and functionality. Ecosystem characteristics may be stable in nature (e.g. soil type or topography) or dynamic and changing as a result of both natural processes and human activity (e.g. precipitation and temperature, water quality or species abundance).

5.29 Ecosystems have many characteristics, and there is no requirement that all of them be integrated into condition accounts. Generally, the focus in assessing condition will be on characteristics that can show a directional change over consecutive accounting periods in a scientifically sound manner. However, data on stable characteristics, which are often of direct relevance in the delineation of ecosystem assets and the modelling of flows of ecosystem services, should also be collected. The generic term for this type of data is ancillary data, which encompasses data that are used in the compilation of accounts but may not be directly reported in ecosystem accounts. In addition to data on stable ecosystem characteristics, ancillary data include data on demographics, emissions of pollutants, agricultural management practices such as fertilizer application and irrigation, types of natural resource management and expenditure on ecosystem restoration (Czúcz and others, 2021b). Appropriate selection of the relevant characteristics and of ecosystem variables is discussed in more detail in section 5.2.4.

5.2.3 Ecosystem condition typology

5.30 ***The SEEA ecosystem contition typology (ECT) is a hierarchical typology for organizing data on ecosystem condition characteristics.*** Through its presentation of a meaningful ordering and coverage of characteristics, the ECT can be used as a template for variable and indicator selection and can provide a structure for aggregation.

The typology also establishes a common language to support increased comparability among different ecosystem condition studies.

5.31 Ecosystems and their characteristics are highly complex, and the ECT strikes a balance between meeting statistical requirements and purposes and being ecologically meaningful in the context of ecosystem structure, function and composition. Since different ecosystem types have different characteristics, which should in turn be described by different variables and indicators, the ECT is designed to be universal. Indeed, it is expected to be relevant for all realms and biomes, while also supporting direct reference to ecosystem-specific metrics at lower levels. Section 5.5.2 provides an indicative set of ecosystem condition variables for biomes structured in accordance with the ECT. More detailed discussion on each ECT class and the relationship of the ECT to other relevant classification systems is provided in Czúcz and others (2021a).

5.32 The ECT has six classes, as listed in table 5.1. This typology can be applied for ecosystem characteristics, as well as for ecosystem condition variables and indicators, for which it is used to create a reporting and aggregation structure. Under the classification, a set of ecosystem condition groups and classes have been derived. The aim was for those groups and classes to be both exhaustive and mutually exclusive (each metric can be assigned to only one class). It must be recognized that composition, structure and, particularly, function are extremely broad concepts that may be interpreted in different ways. To avoid ambiguity and to ensure the *mutual exclusivity* of the classes, the following interpretations for each class should be applied.

5.33 **Physical state characteristics** (class A1) include the physical descriptors of the abiotic components of the ecosystem (soil, water, air). Physical stocks (e.g. water table level, impervious surfaces) that may be subject to degradation due to human pressures are relevant choices, as they are sensitive to change and relevant for policy interpretation. This class thus also includes variables related to extreme temperature, rainfall or drought events linked to climate change.

Table 5.1
SEEA ECT

ECT groups and classes	
Group A: Abiotic ecosystem characteristics	
	Class A1. Physical state characteristics: physical descriptors of the abiotic components of the ecosystem (e.g. soil structure, water availability)
	Class A2. Chemical state characteristics: chemical composition of abiotic ecosystem compartments (e.g. soil nutrient levels, water quality, air pollutant concentrations)
Group B: Biotic ecosystem characteristics	
	Class B1. Compositional state characteristics: composition/diversity of ecological communities at a given location and time (e.g. presence/abundance of key species, diversity of relevant species groups)
	Class B2. Structural state characteristics: aggregate properties (e.g. mass, density) of the whole ecosystem or its main biotic components (e.g. total biomass, canopy coverage, annual maximum normalized difference vegetation index (NDVI))
	Class B3. Functional state characteristics: summary statistics (e.g. frequency, intensity) on the biological, chemical and physical interactions between the main ecosystem compartments (e.g. primary productivity, community age, disturbance frequency)
Group C: Landscape-level characteristics	
	Class C1. Landscape and seascape characteristics: metrics describing mosaics of ecosystem types at coarse (landscape, seascape) spatial scales (e.g. landscape diversity, connectivity, fragmentation)

5.34 **Chemical state characteristics** (class A2) include descriptors of the chemical composition of the abiotic ecosystem components. This typically involves a focus on the accumulated stocks of pollutants or nutrients in soil, water or air. Indicators should describe, similarly to indicators for *physical state characteristics*, state ("stocks" of pollutants) rather than flows (emission of pollutants), that is, stock variables should be sensitive to changes in flows.

5.35 **Compositional state characteristics** (class B1) include a broad range of "typical" biodiversity characteristics that describe the composition of ecological communities from a biotic perspective. These include characteristics such as presence/abundance of a species or taxonomic group and diversity of specific groups at a given location and time. From a location-based perspective (required for spatial consistency), the distribution of a species also reflects species composition (local presence). Compositional characteristics can therefore concern the presence/absence or abundance of individual species, taxonomic groups (birds, butterflies, provenance of a species) or non-taxonomic guilds (e.g. soil invertebrates, macro-zoobenthos). Characteristics that concern specific functional groups (e.g. pollinators, nitrogen fixers, predators, decomposers) should be considered *functional state characteristics*. Abundance characteristics of very large guilds (e.g. trees, phytoplankton) making up entire ecosystem compartments should be considered *structural state characteristics* (biomass, vegetation).[53]

5.36 **Structural state characteristics** (class B2) include characteristics focused primarily on the vegetation and biomass of ecosystems that reflect the amount of local living and dead plant matter. This class includes all characteristics concerning vegetation density and cover, as related to either the whole ecosystem or just specific compartments (e.g. canopy layer, belowground biomass, litter). For marine and freshwater ecosystems, this class can include phytoplankton abundance or plant biomass (e.g. seagrasses). There is some overlap between *compositional* and *structural* state characteristics, particularly for ecosystem types based on individual foundation species, such as mangroves, or where species groups and vegetation compartments coincide (e.g. trees on savannas, lichens on mountain rocks). Where overlap occurs, such cases should be registered in this class (structural).

5.37 **Functional state characteristics** (class B3) include characteristics related to relevant ecosystem processes (e.g. frequency, intensity) that are not already covered by other ECT classes. Information on the state of specific functional groups of species that perform ecosystem functions (e.g. producers, pollinators, nitrogen fixers, predators, decomposers) could be included here. *Ecosystem functions* is a diverse umbrella concept, which is used differently by the various research communities (Pettorelli and others, 2018). Many of the characteristics that can be viewed as ecosystem functions can also be viewed as compositional state descriptors (e.g. species abundances), structural state descriptors (e.g. plant biomass) or abiotic state descriptors (e.g. surface albedo). It is good practice to avoid placing functional characteristics in this class if they can be readily included in another class.

5.38 **Landscape and seascape characteristics** (class C1) include characteristics of ecosystem assets that are quantifiable at larger (landscape, seascape) spatial scales but have an influence on the local condition of ecosystems and can be attributed to individual ecosystem assets. Examples are metrics that quantify how an ecosystem asset is connected to other ecosystem assets of the same ecosystem type; how close ecosystem assets are situated to certain pressures, such as intensive agriculture; or how condition is influenced by other assets, for instance, through measurement of the condition of ecosystem assets that are part of a river network. In principle, there is no limit to the distance that should be considered when assessing landscape and seascape characteristics as long as that distance does not fall outside the EAA.

[53] It should not be inferred from use of biodiversity characteristics to describe the composition of an ecosystem asset that this information is sufficient to completely describe species composition (a related concept), which requires additional information concerning the links between an individual species and wider spatial scales.

5.39 Metrics of connectivity and fragmentation focus on important landscape and seascape characteristics in the context of a specific ecosystem type (or group of ecosystem types), for example, fragmentation of a forested area through agricultural activities. Landscape and seascape connectivity can be interpreted and measured very differently in terrestrial, freshwater and marine biomes. In the case of ecosystem assets that are themselves mosaics of various ecosystem types (e.g. cropland with nested semi-natural vegetation fragments), indicators of the abundance or the spatial pattern (connectivity) of the ecosystem types can also be hosted under this class.

5.40 Chapters 3 and 4 highlighted the important distinction between ecosystem types whose ecosystem processes are primarily naturally driven and those ecosystem types that are more directly influenced by intensive human activity and management (anthropogenic ecosystem types). This distinction is also important in connection with the measurement of ecosystem condition. The ECT applies to all ecosystem types, but it is to be noted that there is likely more similarity among the characteristics selected for measuring the ecosystem condition of natural and semi-natural ecosystem types than among those characteristics selected for assessing the condition of anthropogenic ecosystem types.

5.2.4 Ecosystem condition variables and their selection

5.41 ***Ecosystem condition variables are quantitative metrics describing individual characteristics of an ecosystem asset.*** A single characteristic can have several associated variables, which may be complementary or overlapping. Variables differ from characteristics (even if the same descriptor is applied to them) since they are clearly and unambiguously defined (through measurement instructions, formulae, etc.) and are associated with well-defined units of measurement of quantity or quality. Examples of variables include number of bird species, tree coverage (percentage) and turbidity (measured in nephelometric turbidity units (NTUs)).

5.42 Generally, selection of variables should prioritize those that reflect a role in ecosystem processes, and hence contribute to whole-ecosystem functioning, and their risk of change (Mace, 2019). Environmental variables should reflect stocks rather than connected flows, which are often more obvious and observed as pressures or degradation processes. Examples of stocks that are appropriate as measured variables include thickness of the soil layer, concentration of pollutants or abundance of invasive species. These may be considered renewable or degradable stocks. Variables selected to reflect ecological processes can include the presence, abundance or diversity of species with specific biological attributes that reflect interactions within the ecosystem. Classifications of functionally equivalent species based on sets of traits, described in terms of their response to environmental factors, provide useful metrics of biodiversity and the relationship with ecosystem integrity (Cernansky, 2017; Lavorel and others, 1997). Examples of functional variables include fruit-eating species that disperse seeds, nectar-eating species that pollinate, decomposer organisms and canopy emergent species that provide habitat for epiphytes.

5.43 Variables used to measure ecosystem condition are those that are likely to change because of human interventions. However, as many ecological processes and their responses to human or environmental impacts are complex, response functions of variables may be non-linear. For example, excess nutrients running off from cropland into a shallow lake can cause a sudden ecosystem response where the system flips from a stable clear state into a stable turbid state. The form of these responses can be quantified and interpreted based on understanding of the ecological processes.

5.44 Selection criteria should be used to guide the identification of variables (Czúcz and others, 2021b). Variables that are superior with respect to the selection criteria – for example, variables that are more sensitive to change – should be favoured for inclusion within an ecosystem condition account. The 12 criteria listed in appendix A5.1 provide a basis for selection. The first 10 criteria are decisive determinants of whether a specific variable (and/or the underlying characteristic) is eligible for inclusion in ecosystem condition accounts. The last two criteria ensure that the set of variables will represent the state of the ecosystem in a meaningful way.

5.45 Altogether, condition accounts should cover as much relevant ecological information as possible, but parsimoniously, that is, using as few variables as possible. It is not expected that the measurement of condition would require the inclusion of a vast number of characteristics and variables. From an ecosystem accounting perspective, the aim is to provide a broad indication of the change in condition rather than to fully map the functions of every ecosystem asset.

5.46 The most appropriate breadth and level of detail for variables selected to characterize ecosystem condition are difficult to standardize given the range of ecosystem types and differences across countries. The ECT, together with the criteria for selection of variables, supports adoption of a pragmatic structured approach that can be applied in all circumstances and can encompass measurement at a range of scales. Ideally, the compilation of ecosystem condition accounts should ensure that for each ecosystem type, at least one variable is selected for each of the six ECT classes. This rule of thumb aims towards ensuring a minimum level of comprehensiveness in the full set of condition variables.

5.47 Based on an evaluation of examples of existing ecosystem condition accounts, a set of about 6 to 10 well-selected indicators for a given ecosystem type should provide sufficient information to assess the overall condition of an ecosystem asset. In practice, it is important to incorporate knowledge of local ecosystems. The selection of variables and metrics should be based on existing ecological knowledge and monitoring systems, with direct involvement of ecologists in the selection process.

5.2.5 Ecosystem condition variable account

5.48 The structure of the ecosystem condition variable account is presented in table 5.2, where opening and closing entries are recorded for selected variables for an ecosystem type. The variables are grouped based on the ECT.

Table 5.2
ECV account

	Variables		Ecosystem type		
SEEA ECT class	Descriptor	Measurement unit	Opening value	Closing value	Change
Physical state	Variable 1				
	Variable 2				
Chemical state	Variable 3				
Compositional state	Variable 4				
	Variable 5				
Structural state	Variable 6				
Functional state	Variable 7				
Landscape/seascape characteristics	Variable 8				

5.49 Through the initial focus on variables, a structured system is provided for recording data on ecosystem condition. In particular, the use of standard classes of ecosystem types allows clear connections to be drawn to measures of ecosystem extent and flows of ecosystem services that are organized using the same classes.

5.50 Particular emphasis should be placed on the definition and documentation of variables and metrics included in the account since it is common for a single descriptor to be used for related but different variables. The documentation should contain enough information to enable scientific reproducibility and should be unambiguously linked to the short names used in the variable and indicator accounts. The content of the documentation should be capable of being communicated effectively to users of the accounts.

5.51 Data in ecosystem condition variable accounts can provide useful information on the state of an ecosystem and its change over time. Soil pH, for example, is a variable that is sensitive to change due to human land management, and it is useful to report on the monitoring of this change, irrespective of a reference level, in a condition account in order to demonstrate changes in soil properties resulting from human impacts or changing environmental factors.

5.52 Further, the condition variable account can be used to compare observed measurements of certain variables to information on critical ecosystem thresholds derived, for example, from scientific studies or fisheries management work. For example, freshwater pH values indicate clearly whether biological life is feasible in a given water body, whether soil nutrient enrichment above a certain level will lead to the extinction of sensitive species and whether the age structure of a fish population can provide a good indication of whether it is being exploited at a sustainable yield level or beyond. The condition variable account can also be used for direct comparison with politically determined target values, related, for example, to species richness or (bathing) water quality.

5.53 The recording of variables in this account reflects an explicitly neutral approach since each entry is not compared with a baseline and there is no implied judgment on relative importance, for example, entries cannot be interpreted as being high, medium or low. Since there is no information incorporated in the account on interpreting the data, the focus in using the data in this account should be on monitoring and reporting change in variables over time. The information would therefore support the preparation of indicators that describe changes in ecosystem condition.

5.54 In an EAA, each ecosystem asset of a single ecosystem type (e.g. different patches of forest in an EAA) can have a different value for the same condition variable (e.g. different values for canopy cover). This spatial variation is caused by spatially explicit patterns of pressures on ecosystems, ecosystem management or characteristics that shape ecosystems such as slope and elevation. To take the spatially explicit character of ecosystem condition into account, the values recorded in an ecosystem condition variable account should be calculated as the area-weighted arithmetic mean of ecosystem assets belonging to the particular ecosystem type within the EAA. Other statistical moments (e.g. variance, median, minimum, maximum values or the number or area of ecosystem assets with a value above a certain threshold) can also be recorded if they are considered useful. Area-weighted averaging results in a condition variable account that describes the average values of variables for an ecosystem type within an EAA. It follows that if the variable values for one or more assets changes between accounting periods, the average value for the ecosystem type will also change.

5.55 Qualitative variables or measures such as species presence or water quality that are measured on an ordinal scale from low to high can be used as well. For these variables, the account records the relative share of one of the classes over the entire EAA (e.g. the percentage of ecosystem assets where a particular species is present).

5.56 The common temporal units for aggregation in accounting are years. However, depending on the variable, data will not all pertain to the same point in time or period. In addition, data are collected at different temporal resolutions ranging from seconds or days (e.g. for air quality measurements) to weeks, months or seasons (e.g. for productivity measurements from Earth observation) or years or multiple years (e.g. for land-cover changes, species records). Converting these observations to a common temporal unit or a common reporting year can be achieved using various methods. Temporal aggregation entails summing or averaging values taken within a time period (for instance, one year). Linear interpolation can be used to calculate a value for a specific year for which no measurement data are available based on the values of the preceding and following years for which data are available. Recording smoothed data in the condition account, for instance, by taking a moving average over several time periods, can be appropriate for tracking the trends of highly dynamic ecosystem variables and for comparing them with trends obtained for variables that are less dynamic.

5.57 Care should be taken when variables are added directly to the condition account at the ecosystem type or EAA level since measurement at these levels does not necessarily reflect the spatial variation of condition across different ecosystem assets. An example in this regard is the total number of species observed in an ecosystem type within an EAA (also known as gamma diversity). While species richness of an EAA is an important variable with respect to understanding the state of biodiversity, it might be less appropriate when quantifying the ecosystem condition of a specific ecosystem type. Thus, where species richness is used as an ecosystem condition variable, it is more appropriate to measure the local species richness of different ecosystem assets and report average species richness in the compilation of a condition account.

5.58 In practice, many data are available at an aggregated level for EAA, for instance, data based on the range or distribution of species or indices used globally such as the Living Planet Index or the Ocean Health Index.[54] While those data may appear to be suited for direct inclusion in an ecosystem condition account, care is needed to ensure consistency between the spatial scale used in their measurement and the spatial scale used for other variables. Ideally, all data should be capable of being attributed to the ecosystem asset level.

[54] See www.livingplanetindex.org and www.oceanhealthindex.org/.

5.59 There is a wide array of potential data sources at global, national and local levels. From a statistical perspective, relevant data may be available within the context of the Framework for the Development of Environmental Statistics (United Nations, 2017) and the associated Basic Set of Environment Statistics (ibid., annex A).

5.3 Ecosystem condition indicators

5.3.1 Deriving ecosystem condition indicators from variables

5.60 ***Ecosystem condition indicators are rescaled versions of ecosystem condition variables.*** They are derived through setting condition variables against reference levels determined with respect to ecosystem integrity. Two steps are involved. First, data values for each variable are transformed into values along a common dimensionless scale, with the two end points of the scale (or a range along the scale) representing an upper-scale end point (1 or 100 per cent) and a lower-scale end point (0 or 0 per cent) for that variable. It is important to note that while the upper-scale end point (100 per cent) often corresponds to high values of the underlying condition variable, the opposite is also possible, that is to say, low values for a variable (e.g. a variable that measures pollution levels) can reflect a high condition score.

5.61 Second, the transformed data are converted to ecosystem indicators. The simplest conversion uses two reference levels to reflect a high or low condition score. In this case, the indicator is calculated by applying a linear transformation, as shown in the following formula:

$$I = (V - V_L) / (V_H - V_L),$$

where I is the value of the indicator, V is the value of the variable, V_H is the upper (high) reference level (the value of the condition variable relating to the upper end point of the indicator scale) and V_L is the lower reference level (i.e. the value of the variable at the lower scale end point).

5.62 Other types of rescaling functions can be used but they may not be appropriate for all metrics, such as those including both positive and negative numbers, and hence should be clearly documented and justified. For variables where an increase in variable value reflects a lower condition score, V_H will be lower than V_L. For example, the upper reference level of a pollutant may be equated to a variable value of zero since this represents a high level of condition. This way of rescaling ensures that higher indicator values are always associated with a state closer to the reference condition, even if this is the opposite of the original scale for the variable. In rare cases, the observed value of the variable might be out of the range of the two reference levels, for example, above the upper reference level. In such cases, it is recommended that the values of the indicator be truncated at 0 (0 per cent) or 1 (100 per cent) (Paracchini and others, 2011).

5.63 Applying a reference level converts the variable from a measure of trends in ecosystem characteristics to a means of assessing ecosystem condition in relation to the reference. Such normalization adds value in the interpretation of trends and is also required by any later aggregation steps, which need commensurate metrics measured on the same scale using common units (Nardo and others, 2005).

5.64 A set of indicators for a condition account can include some common or global indicators in addition to indicators specific to an ecosystem type. Examples of indicators are presented in section 5.5.1.

5.3.2 Reference levels

5.65 ***A reference level is the value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable.*** The difference between the value of a variable and its upper reference level represents the distance from the reference condition. Following the steps outlined above, the value of the reference level is used to rescale a variable to derive an individual condition indicator. Reference levels are defined in a structured and consistent manner across different variables within an ecosystem type and for the same variable across different ecosystem types. This ensures that the derived indicators are compatible and comparable and that their aggregation is ecologically meaningful.

5.66 Reference levels are usually set with upper and lower levels reflecting the limits or end points of the range of a condition variable that can be used in rescaling. Accordingly, the upper reference level should correspond to the value of the variable when the ecosystem is in a reference condition (e.g. the natural state), and the lower reference level should refer to the value of the variable when the ecosystem is in a degraded state (such as ecosystem collapse) where ecosystem processes are below a threshold for maintaining function (David A. Keith and others, 2013). One of the reference levels can often be replaced by the natural zero value of the variable, for example, zero abundance for a species (local extinction), or the lack of a specific pollutant. Reference levels applied to the same variables are likely to differ for different ecosystem types. For example, using the NDVI to measure the variable of biomass quantity requires different reference levels for forest, savanna and grassland ecosystems.

5.67 Individual reference levels can be set once a reference condition is selected. Different methods are available for establishing a reference condition and assigning values for the reference levels of ecosystem condition variables (see appendix A5.2 for strengths and weaknesses of these methods).

5.68 Different reference levels can be set depending on the purpose of an individual indicator. As a result, different indicators may be derived from the same variable within the same ecosystem. The purpose of measurement of ecosystem condition in SEEA EA is to measure ecosystem integrity and for this purpose the reference level should be established in relation to a common reference condition, as described below.

5.3.3 Reference condition

5.69 ***A reference condition is the condition against which past, present and future ecosystem condition is compared in order to measure relative change over time.*** It is the condition of an ecosystem that is used for setting the upper reference levels of the variables that reflect high ecosystem integrity. Consequently, the reference condition corresponds to a state where all condition indicators have a (spatially averaged) value of 1 (100 per cent). The best way to ensure the consistency of reference levels for different variables describing the same ecosystem asset is to start from a single reference condition. Using the concept of reference condition, the condition of an ecosystem asset is measured in terms of the distance between its current condition and its reference condition.

5.70 For ecosystem accounting purposes, the reference condition is based on the principle of maintaining ecosystem integrity, stability and resilience (over ecological time frames).[55] For many ecosystem types, it refers best to the natural state (i.e. the ecological state of a natural ecosystem) in terms of ecosystem characteristics at their natural condition, while allowing for dynamic ranges. The metrics of condition represent the distance from the natural condition irrespective of the characteristic, ecosystem type or potential desired outcome from a human perspective. The reference condition of an ecosystem corresponds to the condition where structure, composition and function are dominated by natural ecological and evolutionary processes including food chains, species populations, nutrient and hydrological cycles and self-regeneration, and involving dynamic equilibriums in response to natural disturbance regimes. An ecosystem at a natural reference condition exhibits an absence of major human modification. An ecosystem at its reference condition attains maximum ecosystem integrity (Gibbons and others, 2008; Mackey and others, 2015; Palmer and Febria, 2012).

5.71 Using the natural state as the reference condition allows recognition of the characteristics of the natural state and change from the natural state to be reflected in ecosystem accounts. The natural state may not be related to supply of ecosystem services and may not be the target of current legislation, policy or ecosystem management objectives. However, measuring condition relative to the natural state provides an important means of understanding the degree of ecosystem change that has taken place, as well as supporting the assessment of many environmental policies and associated objectives concerning conservation values.

5.72 Using the natural state as the reference condition is preferred and recommended. However, in many cases, it may not be possible to define a reference condition as natu-

[55] Many related meanings have been assigned to the term *reference condition* for different purposes related to varying levels of human disturbance, where each refers to specific types of assessments. Appendix A5.2 provides an explanation of the various alternative assessment frameworks for reference condition and associated approaches to measurement.

ral in absolute terms, since the environment may have changed owing to both human and natural processes. In cases where a natural state does not represent a meaningful reference for condition accounts – particularly for anthropogenic ecosystems under varying degrees of cultivation (such as cropland, pastures and managed forests) and urban ecosystems – alternative reference conditions, still characterized by integrity, stability and resilience, can be established and regarded as anthropogenically derived reference conditions.

5.73 Based on a common principle for defining reference conditions, a range of methodological options may be used for establishing reference conditions, given the differences in ecosystem types, disturbance regimes and data availability. Appendix 5.2 presents an assessment framework that can help to distinguish between natural and anthropogenic ecosystem states and summarizes the possible approaches to selecting a reference condition. It can be difficult to determine reference conditions and their associated reference levels appropriately and explicitly, and it is important to describe the rationale for their selection and their links to the purpose of the accounts.

5.74 Since both the timespan and extent of human influence have varied in different parts of the world, assigning a date in time as a reference condition is problematic. For example, there has been variation in the time of human settlement, development of agriculture, hunting, domestication of livestock, use of fire to influence vegetation structure and composition, major land clearing and intensive production. More generally, using inconsistent reference conditions across ecosystem types prevents meaningful comparisons, and there may be considerable variability and inconsistency from one year to another owing to ecosystem dynamics.

5.75 Developing reference conditions to assess changes in ecosystem condition is important in supporting international conventions. The selection of a reference condition should be applied as consistently as possible across the different realms (terrestrial, freshwater, subterranean and marine), biomes and EFGs. Globally agreed reference conditions are useful in supporting global comparisons, for instance, for the purpose of evaluating commitments of individual countries to ecosystem maintenance and restoration (see, for example, Heather Keith and others (2020)). However, some of these reference conditions may incorporate policy target-related elements and hence may not fully reflect the conceptual basis of a reference condition for ecosystem accounting purposes.

5.3.4 Ecosystem condition indicator account

5.76 The structure of the ecosystem condition indicator account (see table 5.3) builds directly on the ecosystem condition variable account (see table 5.2) by relating each variable to a reference level. Each variable is rescaled to a uniform dimensionless scale [0, 1] using the variable's reference level. The data in the indicator account allows descriptions of trends in condition to be interpreted relative to an agreed reference condition based on ecosystem integrity. This allows for statements concerning whether, for a given variable, ecosystem condition can be considered high (close to the reference level) or low (distant from the reference level). The indicator account can be used to monitor and report change in values over time.

5.77 In the set of ecosystem accounts, the ecosystem condition indicator account is a key output. It organizes key ecological data in a structured manner that allows comprehensive reporting on the ecosystem integrity of the ecosystems within an EAA across a range of ecosystem characteristics. Regular reporting under an ecosystem condition indicator account that tracks trends using a number of relevant indicators is intended to support an extensive and ecologically informed discussion of both the effectiveness of strategies aimed at improving ecosystem condition and the changing capacity of ecosystems to supply ecosystem services. There is not a direct linear relationship between changes in ecosystem condition and changes in ecosystem capacity. Accounting for condition therefore provides a structured framework for collating the data needed to analyse this relationship in combination with data on flows of ecosystem services as described in chapter 6. Chapter 6 also defines the concept of ecosystem capacity and describes ways in which its measurement may be considered.

Table 5.3
Ecosystem condition indicator account

	Ecosystem type								
	Indicators		Variable values		Reference level values		Indicator values (rescaled)		
SEEA ecosystem condition typology class	Descriptor	Measurement unit	Opening value	Closing value	Upper level (e.g. natural)	Lower level (e.g. collapse)	Opening value	Closing value	Change in indicator
Physical state	Indicator 1								
	Indicator 2								
Chemical state	Indicator 3								
Compositional state	Indicator 4								
	Indicator 5								
Structural state	Indicator 6								
Functional state	Indicator 7								
Landscape/seascape characteristics	Indicator 8								

5.78 Data from the ecosystem condition indicator account also underpin the derivation of composite indices of ecosystem condition. Such indices may be of considerable power in conveying general messages focused on changes in ecosystem condition. A number of different aggregations of indicators from a single ecosystem condition indicator account are possible following different approaches to aggregation. Those approaches and relevant assumptions are discussed in section 5.4. Irrespective of the approach to aggregation that is applied, it remains appropriate to compile an ecosystem condition indicator account so that the summary messages of the composite indices can be appropriately interpreted and understood.

5.4 Aggregate measures of ecosystem condition

5.4.1 Ecosystem condition indices

5.79 The derivation of aggregate ecosystem condition indices is possible where there is interest in reporting on ecosystem condition at higher levels of aggregation than those presented in the ecosystem condition indicator account. The aggregation of ecosystem condition indicators aims towards generating summarized information from a large number of data points. This can be useful in communicating general trends. At the same time, aggregation of a variety of indicators can conceal important information reflected in individual indicators. Hence, aggregate indices require careful interpretation, particularly where individual component indicators show opposite trends. Thus, within SEEA EA, the derivation of condition indices is optional, and where it is undertaken, a clear link should be established to information on movements in individual indicators as described in stage two.

5.80 The hierarchical approach to aggregation reflects the structure of the indicator classification typology. First, aggregated subindices are derived from the indicators and an aggregated index is then derived from the subindices. Further, hierarchical aggregation schemes should contain a description of how missing indicators or subindices are handled. The hierarchical structure signifies that indices should be scalable across spatial resolutions.

5.81 ***Ecosystem condition indices and subindices are composite indicators that are aggregated from the combination of individual ecosystem condition indicators recorded in the ecosystem condition indicator account.*** The aggregation process is underpinned by using compatible reference levels from a common reference condition. Thus, component indicators are scaled according to their reference levels, normalized to a common scale and direction of change and combined to form a composite index. The use of a typology for indicators and an appropriate aggregation scheme allows derivation of various subindices and overall condition indices. General guidance on the derivation of these measures can be found in, for example, Andreasen and others, (2001); Buckland and others (2005); Burgass and others (2017); Organisation for Economic Co-operation and Development (2008); and van Strien and others (2012).

5.82 The structure of ecosystem condition accounting described in this chapter allows for aggregation in several ways. For example, aggregation is possible across indicators within the same ECT class, across classes of characteristics in the ECT or across ecosystem types. Thus, subindices derived through aggregation can relate to specific typology classes (e.g. structural state of temperate woodlands) or ecosystem types (e.g. an ecosystem condition index for rivers).

5.83 One example in this context is the creation of an overall ecosystem condition index where aggregation can take the form of a condition index applied to each ecosystem type, weighted by the area of the ecosystem type within the EAA, then summed for all ecosystem types in the EAA to derive an overall ecosystem condition index (Brink, 2007; Czúcz and others, 2012).

5.84 Aggregation requires expert opinion in selecting groups of indicators and mathematical methods based on an ecological understanding of ecosystems and a clearly defined purpose for the resultant index. Data for individual variables or indicators should be preserved in a disaggregated form and at as high a resolution as possible within the information system. Consequently, aggregation is the last step in the analysis, and it should be possible to scale up and down and across at different scales depending on the purpose and form of analysis.

5.85 Aggregation has both thematic and spatial aspects. The basic thematic units are the ecosystem condition indicators, which are dimensionless and have a common scale. The indicators can be combined according to the ECT classes and groups. Within each ecosystem type, there is a different list of relevant indicators, but the typology classes and groups are the same for all ecosystem types. Accordingly, the relevant levels of thematic aggregation are subindices (condition of typology classes or groups within an ecosystem type); indices (condition of an ecosystem type in an EAA); and overall indices (overall condition of multiple ecosystem types in an EAA).

5.86 Thematic aggregation assumes that different indicators can compensate for each other, depending on the structure of the index. For example, number of forest bird species and amount of deadwood are forest condition indicators and increasing values of both indicators are associated with increasing condition. Both indicators can, however, have different directions of change, for example, forest bird numbers may be declining but quantities of deadwood may be increasing. In this case, thematic aggregation might lead to the conclusion that the forest condition remains stable and hence additional ecological interpretation is likely to be needed to confirm such an assessment.

5.87 Spatial aggregation involves aggregation across ecosystem types. Care is required in this kind of aggregation, as some ecosystem types are fundamentally different and so aggregation across them may not always be meaningful. Aggregation across ecosystem types from different realms (e.g. marine and terrestrial) or with different reference conditions (natural or anthropogenic) is not recommended. Aggregation should be confined to ecosystem types that have the same reference condition so that the increases and decreases in condition of each group can be identified.

5.88 The common temporal units for aggregation in accounting are years. However, temporal aggregation can be carried out at different periodicities depending on the purpose and other information to which it is related, for example, financial year for economic data or growing seasons for plants.

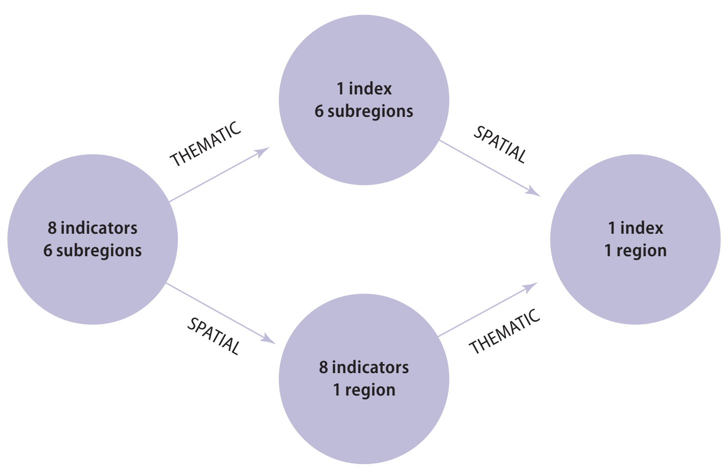
5.89 The approaches to spatial aggregation described here involve aggregation of variables that are meaningful at the level of individual ecosystem assets. The resulting aggregate indicators are therefore average measures of condition reflecting the condition of the constituent ecosystem assets.

5.90 Biotic ecosystem characteristics and their associated variables and indicators have metrics at a range of scales from local to global. Quantitative assessment of biodiversity across these scales is imperfectly nested and therefore cannot always be upscaled or aggregated simply. Several biodiversity indicators emerge only at broad (e.g. national or continental) spatial scales and cannot be produced as "sums" of smaller parts (e.g. beta diversity of large areas). Hence, for some purposes, in particular aggregate measures of biodiversity, it would be appropriate to also incorporate data on variables at a range of scales. Relevant considerations are further discussed in section 5.5.4.

5.4.2 Potential aggregation functions and weights

5.91 Aggregation functions and weights are used in various forms in each type of aggregation operation. Ideally, aggregation operations should be commutative, that is to say, subsequent operations should lead to the same result irrespective of the order in which those operations are performed (see figure 5.1).

Figure 5.1
Aggregation commutativity subsequent aggregation operations result in the same aggregated values, independent of the order of the operations



5.92 In principle, there are several choices for aggregation functions for each type of aggregation operation that can be distinguished, depending on the purpose of the index. The range of types of functions used to calculate central tendency include arithmetic mean, geometric mean, harmonic mean, minimum and maximum operators, quantiles and median. The arithmetic mean is the most commonly used function, but the geometric and harmonic means have greater sensitivity to low values and to skewed distributions. Hence, the geometric mean is often used in environmental science for describing statistics associated with variables that tend to vary in space or vary by several orders of magnitude. Minimum or maximum operator or threshold detection approaches are often used to give consideration to the importance of the lowest values or poorest condition of an indicator or, alternatively, the highest values or best condition of an indicator. The "one-out, all-out" approach, where the condition index is based on the lowest-value indicator, represents a special case where the minimum function is used as the central tendency.[56]

[56] This approach has been applied in the derivation of Sustainable Development Goal indicator 15.3.1 on land degradation.

5.93 The selection of a weighting system depends on the relative importance of each indicator to an assessed overall condition of the ecosystem. The approach to weighting should have a scientific rationale and incorporate the input from ecologists with expertise related to specific ecosystem types. For spatial aggregation, area-weighted sums and means are a typically good choice. Equal weighting assumes equal importance, and while this is the most common approach for thematic aggregation, equal importance may not necessarily be true across all indicators. Non-equal weighting may be appropriate if there is an imbalance in availability of indicators (e.g. some characteristics may be represented with more indicators than others) or when the different characteristics, measured by their respective indicators, play relatively different roles from an ecological perspective. Relationships between characteristics may be non-linear, and different thresholds may apply.

5.94 In the selection of methods for the aggregation of condition metrics derived for individual spatial units, the landscape context (e.g. configuration of ecosystem assets within a catchment) and the derivation of representative mean and range in condition should be considered. In some cases of aggregation, a combination of approaches of functions and weightings are appropriate for different indicators associated with threshold effects or differing relative importance. Methods for weighting and normalizing scores can be complex and can influence the outputs. Therefore, documentation and explanation of the assumptions are important and the applicability of aggregated indices across characteristics or ecosystem types should be tested.[57]

[57] Examples of evaluation of indices can be found, for example, in Andreasen and others (2001); Buckland and others (2005); Fulton, Smith and Punt (2005); and Rowland and others (2020).

5.95 Many of the options for aggregation are widely used in established environmental indicator frameworks. For example, the human development index applies arithmetic means for subindices, followed by a geometric mean for the overall index. A "precautionary" one-out, all-out approach (where a single declining indicator signifies a decline in condition, whereas improvement is based on an ensemble of increasing indicators) is used in the assessment of the conservation status linked to the European Union Birds and Habitats Directives, the IUCN Red List of Threatened Species and the IUCN Red List of Ecosystems. Nevertheless, neither the purpose nor the data types under these aggregation frameworks match those of the SEEA EA condition accounts. Further scientific studies should explore the advantages and disadvantages of particular aggregation strategies (i.e. combinations of aggregation functions and weighting schemes for the various aggregation dimensions), including consideration of the handling of uncertainties in measurement.

5.4.3 Presentation of ecosystem condition indices

5.96 As described above, and as required, it is possible to aggregate ecosystem condition indicators to form subindices according to the ECT classes both within ecosystem types and across different ecosystem types. Aggregation of indicators requires scaling/normalization of indicator values against a single reference condition for the ecosystem type, so that different variables and classes of characteristics can be compared. Aggregated subindices and indices have the same range and direction as indicators, for example [0 – 1]. An aggregated subindex is derived for each class in the ECT that provides a composite measure from the combination of indicators that describe the same class in the typology for a given ecosystem type. An ecosystem condition index is derived from a second aggregation step using the subindices for each ecosystem type ("mean values" approach). Table 5.4 presents the derivation of various condition indices using stylized indicator values.

5.97 An alternative method for presenting data of the aggregate indices is to record the areas of each ecosystem type that is covered by various ranges of ecosystem condition relative to the reference condition. For example, an account for the ecosystem type forests could show the total area of forest divided into low, medium or high condition areas. Area values can be reported in absolute terms (e.g. hectares) or in relative terms (as a percentage of the total area). Different threshold scores can be used based on different methodologies to define the number of intervals and their range ("discretized ranges" approach). Using stylized indicator values and assumed areas, table 5.5 displays the derivation of condition indices reflecting discretized ranges. The mean values and the discretized ranges approaches have both been used in existing condition accounts (Maes and others, 2020).

Table 5.4
Ecosystem condition indices reported using rescaled indicator values (mean values approach)

		Ecosystem type				
	Indicators	Indicator value			Index value	
SEEA ECT class	Descriptor	Opening value	Closing value	Indicator weight	Opening value	Closing value
Physical state	Indicator 1	0.5	0.25	0.05	0.025	0.013
	Indicator 2	0.9	0.7	0.05	0.045	0.035
	Subindex				*0.07*	*0.048*
Chemical state	Indicator 3	0.625	0.5	0.1	0.063	0.05
Total abiotic characteristics					0.133	0.098
Compositional state	Indicator 4	0.94	0.89	0.067	0.063	0.062
	Indicator 5	0.75	0.50	0.033	0.025	0.017
	Subindex				*0.088*	*0.079*
Structural state	Indicator 6	0.5	0.25	0.12	0.06	0.03
Functional state	Indicator 7	1	0.66	0.08	0.08	0.053
Total biotic characteristics					0.228	0.162
Landscape and seascape characteristics	Indicator 8	0.5	0.2	0.5	0.25	0.1
Ecosystem condition index	**Index**			**1.0**	**0.611**	**0.360**

Table 5.5
Ecosystem condition indices reported using discretized ranges (area (percentage)) in each range of condition

SEEA ECT class	Indicators		Ecosystem type					
			Opening value			Closing value		
	Descriptor	Indicator weight	High	Medium	Low	High	Medium	Low
Physical state	Indicator 1	0.05	10	80	10	5	45	50
	Indicator 2	0.05	70	25	5	60	20	20
	Subindex		*40*	*52.5*	*7.5*	*32.5*	*32.5*	*35*
Chemical state	Indicator 3	0.1	30	40	30	20	50	30
Compositional state	Indicator 4	0.067	80	15	5	80	10	10
	Indicator 5	0.033	100	0	0	0	0	100
	Subindex		*86.6*	*10.1*	*3.4*	*53.6*	*6.7*	*39.7*
Structural state	Indicator 6	0.12	30	30	40	10	20	70
Functional state	Indicator 7	0.08	100	0	0	50	30	20
Landscape and seascape characteristics	Indicator 8	0.5	30	30	40	20	20	60
Ecosystem condition index	**Index**	**1.0**	**42.2**	**28.9**	**28.9**	**25.8**	**23.7**	**50.5**

5.98 Tables 5.4 and 5.5 present the derivation of ecosystem condition indices for one ecosystem type. For presentational purposes, it may be appropriate to summarize the results for a number of ecosystem types in one table. Table 5.6 shows such a structure, allowing for the recording of opening and closing condition values and changes in those values due to changes in the component characteristics. A total index across ecosystem types is not shown, as this would require aggregation across ecosystem types that apply different reference conditions, and this is not recommended. Further, owing to the use of different reference conditions for different ecosystem types, care should be taken in comparing condition scores across ecosystem types.

5.5 Considerations in the measurement of ecosystem condition

5.5.1 Introduction

5.99 The three-stage approach to accounting for ecosystem condition provides an appropriate structure for measurement. Nonetheless, there is a range of considerations and issues that affect measurement in practice. The present section discusses these issues.

5.5.2 Variables for selected ecosystem types

5.100 Following the approach described above, the measurement of ecosystem condition requires the selection of variables covering relevant ecosystem characteristics for different ecosystem types. The general principles and criteria for the selection of variables have been outlined in section 5.2 and by Czúcz and others (2021b). In this section, a short summary is provided of considerations related to selection of variable for a number of key ecosystem types. As noted above, in practice, it is important that ecologists and related specialists with knowledge of the ecosystem types concerned be involved in the process of variable selection, as well as in the determination of reference conditions and levels.

Table 5.6
Ecosystem condition account (condition indices) for multiple ecosystem types

Accounting entries	Stylized ecosystem types					
	Forests	Lakes	Crop-land	Urban areas	Wet-lands	Sea-grass
Opening condition value						
Change in abiotic ecosystem characteristics (physical and chemical state)						
Change in biotic ecosystem characteristics (composition, structure and function)						
Change in landscape/seascape characteristics						
Net change in condition						
Closing condition value						

5.101 An indicative selection of variables is presented in table 5.7, which shows possible variables for selected biomes and functional groups (following IUCN GET) and according to the classes of the ECT. The physical state variables consider mostly changes in water content and soil for terrestrial ecosystems and water clarity for aquatic ecosystems. Chemical state variables include pH, soil organic carbon content and concentrations of nutrients and pollutants. The compositional state can be measured using the diversity of various taxa such as tree species, birds, reptiles, fish or macroinvertebrates. Clearly, other species or taxa can be used as well to measure the condition of ecosystems. The structural state variables are often related to vegetation cover or specific aspects thereof. Functional state variables express ecosystem characteristics such as productivity or decomposition processes. In a few cases, table 5.7 explicitly mentions these characteristics to clarify the relationship with the selected variable.

5.102 The selections shown are not exhaustive and are not intended to reflect definitive measurement guidance for the selection of variables. In the first instance, it is expected that local context would be considered in the selection of variables, in other words, that the measurement of ecosystem condition would be grounded in specific ecological knowledge and expertise. Of particular relevance in this regard is knowledge of the underlying EFGs and more detailed subtypes and their composition within a country or region. In this regard, the table should provide the basis for a structured conversation between account compilers and local experts.

5.103 Second, the descriptors in the table refer to a mix of variables and data sources. These examples provide an indication of the potential for measurement. However, in practice, selection of variables and indicators requires careful consideration to ensure their appropriate interpretation, for example, concerning directionality. Additional guidance on the selection of variables and the collection of data will be developed.

Table 5.7
Examples of ecosystem condition variables for selected ecosystem types

		A1 Physical state	A2 Chemical state	B1 Compositional state	B2 Structural state	B3 Functional state	C1 Landscape/seascape
T1	Tropical/sub-tropical forests	Soil water availability in the driest quarter; wetness	Soil organic carbon content; leaf and litter nitrogen concentration	Tree species richness; bird species richness	Tree cover density; dominant tree height; number of canopy layers; deadwood volume; forest age class distribution; density of epiphytes	Dry matter productivity; presence of seed dispersing species (capacity for regeneration); water stress index	Forest area density; landscape diversity; forest connectivity; ratio of edge distance to interior area of forest patches
T2	Temperate-boreal forests and woodlands biome	Vegetation water content (NDWI)	Soil organic carbon content; air pollutant concentration; foliar and litter nitrogen concentration	Tree species richness; lichen species richness; bird species richness	Forest floor depth (soil layer thickness); tree cover density; deadwood volume; forest age class distribution	Dry matter productivity; density of trees with hollows for nesting; presence of top predator species (food web functionality); NDVI; water stress index	Forest area density; landscape diversity; forest connectivity
T3	Shrublands and shrubby woodlands	Percentage burned area; soil layer thickness	Soil organic carbon content; soil phosphorus concentration	Bird species richness	Tree cover density	Dry matter productivity; proportion of re-sprouting species after fire (capacity for regeneration)	Landscape diversity; shrubland/forest connectivity
T4	Savannas and grasslands	Percentage bare ground	Soil organic carbon content; soil pH	Bird species richness; butterfly species richness; proportion of non-native species	Presence/density of trees/ shrubs	Dry matter productivity abundance of termite mounds	Connectivity of trees; grassland connectivity
T5	Deserts and semi-deserts	Water availability; degree of surface crusting	Soil pH	Reptile species diversity or abundance	Vegetation cover	Density of viable seeds in soil (capacity for regeneration)	Spatial distribution of waterholes
T6	Polar-alpine (cryogenic)	Percentage bare ground; snow depth; extent of sea ice	Pollutant concentrations	Lichen species richness	Vegetation cover; lichen cover or abundance on rocks		Diversity of habitat types; connectivity of routes for migratory species
T7.1	Annual croplands	Water-holding capacity; soil bulk density; NDWI	Soil organic carbon content; soil nutrient availability	Bird species richness	Share of organic farming; crop diversity; share of time or area as fallow land	Soil respiration rate (decomposition); gross primary production	Presence/share of semi-natural vegetation fragments (small woody features); landscape diversity (mosaic)
T7.4	Urban and industrial ecosystems	Imperviousness	NO_2 concentration	Bird species richness	Share of urban green space; vegetation or tree cover		Average distance of residents to urban green space; landscape diversity (mosaic)
TF1	Palustrine wetlands	Wetness; surface water area; water flow; water-holding capacity; duration of water inundation/ saturation	Nitrogen concentration; phosphorus concentration	Bird species richness; dragonfly and damselfly species richness	Vegetation cover by native macrophytes	Biological oxygen demand	Landscape diversity; wetland/water connectivity; intensity of surrounding land use within a 50 m buffer area

Table 5.7
Examples of ecosystem condition variables for selected ecosystem type (*continued*)

		A1 Physical state	A2 Chemical state	B1 Compositional state	B2 Structural state	B3 Functional state	C1 Landscape/seascape
F1	**Rivers and streams**	River flow (relative to ecological base flow); permanence of water flow; sediment load	Nitrogen concentration; phosphorus concentration;	Macroinvertebrate species richness	Area of riverbanks vegetated	Biological oxygen demand	Share of river flow controlled by barriers; presence of anadromous fish; river system fragmentation
F2	**Lakes**	Water clarity; water regime (permanence); water flow; sediment load	Nitrogen concentration; phosphorus concentration; chlorophyll a concentration	Fish species richness	Steepness of water temperature depth profile (structure of vertical profile of lake); ratio between biomass of predatory fish and total fish biomass; ratio between zooplankton and phytoplankton	Biological oxygen demand; ratio between productivity and biomass	Connectedness of riparian vegetation within catchment; share of lake shoreline covered with natural vegetation
F3	**Artificial wetlands**	Water clarity	Nitrogen concentration; phosphorus concentration	Fish species richness	Steepness of water temperature depth profile; frequency and extent of algal blooms	Percentage area available as fish nursery	
M1	**Marine shelf**	Water clarity (turbidity); (micro)plastic concentration	Chlorophyll a concentration; percentage anoxic area; oxygen concentration; pH (or dissolved CO_2)	Coral species richness; fish species richness	Reef "bleachedness"; kelp/seagrass height, density or cover; live coral cover	Trophic composition number (food web functionality); ratio between fishing mortality and fishing at maximum sustainable yield; biological oxygen demand	Seagrass meadow cover
M2	**Pelagic ocean waters**	(Micro)plastic concentration; water clarity	Chlorophyll concentration; percentage anoxic area; oxygen concentration	Fish species richness; plankton species richness	Plankton concentration or abundance	Trophic composition number (food web functionality); ratio between fishing mortality and fishing at maximum sustainable yield	
M3	**Deep-sea floors**	Light intensity; sea floor sediment density	Oxygen concentration	Invertebrate species richness	Habitat diversity		

Note: The present table is indicative only and is not intended to provide definitive measurement guidance for the selection of variables (or characteristics) in any given context. Ecosystem types are based on IUCN GET (David A. Keith and others, eds., 2020). Variables are grouped following the SEEA ECT. In some cases, the associated ecosystem characteristic is added in parentheses.

5.104 It should not be assumed that all data used for account compilation are sourced from direct field observations. While this might be ideal, such an assumption is unrealistic. In practice, many data are sourced from combining field observations with national environmental and statistical data and remote sensing, including satellite data.

5.5.3 Use of data on environmental pressures

5.105 The measurement of environmental pressures is often considered an indirect approach to measuring ecosystem condition (European Commission, 2016). ***An environmental pressure is a human-induced process that alters the condition of ecosystems*** (Maes and others, 2018). If there are few data available on state, then measures of pressures on ecosystems can be considered a useful surrogate, as long as the relationship between the two is well understood and justified (Bland and others, 2018). The ECT is sufficiently flexible to be able to host variables that report pressures on ecosystems as alternatives for variables that directly measure condition. For example, air emissions or pesticide use can be reported under chemical state; soil sealing or sea level rise can substitute physical state variables; and data on introductions of invasive alien species can be reported under compositional state. In some cases, there may be little difference between a state and a pressure indicator and, in other cases, where there is a considerable lag between evidence of a pressure and a resultant change in state, a measure of pressure may provide relevant information.

5.106 For most local pressures (e.g. poor cultivation practices, pollution, invasive species), there is an underlying variable that reflects the ecosystem response to that pressure. This underlying variable can be considered an environmental stock (e.g. thickness of the soil layer, concentration(s) of substances or abundance of species) that is gradually affected by the pressure. Typically, indicators of such stocks can meet all of the selection criteria so that they can be highly appropriate for use in condition accounting compared with indicators of the connected flows (e.g. degradation/depletion rates, fluxes, flows or other indicators of flow intensity).

5.107 Use of indicators of environmental stocks as condition indicators yields multiple further advantages. They can be used to formulate pertinent and very clear policy messages on ecosystem degradation (involving a change in those environmental stocks); and through the degree of policy attention, those environmental stocks that are perceived to be the most valuable or the most endangered will be highlighted.

5.108 Identifying environmental stocks in a condition account is particularly relevant when ecosystem extent is measured using remote sensing. Remote sensing detects a stock loss due to a change in ecosystem type (e.g. through clearing of vegetation) but may not detect a stock loss due to a decline in condition (e.g. through loss of understory or weed invasion). Thus, while there are distinct advantages in using indicators of environmental stocks, there may also be measurement challenges; hence, measurement of environmental pressures may be appropriate.

5.109 An important type of environmental pressure is overharvesting, which can frequently be linked to environmental stocks (e.g. timber stocks in forests or fish stocks in marine ecosystems). In this case, the associated ecosystem types can have a specific target ecosystem service (typically a provisioning service) and traditional ecosystem management is aimed at maximizing the flows of that service (de Groot and others, 2010). The intensity of these management activities has been shown to exert strong influences on the supply of a broad range of services, extending well beyond the original target ecosystem service (Santos-Martín and others, 2019).

5.110 Where the pressure relates to expansion of agricultural activity, the effects may be captured by changes in ecosystem extent, depending on the intensity of the agricultural practices. The focus of condition measurement should then be on change in the state of the relevant ecosystem type but measures of pressures such as livestock per hectare or rates of fertilizer and pesticide use may provide important data that support policy and analysis, especially where the change in state occurs some time after the environmental pressure is observed.

5.111 Some environmental pressure indicators (e.g. measures of GHG emissions, demographic changes) provide a broad measure of potential effects on the condition of ecosystems but do not provide direct measures of condition for individual ecosystem assets and hence are not suitable for use in ecosystem condition accounts. Rather, the focus should be on assessing the effects of these broader pressures on local ecosystems.

5.112 Indicators of protection status (e.g. location, area or representativeness of protected areas) are also frequently proposed as proxy measures for condition if no other information is available (see, for example, Maes and others (2016)). Protection could be thought of as a rough proxy for reduced pressures, especially for reduced overexploitation (i.e. indicating lower management intensities). However, indicators describing policy interventions performed in response to management or conservation objectives are not considered to be appropriate condition indicators. There is no inherent relationship between protection status and other indicators of ecosystem condition, for example, an ecosystem could be protected and nevertheless be in poor condition. In order to avoid confusion and double counting, the use of indicators describing policy response categories should be avoided. The inclusion of such indicators would, among other issues, compromise the potential to use the accounts to assess the effects of policy responses, for example, the effect on condition of establishing a new protected area.

5.5.4 Role of biodiversity in ecosystem condition accounts

5.113 Following the definitions under the Convention on Biological Diversity, biodiversity is the variety of life within species (genetic diversity), between species and between ecosystems (article 2) and ecosystems are shaped by the interactions among species, and between species and the non-living environment (ibid.). As a consequence, there is overlap in how biodiversity and ecosystems are measured.

5.114 Biodiversity is integral to the maintenance of ecosystem integrity, which is the reference against which the condition of ecosystem assets is assessed. Thus, in the ECT (table 5.1), the overlap in measurement is evident mainly in biotic ecosystem characteristics. Variables that describe species composition, ecosystem structure and ecosystem processes are also used to characterize biodiversity and are therefore considered essential biodiversity variables.[58]

5.115 While there is overlap, there is also a difference between measuring biodiversity and measuring ecosystem condition. Ecosystem condition accounts consider the physical and chemical quality of the ecosystem along with biotic health and often focus on species-related metrics to account for biodiversity. Variables that describe between-ecosystems diversity are generally less appropriate and are rarely used to measure the condition of a single ecosystem asset or ecosystem type. The relevant biodiversity metrics for assessing an individual ecosystem asset's condition include characteristics of composition, structure and function, as well as landscape characteristics where they can be attributed to the condition of an individual ecosystem asset. In particular, indicators of local species diversity are likely to be relevant.

5.116 Before selecting species-based metrics to assess the condition of ecosystems, it is important to realize that there are different spatial and temporal dynamics between individual species and ecosystems. Therefore, not all species or species-based biodiversity indicators are suitable for assessing condition at all scales. For instance, to meas-

58 For further information, see https://geobon.org/ebvs/what-are-ebvs/.

ure the long-term condition of a single ecosystem, monitoring non-mobile species that are sensitive to pollution, such as lichens, may be more appropriate and cost-effective, compared with observing an occasional visiting species that uses the ecosystem only to rest during its seasonal migration. However, observations of migrating species may be important for understanding the importance of that ecosystem for species conservation at a broader scale.

5.117 Consequently, some individual biodiversity metrics, such as diversity of ecosystem types within an EAA, should not be attributed to individual ecosystem assets and should instead be considered emergent properties. As a result, these metrics will not be incorporated in aggregate measures of ecosystem condition based on the condition of individual ecosystem assets. The emergent properties can be incorporated in aggregate measures of biodiversity, for example, at ecosystem type and EAA scale, using aggregation approaches that appropriately consider the relevant process-related and pattern-related issues. The background paper entitled "Addressing spatial scale in deriving and aggregating biodiversity metrics for ecosystem accounting" (Larsen and others, 2021), which summarizes the relevant spatial aggregation issues and methodological approaches, provides appropriate guidance.[59]

[59] See https://seea.un.org/sites/seea.un.org/files/documents/EEA/seea_ea_background_paper_spatial_aggregation_of_biodiversity-focused_metrics_final.pdf.

5.5.5 Accounting for ecosystem conversions

5.118 Ecosystem conversions occur when part or all of an ecosystem asset changes from one ecosystem type to another between the beginning and the end of an accounting period. Examples of ecosystem conversions include clearing of a natural forest for use by grazing animals; conversion of a natural grassland to cropland; draining a wetland and ploughing for agriculture; creation of a new hydropower reservoir; natural encroachment following permafrost melt; and potential future flooding of coastal areas due to sea level rise. The identification and recording of ecosystem conversions, which should appear in the ecosystem extent account, are discussed in chapter 4.

5.119 Concerning the measurement of condition, four practical measurement challenges emerge in the context of ecosystem conversions:

(a) In some cases, thresholds for the condition indicators are required to identify the conversion from one ecosystem type to another. Those thresholds depend on how the ecosystem type is classified and delineated and the specific indicators applied. For example, in the conversion of a forest to a shrubland or grassland, the canopy cover threshold at which the ecosystem is no longer to be classified as a forest needs to be determined. Hence, rules or thresholds are required to determine changes in ecosystem type that result in reclassification;

(b) To enable reclassification, rules are often required specifying a time period during which the change must remain present, so as to distinguish permanent change from temporal variability;

(c) Selection of the set of condition indicators used to describe the ecosystem types is important so that a change in the level of one or more indicators can signal a conversion to another ecosystem type. For example, canopy cover is a poor indicator for detecting the difference between a natural forest and a plantation but a good indicator of the difference between a forest and a grassland;

(d) The spatial scale of assessment of condition indicators – that is, the level of aggregation of spatial units for reporting within an accounting area – is important. Metrics for condition indicators that may be used to assess conversions likely occur at different scales, from point sources to emergent landscape scales.

5.120 These measurement challenges are confronted in the first instance in the compilation of the ecosystem extent accounts described in chapter 4. In those accounts, the change in the area of ecosystem types between the opening and closing of the accounting period is recorded in gross terms, that is, both the additions and reductions in the area of ecosystem types are recorded. The characteristics and criteria for the delineation of ecosystem types underpin the recording of conversions. Maintaining a time series of ecosystem extent accounts supports understanding of the relative extent of different ecosystem types and also supports analysis of conversions from natural to anthropogenic ecosystem types.

5.121 From an ecosystem condition measurement perspective, ecosystem condition for the converted area is measured with respect to the ecosystem type present at the end of the accounting period using the relevant characteristics and indicators. Where ecosystem conversions occur, this implies that for a converted area, the relevant set of characteristics and indicators and the associated reference levels are different from those used at the beginning of the period. Significant care should therefore be taken in interpreting the change in condition over time for the converted area, and it is recommended that, as a general approach, the converted areas be either excluded from the analysis of change or handled as a distinct type of area in any aggregations.

5.122 At the same time, there is often strong interest in understanding ecosystem conversions involving the change from natural to anthropogenic ecosystem types. To support analysis of those changes beyond measures of changes in extent, it may be appropriate to provide complementary measures of changes in ecosystem condition for all ecosystem types (i.e. both natural and anthropogenic ecosystems) relative to a natural reference condition. This analysis will be most relevant where changes have occurred relatively recently, for example, over the past 200 years.

5.5.6 Relationships among ecosystem condition, ecosystem capacity and ecosystem degradation

5.123 The ecosystem accounting framework encompasses the intention to record data on both stocks of ecosystem assets and flows of ecosystem services. The general conception is that the extent and condition of ecosystem assets exert an influence on the flows of ecosystem services both in the current period and in future periods. Also, in some cases, the supply and use of ecosystem services impact ecosystem condition. The connection between those stocks and flows is reflected in the concept of ecosystem capacity. Measurement of ecosystem capacity is related to but different from the measurement of ecosystem condition. Section 6.5 provides a longer discussion of ecosystem capacity in the context of ecosystem accounting.

5.124 Ecosystem degradation is the decrease in the value of an ecosystem asset over an accounting period that is associated with a decline in the condition of the asset during that accounting period (see sect. 10.2). Since the value of an ecosystem asset will be related to future flows of ecosystem services, there are connections among the concepts of ecosystem condition, ecosystem capacity and ecosystem degradation. However, those concepts are not identical, and it need not be the case that declines in condition necessarily imply ecosystem degradation. Appendix A10.1 provides a discussion on the links between measures of ecosystem condition and ecosystem degradation and other changes in the value of ecosystem assets.

5.6 Applications of ecosystem condition accounts

5.125 Ecosystem condition accounts can be compiled at regional, national and international scales for a wide range of applications. Data for different components of condition accounts, such as ecosystem variables, indicators, reference levels, reference conditions and ecosystem condition indices, are used for different applications. Ensuring consistency in terms, definitions and metrics within the information system provided by the ecosystem accounts and any policies that refer to them helps to ensure effective application.

5.126 Condition accounts are used to synthesize information on changes in the state of ecosystem assets over time. This information can be used to inform policy- and decision-making across a range of sectors that impact or depend on ecosystems and natural resources, including land-use planning, environmental impact assessment, agricultural planning and authorization processes, and programmes for ecosystem rehabilitation or restoration. Overall measures (such as an ecosystem condition index) can be used to inform strategic planning at the national level. Where accounts are compiled with spatially explicit detail and include information on particular characteristics of ecosystem assets, the accounts can also be used to inform landscape-level planning.

5.127 The use of variables, indicators or ancillary information to assess the capacity of ecosystems to supply ecosystem services is an important application that serves the purpose of informing policy on the future availability of ecosystem service flows from ecosystem assets. As described in chapter 10, information on future ecosystem service flows may be used for estimating the monetary value of ecosystem assets. Further, condition accounts can be used to analyse the impact that activities associated with supplying ecosystem services (e.g. timber harvesting) are having on ecosystem condition.

5.128 Several examples demonstrate the range of applications of ecosystem condition accounts in providing information. Quantification of indicators and reference levels can be used to operationalize the definitions of ecosystem degradation and enhancement (restoration). Further, indicators of ecosystem condition could be combined with information on ecological thresholds (e.g. concerning points of change in ecosystem type) to assess the risk of change or, alternatively, to assess the degree of resilience within ecosystems under conditions of change. This could allow condition accounts to inform the identification of threatened ecosystems (see, for example, David A. Keith and others (2013)).

5.129 Assessment of ecosystem capacity to supply ecosystem services depends on complex interrelationships of multiple indicators for determining threshold levels in defining sustainability. Connecting the critical levels of ecosystem capacity back to the ecosystem condition variables that have the highest level of influence on specific ecosystem services is an important area of future research. Such research would support use of information in the ecosystem accounts to quantify the “critical natural capital” concept described in economics (Ayres, van den Bergh and Gowdy, 2001) or the “planetary boundaries” concept in ecology (Rockström and others, 2009).

5.130 The development of ecosystem condition accounts has the potential to make many key policy commitments measurable and thus more likely to be implemented at the national and international levels. The measurement may then, in turn, support the design and development of policy and associated targets. International policies where the information from ecosystem condition accounts can be applied include measures of land degradation to support the goal of land degradation neutrality (LDN) under the United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa,[60] the Sustainable Devel-

[60] See www.unccd.int/actions/achieving-land-degradation-neutrality.

opment Goals[61] and the Kunming-Montreal Global Biodiversity Framework.[62] Further, inclusion of the concept that ecosystem integrity must be promoted within the context of accounting for national emissions reductions in the Paris Agreement, adopted under the United Nations Framework Convention on Climate Change,[63] demonstrates significant progress towards the adoption of a holistic approach to environmental issues. This concept is developed further in a report describing specific mitigation actions (Dooley and others, 2018).

61 See www.un.org/sustainabledevelopment/sustainable-development-goals/.

62 See www.cbd.int/gbf.

63 See https://cop23.unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement.

Appendix A5.1
Selection criteria for ecosystem characteristics and their metrics (variables and indicators)

Criterion	Short description
Conceptual criteria	
Intrinsic relevance	Characteristics and metrics should reflect the existing scientific understanding of ecosystem integrity, supported by the ecological literature
Instrumental relevance	Characteristics and metrics should be related to the availability of ecosystem services (characteristics that exert the strongest influence on the highest priority services should be favoured)
Directional meaning	Characteristics and metrics need to have the potential for a consensual interpretation, in other words, it should be clear whether a change is favourable or unfavourable with respect to ecosystem integrity
Sensitivity to human influence	Characteristics and metrics should be responsive to known socioecological leverage points (key pressures, management options)
Framework conformity	Characteristics and metrics should be differentiated from other components of the SEEA EA framework
Practical criteria	
Validity	Metrics need to represent the characteristics that they address in a credible and unbiased manner
Reliability	Metrics need to be accurate, reliable and reproducible, with potential sources of error explored and documented
Availability	Metrics covering the studied spatial and temporal extents with the required resolution need to be achievable in terms of the resources and time available
Simplicity	Metrics should be as simple as possible
Compatibility	The same characteristics should be measured with the same (compatible) metrics in the different ecosystem types and/or different EAAs (countries)
Ensemble criteria (for the whole set of variables and indicators)	
Comprehensiveness	The final set of metrics, as a whole, should cover all of the relevant characteristics of the ecosystem, providing a complementary set of measures
Parsimony	The final set of ecosystem condition metrics should be free of redundant (correlated) variables

Note: A detailed discussion of these selection criteria is presented in Czúcz and others (2021b).

Appendix A5.2
Options for establishing reference conditions for natural and anthropogenic ecosystems

A5.1 Before selecting a reference condition against which to assess the condition of an ecosystem, it is essential to consider an appropriate assessment framework for selection of a reference condition (see sect. 5.3.3). Table A5.2.1 presents such a framework, which distinguishes natural from anthropogenic ecosystem states and provides four possible reference conditions for each ecosystem state. The possible reference condition options for natural ecosystems are undisturbed or minimally disturbed, historical, least disturbed and contemporary (Jakobsson and others, 2020; McNellie and others, 2020; Stoddard and others, 2006). For anthropogenic ecosystems, possible reference condition options are historical, least disturbed, contemporary and best attainable (Kopf and others, 2015). For semi-natural or lightly managed ecosystems, any of the four options for anthropogenic ecosystems could be used.

A5.2 The choice of an appropriate assessment framework depends on many factors and cannot be prescribed. In an accounting context, it is important that the reference condition be explicit and that the rationale for its selection be explained. For instance, European dry heathlands, which are rich in biodiversity, can be considered semi-natural ecosystems requiring light human management with minimal disturbance in order to maintain a semi-natural state and to prevent forest growth. In this case, a least disturbed or contemporary condition may be most appropriate. In contrast, heavily polluted and drained wetlands can be considered natural systems in poor ecological condition and assessed as such, relative to a reference condition of least disturbed or historical.

A5.3 Cropland that was abandoned some time ago and is reverting to a natural state provides an example where the choice of reference condition may depend on the objective of use. The ecosystem could be assessed relative to historical or best attainable condition for use as cropland or relative to undisturbed or minimally disturbed condition when the objective is restoration. Which of these reference conditions is more appropriate will be context-dependent. An intensively managed ecosystem such as active cropland or an urban park could be assessed relative to a reference condition of best attainable or contemporary.

Methods for estimating the reference condition and reference levels for ecosystem condition variables

A5.4 The following eight methods are potentially available for estimating the reference condition as a means of operationalizing the theoretical categories in table A5.2.2. Methods 1 to 4 represent approaches that should be considered first to describe and quantify the reference condition and, in particular, to establish the values for upper and lower reference levels of ecosystem condition variables. Methods 5 to 7 can be considered alternatives when methods 1 to 4 cannot be applied or when policy or legislative drivers dictate that methods 5 or 6 may be used. Method 7 may be particularly relevant in capturing indigenous knowledge and perspectives. Method 8 constitutes a combination of methods.

Table A5.2.1
Assessment framework for selection of a reference condition

Ecosystem	Possible reference condition
Natural: an ecosystem that is influenced predominantly by natural ecological processes and characterized by a stable ecological state maintaining ecosystem integrity; ecosystem condition ranges within its natural variability. Examples (with reference to table 3.2): primary and old-growth forests (T1, T2), natural grasslands and savannas (T4), natural lakes (F2), wetlands (TF1)	**Undisturbed or minimally disturbed**: condition of an intact ecosystem with maximal ecosystem integrity and with no or minimal disturbance
	Historical: condition of an ecosystem at some point or period in its history (e.g. the pre-industrial period or the period of pre-intensive agriculture) that is considered to represent its stable natural state
	Least disturbed: best ecosystem condition currently available
	Contemporary: condition of an ecosystem at a certain point or period in its recent history for which comparable data are available
Anthropogenic: an ecosystem that is influenced predominantly by human activities and for which a stable natural ecological state is unattainable and future socioeconomic interventions are required to maintain a new stable state Examples (with reference to table 3.2): urban green spaces and croplands (T7), artificial waterbodies (F3), anthropogenic marine systems (M4)	**Historical**: condition of an ecosystem at some point or period in its history (e.g. the pre-industrial period or period of pre-intensive agriculture) that is considered to represent a stable socioecological state
	Least disturbed: best ecosystem condition currently available
	Contemporary: condition of an ecosystem at a certain point or period in its recent history for which comparable data are available
	Best attainable: expected condition of an ecosystem under best possible management practices and reflecting a stable socioecological state

A5.5 **1. Reference sites.** If pristine or minimally disturbed sites are available, they can be used to establish a reliable measure of the mean and statistical distribution of condition variables. Reference sites can be identified using expert or traditional knowledge as well as statistics and artificial intelligence if long-term time series with data describing ecosystem disturbance are available. Monitoring reference sites is probably the most straightforward method for establishing reference conditions and for determining the reference levels of condition variables. Seasonal or annual variability, as well as long-term or irreversible ecosystem changes due to climate change or invasive alien species, can be factored in when determining reference levels for ecosystem condition variables. Reference sites can thus be used to establish a dynamic reference condition (Hiers and others, 2012) that can be periodically updated.

A5.6 **2. Modelled reference conditions** can be based on predictive empirical models or potential vegetation models. Models can be used to infer conditions in the absence of human disturbance where representative reference sites are not available. Potential vegetation can be modelled globally and can incorporate scenarios of environmental change. A weakness is that models usually do not involve all of the selected condition variables of the condition account, and the variables in the model often differ from measured variables. To establish reference levels for condition variables, models require use of assumptions related, for example, to scientific debate on the role of megafauna and early humans on potential natural vegetation.

A5.7 **3. Statistical approaches based on ambient distributions.** Least disturbed or best attainable conditions can be estimated by observing the range of values from current ecosystem monitoring and by selecting a reference condition based, for instance, on fifth percentile values as criterion or by assuming that the reference condition is equal to a state with the highest species richness. Statistical approaches are data-driven and therefore pragmatic, accountants are familiar with them, and they are applicable if no reference sites are available. Methods can be applied consistently across variables, through, for example, normalization with the maximum values of available data. Possible drawbacks are the arbitrary nature of the reference condition, spatial inconsistencies caused by use of current data sets, a strongly shifting baseline and a false sense of consistency. Solutions need to be proposed to scale condition variables at levels outside the range of the available data. Variables moving out of their established range (e.g. improving beyond the previous upper reference level) can cause serious complications.

A5.8 **4. Historical observations and paleo-environmental data.** This method uses historical observations or palaeontological data to describe a historical reference condition (typically dating from before 1970 when routine environmental monitoring programmes started). The term "historical observations" refers to a description of a reference condition based on species collections in natural history museums, historical manuscripts and books that describe fauna and flora, photo archives, paintings or other materials that can be used to draw inferences related to the presence of species or the prevalence of certain conditions during a certain period in time. Paleo-environmental data can be used to reconstruct the physical-chemical environment, climate, vegetation and fauna of a certain period in time using material that is buried in the soil. Those data are often collected during engagement in archaeological studies. Examples of data collections relevant to defining a historical ecosystem condition include seed banks for reconstructing flora or remains of fish catches near medieval settlements used to reconstruct fish fauna or determine the presence of specific species. This method can deliver a common baseline for climate and biodiversity science, which is relevant to supporting more integrated climate-biodiversity policies. It can also reveal the magnitude of biodiversity loss. A weakness is that not all ecosystem condition variables can be easily inferred from historical data.

A5.9 **5. Contemporary data.** This method uses contemporary data to describe a contemporary reference condition (typically dating from after 1970 when routine environmental monitoring programmes started). For instance, under the Kyoto Protocol to the United Nations Framework Convention on Climate Change,[64] global atmospheric CO_2 emissions recorded in 1990 have been used as a reference against which to assess the changes in future GHG emissions. The Living Planet Index uses species data collected in 1970 as a reference for assessing changes. Provided that data are available, this is a straightforward approach to setting a reference condition, which is similar to statistical approaches that use ambient data distributions. However, there are several disadvantages. The choice of year may be considered arbitrary. The reliance on contemporary data in evaluating changes can result in a shifting baseline. Appropriate dates differ for different indicators and ecosystem types. If different baseline dates are used in different regions, this creates inconsistencies. Difficulties arise with respect to scaling condition variables at levels that are higher than their reference level, for example, when variables move out of their established range. The method is subject to policy influence and contemporary baselines may diverge greatly from pre-industrial era baselines.

[64] United Nations, *Treaty Series*, vol. 2303, No. 30822.

A5.10 **6. Prescribed levels** of a set of ecosystem condition variables can be used to construct a bottom-up reference condition. Examples of these reference levels include zero values for emissions or pollutants, a specific number of species, established sustainability or threshold levels such as critical loads for eutrophication and acidification, and target levels in terms of legislated quality measures (e.g. air and water quality). Prescribed levels of variables can have clear and straightforward management applications and provide a basis for direct policy response. This method can reflect preferences for a particular use of ecosystem accounting for social, economic or environmental purposes and can also describe a level quantifying an undesirable state required to define the zero end of the normalized scale, for example, where the ecosystem is no longer present or functioning. Prescribed levels, however, are not available for all variables, may be subject to policy influence and may change over time, and may not be developed consistently for all ecosystem types, variables or countries.

A5.11 **7. Expert opinion** usually consists of a narrative statement of expected reference condition. Although an expert's opinion may be expressed semi-quantitatively, qualitative articulation is probably most common (European Commission, 2003). Several weaknesses are inherently associated with such an approach. Therefore, caution should be exercised when using this approach as the sole means of establishing reference condition.

A5.12 **8. Combination of any of the above methods.** Many of the above approaches may be used either singly or in concert for establishing and/or cross-validating reference condition. In practice, it may not be possible to use a single method to describe or quantify reference levels of ecosystem condition variables under a reference condition. For instance, the reference values of variables that describe a historical condition (e.g. the pre-industrial state of an ecosystem) can be determined by a combination of methods: modelling potential vegetation (method 2) based on paleoclimatic data (obtained through method 4). Statistical models and tools exist to combine methods, for example, Bayesian networks can combine statistical distributions (method 3) and expert opinion (method 7). Recent advancements in artificial intelligence will further improve the above-mentioned methods for inferring and describing a reference condition.

Table A5.2.2
Summary of methods for estimating possible reference condition for natural and managed ecosystems

	Natural ecosystems				
		Anthropogenic ecosystems			
Possible reference condition	Undisturbed or minimally disturbed condition	Historical condition	Least disturbed condition	Contemporary condition	Best attainable condition
Methods for estimating reference conditions					
1. Reference sites	x	x	x	x	
2. Modelled reference conditions	x	x	x		x
3. Statistical approaches based on ambient distributions			x		x
4. Historical observations and paleo-environmental data		x			
5. Contemporary data				x	
6. Prescribed levels					x
7. Expert opinion	x		x		x

Section C

Accounting for ecosystem services

Section overview

The broad ambition of SEEA is to comprehensively describe the relationship between the environment and the economy. In many respects, flows of ecosystem services that reflect the contributions that ecosystems make to benefits used in economic and other human activity are a central component of the description of that relationship. Section C of SEEA EA, encompassing chapters 6 and 7, presents the approach to accounting for ecosystem services within the ecosystem accounting framework, which was summarized in chapter 2.

The focus in chapter 6 is on the definition of ecosystem services and associated concepts for accounting purposes. The concept of ecosystem services is relatively new, with a rapid increase in the volume of research and the accompanying literature and studies having occurred in the past 20 years. It is therefore important to clearly articulate the approach to accounting for ecosystem services in SEEA EA. An important part of this articulation entails establishing the connection to the flow of produced goods and services that are recorded in the SNA. Thus, ecosystem services are defined so that, as appropriate, they can be readily recorded as inputs to production processes recorded in the SNA. At the same time, the measurement boundary for ecosystem services is extended to include the contribution of ecosystems to other, non-SNA benefits that people receive from the environment.

In accounting for ecosystem services, the emphasis is placed on recording data on the use of ecosystems by economic units and people both directly and indirectly. Often, there are competing interests where use by some people – for example, for supplying wood biomass – competes with other uses such as global climate regulation. In other cases, the uses may be complementary. The intent in accounting terms is to record the flows that occur and hence support an understanding of the degree to which different uses may be competing or complementary and the extent to which some uses may have a greater effect on ecosystem condition and the continued supply of ecosystem services.

There is a range of measurement boundary and treatment issues such as those concerning links to biodiversity, the treatment of non-use values and the treatment of imports and exports of ecosystem services. All of these matters are considered in chapter 6. Chapter 7 focuses on the appropriate recording of ecosystem services in physical terms using accounting principles. These chapters demonstrate the importance of SEEA EA in establishing an agreed set of concepts, definitions and measurement classes for ecosystem services to support the effective exchange of experiences and the development of comparable reports and outputs.

In many contexts, data on ecosystem service flows in physical terms will provide the core information required to understand the connection between people and ecosystems, for example, with respect to the location of ecosystem supply, the types of users and beneficiaries and the magnitude of the flows. This is particularly relevant for measurement in monetary terms since the majority of ecosystem services are not traded on markets and values for ecosystem service flows must be estimated using various non-market valuation approaches as described in chapter 9.

Chapter 6
Ecosystem services concepts for accounting

6.1 Purpose of accounting for ecosystem services

6.1 In the ecosystem accounting framework, ecosystem services serve as the concept connecting ecosystem assets and the production and consumption activity of businesses, households and governments. The measurement of ecosystem services is thus central to describing an integrated set of ecosystem accounts.

6.2 Since the release of *Ecosystems and Human Well-being* (Millennium Ecosystem Assessment, 2005), there has been a significant increase in the number of studies focused on ecosystem services. These studies, involving researchers from a range of disciplines and from all over the world, have considered many aspects of the definition of and approaches to measurement, including at scales encompassing local ecosystems and communities as well as global assessments. The potential of applying an ecosystem services approach to foster an understanding of the relationship between humans and the environment has been further strengthened through work under various frameworks including The Economics of Ecosystems and Biodiversity initiative (TEEB, 2010), the MAES initiative (Maes and others, 2013); the Natural Capital Project at Stanford University; the Integrated system for Natural Capital and ecosystem services Accounting (INCA) project (Vallecillo and others, 2019b); and IPBES (Díaz and others, 2015), among many others. The approach to accounting for ecosystem services presented here builds on all of this research and practice.

6.3 The measurement of ecosystem services is of particular interest in explaining the variety of contributions that ecosystems make to people and the economy. Such contributions extend well beyond marketed goods, such as timber and fish, and include services such as air filtration, water purification, global climate regulation and recreation-related services. Commonly, those types of services are supplied to communities outside market institutions. The focus of accounting for ecosystem services is to provide a clear description of the range of these services, the spatial heterogeneity of their delivery and their local-to-global beneficiaries, in order that this information may be readily associated with the different ecosystems that supply the services and compared across different ecosystem types.

6.4 An important feature of the rationale for accounting for ecosystem services is that while much economic production (for example, in agriculture, forestry and fisheries) uses inputs directly from ecosystems, those inputs (and any associated degradation) are not explicitly recorded in the national accounting framework. In ecosystem accounting, ecosystem services are clearly differentiated from the goods and services that are produced, that is to say, the ecosystem services are recorded as the contributions of ecosystem assets to the production of those goods and services. In effect, this approach extends supply chains and treats ecosystem assets as suppliers or producing units.

6.5 The explicit recording of the contribution of ecosystems to both current marketed production and wider benefits accruing to individuals and society encourages a wider understanding of the role of ecosystems and the possible effects of a change in their extent and condition (e.g. due to changes in land use, spatial planning and protected status). This focus can support an understanding in particular of those ecosystem services that may be at risk of being lost or becoming scarce.

6.6 Accounting for ecosystem services does not provide a complete assessment of the entire relationship between ecosystems and people. While the conceptual scope of ecosystem services is broad, there are a range of other benefits that are not captured, for example, those involving relational and intrinsic values. Nonetheless, a focus on ecosystem services does yield important information describing use of and dependence on ecosystems. Further, based on such information, together with information on the extent and condition of ecosystem assets, data on expenditure on environmental protection and resource management and data on economic activity, a rich portrayal of that relationship can be achieved. In this respect, there is an important link to the data of the SEEA Central Framework and the SNA in respect of understanding relevant environmental pressures and policy responses. The subject of how these factors impact on ecosystem assets and hence on the flows of ecosystem services has an important role to play in informing relevant aspects of policymaking.

6.7 The present chapter provides descriptions and definitions of the various concepts and principles that are applied in accounting for the supply and use of ecosystem services. Using these concepts and principles, the chapter outlines a reference list of selected ecosystem services and associated descriptions to support account compilation and comparison of methods and findings. This chapter also provides additional explanation on the treatment of specific services and associated environmental flows, thereby establishing the measurement scope that is appropriate for ecosystem accounting.

6.2 Concepts and principles in accounting for ecosystem services

6.2.1 Ecosystem services

6.8 The key concepts under the ecosystem accounting framework related to ecosystem services concern (a) supply of ecosystem services to users; and (b) contribution of ecosystem services to benefits (i.e. the goods and services ultimately used and enjoyed by people and society). Directly below, these concepts are placed in context for ecosystem accounting purposes.

6.9 Following the general framework of ecosystem accounting, each ecosystem asset supplies a set or bundle of ecosystem services. Following the framing described in chapter 2, ***ecosystem services are the contributions of ecosystems to the benefits that are used in economic and other human activity.*** Under this definition, use incorporates direct physical consumption, passive enjoyment and indirect receipt of services. Further, ecosystem services encompass all forms of interaction between ecosystems and people, including both in situ and remote interactions.

6.10 In ecosystem accounting, ecosystem services are recorded as flows between ecosystem assets and economic units, where economic units encompass the various institutional types included in the national accounts, such as businesses, governments and households. Flows of ecosystem services are sometimes reflected in direct physical flows (when, for example, fish are removed from a marine ecosystem), but they may also be reflected in the indirect receipt of ecosystem services, such as flood control services.

6.11 Following the cascade model describing flows of ecosystem services,[65] the supply of an ecosystem service will be associated with an ecosystem structure or process or a combination of ecosystem structures and processes that reflect the biological, chemical and physical interactions among ecosystem components (Potschin and Haines-Young, 2017). Their characteristics can be aggregated into different groups of functional outcomes (Schneiders and Müller, 2017). These processes and characteristics are observable and measurable but are not themselves flows of ecosystem services as defined in ecosystem accounting, since this requires a connection to be made to users. This alignment between supply and use is a foundational accounting concept (see SEEA Central Framework, sect. 3.2) and applies in both physical and monetary terms. The recording of ecosystem services pertains to total flows over an accounting period (e.g. one year), and an entry will therefore reflect a total flow per unit of time.

6.12 In much of the ecosystem services literature, the term "supply" refers to an ecosystem's potential or capacity to supply services irrespective of use, while the term "use" refers to the actual flow to people. In ecosystem accounting, following standard accounting treatments, the measures of supply and use are equivalent and will be equal to the actual flow between the ecosystem asset and people. At the same time, the concept of ecosystem capacity is highly relevant in this regard, and a discussion of this concept in the context of ecosystem accounting is provided in section 6.5.

6.13 In many cases, ecosystem services contribute to benefits in combination with other inputs, such as labour and produced capital. These "joint production" contexts are an important feature of the relationship between ecosystem assets and economic and other human activity, and they highlight the need to differentiate between ecosystem services and benefits. The types of benefits are discussed further in section 6.2.2.

6.14 The relationship between the supply of ecosystem services and their use will not always entail a flow from one ecosystem asset to one economic unit or user. In some cases (e.g. that of flood control services involving a range of ecosystem types within a catchment), ecosystem services will be supplied through a combination of ecosystem assets. In other cases, one ecosystem service will be used by different economic units. For example, air filtration services contribute to benefits used by both households and businesses. The different types of benefits and the types of users to which they are linked are discussed in section 6.2.2.

6.15 In some cases, ecosystem services will be an indirect contribution to benefits. For example, the nursery population services supplied by seagrass meadows are an input to the supply of fish biomass provisioning services, which in turn contribute to the benefit of marketed fish. In this case, the nursery population service is treated as intermediate, while the biomass provisioning service is final. Final and intermediate ecosystem services are discussed further in section 6.2.3.

6.2.2 Benefits

6.16 ***Benefits are the goods and services that are ultimately used and enjoyed by people and society.*** The use of the term "benefit" in ecosystem accounting is derived from, but is applied more broadly than, the SNA definition of an economic benefit. In the 2008 SNA (para. 3.19), ***an economic benefit is defined as denoting "a gain or positive utility arising from an action***", where an action or activity entails production, consumption or accumulation and utility concerns the satisfaction of a human need or an improvement in well-being.[66] As applied in ecosystem accounting, the term "benefit" reflects a gain or positive contribution to well-being arising from the use of ecosystem services.

65 This framing reflects the general framing of the well-recognized cascade model (Haines-Young and Potschin, 2012; Potschin and Haines-Young, 2016) and the framing provided by Boyd and Banzhaf (2007). Central to these framings is the view that ecosystem services are "contributions to benefits" rather than being "equivalent to benefits", which was the framing applied in the Millennium Ecosystem Assessment (2005). The language of contributions is also present in the IPBES approach (Díaz and others, 2015), which adopts the term "nature's contributions to people". The focus on contributions is directly suited to the accounting approach of SEEA EA and the application of supply-use principles.

66 The term "utility" is used here, as in the SNA, to provide a conceptual reference point rather than a measurement objective.

6.17 Benefits are treated as either SNA benefits or non-SNA benefits. ***SNA benefits are goods and services that are included in the production boundary of the SNA.*** Examples of SNA benefits include all food, water, energy, clothing, shelter and recreation services available for purchase. As contributions to SNA benefits, ecosystem services are readily seen as inputs into an existing production process, and consequently SNA benefits can be seen as resulting from a joint production process involving ecosystems and various other inputs including produced assets and labour. It may be useful to distinguish between inputs involved in the supply of ecosystem services (e.g. use of fertilizers in the growing of crops) and inputs involved in accessing or using ecosystem services (e.g. use of vehicles to drive to parks for recreation). In both contexts, the aim in ecosystem accounting is to isolate and record the ecosystem's contribution to the benefits received.

6.18 ***Non-SNA benefits are goods and services that are not included in the production boundary of the SNA.*** Examples of non-SNA benefits include clean air and flood protection provided by ecosystems. In line with the definition of benefits, the scope of non-SNA benefits for ecosystem accounting purposes is limited to contributions to people and society. It therefore excludes contributions of ecosystems to their own longer-term condition and potential to supply ecosystem services in the future. While there may be benefits associated with maintenance of ecosystem condition, they are reflected in the ecosystem accounts either through the ecosystem condition account or in terms of changed flows of ecosystem services, which are recorded at the time they occur.

6.19 The measurement scope of ecosystem services is set so that flows of ecosystem services do not overlap with the flows of goods and services recorded in the SNA (i.e. SNA benefits). The measurement scope of goods and services recorded in the SNA is defined by the SNA production boundary. In ecosystem accounting, all ecosystem services are outside the SNA production boundary.

6.20 It is also relevant to consider the private and public nature of ecosystem services and the link to benefits in terms of the following three situations:

(a) There are ecosystem services that contribute to benefits that are used by one user and it is feasible to exclude others from using those services (e.g. supply of fodder in rearing livestock on private landholdings). Such ecosystem services satisfy the economic definition of pure private goods as being rival and excludable;

(b) There are ecosystem services that contribute to benefits that are used by one user but it is not feasible to exclude others from using those services (e.g. recreation-related services supplied by a public park). Such ecosystem services satisfy the economic definition of common pool resources as being rival and non-excludable;

(c) There are ecosystem services that contribute to benefits that can be used simultaneously by multiple economic units, and it is not feasible to exclude others from using those services (e.g. global climate regulation services). Such ecosystem services satisfy the economic definition of pure public goods as being non-rival and non-excludable.

6.21 Through an application of these distinctions, those ecosystem services that contribute to public goods can be treated analogously to those services described in the SNA as collective consumption services. Such distinctions are relevant in the allocation of ecosystem services to users (as discussed further in chap. 7) and in the integration of ecosystem services and ecosystem assets in the extended sequence of sector accounts described in chapter 11.

6.22 As noted, there is a link between the definitions of benefits and well-being. In a wider economic framing, well-being is commonly described in terms of welfare and utility,[67] which in turn may be linked to the consumption of goods and services[68] and the receipt of benefits. In this context, the assessment of changes in welfare and well-being considers both positive and negative effects on utility.

6.23 From an accounting perspective, a distinction can be made between outputs and outcomes (see Organisation for Economic Co-operation and Development, Working Party on National Accounts (2008)). For example, health outputs concern the production of services supplied by doctors and hospitals, while health outcomes reflect a particular state or condition to which people attach utility. In this framing, outputs contribute to outcomes. There may be considerable analytical interest in estimating the value of health and other individual and social outcomes, but this is not the focus of measurement in ecosystem accounting.

6.2.3 Final and intermediate services

6.24 The primary focus of ecosystem accounting is the measurement of final ecosystem services. ***Final ecosystem services are those ecosystem services in which the user of the service is an economic unit.*** Economic units include businesses, governments and households. Thus, every final ecosystem service represents a flow between an ecosystem asset and an economic unit.

6.25 A focus on accounting for final ecosystem services is appropriate where the focus of measurement is the direct connection between people and ecosystems. However, there is a range of connections among ecosystem assets involving an assortment of ecosystem structures and processes that are relevant in determining the supply of final ecosystem services. For example, populations of wild fish may be caught at sea while the associated nurseries are located in seagrass meadows closer to shore. Thus, while the overall contribution of ecosystems is embodied in the catch of wild fish (a final ecosystem service), this recording does not reveal the indirect contribution of the seagrass meadows.

6.26 Conceptually, the ecosystem accounting framework allows the indirect contributions of ecosystem assets to be recorded as intermediate services. As is the case for final ecosystem services, intermediate services represent contributions to benefits. Thus, ***intermediate services are those ecosystem services in which the user of the ecosystem services is an ecosystem asset and where there is a connection to the supply of final ecosystem services.***

6.27 Since intermediate services are defined with respect to a sequence of inputs and outputs within the environment, they have the potential to be recorded both within and between ecosystem assets. For example, the nursery services provided by seagrass meadows may contribute to fish caught either in the same location or elsewhere. This treatment allows the recording of intermediate services, and therefore the various indirect contributions of ecosystems, to be undertaken irrespective of the size of the ecosystem assets. Chapter 7 elaborates further on the approach to recording intermediate services in ecosystem accounting, particularly as it concerns recording ecosystem services related to the production of biomass, such as crops.

6.28 For ecosystem accounting purposes, the measurement of intermediate services should focus generally on cases where there are observable connections between ecosystem assets that are of high analytical or policy interest (involving, for example, the role of wild pollinators in supporting the production of crop biomass or connections among trophic layers for fish species).

[67] Well-being may also be expressed in terms of capabilities (Sen, 1999).

[68] In this context, "consumption" includes both the transformation of materials (e.g. the use of timber to build houses or for energy) and the passive receipt of non-material ecosystem services (e.g. the aesthetic enjoyment of viewing landscapes).

6.29 Potentially, highly complex interlinkages between different ecosystems can be recorded within a supply and use accounting structure. However, ecosystem accounting should remain focused on recording final ecosystem services, and entries for intermediate services should concern only those flows that can be clearly connected to a final ecosystem service and that are of particular relevance for ecosystem management, as illustrated in the above examples. It is not the ambition of ecosystem accounting to provide full documentation of all ecological processes or connections.

6.30 Recording intermediate services as exchanges among ecosystem assets is not equivalent to recording the wide array of biophysical flows within and between ecosystems that reflect ongoing ecological processes and associated characteristics. Such flows were referred to in SEEA EEA as intra- and inter-ecosystem flows. While these processes and associated characteristics are certainly fundamental to the supply of ecosystem services, a complete mapping of intra- and inter-ecosystem flows is beyond the scope of ecosystem accounting. Nonetheless, there may be interest in understanding the extent to which the various ecological processes are well functioning, for example, so as to understand the ability of an ecosystem to provide ecosystem services into the future. In ecosystem accounting, the maintenance of well-functioning ecosystems is considered in the measurement of ecosystem condition and ecosystem capacity.

6.2.4 Users and beneficiaries

6.31 In accounting, the supply and use of ecosystem services in the production of benefits can be considered, in many contexts, as the first step in a longer economic “supply” chain. For example, a water supply company’s use of water purification services will be an initial step in the abstraction and distribution of water to a wide range of economic units, including businesses, governments and households. For clarity of expression, all of these economic units may be referred to as beneficiaries of ecosystem services, but the economic unit that has the direct connection to the ecosystem, that is, the unit that is the counterparty in the interaction with the ecosystem, is labelled the user of the ecosystem service. In this example, the user of water purification services is the water supply company, while the other economic units are beneficiaries. The set of users should be considered a subset of the set of beneficiaries.

6.32 In recording flows of ecosystem services to various users and beneficiaries, it is relevant to consider the location of use relative to the location of the supplying ecosystem. This would extend to consideration of imports and exports of ecosystem services and the associated benefits. The mapping of ecosystem services flows to users and beneficiaries and the recording of exports and imports of ecosystems services are discussed further in chapter 7.

6.2.5 Abiotic flows

6.33 The discussion and literature on ecosystem services have tended to focus on those flows that are primarily associated with an ecosystem’s biotic components and processes, that is, flows associated with living components such as plants and animals. However, since the definition of an ecosystem involves the interaction of biotic and abiotic components, a neat separation that treats ecosystem services as purely or predominantly biotic is not appropriate.

6.34 Further, there are a range of benefits that people obtain from the environment that reflect contributions that appear to fall outside the scope of ecosystem services. Examples include extraction of fossil fuels and mineral ores, abstraction of water, energy obtained from wind and solar sources and benefits associated with the role of soils and bedrock in supporting buildings and transport infrastructure.

6.35 To support discussion of these various flows and appropriate and comparable recording with respect to ecosystem services, SEEA EA adopts a framing of contributions from the environment that distinguishes (a) ecosystem services; (b) abiotic flows; and (c) spatial functions, as shown in table 6.1. In this framing, ***abiotic flows are contributions to benefits from the environment that are not underpinned by, or reliant on, ecological characteristics and processes.***

6.36 This framing has the following key features:

- Ecosystem services are distinct from abiotic flows, while both reflect contributions from the environment.
- Ecosystem services are underpinned by various ecological characteristics and processes that involve both biotic and abiotic components to varying degrees. Thus, ecosystem services encompass services that are both predominantly biotic (e.g. air filtration services provided by forests) and predominantly abiotic (e.g. coastal protection services provided by sand dunes).
- Abiotic flows arise through the abstraction and extraction of resources, where a distinction is made between those flows related to geophysical sources (i.e. sources related to climate and the atmosphere) and those related to geological resources. Depending on the location of the resources and the point of abstraction or extraction, geological resources may be attributed as flows from ecosystem assets (e.g. sand and gravel) or from deep geological resources.
- Spatial functions are treated neither as ecosystem services nor as abiotic flows. Two main types are identified: (a) use of the environment for transportation and movement on land or water or through the air or as a base for buildings and structures; and (b) use of the environment as a location in which pollutants and waste are deposited, that is, use of the environment as a sink (excluding the remediation of such residuals by ecosystems, which is treated as an ecosystem service).[69]

[69] While this could be extended potentially to include recording of the use of the atmosphere as a sink for GHG emissions, such a treatment is not developed in SEEA EA.

6.37 Compilers are encouraged to record abiotic flows from geophysical sources and from geological resources extracted from ecosystem assets together with ecosystem services, since analysis of environmental trends for spatial areas may be greatly enhanced through joint consideration of those flows. This is particularly the case for flows of water. Indeed, the treatment of water abstraction and supply is extremely important and is discussed explicitly in section 6.4. There is no expectation that compilers of ecosystem accounts will record abiotic flows from deep geological resources or flows related to spatial functions. Accounting for abiotic flows should be undertaken consistent with the advice provided in the SEEA Central Framework, for example, concerning flows of energy, water and mineral and energy resources.

6.38 Concerning flows of pollutants and waste, it is to be noted that there are related entries in the ecosystem services flow accounts concerning the mediation of these residuals, and the accounts of the SEEA Central Framework provide the opportunity to record aggregate flows of such pressures. The effect of those pressures on ecosystem condition should be recorded in the ecosystem condition account.

6.39 Flows related to the use of the environment as a location for transportation and movement and for buildings and structures are not recorded explicitly in the SEEA Central Framework or SEEA EA. Relevant information may be recorded in the Central Framework land-use accounts.

Table 6.1
Framing of contributions to benefits from the environment

Ecosystem services[a] Provisioning services Regulating and maintenance services Cultural services		
Abiotic flows	Geophysical sources Flows related to geophysical processes including abstraction of water (including groundwater) and capture of wind, solar, tidal, geothermal and similar sources of energy	
	Geological resources Flows related to geological resources including extraction of fossil fuel, mineral ores, sand and gravel	
Spatial functions	Flows related to the use of the environment as a location for transportation and movement and for buildings and structures	
	Flows related to the use of the environment as a sink for pollutants and waste (excluding the remediation of pollutants and wastes recorded as ecosystem services)	

a Following section 6.3.4, non-use values are not treated as ecosystem services, but data concerning them may be recorded under "ecosystem and species appreciation" to recognize these types of connections to the environment.

6.40 The monetary value of abiotic flows and spatial functions are captured generally in current SNA-based values, for example, in the value of resources extracted or in market values that reflect the use of land to support buildings and structures, with the main exception being flows related to use of the environment as a sink for pollutants and waste.

6.2.6 Identifying flows of ecosystem services

6.41 To support consistent application of the boundary between ecosystem services and benefits, a tool referred to as a logic chain is applied. The intent is to provide a standard framing for recording information relevant to the description and measurement of individual ecosystem services. A logic chain reflects a sequence in which an ecosystem asset supplies an ecosystem service to an economic unit that uses that ecosystem service as an input to a production or consumption activity leading to an SNA or non-SNA benefit. Logic chains can be presented graphically as well as in a table (as shown in table 6.2).

Table 6.2
Generic logic chain using air filtration services as an example

Ecosystem service	Common ecosystem types	Factors determining supply		Factors determining use	Potential physical metrics, as in appendix A6.1	Benefits	Main users and beneficiaries
		Ecological	Societal				
Air filtration services	Forest and woodland	Type and condition of vegetation, especially functional state (e.g. leaf area index) and chemical state (e.g. ambient pollutant concentration)	Ecosystem management; location, type and volume of released air pollutants	Behavioural responses; location and number of people and buildings affected by pollution	Tons of pollutants absorbed, by type of pollutant (e.g. particulate matter less than 10 micrometres in diameter (PM10) or less than 2.5 micrometres in diameter (PM2.5)	Reduced concentrations of air pollutants resulting in improved health outcomes and reduced damage to buildings (non-SNA benefit)	Households; businesses (through reduced damage to buildings)

6.42 As shown in table 6.2, each logic chain for a given ecosystem service has a number of components: (a) the ecosystem service; (b) the common ecosystem type or types; (c) factors determining supply; (d) factors determining use; (e) potential physical metrics; (f) associated benefit or benefits; and (g) main users and beneficiaries. The following points are highlighted in respect of each component:

- **Ecosystem services.** A logic chain should focus on a single ecosystem service, recognizing that it may contribute to a number of benefits.
- **Common ecosystem types.** All ecosystem services are treated as being supplied by ecosystem assets, either individually (e.g. forest providing air filtration services to a neighbouring town) or in combination (e.g. ecosystems within a catchment providing water flow regulation services).
- **Factors determining supply.** Both ecological and societal factors should be considered in describing factors determining supply. From an ecological perspective, particular ecosystem characteristics may be relevant to the supply of ecosystem services, for example, the presence of particular species or soil type; or aspects of ecosystem condition, such as pollutant concentrations and soil organic carbon levels. Human factors can determine the supply of regulating services, for example, air filtration services require some release of air pollutants. Further, where there is joint production of benefits, for example, in the growing of crops, it would be relevant to recognize human inputs such as labour, produced assets (e.g. tractors) and intermediate consumption of goods and services (e.g. fuel, fertilizer).
- **Factors determining use.** It is relevant to describe not only the factors involved in supply but also how people and economic units engage with the ecosystem in order to use the ecosystem service. In the case of air filtration, the relevant factor concerning use is the number of people in proximity to the forest or other type of ecosystem involved. Without a description and quantification of use, no flow of an ecosystem service should be recorded. Where the logic chain concerns an intermediate service, the connection to people and economic units is indirect and there should be a focus on the way in which the receiving ecosystem asset uses the ecosystem service.
- **Potential physical metrics.** A physical metric is needed that provides a clear focus for measurement. It should be recognized that this metric may be a proxy for the ecosystem service and will vary depending on data availability. For example, a suitable metric for air filtration is tons of pollutant absorbed, by type of pollutant (e.g. PM2.5, PM10)
- **Benefits.** While the focus of ecosystem accounting is on identifying the contribution of ecosystems as reflected in ecosystem services, it is commonly through the observation of benefits that the identification of the role of ecosystems can be described. From air filtration, the benefit of reduced concentrations of air pollutants will accrue to households through improved health and to building owners through reduced damage to property.
- **Main users and beneficiaries.** Different economic units use ecosystem services and in some cases, the same service may be used by different types of economic units. For example, air filtration services are used by households and businesses.

6.43 Following the design of the generic logic chain presented in table 6.2, indicative logic chains for a range of ecosystem services have been included in appendix A6.1 to support measurement and implementation. An online supplement is being developed that will outline logic chains for all of the ecosystem services included in the reference list.

6.3 Reference list of selected ecosystem services

6.3.1 Principles underpinning the reference list of selected ecosystem services

6.44 There is a wide range of ecosystem services that fall within the conceptual scope of the definition of ecosystem services. Notwithstanding significant advances in the development of classifications of ecosystem services, in particular the Common International Classification of Ecosystem Services (CICES)[70] and the National Ecosystem Services Classification System (NESCS Plus),[71] an internationally agreed classification of ecosystem services has not been finalized. In its absence, a reference list of selected ecosystem services has been developed for SEEA EA by combining the findings derived from work related to CICES and NESCS; work under other initiatives on the typology and classification of ecosystem services (e.g. the Millennium Ecosystem Assessment, TEEB and the "nature's contributions to people" approach of IPBES) and the outcomes of the consultation on the revision of SEEA EEA. The primary criterion for inclusion of an ecosystem service in the reference list of selected ecosystem services is that the service be regarded as constituting a relevant and important ecosystem service in many countries and contexts.

6.45 The reference list of selected ecosystem services provides labels and descriptions for a set of key ecosystem services relevant for ecosystem accounting. It is intended to provide clarity on measurement scope and focus for ecosystem services and should therefore support consistency of measurement. The reference list will thereby support discussion among compilers of ecosystem accounts, comparison of measurement and valuation techniques and comparison of accounting results.

6.46 The reference list is a pragmatic grouping of ecosystem services designed to support accounting rather than a full ecosystem services classification system. It is intended that a complete and internationally agreed classification of ecosystem services will be developed. To support that development and to allow those using existing classification systems to be linked to the reference list, correspondences to CICES and NESCS and other ecosystem services classifications and typologies have been made available as an online supplement to SEEA EA.

6.47 Since it contains selected ecosystem services, the reference list is not exhaustive. However, it does include categories for "other" ecosystem services to allow for services not included in the list to be recorded in the ecosystem accounts, subject to their satisfying the definition of ecosystem services used in SEEA EA and associated treatments. Where additional ecosystem services are included in a set of ecosystem accounts, it is important that the description, labelling and measurement of those ecosystem services ensure that they do not overlap with other services included in the reference list. This will prevent double counting of ecosystem services and will facilitate comparisons between accounts.

6.48 Each ecosystem service in the reference list is described so as to ensure that there is no double counting of the ecosystem contributions of individual ecosystem services in the reference list. The focus in applying this principle will vary by type of ecosystem service. For provisioning services, the mutual exclusivity is connected with use of a classification of biomass outputs such as of agricultural products. For regulating services, the focus is on distinguishing the roles of different ecological processes. For cultural services, the focus is on describing the types of interactions that individuals have with ecosystems, for example, whether they take place within or outside ecosystems.

70 See https://cices.eu/resources/.

71 See www.epa.gov/eco-research/national-ecosystem-services-classification-system-nescs-plus.

6.49 Further, the reference list includes ecosystem services that can be either final ecosystem services (i.e. services used by economic units) or intermediate services (i.e. services used by ecosystem assets). Moreover, and particularly for regulating and maintenance services, a single ecosystem service may be final or intermediate, depending on the context. The distinction between a final and an intermediate service reflects the user of the service not the service itself. In concept, since each ecosystem service flow is recorded separately, a distinct treatment as either final or intermediate can be determined depending on the use context. Particularly in accounting for biomass provisioning services, care is needed to ensure that the appropriate combination of inputs and outputs of ecosystem services are recorded so that the net contribution of the ecosystem assets is identified. Chapter 7 provides further discussion on the appropriate recording of ecosystem services following an SUT approach.

6.50 In accordance with the requirements of ecosystem accounting, the reference list does not incorporate a distinction based on the type of supplying ecosystem asset or a distinction based on the nature of the use of the ecosystem service (e.g. whether the service is for use by households or business, for nutrition or energy, etc.). The information on the supplying ecosystem assets and the using economic units is evident from the place in the SUT where the ecosystem service flow is recorded. The SUTs apply existing classifications of ecosystem types (e.g. IUCN GET or an equivalent national classification) and of economic units (e.g. ISIC or an equivalent national classification) to organize information on each ecosystem service flow.

6.3.2 Presentation of the reference list of selected ecosystem services

6.51 The reference list of selected ecosystem services with associated descriptions is presented in table 6.3. The structure of the list at the highest level encompasses three broad categories – provisioning services, regulating and maintenance services, and cultural services – which are defined as follows:

- ***Provisioning services are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems.***
- ***Regulating and maintenance services are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles and thereby maintain environmental conditions beneficial to individuals and society.***
- ***Cultural services[72] are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contribute to a range of cultural benefits.***

6.52 Within each of these broad groups, a number of ecosystem service types are included along with some subtypes. Regulating and maintenance services are grouped roughly under the headings of services related to climate, air, soil, water, habitat and species.

6.53 To ensure that the coverage of the ecosystem accounts is as comprehensive as possible, compilers are encouraged to include as many types of ecosystem services as possible. A progressive expansion over time of the range of ecosystem services included in the accounts may be appropriate, considering data and resource availability and the relative significance of the ecosystem services.

6.54 Notes are provided following table 6.3 to support understanding of the table and its application. Additional detail on some of these notes is provided in section 6.4 concerning the treatment of selected ecosystem services.

72 The label "cultural services" is a pragmatic choice, reflecting its long-standing use in the ecosystem services measurement community. It is not meant to imply that culture itself is a service; rather it is a summary label and as such is intended to capture the variety of ways in which people connect to, and identify with, nature and the variety of motivations for those connections.

Table 6.3
Reference list of selected ecosystem services

ECOSYSTEM SERVICE		DESCRIPTION
Provisioning services		
Biomass provisioning services	Crop provisioning services*	Crop provisioning services are ecosystem contributions to the growth of cultivated plants that are harvested by economic units for various uses, including food and fibre production, fodder and energy. These are final ecosystem services.
	Grazed biomass provisioning services*	Grazed biomass provisioning services are ecosystem contributions to the growth of grazed biomass that is an input to the growth of cultivated livestock. These services exclude ecosystem contributions to the growth of crops used to produce fodder for livestock (e.g. hay, soybean meal). Those contributions are included under crop provisioning services. These are final ecosystem services but may be intermediate to livestock provisioning services.
	Livestock provisioning services*	Livestock provisioning services are ecosystem contributions to the growth of cultivated livestock and livestock products (e.g. meat, milk, eggs, wool, leather) that are used by economic units for various purposes, primarily food production. These are final ecosystem services. No distinct livestock provisioning services are to be recorded if grazed biomass provisioning services are recorded as a final ecosystem service.
	Aquaculture provisioning services	Aquaculture provisioning services are ecosystem contributions to the growth of animals and plants (e.g. fish, shellfish, seaweed) in aquaculture facilities that are harvested by economic units for various uses. These are final ecosystem services.
	Wood provisioning services	Wood provisioning services are ecosystem contributions to the growth of trees and other woody biomass both in cultivated (plantation) and in uncultivated production contexts that are harvested by economic units for various uses including timber production and energy. These services, which exclude contributions to non-wood forest products, are final ecosystem services.
	Wild fish and other natural aquatic biomass provisioning services	Wild fish and other natural aquatic biomass provisioning services are ecosystem contributions to the growth of fish and other aquatic biomass that are captured in uncultivated production contexts by economic units for various uses, primarily food production. These are final ecosystem services.
	Wild animals, plants and other biomass provisioning services	Wild animals, plants and other biomass provisioning services are ecosystem contributions to the growth of wild animals, plants and other biomass that are captured and harvested in uncultivated production contexts by economic units for various uses. The scope includes non-wood forest products (NWFP) and services related to hunting, trapping and bioprospecting activities; but it excludes wild fish and other natural aquatic biomass (included in the class directly above). These are final ecosystem services.
Genetic material services		Genetic material services are ecosystem contributions from all biota (including seed, spore or gamete production) that are used by economic units, for example, (a) to develop new animal and plant breeds; (b) in gene synthesis; or (c) in product development directly using genetic material. These are most commonly recorded as ecosystem services intermediate to biomass provisioning.
Water supply*		Water supply services reflect the combined ecosystem contributions of water flow regulation, water purification and other ecosystem services to the supply of water of appropriate quality to users for various purposes, including household consumption. These are final ecosystem services.
Other provisioning services		
Regulating and maintenance services		
Global climate regulation services		Global climate regulation services are ecosystem contributions to reducing concentrations of GHGs in the atmosphere through the removal (sequestration) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems. These services, which support the regulation of the chemical composition of the atmosphere and oceans, are final ecosystem services.
Rainfall pattern regulation services (at subcontinental scale)		Rainfall pattern regulation services are ecosystem contributions of vegetation, in particular forests, to maintaining rainfall patterns through evapotranspiration at the subcontinental scale. Forests and other vegetation recycle moisture back to the atmosphere where it is available for the generation of rainfall. Rainfall in interior parts of continents fully depends upon this recycling. These may be final or intermediate ecosystem services.
Local (micro and meso) climate regulation services		Local climate regulation services are ecosystem contributions to the regulation of ambient atmospheric conditions (including micro- and mesoscale climates) through the presence of vegetation that improve people's living conditions and support economic production. Examples include evaporative cooling provided by urban trees ("green space"), the contribution of urban water bodies ("blue space") and the contribution of trees to providing shade for humans and livestock. These may be final or intermediate ecosystem services.

Table 6.3
Reference list of selected ecosystem services (*continued*)

ECOSYSTEM SERVICE		DESCRIPTION
Air filtration services		Air filtration services are ecosystem contributions to the filtering of airborne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly plants, that mitigate the harmful effects of those pollutants. These are most commonly final ecosystem services
Soil quality regulation services		Soil quality regulation services are ecosystem contributions to the decomposition of organic and inorganic materials and to the fertility and characteristics of soils, e.g. for input to biomass production. These are most commonly recorded as intermediate ecosystem services
Soil and sediment retention services	Soil erosion control services	Soil erosion control services are ecosystem contributions, particularly the stabilizing effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment (e.g. agricultural activity, water supply). These may be recorded as final or intermediate ecosystem services.
	Landslide mitigation services	Landslide mitigation services are ecosystem contributions, particularly the stabilizing effects of vegetation, that mitigate or prevent potential damage to human health and safety and damaging effects to buildings and infrastructure that arise from the mass movement (wasting) of soil, rock and snow. These are final ecosystem services.
Solid waste remediation services		Solid waste remediation services are ecosystem contributions to the transformation of organic or inorganic substances, through the action of microorganisms, algae, plants and animals, that mitigate their harmful effects. These may be recorded as final or intermediate ecosystem services.
Water purification services (water quality regulation)	Retention and breakdown of nutrients	Water purification services are ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of those pollutants on human use or health. These may be recorded as final or intermediate ecosystem services.
	Retention and breakdown of other pollutants	
Water flow regulation services	Baseline flow maintenance services	Water regulation services are ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water and gradually release it during dry seasons or periods through evapotranspiration and hence secure a regular flow of water. These may be recorded as final or intermediate ecosystem services.
	Peak flow mitigation services	Water regulation services are ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water and hence mitigate the effects of flood and other extreme water-related events. Peak flow mitigation services are supplied together with river flood mitigation services in providing the benefit of flood protection. These are final ecosystem services.
Flood control services	Coastal protection services	Coastal protection services are ecosystem contributions of linear elements in the seascape (e.g. coral reefs, sand banks, dunes or mangrove ecosystems along the shore) to protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities. These are final ecosystem services.
	River flood mitigation services	River flood mitigation services are ecosystem contributions of riparian vegetation, which provides structure and a physical barrier to high water levels and thus mitigates the impacts of floods on local communities. River flood mitigation services are supplied together with peak flow mitigation services in providing the benefit of flood protection. These are final ecosystem services.
Storm mitigation services		Storm mitigation services are ecosystem contributions of vegetation, including linear elements, in mitigating the impacts of windstorms, sandstorms and other types of storms (other than water-related events) on local communities. These are final ecosystem services.
Noise attenuation services		Noise attenuation services are ecosystem contributions to reduction of the impact of noise on people that mitigate its harmful or stressful effects. These are most commonly final ecosystem services.
Pollination services		Pollination services are the ecosystem contributions of wild pollinators to the fertilization of crops that maintain or increase the abundance and/or diversity of other species that economic units use or enjoy. These may be recorded as final or intermediate services
Biological control services	Pest control services	Biological control services are ecosystem contributions to reductions in the incidence of species that may prevent or reduce the effects of pests on biomass production processes or other economic and human activity. These may be recorded as final or intermediate services.
	Disease control services	Disease control services are ecosystem contributions to reductions in the incidence of species that may prevent or reduce the effects of species on human health. These are most commonly final ecosystem services.

Note: Further explanations related to ecosystem services marked with an asterisk (*) are provided below and in section 6.4.

Table 6.3
Reference list of selected ecosystem services (*continued*)

ECOSYSTEM SERVICE	DESCRIPTION
Nursery population and habitat maintenance services	Nursery population and habitat maintenance services are ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy, either through the maintenance of habitats (e.g. for nurseries or migration) or the protection of natural gene pools. These are intermediate services and may be inputs to a number of different final ecosystem services including biomass provisioning and recreation-related services.
Other regulating and maintenance services	
Cultural services	
Recreation-related services	Recreation-related services are contributions of ecosystems, in particular through their biophysical characteristics and qualities, that enable people to use and enjoy the environment through direct, in situ, physical and experiential interactions with the environment. These include services both to locals and to non-locals (i.e. visitors, including tourists). Recreation-related services may also be supplied to those engaging in recreational fishing or hunting. These are final ecosystem services.
Visual amenity services*	Visual amenity services are ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems, that provide sensory benefits, especially visual. These services combine with other ecosystem services, including recreation-related services and noise attenuation services, to underpin amenity values. These are final ecosystem services.
Education, scientific and research services	Education, scientific and research services are ecosystem contributions, in particular through their biophysical characteristics and qualities, that enable people to use the environment through intellectual interactions with it. These are final ecosystem services.
Spiritual, artistic and symbolic services	Spiritual, artistic and symbolic services are contributions of ecosystem, in particular through their biophysical characteristics and qualities, that are recognized by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire them to express themselves through various artistic media. These are final ecosystem services.
Other cultural services	
Flows related to non-use values	
Ecosystem and species appreciation	Ecosystem and species appreciation concerns the well-being that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use.

6.55 **Services related to biomass provisioning.** As discussed further in section 6.4, the recording of ecosystem services in relation to cultivated production of crops, livestock and other products can be undertaken in different ways. Cultivated production processes occur along a continuum, with the contribution of ecosystems ranging from high to low. In measuring ecosystem services associated with crops and wood, it is most common to measure the biomass that is harvested. The estimated ecosystem contribution (or share) should vary depending on the production context but, if this is not possible, a proxy measure may be used based on the gross biomass harvested. Alternatively, a range of specific ecosystem services, for example, pollination, local climate regulation and water flow regulation, may be measured that collectively reflect the ecosystem contribution to biomass growth. Under this second approach, the ecosystem service of crop provisioning is not recorded. Where the harvested biomass is recorded as the final ecosystem service, the various specific ecosystem services may be recorded as intermediate services.

6.56 In measuring ecosystem services associated with livestock, estimation of the ecosystem contribution should focus on the direct interaction between the livestock and ecosystems, primarily pastures. Thus, the key final ecosystem service will be grazed biomass, but other services, such as local climate regulation, may also be relevant since ecosystems will provide a bundle of services supporting livestock. Using this measurement approach, no estimates of livestock provisioning services should be recorded. However, if livestock provisioning services are recorded, for example, based on weight gain or outputs of milk and eggs, it is essential that an ecosystem contribution be measured since in rearing livestock, especially in intensive farming systems, there may be very little direct connection with ecosystems.

6.57 **Services related to water supply.** As discussed further in section 6.4, ecosystem services related to water supply, for example, water flow regulation and water purification, may be measured as distinct and separate final ecosystem services, or they may be measured as a combined ecosystem service, using water supply as a proxy measure to reflect the overall ecosystem contribution.

6.58 **Services related to amenity.** Amenity-related services arise in the context of benefits that people obtain from living or working in a specific location. They are most usually considered in relation to specific characteristics of a place of residence. In the ecosystem services reference list, a number of services are considered to contribute to a location's amenity including visual amenity services, recreation-related services and noise attenuation services. Where possible, each of these should be measured as distinct, but in practice, measurement of a combination of amenity-related services may be required.

6.59 **Recording final and intermediate services.** The descriptions in the reference list provide indications as to whether an ecosystem service would be expected to be recorded as final or intermediate, recognizing that in practice the specific context will be the determining factor. Generally, it is expected that, with the exception of the context of biomass provisioning, most ecosystem services will be recorded as final ecosystem services. There may be some other contexts in which a connection between ecosystem services can be identified, for example, tourism areas where nursery and habitat maintenance services support recreation-related services, but it is not expected that many intermediate services would be recorded as a matter of standard practice.

6.3.3 Links between biodiversity and ecosystem services

6.60 SEEA EA has adopted the aforementioned definition of biodiversity under the Convention on Biological Diversity where ecosystem, species and genetic diversity are recognized as the broad components of biodiversity. Those components are not considered ecosystem services in themselves but there are distinct elements within them that can be directly linked to ecosystem services supply. For example, specific genes (DNA sequences) can serve as a provisioning service option for the pharmaceutical industry; pollinator species can provide important pollinating services to the agricultural sector; certain plant species can support the development of medicines (a provisioning service); the presence of well-known species (e.g. lions and elephants) can underpin recreation-related services; and ecosystems such as forests and beaches can provide recreational areas. A diversity of genes, species and ecosystems thus provides a greater range of ecosystem service options.

6.61 More broadly, the interactions between different components of biodiversity are essential for cycling energy, nutrients and other materials through the environment (Mori and others, 2013). This is fundamental for maintaining the various ecosystem processes and functions that underpin ecosystem services supply

(Bolt and others, 2016). Further, as biodiversity is lost, these ecosystem processes may be impacted. For example, with the loss of different ecosystems, ecosystem processes are altered at landscape scale; and with the loss of species and their populations from ecosystems, the different functional roles they perform (e.g. decomposing, pollinating, dispersing seeds) are lost as well. Consequently, biodiversity loss directly threatens ecosystem processes and the supply of many ecosystem services across multiple scales.

6.62 Biodiversity also plays a fundamental role in maintaining the ability of ecosystem assets to supply ecosystem services in the future. The presence of a diversity of organisms (e.g. multiple species including the genetic diversity within them) performing a given function within an ecosystem boosts the ability of that ecosystem asset to maintain functionality and supply ecosystem services, which results from the fact that different environmental changes or shocks will affect individual elements of this diversity in different ways. This ability of ecosystems to tolerate shocks and disturbances while maintaining the same level of functioning is often referred to as ecosystem resilience (see, e.g. Mori and others, (2013), Thompson and others (2009) and Walker (2019)) and may be considered to have an "insurance value" (Baumgärtner, 2007).

6.63 Elements of biodiversity that do not provide ecosystem services at present may provide valuable ecosystem services in the future. For example, a tropical tree species might prove to be the only source of a drug capable of combating a major new human disease. This role of biodiversity can be linked to the concept of "option value" (Faith, 2018; Weitzman, 1992).

6.64 Further, the existence of biodiversity and the desire for its ongoing preservation are also connected to non-use values that people assign to the environment and that include existence and bequest values. Non-use values are discussed in section 6.3.4.

6.65 The connections between biodiversity and human activity operate in two directions: biodiversity supports the supply of ecosystem services and biodiversity itself is impacted by the type of ecosystem use, as a result, for example, of harvesting practices for timber and fish and the extent of tourism activity. Choices concerning restoration and protection activity will also have impacts on biodiversity.

6.66 There still remains considerable uncertainty with respect to the specifics of the relationships between biodiversity and ecosystem services supply (P.A. Harrison and others, 2014; Mace, Norris and Fitter, 2012), in particular regarding where "tipping points" and boundaries for biodiversity loss may lie in the context of ecosystem services supply (Mace and others, 2015). Such uncertainty should encourage a precautionary approach to the management of biodiversity for sustainable ecosystem services supply. This issue is relevant in the consideration of ecosystem capacity, which is discussed in section 6.5.

6.67 More generally, it is not the case that increases in biodiversity is necessarily reflected in increases in flows of individual ecosystem services. For some ecosystem services (e.g. as related to biomass provisioning), it is likely that increasing ecosystem service flows will be correlated with declines in biodiversity. Since the relationship between biodiversity and individual ecosystem services varies, care should be taken in making assumptions regarding anticipated changes in the direction of ecosystem service flows associated with different levels of biodiversity.

6.68 The strong emphasis placed on biological "variability" or "diversity" is clearly reflected in the definition under the Convention on Biological Diversity. In the context of ecosystem accounting, biodiversity can then be viewed as an emergent property of a set of ecosystem assets and the community assemblages within them. These ecosystems and communities interact and support multiple ecosystem processes that underpin the capacity for current and future ecosystem services supply. Given the link between biodiversity and ecosystem services supply, the roles played by diversity across all three of its components (ecosystems, species and genes) and across scales should be considered.

6.3.4 Treatment of non-use values

6.69 From an economic perspective, the relationship between people and the environment is commonly characterized as encompassing both use and non-use values, as described within the context of the total economic value framework (Pearce and Turner, 1990). The recording in an accounting framework of use values – that is, values arising when the benefit to people is revealed through their direct, personal interaction with the environment (e.g. when harvesting food, hiking in forests, benefiting from cleaner air) or through indirect use (e.g. regulation of water flows providing flood mitigation) – is relatively straightforward in concept and is the focus of measurement in SEEA EA.

6.70 The treatment of non-use values in an accounting setting requires additional considerations. In the context of the environment, non-use values are those values that people assign to ecosystems (including the associated biodiversity), irrespective of whether they use (directly or indirectly), or intend to use, those ecosystems. Two main types of non-use value are bequest value, where the value is based on ensuring that the ecosystem is available to future generations, and existence value, where the value is based on the knowledge that the ecosystem is currently present. In both cases, the benefit of the non-use value accrues to an individual in the present. Hence, for accounting purposes, the two values receive the same treatment.

6.71 An option value is another type of value that arises in the context of ecosystem services. From an accounting perspective, an option value is considered a type of use value to the extent that the underlying motivation for assigning these values is to ensure that ecosystems are able to provide ecosystem services in the future, including ecosystem services that may be currently unknown or that are not being used. Option values thus capture situations in which ecosystem services are not currently being used but such situations are different from situations in which the concept of non-use would apply. Conceptually, option values are associated with measures of ecosystem condition and biodiversity and measures of the expected future flows of ecosystem services incorporated in measures of the NPV of ecosystem services.

6.72 Unlike flows of ecosystem services, there is no direct or indirect interaction with the environment associated with non-use values. Consequently, while non-use values require that ecosystems exist and may be associated with flows of environmental knowledge or information, from an accounting perspective, a transaction is not considered to have taken place consistent with the framing used for recording ecosystem services in SEEA EA.

6.73 Nonetheless, as this type of connection to the environment is of considerable importance, a separate type of flow has been included in the ecosystem services reference list: ecosystem and species appreciation. This is to allow compilers to record data that can be directly associated with non-use values. For example, it may be relevant to record data on the presence or abundance of iconic species. Further, estimates of non-use values in monetary terms may be of particular policy interest. As discussed in chapter 12, these values can be presented in complementary valuations.

6.3.5 Treatment of ecosystem disservices

6.74 Consistent with the accounting treatment of transactions, the recording of ecosystem services includes positive exchanges between ecosystem assets and economic units in the sense that they contribute to benefits. This does not imply that outcomes arising from transactions are necessarily all positive (e.g. the purchase of cigarettes can lead to poor health outcomes) or that all transactions are similarly motivated (e.g. some purchases such as fire alarms are made to limit potential negative consequences). However, the transactions themselves all entail the exchange of positive quantities of a good or service.

6.75 There is a range of contexts in which the outcomes of interactions between economic units and ecosystem assets are negative from the perspective of the economic units. Examples include the effects of pests on crop production, increases in disease from environmental vectors such as mosquitoes or zoonotic episodes, and the presence of flies at a social event. Collectively, these outcomes have been labelled ecosystem disservices. From an economic perspective, it appears natural to deduct these flows from positive ecosystem services to estimate the "net" connection between people and ecosystems.

6.76 However, from an accounting perspective, although it is possible to record relevant physical flows and quantities such as the number of pests or the number of people affected by malaria, none of these negative connections can be considered to reflect an exchange of positive quantities of a good or service and hence are not considered transactions for accounting purposes. Further, as regards the precise nature of the net connection at a societal level, it must be recognized that different people may have different values with respect to the same ecosystem asset (e.g. trees that provide shade may also obstruct some people's view).

6.77 While these flows are not transactions, the negative effects of ecosystem disservices can be reflected in accounting entries and related to ecosystem assets. Two main contexts can be considered. First, the negative effects may be reflected in reduced flows of ecosystem services (e.g. reduction in biomass provisioning services because of invasive pests). In this case, the extent of the negative effect may be determined by using the accounts to compare two different scenarios (e.g. one with and one without pests). This constitutes an analytical step rather than an accounting entry.

6.78 Second, the impacts of disease and other effects on human health can, in broad accounting terms, be reflected in a loss of human capital, which in turn may be reflected in reduced production (e.g. days lost due to poor health). Again, analysis would be required to determine the extent of the contribution of the ecosystem disservice relative to other factors.

6.79 Thus, while the accounting approach does not allow for direct recording of ecosystem disservices, it does provide a framework for the analysis of their effects. Further, the same approach can be applied in the context of analysis of negative environmental externalities, such as emissions from peatlands, where the flows, instead of being ecological in origin, are related to the activities of economic units. For example, the loss of ecosystem services – such as global climate regulation services, arising from peatland emissions – will be recorded in the accounts and there is potential for any health effects arising from the clearing of peatlands (e.g. effects linked to related forest fires and smoke) to be shown in a loss of human capital.

6.80 While the welfare effects themselves are not fully incorporated in accounting entries, the data from the accounts can underpin the assessment of their magnitude. This topic is discussed further in chapter 12, where complementary accounting tables show how estimates of the monetary value of externalities can be presented in an SUT format for both ecosystem disservices and negative environmental externalities.

6.4 Treatment of specific ecosystem services and other environmental flows

6.4.1 Treatment of biomass provisioning services

6.81 There is clear recognition that people source and use biomass from ecosystems in a wide variety of ways and for different purposes, including for food, fibre and energy. Sometimes biomass is harvested directly by final consumers (e.g. those engaged in subsistence production, households picking berries in a forest), but the majority of biomass is grown, harvested or accessed by farmers, foresters and fishers (by economic units both small and large) that supply it to other economic units. Determining the appropriate treatment of the integral biomass provisioning services is complicated by the variety of biomass types and the range of ways in which people grow and harvest biomass from the environment.

6.82 Biomass provisioning services are ecosystem contributions to SNA benefits that take the form of food, feed, fibre and energy outputs produced and consumed by economic units. In line with treatments in the SNA, all biomass provisioning that is input to subsistence production of agriculture, forestry and fisheries should be included in the scope of ecosystem accounts. This includes, for example, the collection and harvest of non-wood forest products and the growing of vegetables in backyard gardens.

6.83 While all biomass harvested is considered an SNA benefit, the recording of these flows in the SNA entails a distinction between cultivated and natural (non-cultivated) production processes based on the extent to which an economic unit manages or controls the growth of the biomass. The range of natural and cultivated production processes recorded in SEEA EA aligns with the scope of activity recorded in the SNA.

6.84 In natural production processes, all of the biomass that is harvested is considered the contribution of the ecosystem. Examples in this regard include harvesting of timber from natural forests, capture fishing from wild fish stocks and hunting and trapping of wild animals (including bush meat). The measurement of the ecosystem service should be aligned with the gross quantity of biomass that is harvested, that is, the gross natural resource input, following the SEEA Central Framework (sect. 3.2.2). This will be different from the total stock of biomass available for harvest and different from the biomass that is used in a subsequent production or consumption process. For example, felling residues and discarded catch should be considered part of the ecosystem service flow. This treatment applies irrespective of (a) the length of time over which the biomass has been growing; and (b) the nature of the product (e.g. the gross biomass harvested, which includes honey from wild bees). Thus, the focus is solely on the quantity of the biomass that is harvested or accessed since this reflects the total use (or input) of the ecosystem's resources. The services associated with the biomass from natural production processes are recorded during the accounting period in which it is harvested or accessed.

6.85 In cultivated production processes, joint production is considered to occur when the role of the ecosystem in supplying the biomass intersects with the activity (and associated human inputs, e.g. labour and produced assets) of people and economic units. The activities of economic units in this joint production process can be separated into those involving growth of the biomass (e.g. application of fertilizers and pesticides) and those involving harvest of the biomass. The contribution of the ecosystem occurs up to the point of harvest.

6.86 There is a very wide range of cultivated production contexts. Thus, the extent of human activity in the management of biomass growth can be very high (e.g. for hydroponically grown strawberries) or very low (e.g. for lightly managed native forests). Depending on the type of biomass and the related product, the timing and context of the growth and harvest can vary significantly. Further, within each production context there is a wide variety of management practices, and there may be more than one benefit that is generated. For example, the general activity of corn production may produce food as well as biomass for the production of energy, and cattle production can supply food as well as hides for leather and bones for fertilizer.

6.87 Although there is a diversity of cultivated production contexts, the conceptual intent for ecosystem accounting remains consistent, that is, measuring the ecosystem contribution, while accepting that in different production contexts the relative contribution of ecosystems will vary. The measurement of the ecosystem contribution in different contexts can be considered in two distinct ways. One approach uses the biomass harvested as the measurement focus for identifying the overall ecosystem contribution and the other focuses on the various types of ecosystem contributions such as those involving nutrients, water, soil retention or pollination, which will be used in different combinations in different contexts.

6.88 Under the first measurement approach, particularly when cultivated production is of high intensity, there may be a significant difference between the ecosystem contribution and the gross biomass harvested (Cerilli and others, 2020). This difference may increase, owing to, for example, additional fertilizer, enhanced seed varieties or intensified management even while the extent of the ecosystem asset under use decreases (e.g. through conversion to settlements). Biotic elements that contribute positively to biomass growth (e.g. humus content) may also deteriorate. Compilers are thus encouraged to estimate the ecosystem contribution to cultivated biomass production processes especially where these might be changing over time.[73]

6.89 In practice, there is a considerable measurement challenge in either identifying all of the relevant individual ecosystem inputs or accurately measuring the ecosystem contribution to the gross biomass that is harvested in a way that reflects the diversity of cultivated production contexts and covers all types of biomass. Consequently, where the relative contribution cannot be estimated, the gross biomass harvested may be used as an adequate proxy measure for the flow of biomass provisioning services in cultivated production contexts, irrespective of the extent of human inputs and the intensity of management.

6.90 Whether the ecosystem contribution is measured directly or not, it is recommended that additional information be provided on the cultivated production contexts, including, for example, data on the gross biomass harvested in intensive and extensive production contexts or through organic farming. Further, measurement by biomass type and by relevant ecosystem characteristic (e.g. soil type, climatic zone) and data on variables such as soil fertility, soil-water availability and fertilizer use are likely to assist in facilitating a better understanding of the relative ecosystem contribution. Such information may also be used to support estimation of the ecosystem contribution, for example, by comparing yield levels in intensive, extensive and organic farming systems.

6.91 Under the second measurement approach, each relevant ecosystem service is measured directly, with the intent to provide sufficient coverage of specific services so that the overall ecosystem contribution to the production of biomass is reflected appropriately. It is to be noted that these specific ecosystem services, such as pollina-

[73] Methods have been developed for this purpose, including the use of input-output data sets and agronomic and agricultural production functions and energy/energy-based approaches. An example can be found in Vallecillo and others (2019a), chapter 3, where an energy-based ratio is applied to assess ecosystem contribution and separate it from human input.

tion, may also be recorded under the first measurement approach, but they are shown as intermediate services.

6.92 In line with SNA time of recording treatments, ecosystem services in cultivated production contexts are recorded progressively over the life of the biomass. Thus, services associated with production of timber from plantation forests should be recorded progressively as the timber resources grow in line with the recording of the growth of this resource in the national accounts as a work in progress. Where multiple types of biomass are harvested from a single ecosystem asset over the course of an accounting period (e.g. through cultivation of summer and winter crops), all biomass harvested should be attributed to the same ecosystem asset.

6.93 The measurement of both the ecosystem contribution and the gross harvested biomass requires a clear measurement target. A different measurement target is used for plants and livestock. For cultivated plants, the ecosystem services are measured in relation to the quantity harvested, for example, quantities of corn, timber or apples. This flow is recorded as supplied by the relevant ecosystem and used by the economic unit managing the cultivation (e.g. the farmer).[74]

6.94 For cultivated livestock, the measurement target is the extent of the connection between the livestock and relevant ecosystem assets, primarily natural and cultivated pastures. Depending on the cultivation context, there may be some disconnect between ecosystems and the production of livestock and livestock products. Therefore, where the livestock production process does not involve a direct connection with an ecosystem (as occurs, for example, in some forms of intensive chicken, cattle and pig rearing), no ecosystem services should be recorded. In these cases, the associated ecosystem services are limited to the ecosystem contribution to the production of feed and supplements (e.g. hay, soybean meal, pellets), which would be recorded as crop provisioning services.

6.95 To ensure a focus on the ecosystem contribution, it is recommended that the grazed biomass provisioning services be measured as the primary ecosystem contribution. Other ecosystem contributions such as water supply and local climate regulation (through, for example, provision of shade by trees and protection of livestock from wind) may also be incorporated. These various contributions are recorded as final ecosystem services, and no distinct livestock provisioning services should be recorded. It is also possible to measure livestock provisioning services reflecting the weight gain in livestock or the production of products such as milk and eggs. However, in these cases it is essential to estimate an ecosystem contribution since there rearing livestock may involve very little direct connection with ecosystems, especially in intensive farming systems as noted above.

6.96 The treatment of livestock applies by extension to other animals (mainly fish) raised in aquaculture facilities (both marine and freshwater) whose cultivation involves the provision of feed inputs, including fish meal. Thus, the gross biomass harvested from aquaculture should not be used as a proxy for the ecosystem contribution. An exception arises where no feed or other inputs are provided (e.g. in the farming of oysters). In these cases, the ecosystem service can be appropriately measured using the gross biomass harvested. Where aquaculture is undertaken without a direct connection to a surrounding ecosystem asset, no ecosystem services should be recorded.

6.97 To complete the description of the treatment of biomass provisioning services, the following four other commonly considered issues are noted:

- **Links to cultural services.** There are many instances in which the harvesting of biomass occurs in a recreational or cultural context. For example, people catch wild animals, especially fish, as part of their rec-

[74] The subsequent sale of harvested outputs by the economic unit along the supply chain is recorded in the standard SNA production accounts. Double counting is avoided by ensuring that there are entries for both the supply and the use of the ecosystem service. The net effect with respect to the farmer's value added is thereby left unchanged, but the contribution of the ecosystem is recognized.

reational activities, and there may be traditional harvests undertaken by indigenous groups. If the harvest is retained for subsequent consumption, then the quantity of the associated biomass should be included as part of biomass provisioning services. At the same time, there would be a connection to the measurement of cultural services. In these instances, flows of cultural services should be recorded in addition to biomass provisioning services.

- **Services related to wild fish provisioning services.** For cultivated biomass provisioning services, it should be straightforward conceptually to attribute the service to a specific ecosystem asset since there will be a distinct location where the biomass is grown and harvested. For uncultivated biomass provisioning, this may be more challenging, especially for fish biomass. In concept, for wild fish biomass, the relevant supply location is the place at which the interaction with the ecosystem occurs, that is, the place where the catch occurs. However, it is well recognized that there may be multiple ecosystems that are important for the growth of wild fish. To convey their relative importance, intermediate services can be recorded reflecting the connections between ecosystem assets. This would include, for example, recording nursery services from seagrass meadows for certain species. The extent to which this measurement is possible would depend on the data available and levels of ecological knowledge.

- **Trade in biomass products.** Given the extent of international trade in agricultural, forestry and fisheries products, there is commonly a large spatial disconnect between the location of harvest (where the ecosystem service is recorded as having been provided), the location of subsequent processing and manufacturing and the location of final household consumption. As further explained in chapter 7, following accounting principles, the location of harvest is recorded as the location of both the supply and the use of ecosystem services. Thus, there is no international trade in biomass provisioning services to be recorded. It is possible using input-output techniques to trace the flow of associated or derivative products within the international economy, for example, to derive ecosystem service footprints.

- **Losses in biomass production.** A feature common in the harvesting of biomass is that not all of the harvested biomass is retained and used in the subsequent production process. The inputs that are not retained are referred to in the SEEA Central Framework as natural resource residuals and include felling residues, discarded catch and harvest losses. In the SNA, the focus is on the output ultimately sold by the producer and therefore, in physical terms, the measure of output will be net of these losses. In the Central Framework (sect. 3.3.2), compilers are encouraged to record the flows in gross terms, since this reflects the actual flow of inputs from the environment. For ecosystem accounting, it is recommended that the principles of the Central Framework be applied so that the quantity of biomass provisioning services will be equal to the harvest in gross terms, that is, before harvest losses, felling residues and discarded catch are deducted. Even though, in terms of progression through the supply chain, there is no final use of residuals by economic units, they do represent contributions from the ecosystem to the production process.

6.4.2 Treatment of water supply

6.98 Treatment of the abstraction of water by economic units, including households, for use in production processes (e.g. irrigation, cooling) or for consumption lies on the ecosystem services measurement boundary. There is no doubt that flows of water are highly relevant in both ecological and economic contexts, with the volume of water supply being determined largely by hydrological cycles. At the same time, the availability and quality of water in any given location are directly affected, to varying degrees, by ecosystem structures and processes. Consistent with the general definition of ecosystem services, it is the ecosystem contribution that is the primary focus of measurement in ecosystem accounting.

6.99 In ecological terms, there is a range of factors that contribute to the availability and quality of water. Two primary types of processes are (a) those related to the regulation of base flows of water including precipitation, run-off, infiltration and evapotranspiration, leading to water absorption and release; and (b) those related to the purification of water. These and other relevant ecological processes are likely to involve multiple ecosystem assets of varying types within a catchment context, for example, forests, cropland, wetlands and rivers. These ecological processes can be considered inputs to water supply.

6.100 In compiling ecosystem accounts, there are a number of considerations in best reflecting the relevant ecosystem contribution. First, a distinction should be made between different purposes of water abstraction. In particular, a distinction should be made between abstraction that is less dependent on the quality of the water abstracted, for example, in cases where the water is used for cooling, hydroelectric power generation or desalination, and abstraction in cases where water quality is an important factor, for example, in domestic consumption. Making this distinction allows the relevant ecosystem contributions to be targeted appropriately (e.g. water purification services will not be relevant inputs for non-quality-dependent water abstraction).

6.101 Second, if the purpose of abstracting water from the environment does not require the water to be of suitable quality, the flow of water should be recorded as an abiotic flow, equal to the volume of water abstracted. This would include, for example, the collection of rainwater in tanks.

6.102 Third, if the purpose of abstracting water does require the water to be of suitable quality and hence ecosystem contributions are involved, ideally, these contributions should be measured directly and recorded as final ecosystem services. For example, this may involve recording flows of water purification services and water flow regulation services. Where such direct measurement is possible, the actual flows of water abstracted should be recorded as abiotic flows, equal to the volume of water abstracted.

6.103 Finally, if the direct contributions to water supply cannot be separately recorded, it is appropriate to record the volume of water abstracted as a proxy for the ecosystem contributions. This flow should be recorded as a final ecosystem service. If such a measurement approach is adopted, there should be no entry for abiotic flows related to those volumes of water.

6.104 To support comparability across sets of accounts, irrespective of the measurement approach adopted, all flows of abstracted water should be recorded in the ecosystem accounts either as ecosystem services or as abiotic flows. Further, recording of flows of surface water and groundwater abstraction should align with definitions and treatments under the SEEA Central Framework (sect. 3.5: Physical flow accounts for water).

6.105 A significant volume of water is abstracted from groundwater sources from both deep and shallow aquifers. The treatments outlined above also apply to groundwater. Water abstracted from marine ecosystems, for example, for desalination or use as cooling water, should be treated as an abiotic flow, following the treatment outlined above.

6.106 In accordance with the SEEA Central Framework, water used for hydroelectric power generation is treated as abstracted, that is, it is considered to have been removed from the environment and to have entered into the economy, notwithstanding its immediate return and potential to affect water quality. Water abstracted for hydroelectric power generation is commonly treated as an abiotic flow, although in some contexts, surrounding landscapes may provide ecosystem services that support hydroelectric power generation, for example, through sediment retention. In these contexts, the treatment outlined above can be applied.

6.4.3 Measurement of global climate regulation services

6.107 The measurement and analysis of climate change commonly focus on the emission of GHGs as a result of economic and human activity and the associated changes in concentration of those gases in the atmosphere. Ecosystem accounting places a complementary measurement focus on the role of ecosystems in mitigating climate change through their ability primarily to remove carbon from the atmosphere and to store carbon. Global climate regulation services thus reflect ecosystem contributions to reducing concentrations of GHGs in the atmosphere and stabilizing the climate and in turn avoiding damages that arise due to climate change. The measurement approach described here focuses on carbon since this is absorbed from the atmosphere by plants and sequestered in ecosystems. It is recognized that some types of ecosystems can also be a source of GHGs (CO_2, methane (CH_4) and nitrous oxide (N_2O)), which is often, but not necessarily, related to ecosystem degradation.

6.108 The approaches to accounting for the role of ecosystems in global climate regulation described here are based on the comprehensive recording of stocks and changes in stocks of carbon (i.e. a physical carbon stock account). Ideally, this would encompass measurement of the opening and closing stocks of carbon stored in biomass (both above and below ground), in debris and in soil and sediment, across the full range of ecosystem types within an EAA, including marine ecosystems, as appropriate.[75] Changes in the carbon stock reflect the removal of carbon from the atmosphere and the loss of carbon from those stocks for a wide variety of reasons, including timber harvest, reforestation activity, conversion of peatlands to agricultural production, natural decomposition of organic material and effects of wildfires.

6.109 The measurement of global climate regulation services does not require measurement of all stocks and changes in stocks of carbon, as the scope is restricted to biocarbon. For example, data are not required concerning deposits of fossil fuels, emissions of carbon through the consumption of fossil fuel or the accumulation of carbon in the atmosphere. Nonetheless, a complete accounting for all carbon stocks and flows is highly recommended as a means of supporting coherence in measurement and a wider discussion on climate change and associated policy issues. The role of accounting for carbon in supporting the discussion of climate change is further considered in section 13.4 of chapter 13.

6.110 In SEEA EA, two components, carbon retention and carbon sequestration, are considered in the measurement of global climate regulation services. The carbon retention component reflects the ability of ecosystems to accumulate and retain the stock of carbon, that is, ecosystems supply a service through the avoided emission of

[75] This scope is broader than required according to the reporting requirements under the United Nations Framework Convention on Climate Change, which focus on anthropogenic emissions (proxied by assessing the emissions from managed lands). See also the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, available at www.ipcc-nggip.iges.or.jp/public/2006gl/index.html; and the 2019 Refinement to the 2006 Guidelines, available at www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/.

carbon to the atmosphere. Thus, to the extent that the carbon stock held by ecosystems decreases (e.g. owing to ecosystem conversion from forest to cultivated land), the quantity of services provided will decrease. The reverse also holds, that is, increases in stock lead to a rise in carbon retention services over time.

6.111 The carbon retention component of the service is quantified by recording the stock of carbon retained in ecosystems at the beginning of the accounting period (i.e. the opening stock). This is a proxy indicator for the flow of the service, analogous to the quantification of the services supplied by a storage company in terms of the volume of goods stored.

6.112 The total stock of carbon is very large, especially in some ecosystem types such as peatlands. By convention, the measurement scope of the carbon stock for the derivation of the measure of carbon retention is limited to carbon stored above ground and below ground (including seabed), living and dead biomass in all ecosystems and soil organic carbon. In the case of peatlands and relevant organic carbon-rich soils, only the carbon stored to a maximum of two metres below the surface should be included. Inorganic carbon stored in freshwater, marine and subterranean ecosystems is excluded from scope. Within this measurement boundary, for a single ecosystem, the minimum service that can be supplied is zero when the stock of carbon (measured using the scope just described) is zero, that is, no carbon is retained.

6.113 The carbon stored in fossil fuel deposits should not be considered an ecosystem service since these deposits are not part of ecosystem assets. Similarly, the storage of carbon in harvested wood products should not be considered an ecosystem service since this carbon is no longer stored as part of an ecosystem asset but rather within products (e.g. houses, furniture) that are considered part of the economy. Moreover, owing to its short rotation cycle, carbon stored in stocks of cultivated biological resources (e.g. crops, livestock) should not be included in the measurement of carbon retention.

6.114 The carbon sequestration component of the service reflects the ability of ecosystems to remove carbon from the atmosphere. In measuring this component, it is assumed that carbon sequestration concerns only carbon that is expected to be stored for long periods of time. This may involve storage within an ecosystem asset (e.g. a mangrove or wetland) or another form of storage (e.g. in the economy). Carbon that is sequestered but not expected to be stored (e.g. in crops) should be excluded from scope. An appropriate metric is the net ecosystem carbon balance. Where net carbon sequestration is zero or negative, the level of service supplied by an ecosystem is zero. There is a link between the measurement of carbon sequestration (reflecting an increase in the carbon stock) and carbon retention (reflecting the level of the stock). However, since in most cases sequestration in any single year accounts for a small fraction of the stock of carbon retained, carbon sequestration and retention are considered for accounting purposes to be related but distinct contributions to the global climate regulation service.

6.115 In principle, carbon retention and carbon sequestration components should be measured for all ecosystem assets. In practice, it is likely that different ecosystem assets will provide different contexts for measurement. In stable ecosystems, carbon retention is the primary component, while in those ecosystems where there is clear expansion in the stock of carbon, carbon sequestration may be the focus of measurement. Ecosystems whose stock of carbon is at risk of emission – for example, owing to land-use practices (e.g. draining of peatlands, deforestation) or extreme events (e.g. fires) – will be highly relevant. In these cases, there may be little carbon sequestration, and the focus of measurement should be placed on measuring carbon retention.

6.4.4 Identification of cultural services

6.116 There are important connections between people and ecosystems that are not provisioning or regulating in nature. The label "cultural services" is used to encompass many of these "experiential" and non-material connections. The use of this label is a pragmatic choice and reflects its long-standing use in the ecosystem services measurement community. The label is not meant to imply that culture itself is a service; rather it is a summary label and as such is intended to capture the variety of ways in which people connect to and identify with nature and the variety of motivations for these connections.

6.117 Two key considerations are associated with the identification of cultural services for ecosystem accounting purposes. First, it is necessary to determine the relevant set of benefits since these services can be defined only from a user perspective. Second, flows of cultural services, representing an ecosystem's contribution to the benefits, reflect the characteristics and qualities of ecosystems. For many cultural services, recognition of the richness and functionality of the space provided by ecosystems, for example, to support recreation, is fundamental.

6.118 For ecosystem accounting, the cultural benefits to which cultural ecosystem services contribute comprise (a) benefits derived from undertaking activity (including recreation) within ecosystems (i.e. in situ) and (b) benefits derived from having a cultural, spiritual, artistic or similar relational connection to an ecosystem or the biodiversity it contains. The first type of cultural benefits, in which people experience nature directly, is considered to encompass a contribution from the ecosystem, with the understanding that there must also be human inputs of time and potentially of resources (e.g. equipment, travel). Both types of benefits will encompass associated benefits to people's physical and mental health.

6.119 The second type of cultural benefits arises from a wide variety of motivations and may reflect both use and non-use values. This type of benefits, which, as mentioned, includes cultural and spiritual connections, may commonly be a focus of economic transactions, such as donations to non-profit groups that are motivated to protect and conserve ecosystems.

6.120 For accounting purposes, cultural benefits arising from the remote experience of ecosystems, including via various media (e.g. television, music, photos), are excluded from scope. Remaining within scope are a more limited set of benefits and associated services used by those who directly experience the characteristics and qualities of ecosystems (e.g. artists, movie producers) and who, in some instances, may be required to pay for access or similar rights to secure the benefits that are enjoyed by others remotely.

6.121 Given this scope of cultural benefits, cultural services are defined as the perceived or realized qualities of ecosystems whose existence and functioning enable the derivation of a range of cultural benefits. Under this definition, cultural ecosystem services (a) reflect the ecosystem contribution in terms of providing places and opportunities for activity by people; (b) are linked to flows from ecosystems to people that may be considered experiential; and (c) are able to contribute to multiple benefits, that is, one ecosystem and its characteristics or qualities can contribute to different cultural benefits and can be linked to a variety of motivations of different users.

6.122 Based on this definition of cultural services, four types of cultural services are included in the reference list presented in table 6.3 above, namely, recreation-related services; visual amenity services; education, scientific and research services; and spiritual, artistic and symbolic services. A separate class, ecosystem and species appreciation, has also been included in the reference list to allow for recording of data on non-use values (see sect. 6.3.4). A description of these services is shown in table 6.3. In recording these services, there should be consideration of the potential connections among them, given that a single interaction (e.g. a visit to a park) could potentially be recorded as reflecting a range of different services. In such cases, attribution should be based on the primary purpose or motivation of the interaction.

6.123 Cultural ecosystem services contribute to processes involving different combinations of ecosystem assets, produced assets (e.g. access roads, on-site facilities, walking trails, residential location) and human capital (including people's time, experience, knowledge, and physical and perceptive capabilities). Generally, human inputs encompass inputs required to use or access cultural benefits, but some human inputs (e.g. activities to restore or maintain ecosystem condition) are related to the supply of cultural benefits.

6.124 People undertake a range of activities in the environment for a range of purposes. Generally, the focus of cultural services is on activities whose purpose is recreational or personal. However, those people working outdoors – such as farmers, tour guides, landscapers and others who have a relatively direct connection with the environment through their jobs – likely derive some benefit from being outdoors that is similar to the benefit derived from a recreation-related service. The potential ecosystem contributions to these benefits are not recorded explicitly in the ecosystem accounts but where they arise (which is not the case in all outdoor labouring contexts), estimates should be included in measures of visual amenity services.

6.125 Where payments are made by people to economic units that manage ecosystems (e.g. managers of national parks) for access to ecosystems or where payments are made to economic units that support activities in ecosystems (e.g. canoe rental businesses), connections can be made to entries in the standard national accounts.

6.4.5 Treatment of abiotic and other environmental flows

6.126 As introduced in section 6.2.5, there is a range of flows between the environment and the economy that may require discussion of whether there is a material ecosystem contribution that should be recorded as an ecosystem service. In general terms, if there is a clear contribution of ecological characteristics and processes, then the flow can be treated as an ecosystem service. However, if there is no such distinct role, the flow is treated as an abiotic flow. In many cases, this distinction is clear-cut, but there are also a range of boundary cases. As indicated in section 6.2.5, there are a number of types of abiotic and other environmental flows, and it is useful to consider those various boundary cases.

6.127 The treatments described in the present section are intended to provide guidance to compilers on the appropriate treatment for supporting comparability of accounts. It is not possible, however, to envision all possible contexts. Thus, in principle, compilers should return to the definition of ecosystem services (see para. 6.9) and ensure that the focus of measurement is on the ecosystem contribution to benefits. Further, the focus in identifying ecosystem services should be on the nature of ecological characteristics and processes rather than on whether the ecosystem is more or less dominated by biotic or abiotic components (for example, in this regard, it is recognized that deserts, with comparably little biota, and rainforests, with much biota, are both ecosystem types). Since, by definition, ecosystems are a combination of both biotic and abiotic components and involve interactions across various scales, this variation in ecosystem types should not be a key factor in determining whether an ecosystem service is supplied and used.

6.128 Compilers are encouraged to record abiotic and other environmental flows where relevant to the analysis of ecosystem use since commonly there are trade-offs between ecosystem services and those flows. This is particularly the case for geophysical services, including flows of water, wind and solar energy. In recording flows in biophysical terms, there is no defined aggregate of ecosystem services, and consequently the inclusion of additional entries concerning abiotic flows in relevant tables does not impact on recorded aggregates. However, where monetary valuation is undertaken (following the advice in chaps. 8–10), abiotic flows should not be included in the measurement of the value of ecosystem assets. The value of abiotic and other environmental flows may commonly be measured using observed market prices and the NPV of these flows can be recorded alongside the value of ecosystem assets in the extended balance sheet described in chapter 11.

6.129 **Flows related to abiotic components of ecosystems in the supply of regulating and maintenance services.** Since ecosystems are a combination of biotic and abiotic components, the following are treated as ecosystem services, notwithstanding that abiotic components may have a dominant role in some ecosystem types:

- Air filtration services (capture of air pollutants by abiotic components, such as bare and rocky surfaces): here pollutants are absorbed but not by active biotic components
- Coastal protection services provided by unvegetated shingles or sand dunes: here the predominant role of abiotic components within the landscape structure in providing those services is recognized
- Water purification and regulation services from bare but unsealed soil: here water permeating the soil may be improved in quality through water purification services and may also provide a more continuous supply of water to groundwater sources

6.130 **Flows related to the generation of energy.** Flows of energy from non-renewable sources, such as fossil fuels and uranium, are considered to be abiotic flows from geological resources. Where peat is used as an energy source, its extraction should be recorded as an abiotic flow.[76]

[76] It is to be noted that peatlands also supply other ecosystem services, such as global climate regulation and water purification services.

6.131 Three types of flows of energy from renewable sources can be distinguished:

- Energy from biomass, including roundwood and brushwood, maize used for ethanol and so on. Here the flow involves an ecosystem contribution that should be captured as part of estimation of the flow of biomass provisioning services.
- Energy from sources such as wind, solar, geothermal and tidal energy. Here the flows involve geophysical processes and hence are considered abiotic flows from geophysical sources.
- Energy from hydroelectric power generation. For ecosystem accounting, it is considered that the source of the energy is related most substantially to landscape structure and geomorphology (e.g. the fall in a river). Thus, while ecosystem services supplied by the surrounding landscape, such as water regulation of base flows and soil erosion control, are important final ecosystem services, which are to be recorded, the generation of hydroelectric power itself is considered an abiotic flow from geophysical sources.

6.132 **Flows related to residuals from economic activity.** There is a range of residuals that are released through or generated by economic activity, including emissions to air, soil and water and solid waste. In many cases, ecosystems act as sinks or receivers of these residuals. The following three cases are considered:

(a) The case where residuals are actively remediated, broken down or otherwise processed through ecological processes, for example, through air filtration and water purification. In this case, an ecosystem service is measured equivalent to the quantity of residual that is remediated up to the ecological limit or threshold for the given ecosystem asset;

(b) The case where residuals are stored in specific areas, for example, in landfill or mining overburden. This is considered a case where the ecosystem's location is used as a sink service and is treated as a spatial function of the environment; and no ecosystem service or abiotic flow should be recorded;

(c) The case where residuals are passed through an ecosystem, for example, where contaminants from effluent flow into freshwater ecosystems and are subsequently deposited within the sediment or passed on to the marine environment, including in cases where the quantity of residuals released exceeds the ecological limit of the ecosystem's ability to mediate or process them. In this case, the storage of pollutants is not considered to reflect an ecosystem contribution, but it may be considered a sink service. As in the case of (b), no ecosystem service or abiotic flow should be recorded unless some remediation occurs (as in the case of (a)).

6.133 In case (c), increasing concentrations of some residuals are a significant factor in the decline in condition of ecosystems (e.g. excess nitrogen leads to the eutrophication of lakes and bays). These declines in condition should be recorded in the condition account and may be reflected in decreases in future flows of ecosystem services supplied by the affected ecosystems. However, the presence of residuals in an ecosystem is not, of itself, considered to imply the supply of an ecosystem service.

6.134 In the context of case (a) above, the ability of ecosystems to remediate, dilute and store pollutants (e.g. releases of nitrogen) may be regarded as providing a benefit to the polluter since they do not need to capture and store the residuals themselves or otherwise change their practices. Consistent with the guidance above, only the remediation role performed by an ecosystem asset is recorded as an ecosystem service for ecosystem accounting purposes. Benefits to the polluter that arise from the dilution or storage of pollutants are considered spatial functions of ecosystems. These flows may be recorded separately.

6.135 The use of the relevant ecosystem services (e.g. water purification) and any spatial functions (e.g. storage of pollutants) may be assigned to the polluter where there is a direct economic benefit to the polluter from that use of the ecosystem (generally a reduction in operating costs). However, in line with the treatments in the three cases outlined above, since the total quantity of the residuals released may exceed the ecosystem's ability to remediate them, only a portion of the direct economic benefit should be treated as an ecosystem service. Where the use of ecosystem services is recorded in this way, it is also possible to assign the use of the relevant ecosystem services (e.g. water purification) to other economic units that subsequently use the ecosystem and hence benefit from cleaner water, air and soil (e.g. water supply companies).

6.136 Flows related to the use of the environment for undertaking economic and other activities: spatial functions. These flows are related primarily to the fact that all activities take place in a location. Flows related to the use of the environment for those activities are treated as spatial functions within the broader framing of abiotic flows. While ecosystems are by definition present in those locations, there are no ecological processes providing a contribution to those activities that should be recorded as ecosystem services. This implies that the benefits derived from land in supporting buildings, houses, roads, railways and other structures and the associated values related to location are not considered to incorporate ecosystem services. Further, there is no abstraction or extraction from the ecosystem that would require recording abiotic flows. Navigation on rivers, where the flow of water supports transportation of people and goods, presents a unique case. In this case, there may be a contribution of ecosystem processes, primarily with respect to water flow regulation, which should be recorded as a final ecosystem service.

6.137 In many cases, there is a significant monetary value associated with these uses of the environment, including the value of land under houses. This value should be included in the value of land in the extended balance sheet described in chapter 11.

6.5 Ecosystem capacity

6.5.1 Introduction

6.138 General interest in the concept of ecosystem capacity stems from interest in understanding issues involving the balance of supply and use of ecosystem services. These issues include the extent to which the current pattern of use of an ecosystem is beyond current limits of regeneration and absorption, thereby affecting the well-being of current generations; the extent to which the actual or potential use of ecosystem services reflects the condition of the ecosystem asset; and the relative effects of alternative ecosystem management arrangements on the supply and use of ecosystem services.

6.139 Generally, the underlying concern is related to the potential loss of the quantity and quality of ecosystem assets and the subsequent impacts on the current and future flows of ecosystem services. In some cases, the focus is on local limits with respect to regeneration and overuse; in other cases, the limits concern tipping points, involving substantive changes in ecosystem type or breaches of other, broader systemic limits.

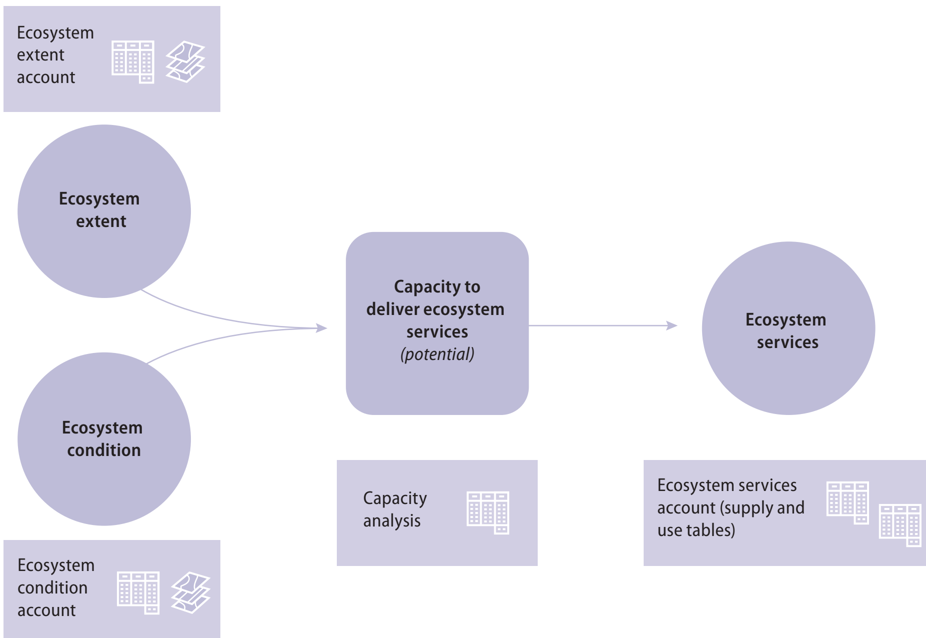
6.140 In an accounting context, the concept of ecosystem capacity has been envisaged most commonly as embodying a link between measures of ecosystem asset extent and condition, on the one hand, and measures of ecosystem services supply and use, on the other. Figure 6.1 highlights the nature of the general relationship that is the focus of ecosystem capacity in SEEA EA. It is to be noted that the accounts themselves, in particular the SUTs, do not require estimates of ecosystem capacity for their compilation, but assessment of capacity can directly support the interpretation and application of accounting entries. Indeed, accounting provides a relatively natural measurement platform for considering the inherent systemic linkages between the current and future patterns of supply and use of ecosystem services and the current and future state of ecosystem assets. The present section summarizes the relevant considerations.

6.5.2 Defining ecosystem capacity for accounting purposes

6.141 In the context of SEEA EA, ***ecosystem capacity is the ability of an ecosystem to generate an ecosystem service under current ecosystem condition, management and uses, at the highest yield or use level that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem.***

6.142 This definition reflects a variety of contributions to the discussion on ecosystem capacity in an ecosystem accounting framework, including, for example, the work of Hein and others (2016) and La Notte and others (2019). Given the variety of perspectives on ecosystem capacity, consideration of the following points is required to facilitate an appropriate interpretation of the definition's intention and meaning. The need for further research and discussion is also recognized, as attested by the fact that ecosystem capacity constitutes a specific topic in the SEEA EA research and development agenda (annex II).

Figure 6.1
Relationships between capacity to deliver ecosystem services and the ecosystem accounts



Source: Adapted from Maes and others (2018), figure 2.2.

6.143 First, while it is relatively common for the concept of ecosystem capacity to be framed in a way that speaks to the ability of an ecosystem asset to generate a bundle of ecosystem services, the focus of the definition here is on the capacity of an ecosystem asset to supply a single ecosystem service. In concept, considering a bundle of services would be ideal and would be linked directly to a range of material in the literature on ecosystems and biodiversity concerning, for example, maintenance of ecosystem functions (Mori and others, 2013) and option and insurance values of ecosystem assets (see the discussion in sect. 6.3.3 on the links between ecosystem services and biodiversity).

6.144 Further, a systemic approach to ecosystem capacity can be related to a discussion on the ecosystem characteristics and processes that underpin flows of ecosystem services and to the related conception that an ecosystem needs to supply services to itself in order to support its functioning. In SEEA EA, intermediate services are recorded only when they can be linked to final ecosystem services and should not be recorded solely in the context of maintaining ecosystem function. There may be interest in the recording of various physical flows within and between ecosystems that reflect ecosystem processes, but this is not a feature of ecosystem accounting per se (except when those flows relate to flows of ecosystem services or support the measurement of ecosystem condition).

6.145 Although using a broader and more systemic measurement approach to ecosystem capacity would be ideal, individual ecosystem services are more measurable; and while a focus on individual ecosystem services is more limited, it can be of direct relevance in decision-making, for example, in setting policy and management targets.

6.146 While the focus in the above definition is on a single ecosystem service, the measurement of capacity requires consideration of the management of the ecosystem asset as a whole since, for an individual ecosystem, the capacities for each service within a bundle are connected. Generally, the concept of ecosystem capacity is most relevant for services that can be overused (e.g. provisioning services). With respect to services for which there is no equivalent concept of overuse (e.g. flood control or global climate regulation) and no sustainability threshold, capacity needs to be considered differently. La Notte and others (2019) discuss these differences related to the concept of ecosystem capacity by type of service.

6.147 Second, this definition can be applied using two main approaches. One approach is underpinned by the assumption that the current ecosystem asset context will not change into the future. This implies that no consideration is to be given to the potential effects of external drivers (e.g. population growth or climate change) on the ecological limits of an ecosystem with respect to a specific service or on the use of that service. This measurement approach is likely to be more viable, at least in the short term.

6.148 In an alternative approach, assumptions are made concerning future changes in the ecosystem asset itself and/or in the expected patterns of ecosystem service use. Also relevant here are assumptions regarding expected interactions (trade-offs and/or synergies) within the ecosystem in the supply of different ecosystem services (e.g. between timber provisioning services and air filtration services). Making different assumptions regarding future changes and interactions will alter the measures of the appropriate ecological limits and consequently affect the measurement of capacity. Ideally, these types of considerations would be applicable in the monetary valuation of ecosystem assets using an NPV formulation as described in chapter 10.

6.149 The following observations are also relevant to the application of this definition:

- In physical terms, the measure of capacity for generation of an individual ecosystem service should be expressed in the same quantification or measurement units as those used for the actual flow of the ecosystem service. Thus, capacity would most commonly be expressed in units of rate per year. When considering measures over multiple ecosystem assets (e.g. for a single ecosystem type), it may also be relevant to present measures in terms of rates per spatial unit (e.g. hectares, volumes), with the understanding that those rates will not be constant across an ecosystem asset or ecosystem type.
- Under the first approach, it would be appropriate to take longer-term cycles of management or disturbance into account, for example, the long management cycles (40–100 years) of rotational harvesting of timber. Longer-term effects of patterns of disturbance, such as fire and flood, and ecosystems' adaptation to those disturbances are also relevant considerations. Under the second approach, expectations regarding potential changes in longer-term cycles would be taken into consideration.
- If the ecosystem service is used at current capacity and there is no use beyond the appropriate limit, the condition of the ecosystem asset should remain stable compared with its current level, all else being equal. Since relevant limits can change over time (e.g. owing to climate change), measures of capacity should be regularly reassessed.
- In monetary terms, capacity can be related to the NPV of ecosystem service flows at their sustainability thresholds, that is, by using the sustainable ecosystem service flow, as determined by relevant regeneration and absorption

rates. These capacity-based values can be compared with the NPV of ecosystem services based on the actual expected flows. An example illustrating the differences between sustainable and actual flows and their implications is provided in La Notte and others (2017).

6.150 In applying the above definition, no measure of capacity is recorded for ecosystem services that might potentially be supplied but are not within the current bundle of ecosystem services from an ecosystem asset. However, the same framework may be applied to estimate an ecosystem's *potential supply*, which concerns the ecosystem's ability to generate an ecosystem service, without the constraint of considering current patterns of use but while still requiring that the condition of the ecosystem be unaffected. Another variant, following Hein and (2016), is *ecosystem capability*, which concerns an ecosystem's ability to generate an ecosystem service under current conditions and type of use but irrespective of the potential impacts of increasing the supply of that service on the supply of other ecosystem services. Data from the ecosystem accounts would likely be relevant in the derivation of these complementary measures, but it is to be noted that different assumptions would be required.[77]

[77] Additional sources addressing this topic include Burkhard and others (2014) and Villamagna, Angermeier and Bennett (2013).

6.151 In terms of general interpretation, because of the link between measures of capacity and potential supply and the maintenance of ecosystem condition, a comparison can be made between the actual flow of an ecosystem service recorded in the ecosystem accounts and the flow of that service at its capacity or threshold level, which can be regarded as a sustainable flow. Measures of ecosystem capability may not warrant such a conclusion, that is, a flow related to ecosystem capability may not be sustainable.

6.152 While there is an apparent logical connection between increases in ecosystem condition and increases in capacity, this may not apply for all ecosystem services. For example, in the case primarily of provisioning services, capacity may be higher at levels of condition that are somewhat below the reference condition level. Thus, the general observation that higher levels of condition are associated with higher measures of capacity does not hold in all circumstances. Further, the precise nature of the relationship between falls in condition and falls in capacity may be unclear, at least in the short term.

6.5.3 Defining ecosystem capacity with respect to specific types of ecosystem services

6.153 The description and measurement of ecosystem capacity vary across different types of ecosystem services (La Notte and others, 2019). For provisioning services, capacity is related to the rates of regeneration that are possible under current conditions.

6.154 For regulating and maintenance services, the underlying ecological assumption is that there are limits or thresholds related to the supply of those services. These limits may manifest themselves in various ways. For services where there is remediation of pollutants, such as water purification, the limit is related to the quantity of pollutant that can be remediated and processed. In this case, ecosystem capacity reflects that limit. For services that may be described as providing "buffers", such as water flow regulation and flood control services, there are associated maximum rates of infiltration and related ecological boundaries that may be used to determine ecosystem capacity.

6.155 For cultural services, the issue of capacity arises only in the context of in situ use of the ecosystem. In those cases, capacity measures are related to the maximum number of persons able to visit or enjoy a particular site without causing a loss of ecosystem condition.

6.156 In practice, it may not be necessary to measure ecosystem capacity for all ecosystem services. An initial focus could be on those ecosystem services whose overuse is most likely to have negative effects on ecosystem condition. This might be appropriate from a risk management perspective, providing a sure basis for pri`oritization of ecosystem services with respect to measurement.

6.157 Further, as regards the issue of measurement focus, the concept of ecosystem capacity will be less relevant in cases where there is no – or very limited – use of an ecosystem service (e.g. use of air filtration services by forests in northern Canada). Measurement of ecosystem capacity in these contexts may suggest a level of available capacity that is not consistent with current and expected patterns of use.

6.158 In this context, it is to be noted that the reference in the above definition to current management and uses implies that the measurement of capacity must take into account restrictions on access to or use of ecosystems. For example, if a forest has been designated as a protected area and logging is therefore not possible, then the capacity to supply biomass provisioning services would be zero. Similarly, a beach to which no recreational access is allowed has zero capacity to supply recreation-related services.

6.159 It is expected that through the development of ecosystem accounting generally and the compilation of the various ecosystem accounts, significant further advances can be made in accounting for ecosystem capacity. These include both measurement advances, such as determining best practices in setting thresholds for individual services and moving beyond individual ecosystem services to consider bundles of services from an ecosystem, and conceptual developments, such as the integration of the concept of ecosystem capacity into the definition of ecosystem enhancement and degradation.

Appendix A6.1
Initial logic chains for selected ecosystem services

Ecosystem service	Common ecosystem types	Factors determining supply: Ecological	Factors determining supply: Societal	Factors determining use	Potential physical metrics for the ecosystem services	Benefits	Main users and beneficiaries
Crop provisioning services	Cropland	Soil fertility, especially chemical state (e.g. soil organic carbon, nutrients); climate; water supply; pollination; genetics	Farm management at different stages of production process; harvesting practices; air pollution affecting soil quality	Demand for biomass (e.g. for food)	Gross tons of cultivated plants (e.g. wheat (proxy measure))	Crop products (e.g. harvested wheat (SNA benefit))	Agricultural producers, including household and subsistence production
Grazed biomass provisioning services	Pastures	Soil fertility; climate; water supply; genetics	Farm management at different stages of production process	Demand for biomass (e.g. as food for livestock); farming practices	Gross tons of grazed biomass	Livestock and livestock products (e.g. meat, milk, eggs, wool (SNA benefits))	Agricultural producers, including household and subsistence production; households
Wood provisioning services	Forests, woodland	Soil fertility; climate; water supply; timber stock biomass and composition; genetics	Forest management and harvesting practices	Demand for timber	Gross tons of wood (timber) biomass harvested	Harvested timber (SNA benefit)	Forestry producers, including households
Wild fish and other natural aquatic biomass provisioning services	Mainly marine, freshwater	Stock biomass and composition, especially structural state (e.g. trophic composition number, ratio between fishing mortality and fishing at maximum sustainable yield); chemical state (e.g. temperature, pH, eutrophication, salinity)	Stock management practices; harvesting practice	Demand for aquatic biomass	Gross tons of aquatic products harvested	Harvested aquatic products (SNA benefit)	Fishing industry, including direct household consumption; recreational fishing
Wild animals, plants and other biomass provisioning services (excludes aquatic and wood products)	Many ecosystem types	Ecosystem extent and condition; biomass stock; climate	Ecosystem management	Demand for "natural" products	Tons of biomass harvested	Harvested products (SNA or non-SNA benefit)	Households, businesses
Water supply	Freshwater, marine, groundwater ecosystems	Quantity and quality of water stocks	Catchment management practices	Demand for water by type of quality	Cubic metres of water, by type of quality	Consumptive use by the economy and society (SNA benefit)	Water supply utilities, direct household consumption; other users of water (e.g. farmers)

(Continued)

Ecosystem service	Common ecosystem types	Factors determining supply		Factors determining use	Potential physical metrics for the ecosystem services	Benefits	Main users and beneficiaries
		Ecological	Societal				
Global climate regulation services	Primarily forest, woodland and shrubland ecosystems; also grasslands and cropland, wetlands, marine ecosystems	Ecosystem type and condition, especially structural state (e.g. tree cover density and forest age); atmospheric carbon concentrations	Ecosystem management; GHG emissions	Vulnerability to climate change (exposure, sensitivity and adaptive capacity)	Tons of carbon and other GHGs retained (sequestered and stored)	Reduced concentrations of GHGs in the atmosphere leading to less climate change and fewer adverse effects (non-SNA benefit)	Collectively consumed by government on behalf of society (individuals, households and businesses globally)
Local (micro and meso) climate regulation services	Mainly urban ecosystems (for people); pastures (for livestock)	Ambient atmospheric conditions; type and quantity of vegetation; presence of water bodies	Ecosystem management; urban planning practices	Location of people and animals in relation to vegetation and blue spaces	Number of households with air temperature reduced by more than 5°C on hot days	Improved living conditions and economic production (non-SNA benefit)	Households; businesses
Air filtration services	Mainly forest and woodland	Type and condition of vegetation, especially functional state (e.g. leaf area index) and chemical state (e.g. ambient pollutant concentration)	Ecosystem management; location type and volume of released air pollutants	Behavioural responses; and location and number of people and buildings affected by pollution	Tons of pollutants absorbed by type of pollutant (e.g. PM10[a]; PM2.5[b])	Reduced concentrations of air pollutants providing improved health outcomes and reduced damage to buildings (non-SNA benefit)	Households; businesses (through reduced damage to buildings)
Soil and sediment retention services • **Soil erosion control services** • **Landslide mitigation services**	Many ecosystem types	Topology; geology and soil type; type and condition of vegetation, especially structural state (e.g. vegetated riverbanks); rainfall patterns	Ecosystem management	Demand for agricultural and wood biomass; location of managed water bodies at risk from sedimentation; location of people and buildings at risk from landslides	Tons of soil retained; number of properties with reduced risk of landslide	Soil stability: reduced sedimentation downstream (non-SNA benefit); reduced risk of landslide (non-SNA benefit)	Households and businesses
Solid waste remediation	Many ecosystem types, mainly cropland	Condition of soils, especially as related to microorganisms	Ecosystem management	Type and quantity of solid waste released	Tons of solid waste remediated	Reduced impact of alternative methods of disposal (non-SNA benefit)	Businesses, including household and subsistence production

(*Continued*)

Ecosystem service	Common ecosystem types	Factors determining supply: Ecological	Factors determining supply: Societal	Factors determining use	Potential physical metrics for the ecosystem services	Benefits	Main users and beneficiaries
Water purification services	Many ecosystems, primarily freshwater and marine ecosystems and associated vegetation	Ecosystem type and condition; composition of microorganisms and algae; chemical state (e.g. nitrogen and phosphorus concentrations)	Location type and volume of released water pollutants	Demand for cleaner water for different uses	Tons of pollutants remediated by type of pollutant (nutrients and other pollutants)	Reduced concentrations of water pollutants providing improved health outcomes and/or reduced water treatment costs (non-SNA benefit)	Households and businesses
Water flow regulation services • **Baseline flow maintenance services** • **Peak flow mitigation services**	Terrestrial and freshwater ecosystems within riparian and upstream zones	Extent and condition of vegetation and soils (e.g. water infiltration rate); rainfall patterns	Ecosystem management	Demand for water supply at different times of the year (baseline flow maintenance); extent of existing produced assets and location of properties (peak flow mitigation)	Capacity of reservoirs or alternative forms of storage (cubic metres) otherwise needed to provide same service	Reduced need for other forms of water storage for human use or for flood defence (non-SNA benefit)	Households and businesses
Coastal protection services	Shoreline systems	Extent and condition of vegetation and of other features of coastal margins (e.g. coral reefs, sand banks and dunes); ambient climate factors	Ecosystem management	Extent of existing produced assets (e.g. flood barriers, dykes); location of properties	Number of properties in a lower risk category	Reduced impact or frequency of flood events (non-SNA benefit)	Property owners and residents – households, business, government
River flood mitigation services	Terrestrial and freshwater ecosystems within riparian zones	Extent and condition of riparian vegetation; ambient climate factors	Ecosystem management	Extent of existing produced assets (e.g. flood barriers, dykes); location of properties	Number of people and buildings in a lower risk category	Reduced impact of flood events (non-SNA benefit)	Property owners and residents – households, businesses, government
Pollination services	Many ecosystem types, mainly near cropland areas, but also urban gardens	Abundance and location of wild pollinators	Ecosystem management	Location of crops benefiting from wild pollination	Area of crops pollinated, by type of crop	Reduced need for alternative forms of pollination, including paid pollinator services (SNA benefit)	Cropland ecosystems, ultimately agricultural production including household and subsistence production; households
Nursery population and habitat maintenance services	All ecosystems	Species-level diversity, abundance; condition of ecological communities	Ecosystem management	Demand for biomass, which depends upon nursery and habitat services	Size of biomass stocks dependent upon nursery and habitat services	Continuing supply of ecosystem services (non-SNA benefit)	All ecosystems; ultimately all sectors of society

(Continued)

Ecosystem service	Common ecosystem types	Factors determining supply		Factors determining use	Potential physical metrics for the ecosystem services	Benefits	Main users and beneficiaries
		Ecological	Societal				
Recreation-related services	Many ecosystem types	Extent and condition; presence of iconic landmarks or species; structural state and landscape/seascape characteristics (e.g. percentage of urban green space, distance to open green space)	Ecosystem management including facilities to support access	Accessibility of recreation sites; location of users; demand for outdoor recreation	Number and length (hours) of visits	Physical and mental health; enjoyment (non-SNA benefit)	Households; tourism and outdoor leisure service sectors
Visual amenity services	Many ecosystem types	Landscape setting and condition (e.g. structural state and landscape/seascape characteristics)	Landscape management	Location and design of residential and office buildings; demand for housing in green and blue areas	Number of properties with views of natural landscapes or located near green or blue areas	Higher values of dwellings (SNA benefit); mental health, enjoyment (non-SNA benefit)	Households
Education, scientific and research services	Many ecosystem types	Extent and condition; presence of iconic landmarks or species; structural state and landscape/seascape characteristics	Access to ecological sites of interest	Education policies, research priorities and funding	Number of visits for educational, scientific and research purposes	Intellectual development, advancement of knowledge and understanding (non-SNA benefit)	Educational and research organizations

[a] Particulate matter less than 10 micrometres in diameter.

[b] Particulate matter less than 2.5 micrometres in diameter.

Chapter 7
Accounting for ecosystem services in physical terms

7.1 Introduction

7.1 The aim of accounting for ecosystem services in physical terms is to record, in an accounting structure, the flows of ecosystem services over an accounting period in physical units such as cubic metres or tons. Physical quantification commonly focuses on measurement of ecosystem structures, processes and functions, that is, the supply side of flows of ecosystem services, but quantification of ecosystem contributions can also be carried out through a focus on the use of ecosystem services, for example, the number of visits to a national park. A key focus in accounting for ecosystem services is reconciliation of the supply and use of ecosystem services across multiple ecosystem assets and multiple users.

7.2 Flows of the ecosystem services included in the reference list presented in chapter 6 can be measured in physical, that is, quantitative, terms. Different ecosystem types supply different bundles of ecosystem services to different users. The aim in ecosystem accounting is to provide as comprehensive a coverage of the supply and use of different ecosystem services within an EAA as is practicable. The choice of which ecosystem services to include in a set of ecosystem accounts will depend in part on the data and resources available for the compilation of estimates.

7.3 Ecosystem services flow accounts in physical terms that record the supply and use of ecosystem services may be compiled for a range of reasons and purposes. These include recording and monitoring the different bundles of ecosystem services supplied by different ecosystem types, identifying the users of the services and assessing how these patterns of supply and use are changing over time. This information can underpin analysis of the significance of particular ecosystems as ecosystem service suppliers, support analysis of trade-offs between different ecosystem services as part of spatial planning and land management and provide information to support delineation of areas for specific land uses, including conservation and environmental protection. While some of these applications are appropriate at larger, national scales, in many cases, the use of spatial data on ecosystem services supply and use opens up considerable analytical opportunities at finer scales. Much work on accounting for ecosystem services has been conducted using spatial data and for some services, this is the likely entry point for measurement, particularly of regulating and maintenance services.

7.4 The information on ecosystem services in physical terms can also be used to demonstrate the nature of the connection to the SNA production boundary, which, in turn, can support engagement and discussion of the wider, non-private benefits of ecosystems extending beyond ecosystem contributions to marketed goods and services. Moreover, the data in physical terms can underpin monetary valuation of ecosystem services (see chap. 9).

7.2 Ecosystem services flow accounts in physical terms

7.2.1 Overall structure of ecosystem services flow accounts

7.5 The structure of the ecosystem services flow accounts in physical terms is displayed in tables 7.1a and 7.1b. The structure of these tables follows that of the SUTs described in the SNA and the SEEA Central Framework. In an ecosystem accounting context, ***SUTs are accounting tables structured to record flows of final ecosystem services between economic units and ecosystems and flows of intermediate services among ecosystems.*** Entries can be made in physical and monetary terms.

7.6 The list of ecosystem services provided in tables 7.1a and 7.1b corresponds to the reference list of selected ecosystem services in chapter 6. Conceptually, an SUT in physical terms would contain only entries recorded in the same measurement unit, for example, entries in energy SUTs are recorded in joules and entries in water SUTa in cubic metres. Where this is the case, it is possible to aggregate across the rows of a table. Selected ecosystem services are included in the presentation set out below, and each is recorded using its own measurement units. Consequently, it is not possible to aggregate down the rows in the tables to obtain meaningful aggregates. While individual SUTs for each ecosystem service could be presented, the conceptual considerations concerning the structure of the tables and associated accounting entries would be identical to those discussed here.

7.7 A key principle underpinning the SUT structure is that the supply of ecosystem services must equal the use of those services during an accounting period. This is an application of the supply and use identity (SEEA Central Framework, para. 3.35). Thus, both the supply and the use of air filtration services, for example, should be recorded using the same measurement unit (e.g. tons of PM2.5 absorbed by vegetation).

7.8 The supply table presented in table 7.1a records the flows of different ecosystem services supplied by different ecosystem types. The total supply recorded should include both final ecosystem services and intermediate services. The use table presented in table 7.1b records the use of different ecosystem services by economic units (final ecosystem services) and by other ecosystem assets (intermediate services). For each ecosystem service, the total supply recorded in table 7.1a must equal the total use recorded in table 7.1b. Detailed descriptions of recording principles and specific treatments are provided in the following sections.

7.9 The flows for each ecosystem service are recorded using a measurement unit that is appropriate for that ecosystem service. The column with the heading "Measurement units" would list the measurement unit appropriate for each type of service. Common measurement units include tons, cubic metres and number of visits. In practice, the measurement unit that is applied would depend on the data that are available and the measurement method that is used. There are no prescribed measurement units in SEEA EA but relevant technical guidance is outlined in the *Guidelines on Biophysical Modelling for Ecosystem Accounting* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022a).

7.10 The same units used to measure the supply of the service must be used to measure its use. This applies also where an ecosystem service is supplied by multiple ecosystem types and/or used by multiple economic units. Thus, across a single row (i.e. for a single ecosystem service), the same measurement unit should be applied. This enables a total supply and total use to be estimated for each individual ecosystem service. However, as noted above, since each ecosystem service is measured using a unit appropriate to it, it is not possible to aggregate in order to produce an estimate of the total supply or use of multiple services in physical terms for an ecosystem type or economic unit.

7.11 Each ecosystem service is recorded as being supplied by an ecosystem type. For the purposes of demonstrating the design of a supply table, table 7.1a presents selected ecosystem types based on selected classes at the ecosystem functional group (EFG) level of IUCN GET (see chap. 3 for details). The set of classes shown is not exhaustive for that level. In practice, it is expected that countries will utilize a national or regionally applicable classification of ecosystem types, which may show detail additional to that provided at the EFG level.

7.12 While many ecosystem services are supplied by an individual ecosystem type in a single location, some ecosystem services are supplied by a combination of ecosystem types (e.g. flood mitigation services supplied by a combination of ecosystems within a riparian zone). In these situations, an allocation of the total supply to the relevant ecosystem assets and ecosystem types is required. Section 7.3.1 discusses the spatial allocation of ecosystem services.

7.13 The use table presented in table 7.1b records the use of ecosystem services by economic units (final ecosystem services) and by ecosystem types (intermediate services). Economic units are classified following the general structure of the SNA. Nine industry classes are shown in table 7.1b. Selected industry classes may be more detailed to allow for national contexts. It is recommended that the structure used be aligned with ISIC. The columns for government and households reflect their consumption of ecosystem services, while the column for exports reflects the use of ecosystem services by non-residents (e.g. recreation-related services used by international visitors). For analytical purposes, under the column for households, the households category may be broken down (e.g. by income quintile or by rural/urban households) to distinguish different types of households and thereby provide further detail on the distribution of the use of ecosystem services.

7.14 In the use table, ecosystem types are shown for the three realms (of the four presented in IUCN GET) that are within scope of ecosystem accounting. This higher-level presentation is used for demonstration purposes only and more detailed classes can be provided. The recording of intermediate services by ecosystem type is not applicable for provisioning or cultural services, that is, all of these types of services are final ecosystem services and hence cannot be used by an ecosystem type. Where there are intermediate services that appear to be provisioning services in nature, as reflected, for example, in the connections between trophic layers of fish or the consumption of water by animals, those services should be recorded as part of nursery population and habitat maintenance services.

7.15 In general, the measurement scope of a supply and use account is established on the basis of the ecosystem services supplied by all ecosystem types within an EAA. Ensuring a balance in the recording of supply and use entails the need to record the use of ecosystem services by non-resident economic units, that is, economic units that have a centre of economic interest outside the EAA. This may arise, for example, in the case of cultural services supplied to visitors living outside the EAA. A column at the centre of the use table allows these flows to be recorded as exports of ecosystem services. It is to be noted that the total use of final ecosystem services supplied by ecosystems within an EAA includes exports of final ecosystem services. Imports of ecosystem services supplied by ecosystem assets outside the EAA may also be recorded. Such entries are made in the final column of the supply table. Recording of imports and exports of ecosystem services is discussed further in section 7.2.6.

Table 7.1a
Ecosystem services supply and use account in physical terms – supply table

SUPPLY			Economic units															Ecosystem type (based on the EFG level 3 of IUCN GET)																					
			Industries															Terrestrial												Freshwater			Marine						
																		T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
Ecosystem services (reference list)		MEASUREMENT UNIT	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	**Total industry**	Government consumption	Household consumption	**Total supply by resident economic units**	Supply by non-resident economic units – Imports	**Total supply by economic units**	T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	… …	T2.6 Temperate pyric sclerophyll forests and woodlands	… …	… …	… …	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	… …	FM1.3 Intermittently closed and open lakes and lagoon	M1.1 Seagrass meadows	… …	MFT1.3 Coastal saltmarshes and reedbeds	**Total supply by resident ecosystem assets**	Supply from non-resident ecosystem assets - Imports	**Total supply by ecosystem assets**	TOTAL SUPPLY
Provisioning services																																							
Biomass provisioning	Crop provisioning																																						
	Grazed biomass provisioning																																						
	Livestock provisioning services																																						
	Aquaculture provisioning services																																						
	Wood provisioning services																																						
	Wild fish and other natural aquatic biomass provisioning services																																						
	Wild animals, plants and other biomass provisioning services																																						
Genetic material services																																							
Water supply																																							
Other provisioning services																																							
Regulating and maintenance services																																							
Global climate regulation services																																							
Rainfall pattern regulation services																																							

Table 7.1a
Ecosystem services supply and use account in physical terms – supply table (*continued*)

SUPPLY – Ecosystem services (reference list)	MEA-SURE-MENT UNIT	Economic units – Industries: Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	**Total industry**	Government consumption	Household consumption	**Total supply by resident economic units**	Supply by non-resident economic units – Imports	**Total supply by economic units**	Ecosystem type (based on the EFG level 3 of IUCN GET) – Terrestrial – T1 Tropical-subtropical forests: T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2 Temperate-boreal forests and woodlands: T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	… …	T2.6 Temperate pyric sclerophyll forests and woodlands	…: … …	… …	T7: … …	T7.5 Derived semi-natural pastures and old fields	Freshwater – F1: F1.1 Permanent upland streams	…: … …	FM1: FM1.3 Intermittently closed and open lakes and lagoon	Marine – M1: M1.1 Seagrass meadows	…: … …	MFT1: MFT1.3 Coastal saltmarshes and reedbeds	**Total supply by resident ecosystem assets**	Supply from non-resident ecosystem assets - Imports	**Total supply by ecosystem assets**	**TOTAL SUPPLY**
Local (micro and meso) climate regulation services																																						
Air filtration services																																						
Soil quality regulation services																																						
Soil and sediment retention services																																						
Solid waste remediation services																																						
Water purification services																																						
Water flow regulation services																																						
Flood control services																																						
Storm mitigation services																																						
Noise attenuation services																																						
Pollination services																																						
Biological control services																																						
Nursery population and habitat maintenance services																																						
Other regulating and maintenance services																																						
Cultural services																																						
Recreation-related services																																						
Visual amenity services																																						
Education, scientific and research services																																						
Spiritual, artistic and symbolic services																																						
Other cultural services																																						

Table 7.1b
Ecosystem services supply and use account in physical terms – use table

USE			Economic units															Ecosystem type (based on the EFG level 3 of IUCN GET)																					
			Industries															Terrestrial												Freshwater			Marine						
																		T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
Ecosystem services (reference list)		MEASUREMENT UNIT	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	Total industry	Government consumption	Household consumption	Total use by resident economic units	Exports - final ecosystem services	Total use by economic units	T1.1 Tropical-subtropicalowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	… …	T2.6 Temperate pyric sclerophyll forests and woodlands	… …	… …	… …	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	… …	FM1.3 Intermittently closed and open lakes and lagoons	M1.1 Seagrass meadows	… …	MFT1.3 Coastal saltmarshes and reedbeds	Total use by resident ecosystem assets	Exports – intermediate services	Total use by ecosystem assets	TOTAL USE
Provisioning services																																							
Biomass provisioning	Crop provisioning																																						
	Grazed biomass provisioning																																						
	Livestock provisioning services																																						
	Aquaculture provisioning services																																						
	Wood provisioning services																																						
	Wild fish and other natural aquatic biomass provisioning services																																						
	Wild animals, plants and other biomass provisioning services																																						
Genetic material services																																							
Water supply																																							
Other provisioning services																																							
Regulating and maintenance services																																							
Global climate regulation services																																							
Rainfall pattern regulation services																																							
Local (micro and meso) climate regulation services																																							

Table 7.1b
Ecosystem services supply and use account in physical terms – use table (*continued*)

USE		Economic units															Ecosystem type (based on the EFG level 3 of IUCN GET)																					
		Industries															Terrestrial												Freshwater			Marine						
																	T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
Ecosystem services (reference list)	MEASUREMENT UNIT	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	Total industry	Government consumption	Household consumption	Total use by resident economic units	Exports - final ecosystem services	Total use by economic units	T1.1 Tropical-subtropicalowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	… …	T2.6 Temperate pyric sclerophyll forests and woodlands	… …	… …	… …	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	… …	FM1.3 Intermittently closed and open lakes and lagoons	M1.1 Seagrass meadows	… …	MFT1.3 Coastal saltmarshes and reedbeds	Total use by resident ecosystem assets	Exports – intermediate services	Total use by ecosystem assets	TOTAL USE
Air filtration services																																						
Soil quality regulation services																																						
Soil and sediment retention services																																						
Solid waste remediation services																																						
Water purification services																																						
Water flow regulation services																																						
Flood control services																																						
Storm mitigation services																																						
Noise attenuation services																																						
Pollination services																																						
Biological control services																																						
Nursery population and habitat maintenance services																																						
Other regulating and maintenance services																																						
Cultural services																																						
Recreation-related services																																						
Visual amenity services																																						
Education, scientific and research services																																						
Spiritual, artistic and symbolic services																																						
Other cultural services																																						

7.16 A single supply and use table is compiled for one accounting period (usually one year), that is, the entries for supply and use show the total flows of each ecosystem service for that time period. Ideally, a time series of SUTs would be compiled to enable analysis of changes in the patterns of supply and use over time; however, it may be more practical initially to compile tables once every three or five years to allow for the development of methods and experience. Where a time series of SUTs is compiled, different presentations and arrangements of the components may be required to support the demonstration of time as an additional dimension.

7.17 There may also be considerable interest in the presentation of data on the supply and use of ecosystem services in the form of maps. Overlaying maps for different ecosystem services can provide a ready source of information on places that might be considered ecosystem services "hotspots". It is common for estimates of the supply and use of ecosystem services to be compiled using detailed spatial data so that the flows of ecosystem services can be attributed to specific locations and hence to associated ecosystem types. Where this compilation approach is used, the entries in the SUT that presents flows by ecosystem type will be an aggregation of data drawn from finer scales and the maps and tables will therefore be complementary outputs of the same underlying data.

7.18 Where more aggregate, economy-wide methods are used, for example, where ecosystem service flows are based on aggregate visits to national parks or total volumes of timber harvested for a country, the attribution to ecosystem type may be more generic or stylized, and there may be no accompanying mapped outputs.

7.19 In concept, where compilation of ecosystem services is undertaken using fine-level spatial data, it would be possible to present information on the supply and use of ecosystem services for each individual ecosystem asset. However, in practice, there is no requirement for reporting at this level of detail, especially for accounts covering a national scale or large areas within a country. Thus, the SUTs shown in tables 7.1a and 7.1b focus on recording at the level of ecosystem types regardless of their location.

7.2.2 Applying general supply and use principles in ecosystem accounting

7.20 In concept, in ecosystem accounting, it is considered that each ecosystem supplies or contributes to the supply of a set or bundle of ecosystem services. The following discussion maintains the focus on explaining the principles and treatments of accounting for ecosystem services at the level of individual ecosystem assets. It is recognized that in practice, compilation may commonly be undertaken for ecosystem types and, as noted in the previous subsection, the data presented in an SUT are likely to concern ecosystem types.

7.21 As described in chapter 6, ecosystem services are defined as contributions to benefits and encompass a wide range of services provided to economic units (including households, businesses and governments) and to other ecosystem assets. Distinguishing between services and benefits is meaningful because that distinction:

- Facilitates distinguishing between final ecosystem services and flows of products (SNA benefits) currently recorded in the SNA
- Recognizes the role of human inputs in the production process and that the contribution of ecosystem services to benefits may change over time (owing, for example, to changes in the methods of production)

- Identifies the appropriate target for monetary valuation since the value of final ecosystem services represents only a portion of the overall monetary value of the corresponding benefits

7.22 These features also allow clear articulation and attribution of flows between ecosystem assets and economic units that are represented in accounting terms as supply-use pairs, that is, as transactions.

7.23 As described above, the ecosystem services flow account is structured to record the flows of ecosystem services supplied by ecosystem types and used by economic units during an accounting period. There is no accumulation of ecosystem services such that supply over an accounting period might be matched with an increase in accumulated ecosystem services available for use in future accounting periods. While measurement of the potential or sustainable level of supply that could be delivered by an ecosystem asset is highly relevant, this is not the focus of recording in the supply and use accounts. Section 6.5 provides a discussion on the related concept of ecosystem capacity.

7.24 Recording supply as equal to use means that, from an accounting perspective, ecosystem services are revealed transactions or exchanges. Since, in concept, each recorded exchange is observable, it follows that each ecosystem service is separable, even though the processes through which different ecosystem services are supplied are connected to each other.

7.25 In addition to the requirement of matched supply and use entries, the following key features of supply and use accounting are applied:

- Supply is attributed to an ecosystem type. Where an ecosystem service is supplied jointly by a combination of ecosystems, it is assumed that, if required, the supply can be allocated to individual assets using spatial allocation methods or measurement conventions. This topic is discussed further in section 7.3.
- Use of final ecosystem services is attributed to resident economic units (business, government, households) or non-resident economic units (exports).
- Use of intermediate services is attributed to an ecosystem type.
- For any single transaction of an ecosystem service (i.e. where there is a supply-use pair), the magnitude of the flow is the same for both supply and use in terms of quantity and monetary value.
- Where there are multiple transactions of a single ecosystem service (i.e. where there are multiple supply-use pairs), the SUT allows supply from multiple ecosystem types and use by multiple users to be recorded. Where a total flow pertaining to multiple ecosystem types or multiple users is estimated, attribution to relevant ecosystem types and users would be required to best reflect the underlying transactions.

7.26 Using these principles allows the data recorded in the SUT to support the monetary valuation of ecosystem services (described in chap. 9) and to be considered in alignment with the economic data recorded in the SNA SUT (see 2008 SNA, chap. 14).

7.27 In some cases, the physical flows recorded in the ecosystem services flow account will be the same as those recorded in the PSUTs and asset accounts in the SEEA Central Framework (chaps. III and V). For example, the flow of timber resources harvested from non-cultivated forests will be the same in terms of the reduction in the stock of timber resources in the asset account and the flow of biomass provisioning services in the ecosystem services flow account. This does not represent double counting since each table is designed for a distinct purpose and the flow happens to be relevant in both cases. Compilers are encouraged to cross-check among the various tables to ensure that users are presented with a coherent set of data and to optimize the use of source data and the alignment of methods.

7.2.3 Ecosystem services and benefits

7.28 Where the flow of ecosystem services is an input to the production of an SNA benefit, a supply and use pair is recorded for the ecosystem service in the ecosystem services supply and use account and a separate supply and use pair is recorded in the standard economic supply and use accounts for the transaction in the associated economic good or service, that is, the SNA benefit.

7.29 For example, the supply of biomass provisioning services for rice from a cropland is recorded in the ecosystem services supply and use account as a use of that ecosystem service by a farmer. Entries for these flows are shown in table 7.2.

Table 7.2
Basic ecosystem services PSUT No. 1

	Measurement units	Economic units (selected)			Ecosystem assets (selected types)		
		Agriculture	Government	Households	Forest	Cropland	Grassland
SUPPLY							
ES No. 1: Biomass provisioning services (rice)	Tons					100	
USE							
ES No. 1: Biomass provisioning services (rice)	Tons	100					

Abbreviation: ES, final ecosystem service.

Note: A grey cell signifies "not applicable".

7.30 This recording allows the supply and use of ecosystem services to be connected to entries for the supply and use of goods and services currently recorded in standard economic SUTs. Thus, in this example, flows of biomass provisioning services can be linked to supply-use pairs for the harvested rice and other processed goods that are recorded in the economic supply and use tables reflecting a series of transactions between a farmer, manufacturers and households. It should be noted that the entries in the economic SUTs are in monetary terms. The compilation of extended SUTs building on ecosystem services flow accounts in monetary terms is described in chapter 11.

7.31 Where the flow of ecosystem services is an input to the production of a non-SNA benefit, for example, the contribution of air filtration services to cleaner air, a supply and use pair is recorded for the ecosystem service in the SUT by adding a row. Entries representing flows for both air filtration and biomass provisioning services are shown in table 7.3.

7.32 For many ecosystem services that contribute to non-SNA benefits, the use of the ecosystem service is attributed to the receiver of the non-SNA benefit. In some cases (e.g. for recreation-related services), this is very direct. However, where the ecosystem service contributes to a non-SNA benefit that is considered "collective", the use of the ecosystem service is attributed to the highest level of general government in the EAA, which is considered to use the service on behalf of society as a whole. According to the 2008 SNA (para. 9.4), "a collective consumption service is a service provided simultaneously to all members of the community or to all members of a particular section of the community, such as all households living in a particular region" and "[c]ollective services are the 'public goods' of economic theory". Collective services will thus be both non-rival and non-excludable. The primary example of such an ecosystem service is global climate regulation, the benefits of which are enjoyed by all members of the community.

Table 7.3
Basic ecosystem services PSUT No. 2

	Measurement units	Economic units (selected)			Ecosystem assets (selected types)		
		Agriculture	Government	Households	Forest	Cropland	Grassland
SUPPLY							
ES No. 1: Biomass provisioning services (rice)	Tons					100	
ES No. 2: Air filtration services (PM2.5)	Tons				50		
USE							
ES No. 1: Biomass provisioning services (rice)	Tons	100					
ES No. 2: Air filtration services (PM2.5)	Tons			50			

Abbreviations: ES, final ecosystem service; PM2.5, particulate matter less than 2.5 micrometres in diameter.

Note: A grey cell signifies "not applicable".

7.33 There are cases where a single ecosystem service (e.g. flood mitigation) is used by a number of economic units. In this context, the service will possess some of the characteristics of public goods, although specific beneficiaries can be identified. Ideally, the service should be recorded in the use table as received by multiple economic units, with a distinction being made, for example, between use by households and use by businesses. However, making such a use allocation may be difficult in practice, and, in this case, it is recommended that the use of the service be allocated to general government on behalf of all users.

7.2.4 Recording intermediate services

7.34 Where there is a sequence of intermediate ecosystem services and final ecosystem services, recording the supply and use of each service ensures that the appropriate net effect is shown. Using an example involving the ecosystem services of pollination and biomass provisioning (in this example, provisioning of melons), the supply of pollination services by one ecosystem (natural grassland, where the pollinators are assumed to live) for use in another ecosystem (cropland, where the melons are pollinated) is recorded as supply and use of an intermediate service. Supply of the intermediate service of pollination is attributed to grassland and use of the pollination service is attributed to cropland (as an input to its supply of final ecosystem services, that is, the supply of biomass provisioning). The relevant entries are shown in table 7.4.

7.35 By ensuring that a sequence of supply and use entries are recorded for each type of ecosystem service, the overall contribution of each ecosystem can be determined. For example, through consideration of the column for cropland, the output of biomass provisioning services can be seen to require the input of pollination services from grassland ecosystems. It is to be noted, however, that no aggregation across rows should be undertaken given that the entries reflect the use of different measurement units. Further, it should be noted that there is no double counting implied through the

Table 7.4
Basic ecosystem services PSUT No. 3

	Measurement units	Economic units (selected)			Ecosystem assets (selected types)		
		Agriculture	Government	Households	Forest	Cropland	Grassland
SUPPLY							
ES No. 1: Biomass provisioning services (melons)	Tons					80	
ES No. 2: Air filtration services (PM2.5)	Tons				50		
IS: Pollination services	Number of visits[a]						2 000
USE							
ES No. 1: Biomass provisioning services (melons)	Tons	80					
ES No. 2: Air filtration services (PM2.5)	Tons			50			
IS: Pollination services	Number of visits[a]					2 000	

Abbreviations: ES, final ecosystem service; IS, intermediate ecosystem service; PM2.5, particulate matter less than 2.5 micrometres in diameter.

Note: A grey cell signifies "not applicable".

[a] Number of pollinator visits is one potential measure of the quantity of pollination services. Other metrics may be used.

recording of intermediate services since the user of the intermediate service is different from the user of the associated final ecosystem service.

7.36 In the context of recording physical flows of ecosystem services for cultivated biomass production (see sect. 6.4.1), this approach to recording intermediate services can be applied irrespective of whether the relevant final ecosystem services are measured using gross biomass harvested as a proxy or using a share of biomass harvested to represent the ecosystem contribution. In both of these approaches, the intermediate service flows can be considered inputs to the final flows. However, where the final ecosystem services are measured using a range of individual ecosystem inputs, such as pollination, no measure of biomass harvested is recorded and each input is recorded as a final ecosystem service. It is to be noted that the SUT format is designed for recording multiple connections. However, before the entries are made, the logic of those connections needs to be well understood and to reflect a coherent and robust description of the relationship between ecosystems and human activity in biophysical terms. In the context of cultivated biomass production, this should entail consideration of type of biomass (e.g. crop type), location and method of cultivation.

7.2.5 Recording abiotic flows

7.37 Chapter 6 identified a range of environmental flows, for example, concerning the supply of energy, that do not meet the definition of ecosystem services and are considered abiotic flows. These abiotic flows may be relevant in the assessment of the use of specific ecosystems. For example, in the production of solar energy, it is common to install solar panels, which reduce the potential to use the same location for the generation of ecosystem services. Thus, recording abiotic flows and attributing their supply to individual locations can help to provide a more comprehensive picture of the use of ecosystems.

7.38 Where recording abiotic flows is desired, additional rows may be added to the SUT (tables 7.1a and 7.1b). Each additional row in the supply table would display the supply of the abiotic flow from the relevant ecosystem type (e.g. electricity generated from wind turbines on cropland). Each additional row in the use table would display the use of that abiotic flow by economic units (e.g. electricity generators). Table 7.5 shows how such flows can be incorporated in the supply and use framing through an example where an electricity generator uses wind turbines on cropland to generate electricity.

7.2.6 Exports and imports of ecosystem services

7.39 The measurement scope for ecosystem accounts is set by the EAA, for example, the economic territory of a country including its EEZ. As noted above, for ecosystem services flow accounts this entails a focus on the ecosystem services supplied by all ecosystems within the EAA. There is a range of situations in which the supply of ecosystem services is not used by economic units that are resident[78] in the EAA, that is, situations involving exports of final ecosystem services; and cases where resident economic units use ecosystem services from outside the EAA, that is, cases involving imports of final ecosystem services. There are also situations where dependencies between ecosystem assets cross EAA boundaries, that is, situations involving flows of intermediate services. The present section discusses relevant treatments.

7.40 In the following discussion, it is assumed that the EAA concerns a country. In principle, the same considerations can be applied at a subnational level where the terms *exports* and *imports* are applied to flows between, for example, administrative regions. In practice, recording flows among subnational areas requires significant coordination of data although, given the increasing use of GIS techniques, this task may become more manageable.

78 The concept of residency of economic units is applied based on the definitions and principles of the SNA and the *Balance of Payments and International Investment Position Manual*, 6th ed. (BMP6) (Washington, D.C., International Monetary Fund, 2009).

Table 7.5
Basic ecosystem services PSUT No. 4

	Measurement units	Economic units (selected)			Ecosystem assets (selected types)		
		Agriculture	Electricity supply	Households	Forest	Cropland	Grassland
SUPPLY							
ES No. 1: Biomass provisioning services (melons)	Tons					80	
ES No. 2: Air filtration services (PM2.5)	Tons				50		
IS: Pollination services	Number of visits[a]						2 000
AB: Energy from wind power	kWh					10 000	
USE							
ES No. 1: Biomass provisioning services (melons)	Tons	80					
ES No. 2: Air filtration services (PM2.5)	Tons			50			
IS: Pollination services	Number of visits[a]					2 000	
AB: Energy from wind power	kWh		10 000				

Abbreviations: AB, abiotic flow; ES, final ecosystem service; IS, intermediate ecosystem service; kWh, kilowatt hours; PM2.5, particulate matter less than 2.5 micrometres in diameter.

Note: A grey cell signifies "not applicable".

a Number of pollinator visits is one potential measure of the quantity of pollination services. Other metrics may be used.

7.41 Six cases need specific consideration. First, there are cases where people are visiting from outside an EAA, for example, tourists, who are commonly users of recreation-related services supplied by ecosystems within the EAA. In this case, measurement requires an allocation of the total supply of the service to that group of people as non-residents, that is, the services are recorded as exports.

7.42 Second, there are many cases of exports (and imports) of biomass and related products (e.g. rice, wheat, timber, fish) between countries. In ecosystem accounting, these flows of products are not considered flows of ecosystem services and therefore are not recorded as exports in the ecosystem services flow account. Instead, the ecosystem services can be viewed as embodied in the products traded, with the flows of products recorded in the standard economic SUTs and related balance-of-payments statistics. Analysis of the extent to which traded products encompass embodied ecosystem services can be undertaken, and this may represent an important contribution to the understanding of how consumption in one country may have impacts on the ecosystems of other countries.

7.43 Third, there are often situations, particularly involving regulating and maintenance services, where the users of the ecosystem service are located outside the ecosystem supplying the service. For example, users of air filtration services provided by a forest usually do not live in the forest but in neighbouring communities. Further, the supply of water flow regulation services often involves a number of ecosystem assets across a catchment, with those communities that are being supplied located in just one part of the catchment. Where both the supplying ecosystem assets and the location of the users are in the same EAA, no specific treatment needs to be noted. However, where the location of use is outside the EAA, an export of a final ecosystem service should be recorded to ensure a balance between supply and use. Conversely, where the supply of the service is outside the EAA, an import of a final ecosystem service should be recorded.

7.44 Fourth, there is a subset of the ecosystem services considered in paragraph 7.43 that comprises collective services that are not attributable to individual households or businesses but are treated instead as being used by general government on behalf of the community. The primary example of such services, as noted in paragraph 7.32 above, are global climate regulation services and, indeed, these services can be considered to be of benefit globally, to all people, rather than only in a more localized, ecosystem asset context. By convention, collective services are recorded as used by the government that has jurisdiction over the supplying ecosystem assets, that is, jurisdiction over the EAA, and no exports of collective services are recorded in the system.

7.45 Fifth, consistent with the treatments in the SNA and the SEEA Central Framework, the catching of fish by non-resident operators within a country's EEZ is treated as production of the non-resident operator. In ecosystem accounting, the export of a biomass provisioning service should be recorded in the supply table, which recognizes the input of that country's ecosystems to the production of other countries. A corresponding import of an ecosystem service should be recorded in the accounts of the country in which the fishing operator is resident.

7.46 Sixth, conceptually, there may be flows of intermediate services between EAAs. Examples include provision of fish nursery services by a marine ecosystem in one EAA to biomass provisioning services provided in another EAA, and migration of species between countries, as supported by particular ecosystems, which underpins recreation-related services. However, these flows should be recorded only in specific circumstances of analytical interest, that is, either (a) where the flow of the intermediate service into an EAA (recorded as an import) can be clearly linked to a final ecosystem service supplied by an ecosystem asset within the EAA; or (b) where the flow of the intermediate service from an EAA (recorded as an export) can be clearly linked to a final ecosystem service supplied by an ecosystem asset outside the EAA.

7.47 Given that the measurement scope of an ecosystem services flow account is determined by the set of supplying ecosystem assets within an EAA, there is generally less focus on imports of ecosystem services, which, by definition, are supplied by ecosystems outside the EAA. Indeed, this reality implies that there would likely be a larger measurement challenge in quantifying imports of ecosystem services. Thus, the measurement scope of imports should be determined through identification of flows of ecosystem services that are of particular interest, for instance, in establishing a more complete picture of the use of ecosystem services by resident economic units. For example, the use of recreation-related services by residents who visit locations outside the EAA may be of such interest. Where imports of final ecosystem services are recorded, they are entered in the supply table, and a corresponding use is recorded by type of economic unit in the use table.

7.48 In all cases, appropriate allocation and recording of exports and imports of ecosystem services require an understanding of the location of supply and use and the residency of the economic units involved. This is particularly relevant when an ecosystem service is supplied from a combination of ecosystems within a landscape context in which the ecosystems involved are located on different sides of an administrative boundary (e.g. where the administrative boundary is defined by a river). Further discussion on the spatial allocation of the supply and use of ecosystem services is provided in section 7.3.

7.2.7 Recording cultural services

7.49 Cultural services entail an interaction between people and ecosystems. Consequently, the quantification of those services generally reflects measurement of the type, number of occurrences and/or quality of the interaction. For example, recreation-related services are commonly quantified using the number of visits to a specific natural location. While these measures are not a direct quantification of the ecosystem contribution, they are considered a suitable proxy that can be improved by taking into consideration, as far as possible, the number and length of time of interactions with specific features and characteristics of the ecosystems concerned.

7.50 At the same time, for many cultural services – but primarily for recreation-related services – there are businesses involved in facilitating and supporting interactions between people and ecosystems. Broadly, the types of businesses that are involved either (a) supply access to the ecosystem and/or facilitate activities/experiences within the ecosystem (e.g. covering entry fees, guides, tour operators); or (b) supply goods and services to visitors to support their travel to, and time at, an ecosystem (e.g. hotels, restaurants, transport companies, fuel suppliers).

7.51 To varying degrees, all of these businesses can be seen to have a connection to the ecosystem and may be considered to have included inputs of ecosystem services in their supply of goods and services to visitors. This interpretation is most appropriate in the context of the first type of business, for which it seems likely that, where payments are made by visitors to those businesses (i.e. reflecting an economic transaction between the two parties), there is an implicit payment for an ecosystem service. For transactions involving the second type of business, any ecosystem contribution is likely to be much smaller. For accounting purposes, challenges lie in appropriately distinguishing the ecosystem services within transactions already recorded in the standard economic accounts and identifying the additional contribution of the ecosystem to the overall benefits that arise from people's interactions with ecosystems.

7.52 The recommended treatment for the ecosystem services supply and use account in physical terms is to record a supply and corresponding use for each visitor interaction, showing the supply from the relevant ecosystem type and households as users of the service. This flow should be recorded irrespective of the degree to which there is involvement of businesses in facilitating or supporting an activity.

7.53 In addition, the connection between the ecosystem and relevant businesses should be recorded in a supplementary row. The addition of this row does not imply the need to record additional supply; rather, it enables complementary data on the use of ecosystem services to be provided. Both entries in the use table reflect final ecosystem services. These entries are shown in table 7.6, using suppliers of recreational services as an example of types of business.

7.2.8 Linking the supply of ecosystem services to economic units

7.54 The supply and use tables described in this chapter allow for the recording of flows between ecosystem types as suppliers and economic units as users. There may be interest in a complementary presentation of the data in which the economic units that either own or manage the areas associated with the ecosystem types are shown as suppliers. For example, farmers may be shown as suppliers of biomass provisioning services, global climate regulation services and water flow regulation services reflecting a bundle of ecosystem services supplied by the ecosystem assets within the boundaries of the farms that they own or manage.

7.55 Presentation of data in this way must be handled with care since there is no necessary one-to-one link between ecosystem types and economic units. Most commonly, there is a combination of ecosystem types within a single parcel of land that is owned or managed by an economic unit. In the first instance, then, the starting point for organization of data on the flows of ecosystem services should follow the approach described in chapter 4 in the presentation of ecosystem extent data with respect to economic units.

Table 7.6
Basic ecosystem services PSUT No. 5

	Measurement units	Economic units (selected)		Ecosystem assets (selected types)		
		Recreation services	Households	Forest	Cropland	Grassland
SUPPLY						
ES No. 3: Recreation-related services	Number of visits			180		
USE						
ES No. 3: Recreation-related services	Number of visits		180			
Supplementary data						
Use of ES No. 3 by business	Number of visits	180				

Abbreviation: ES, final ecosystem service.

Note: A grey cell signifies "not applicable".

7.56 Through use of information on the relationship between ecosystem types and economic units, an alternative supply table may be structured, building on table 7.1a, to show under each ecosystem type (e.g. forests), the range of different types of economic units grouped, for example, by industry. Another option would be to show for each type of economic unit (e.g. agriculture), the range of ecosystem types that it manages. Under either presentation, the total supply of a given ecosystem service from a specific ecosystem type should be the same as that recorded following the structure of the supply table shown in table 7.1a. It is also to be noted that the entries in the use table are unaffected by the alternative presentations of the supply table.

7.57 Besides presentation in tabular form, the presentation of this type of information in maps, by overlaying data on ownership and management by economic units, may be particularly useful for some types of policymaking and analysis.

7.3 Considerations in accounting for ecosystem services in physical terms

7.3.1 Spatial allocation of ecosystem services supply and use

7.58 A number of ecosystem services, particularly regulating and maintenance services but also some cultural services, are generated at landscape scale in the sense that this involves a range of ecosystem assets of different types. Examples include the contributions of different ecosystems to water flow regulation and soil erosion control services, which are commonly measured and modelled at a catchment scale rather than for individual ecosystem assets within the catchment.

7.59 For ecosystem accounting, it is appropriate for the measurement of the total supply of an individual ecosystem service to be undertaken at a larger, multi-ecosystem scale in order to derive the best estimate of supply. However, the logic of ecosystem accounting further implies the allocation of total supply to the various ecosystem types involved and, conceptually, to individual ecosystem assets. This allocation can in turn support, for example, an understanding of the critical ecosystems within a catchment.

7.60 In addition to allocating supply to ecosystem types, there is a general interest in linking the supply and use of ecosystem services to the location of ecosystem assets, as reflected in the measurement of ecosystem extent. Such spatial allocation is conceptually feasible since ecosystem services are spatial phenomena.

7.61 Generally, ecosystem services may be supplied from locations that are the same as, or different from, the locations in which they are used and where the benefits are received. Since ecosystem services have varying spatial characteristics and follow certain flow paths (Bagstad and others, 2013; Costanza, 2008), linkages between supply and use can occur via several pathways: Specifically:

- Some benefits from ecosystem services (in situ ecosystem services) are received in the same place in which they are supplied. Most provisioning services fall into this category.
- Some benefits from ecosystem services (omnidirectional ecosystem services) are received in the surrounding landscape or beyond. Global climate regulation services are an example of this type of services, where the benefits are global but the ecological process concerned can occur in any ecosystem.
- Some benefits from ecosystem services (directional ecosystem services) are received downstream or downslope from where they are supplied. For

example, water may be purified upstream from where the consumption of water occurs. Directional ecosystem services can also depend on spatial proximity, that is, people may receive benefits by being near but not necessarily in the relevant ecosystem.

7.62 Building on this framing, the following considerations apply in allocating the supply and use of ecosystem services to ecosystem types and to economic units. Provisioning services are treated as supplied and used in the same ecosystem since, in accounting terms, the exchange between ecosystem and economic unit occurs at the point of harvest, which must take place in situ. Subsequent transactions involving the processing, transportation and sale (including potential export) of harvested materials are the subject of standard economic accounting and are not the focus of ecosystem accounting.

7.63 Regulating and maintenance services are commonly supplied by ecosystems or combinations of ecosystems in one location and used by economic units in other locations. Further, there is a range of cases where a single service is supplied to a range of different economic units that are present in a single area. Specific examples here concern the services of ecosystems used in mitigating the effects of extreme events. For accounting purposes, there remains a need to ensure that total supply and total use are balanced but, in concept, allocation across locations involving multiple ecosystem assets and multiple users can be readily recorded using SUTs.

7.64 Many cultural services are supplied and used in situ since they are based on direct interactions between people and ecosystems. Recreation-related services are the clearest example. At the same time, there are a range of cultural services involving indirect connections and therefore the locations of supply and use would be different. It is to be noted that the location of use of a service is not dependent on the location of residence of the user. Users of in situ ecosystem services may be resident in the ecosystem, near the ecosystem or in another country. In all cases, the location of use is the ecosystem, but the differences in residence are reflected in the classes of user that are identified, for example, through the recording of exports (see sect. 7.2.6).

7.65 For the purposes of compiling an SUT following the structure of tables 7.1a and 7.1b, it is necessary to allocate the supply of ecosystem services to ecosystem types, but it is not necessary to (a) allocate that supply to individual ecosystem assets in specific locations; or (b) record the location of the economic units using the ecosystem services. However, for a range of purposes, especially to support spatial planning and assessment, attribution of ecosystem services supply and use to locations is likely to be of considerable significance. Further, for many ecosystem services, particularly regulating and maintenance services, compilation methods are likely to involve the use of detailed spatial data, in which case allocation to locations can be viewed as a by-product.

7.66 The process of allocating ecosystem services to locations is known as ecosystem services mapping. In this regard, key concepts of relevance for ecosystem accounting are the service providing area (SPA) and the service benefiting area (SBA). For each ecosystem service, the delineation of the SPA and the SBA provides the location and spatial boundary, which would reflect the location of supply and use, respectively. For accounting purposes, it is appropriate to link the SPA with maps of ecosystem extent classified by ecosystem type and to link the SBA with information on the location of different types of economic units (including businesses, government, households) using, for example, cadastral information, as well as with information on the location of users that are resident outside the EAA. Guidance on ecosystem services mapping is available in Burkhard and Maes, eds. (2017).

7.3.2 Determining ecosystem services measurement baselines

7.67 Entries in the ecosystem services flow accounts reflect a total flow over an accounting period, for example, total fish caught from marine areas during a year or total number of plants pollinated. This is different from measuring the change in flow associated with a particular action (e.g. change in pollination due to reductions in the number of pollinators) or measuring the flows relative to different ecosystem types (e.g. the relative contribution of forests and grasslands in water regulation). To ensure that all accounting entries in the ecosystem services flow accounts refer to a total flow and can be compared across different contexts, ecosystem services measurement baselines[79] are used.

[79] Other labels that may be applied include "reference level" and "counterfactual". The term "measurement baseline" is preferred for use in this context.

7.68 Ecosystem services measurement baselines are applied directly in the measurement of regulating and maintenance services but are implicit in the measurement of all ecosystem services. Thus, for provisioning services and cultural services, where it is possible to observe a direct interaction between people and ecosystems, the implicit baseline is zero, that is, the quantification of the flow assumes implicitly the potential for no harvest or no interaction. The quantification of the ecosystem services is therefore appropriately focused on measuring the quantity and type of biomass harvested or the number and type cultural interactions.

7.69 The identification of regulating and maintenance services entails a focus on the extent to which ecological processes contribute to environmental conditions that are beneficial to people and their activities. These processes may involve the remediation or mitigation of a potentially negative impact. For example, air filtration services reduce ambient air pollution concentrations. The negative impacts (a) may be caused by human activities (e.g. most forms of air pollution, GHG emissions), (b) may result from natural events (e.g. storm surges) or (c) may result from natural events that have an increased likelihood of occurring because of human activities (e.g. landslides with a likelihood of occurring because of deforestation activity). However, not all regulating and maintenance services involve the remediation of a negative impact (e.g. pollination involves transferring pollen to enable plant sexual reproduction). In these cases, the implicit measurement baseline is zero (i.e. in the case of pollination, there is no transfer of pollen).

7.70 The quantification of the supply of regulating and maintenance services generally depends directly and significantly upon knowledge of the ecosystem type and its key characteristics, since the role of the ecosystem in supplying services will vary as type and characteristics change. Thus, in assessing the extent to which a particular ecosystem provides regulating and maintenance services, it is normal to make an assumption regarding what services would be supplied if the ecosystem type or its characteristics were different. For example, forests are better than grasslands at capturing air pollutants, and wetlands with well-structured and diverse vegetation are better than wetlands with little vegetation at purifying water of pollutants.

7.71 The comparison of two different ecosystem contexts, one being the measurement baseline context, provides a basis for quantifying the role of the ecosystem in supplying a given service. Thus, an ***ecosystem service measurement baseline is the level of service supply with which a regulating or maintenance service provided by an ecosystem is compared in order to quantify the service.***

7.72 For ecosystem accounting, the use of a common measurement baseline ensures comparability across ecosystem types and across different services. The default measurement baseline is zero, reflecting the assumption that the ecosystem does not supply a particular regulating service. In cases where a zero level of service supply cannot be modelled or meaningfully identified, the baseline should be the amount of service supplied by bare land (i.e. the amount of service supplied where the ecosystem has no vegetation cover) or an alternative worst-case ecosystem scenario. As shown in table 7.7, the application of this default baseline varies by type of service and specific cases are discussed below.

7.73 For air filtration, it is possible to define directly a "no" or "zero" air filtration level and it can be simply stated that the baseline corresponds to zero air filtration, i.e. zero capture of ambient air pollutant by an ecosystem. Thus, the supply of the ecosystem service is equal to the quantity of pollutant absorbed by the ecosystem.

7.74 In other cases, determining a baseline of no service supply independent of any land cover is difficult. For instance, the soil erosion control service is usually quantified using the revised universal soil loss equation (RUSLE).[80] This approach compares actual erosion rates with those for bare land, where the erosion rate for bare land is the maximum potential erosion rate (a worst-case scenario) in a given ecosystem, allowing for soil type and erosivity, slope characteristics, rainfall characteristics and land management factors. In this case, service supply is therefore defined as the reduction in erosion rates compared with bare land. The baseline needs to be bare land since this represents the situation in which there is no ecosystem service supply.

80 For further information, see www.ars.usda.gov/midwest-area/west-lafayette-in/national-soil-erosion-research/docs/rusle/.

Table 7.7
Baselines for selected regulating and maintenance services

Type of service	Baseline	Comments
Global climate regulation services	No/zero carbon retention or sequestration	
Air filtration services	No/zero air filtration	Following the treatment described in section 6.4.5, capture of pollutants by bare and rocky surfaces is included as an ecosystem service.
Water flow regulation services	Bare land	Overland and groundwater flows cannot be zero, and the ecosystem service can be quantified only by comparing a situation with vegetation with a situation where there is no vegetation (i.e. bare land).
Flood mitigation services	Bare land	Flood risks are influenced by geomorphology and can be reduced by tree cover (e.g. riparian forests or mangroves) or dunes along a coast. There is no such thing as "no flood risk" in coastal areas and hence the ecosystem service can be quantified only by comparing the flood risk in a situation with vegetation with the flood risk in a situation without vegetation (i.e. bare land).
Soil erosion control services	Bare land	The service can be quantified by comparing the erosion rate of the current vegetation cover with that for bare land, the difference being the amount of soil/sediment retained.
Water purification services	No purification (i.e. no biological breakdown of water pollutants in the ecosystem)	
Pollination services	No/zero pollination	
Rainfall pattern regulation services	Bare land	It is not possible to model rainfall patterns without assuming some rainfall and evapotranspiration across all components of the landscape. The ecosystem service can be quantified only by comparing a situation with vegetation with a situation where there is no vegetation (i.e. bare land).
Nursery population and habitat maintenance services	No/zero nursery services	

Note: A description of each service is provided in table 6.3 (see chap. 6).

7.75 For services where the focus is regulation of flows (e.g. of water or soil), it is generally not possible to assess the service through comparison with a zero service baseline. This is because the flows occur regardless of whether a service is being provided. Further, while the biotic components of ecosystems modify and affect flows, the flows themselves cannot be conceptualized or modelled without there being abiotic components over which those flows occur. In these cases, the baseline needs to be bare land.

7.76 Finally, in some cases, use of bare land as a baseline may not be considered a very strong decision from a conceptual perspective, or it may appear counter-intuitive, or it might be the case that use of bare land cannot be modelled in a meaningful way. The recommendation is therefore to differentiate, in a systematic manner, between services for which the baseline is bare land and services for which the baseline is zero service supply. Clear communication and clear explanations regarding the chosen methods are required.

Section D

Monetary valuation and integrated accounting for ecosystem services and assets

Section overview

A number of motivations exist for estimating the monetary value of the environment's contribution to the economy and to people. There is also interest in integrated assessments of the connection between the environment and the economy, in particular in understanding changes in broad measures of wealth resulting from human and natural causes, for example, climate change and biodiversity loss. At the same time, monetary valuation is not appropriate in all decision-making contexts, and in all cases it is relevant to use associated biophysical data on stocks and flows.

Among statisticians, the use of monetary values of environmental stocks and flows in the measurement and assessment of the environment has long been a point of discussion and contention. The existence of multiple perspectives on this issue is well recognized. There are differences in points of view on (a) the underlying framing for valuation of environmental stocks and flows; (b) the potential of monetary valuation to support decision-making; (c) the ability to produce reliable estimates in monetary terms in practice; and (d) the role of national statistical offices (NSOs) in producing fit-for-purpose statistics in this area of measurement.

While these different perspectives exist, there is a role for the exchange value-based approach to the monetary valuation of ecosystem services and ecosystem assets described in chapters 8 to 11. At its fifty-second session, in March 2021, the Statistical Commission, in its decision 52/108, recognized that chapters 8 to 11 of SEEA EA describe internationally recognized statistical principles and recommendations for the valuation of ecosystem services and assets in a context that is coherent with the concepts of the SNA for countries that are undertaking valuation of ecosystem services and/or assets. In the same decision, the Commission requested the prompt resolution of outstanding methodological aspects in those chapters as identified in the research and development agenda.

While the recommendations presented in chapters 8 to 11 on valuation reflect the latest knowledge, methods and techniques with respect to measuring and organizing information on ecosystems, it is expected that this knowledge, as well as the data sources and techniques used to compile the accounts, will evolve over time as a result of the ongoing implementation of those accounts. Consequently, as is the case for all statistical methodology documents, it will be necessary to refine and revise the recommendations in the future.

SEEA EA recognizes that describing valuation based on exchange values provides monetary values that exclude welfare measures that may be commonly included in monetary values of the environment used in other contexts. Chapter 12 was prepared to support an understanding of the connections among the various approaches to measurement and analysis in monetary terms.

More generally, as highlighted in the opening chapters of SEEA EA, it is emphasized that monetary values from the accounts and the wider economic values just described do not fully reflect the importance of ecosystems for people and the economy. Assessing the importance of ecosystems therefore requires consideration of a wide range of information extending beyond data on the monetary value of ecosystems and their services, including data on their extent and condition and on the characteristics of the people, businesses and communities that are dependent on them.

It is recognized that there are concerns regarding estimation of monetary values in practice owing to data constraints and the application of valuation techniques. These factors require compilers to consider issues of data quality and uncertainty before compiling and disseminating accounts in monetary terms. It may be appropriate in initial releases to label data in monetary ecosystem accounts as experimental. A range of technical guidance is available to support the compilation, application and interpretation of monetary values and will be enhanced as part of the SEEA EA research and development agenda.

Chapter 8
Principles of monetary valuation for ecosystem accounting

8.1 Purposes and focus of monetary valuation for ecosystem accounting

8.1.1 Purposes of monetary valuation in ecosystem accounting

8.1 A number of motivations exists for the monetary valuation of ecosystem services and ecosystem assets depending on the purpose of analysis and the context for the use of valuations in monetary terms. The different motivations point to different requirements in terms of the concepts, methods and assumptions used for monetary valuation.

8.2 In ecosystem accounting, the primary motivation for monetary valuation using a common monetary unit or numeraire is to have the ability to make comparisons of different ecosystem services and ecosystem assets that are consistent with standard measures of products and assets as recorded in national accounts. This requires the use of exchange values, which in turn facilitates a core ambition of SEEA EA, namely, the description of an integrated system of prices and quantities for the economy and the environment.

8.3 Exchange value-based monetary valuations can support comparing the values of environmental assets (including ecosystems) with other asset types (e.g. produced assets) as part of extended measures of national wealth; highlighting the relevance of non-market ecosystem services (e.g. air filtration); assessing the contribution of ecosystem inputs to production in specific industries and their supply chains; comparing the trade-offs between different ecosystem services through consideration of relative prices; deriving complementary aggregates such as degradation-adjusted measures of national income; evaluating trends in measures of income and wealth; improving accountability and transparency as related to public expenditures on the environment by recognizing expenditure as an investment rather than a cost; providing baseline data to support scenario modelling and broader economic modelling; assessing financial risks associated with the environment; and calibrating the application of monetary environmental policy instruments such as environmental markets and environmental taxes and subsidies.

8.4 Within the space of environment-related monetary valuation more generally, it is common for valuation to focus on measurement of the impacts of changes in ecosystem assets and services on economic and human welfare. For example, valuation may focus on measuring the impacts of improved parks and reduced pollution on human health or the impacts of reduced soil fertility on farm incomes. The valuation of impacts, both positive and negative, is an important requirement in the context of development of specific policy options and policy settings, project evaluation and incentive design. This may include, for example, detailed cost-benefit analysis and the assessment of compensation and damage claims. Such analysis can be complemented, but not replaced, by data from a set of ecosystem accounts based on exchange values, recognizing that it is likely that more detailed and finer-scale data and valuations are required for impact analysis. More broadly, SEEA EA accounts provide a coherent framing for the collection and organization of relevant data and can support an understanding of micro-macro linkages and the assessment of changes over time.

8.5 The SEEA EA approach to monetary valuation, as presented in chapters 8 through 11, is introduced and described in chapter 2. This approach encompasses an awareness that monetary values cannot reflect a comprehensive or complete value of nature and that monetary values are not appropriate for use in all decision-making contexts. There are considerations of particular relevance in this regard, and it is to be noted that they apply to all monetary values, not only the values of ecosystem services and ecosystem assets described in chapters 8 to 11. These considerations make clear that:

- There are multiple value perspectives, including intrinsic and instrumental values, and the monetary values described in SEEA EA do not encompass all of those value perspectives with respect to ecosystem services and ecosystem assets. Further, for assessing some aspects of nature's value (e.g. spiritual connections) an accounting framework might not be suitable. Nonetheless, data on the physical flows of ecosystem services and on the extent and condition of ecosystem assets may support assessment of some other value perspectives.
- Monetary values are of greatest applicability in analysing changes that are marginal, that is, in analysing the effects of relatively small changes in stocks or flows of a particular asset, good or service (e.g. changes in agricultural production associated with changes in soil fertility). When there is a requirement to analyse large, non-marginal changes, such as permanent loss of a water resources, analysis should incorporate the assessment of physical changes in stocks in relation to appropriate thresholds.
- Monetary values for ecosystem services that are not scarce or that are in excess supply may be low or even zero based on the exchange value concept. Although this is consistent with the exchange value concept, such values should be interpreted carefully and in conjunction with PSUTs, in particular because non-scarcity can be a result of regulatory policies or market structures, or may reflect the current relative abundance of the ecosystem type supplying the service.
- Monetary values for non-market goods and services – for example, government-provided health, education and defence services included in the SNA – cannot be based on directly observed market transactions and hence are valued using alternative methods that approximate the exchange value of the relevant goods and services. Since there is no explicit market, the resulting values cannot reflect precisely the general equilibrium effects that would be expected if a market did exist. The extent to which the various valuation methods provide a good approximation varies, and it is to be noted that all methods reflect prices of a partial equilibrium. It is therefore relevant for as much specificity as possible regarding the location and context of the transaction to be incorporated in the application of alternative methods.

8.6 Overall, while there are many contexts in which monetary values can support decision-making, there are also situations in which non-monetary data play a primary role. In this regard, the integrated recording of physical and monetary data in SEEA EA should be of particular benefit.

8.7 The present chapter outlines the core principles of monetary valuation used in ecosystem accounting in its application of national accounting concepts for valuation. These principles are articulated to provide a common basis for discussing and interpreting monetary values in ecosystem accounting and to allow the available valuation techniques to be applied appropriately.

8.1.2 Focus of monetary valuation for ecosystem accounting

8.8 Monetary valuation depends on two factors in an accounting context, namely, (a) the definition and scope of goods, services and assets included; and (b) the valuation concept that is used. In ecosystem accounting, the valuation concept applied is the concept of exchange values. As this is the same valuation concept applied in the SNA, it is therefore a concept that supports comparison and integration with national accounts estimates and a range of analytical and indicator applications as noted above.

8.9 As also noted above, the major part of research and policy on environment-related monetary valuation has been conducted with a focus on measuring changes in welfare, for example, as part of cost-benefit analysis. The total economic value framework (Pearce and Turner, 1990) is commonly applied to assess the economic value of ecosystems. It describes the range of direct use values (e.g. biomass harvesting, recreation), indirect use values (e.g. air filtration, water regulation) and non-use values (e.g. existence values of specific species) that are relevant in providing a comprehensive assessment of changes in welfare. Within this range of use and non-use values, it is usual to apply monetary valuation techniques that assess values of changes in welfare most commonly approximated using measures that include consumer and producer surplus.

8.10 Generally, where analysis is focused on the inputs of ecosystems to the production of marketed goods and services (SNA benefits), for example, agricultural production, there is a good alignment between monetary valuations used for accounting and for welfare analysis. However, since values recorded in the accounts exclude consumer surplus, monetary valuation undertaken for the purpose of accounting for ecosystem services that contribute to non-SNA benefits regularly differs from estimates of monetary values obtained in environmental-economic studies, potentially by significant amounts. Further, when considering a more aggregated value of an ecosystem, the monetary values obtained from ecosystem accounts are limited to the coverage of ecosystem services and are lower owing to the exclusion of non-use values.[81] It is therefore important that compilers of accounts document and explain the coverage and conceptual basis for the monetary values being released and that users recognize that not all monetary values are substitutable. In different analytical and decision-making contexts, different monetary values are relevant.

8.11 While there are differences between monetary valuations responding to different analytical purposes, there are theoretical and practical connections between values recorded in the accounts and welfare values. These connections are summarized in appendix A12.1 to support account compilers in their use of non-market valuation methods for ecosystem services (as described in chap. 9) and to build a common language among accountants and environmental economists.

8.12 Further, it is likely that important information can be derived from an understanding of the gap between accounting values and values obtained using alternative valuation concepts and assumptions. In this context, different monetary values can play complementary roles in supporting decision-making. With this in mind and to complement the exchange value-based approach to the monetary valuation of ecosystem services and ecosystem assets described in chapters 8 to 11, a number of complementary approaches to deriving and presenting monetary values concerning the

[81] While non-use values are excluded from values of ecosystem services in SEEA EA, transactions associated with non-use values, such as donations to environmental charities and payments for eco-friendly products, are recorded in the standard economic accounts. Separate identification of these values is not considered in SEEA EA.

environment and links to the economy are introduced in chapter 12. These approaches include the analysis of externalities and the restoration cost-based approach to the valuation of ecosystem degradation.

8.2 Valuation concepts and principles for accounting

8.2.1 Exchange values and market price concepts in national accounting

8.13 In national accounting, the entries in the accounts in monetary terms reflect their exchange values as defined in the SNA. ***Exchange values are the values at which goods, services, labour or assets are in fact exchanged or else could be exchanged for cash*** (2008 SNA, para. 3.118). The present section outlines the related principles from a general national accounting perspective and the following sections describe the application of those principles for ecosystem accounting.

8.14 For the vast majority of entries in the national accounts, exchange values are measured using data from observed transactions involving market prices. ***Market prices are defined as amounts of money that willing buyers pay to acquire something from willing sellers*** (2008 SNA, para. 3.119).[82] The use of observed market prices implies that the accounts embody information on the revealed preferences of the economic units involved.

8.15 The definition of market prices does not incorporate the expectation that the markets in which exchanges take place satisfy specific institutional arrangements or assumptions. The 2008 SNA (para. 3.119) observes that “a market price should not necessarily be construed as equivalent to a free market price; that is, a market transaction should not be interpreted as occurring exclusively in a purely competitive market situation. In fact, a market transaction could take place in a monopolistic, monopsonistic, or any other market structure”. This being the case, the general interpretation in accounting is that market prices should reflect the current institutional context, that is, the current market structures and associated legal or regulatory arrangements. Consequently, from the perspective of economic theory, market prices used in national accounting likely reflect the presence of various market imperfections.

8.16 While the majority of transactions recorded in the national accounts are based on observed market prices, there are several (often large) transactions for which market prices are not observed and therefore need to be estimated. Thus, in the national accounts, where market price-based transactions are not observable, alternative methods are used to estimate them and hence allow aggregation across market and non-market goods and services in the measurement of production and consumption.[83]

8.17 The SNA recommends various approaches, summarized below, and there has been much evolution in terms of practices. At the same time, in applying the SNA recommendations, compilers in different countries must consider their local context and institutional structures. For example, markets for the same good in different countries may be loosely or heavily regulated, and hence different valuation approaches must be applied. However, notwithstanding the variation in institutional contexts and methods, comparison of national accounts estimates across countries is still possible since the market price principle underpins the exchange values recorded in the accounts.

8.18 Two primary alternative methods are described in the SNA related to transactions in goods and services, namely, (a) adjustment of market prices of similar or analogous items for quality and other differences, as required (2008 SNA, para. 3.123); and (b) where no appropriate market exists, derivation of prices of some goods and services based on the amount that it would cost to produce them currently (ibid., para. 3.135).

[82] The 2008 SNA notes a number of cases where actual exchange values do not represent market prices (e.g. in situations involving transfer and concessional pricing (see paras. 3.131–3.134)).

[83] It is to be noted that the use of these alternative methods to estimate exchange values highlights that the estimation of exchange values does not require the actual exchange of money (cash or the equivalent).

8.19 Cost-based techniques are commonly applied in estimating the value of government-supplied services, including education, health and defence. Indeed, they are required in the context of measuring accounting entries for public goods. In these cases, it may be assumed that the amount of expenditure embodies information about the revealed preferences of a country or community. At the same time, it is accepted that these values for public goods will not reflect the full social benefit arising from the provision of those collectively enjoyed services.

8.20 Transactions in assets are valued using the same approaches outlined above, based on observed prices (e.g. sales of land) or using either of the two alternative methods. Exchange values of assets are also required to underpin entries in asset accounts and balance sheets, that is, exchange values for each asset are required at the opening or closing of the accounting period. The ideal source of exchange values for assets at balance sheet dates are prices observed in markets (e.g. market prices at balance sheet date used to value share portfolios). Where there are no directly observable prices from markets, the SNA describes two approaches for estimating the exchange value of an asset. The first is the written-down replacement cost approach, which recognizes that at any given point in its life, the value of an existing asset (most commonly a produced asset such as a building or machinery) is equal to "the current acquisition price of an equivalent new asset less the accumulated depreciation" (2008 SNA, para. 13.23). The second approach entails using "the discounted present value of expected future returns" (ibid., para. 3.137). The second approach is of primary relevance for ecosystem accounting since there are no observable current acquisition prices of ecosystem assets that encompass the range of ecosystem service values supplied by an ecosystem asset.

8.21 As introduced above, entries in the accounts are usually an aggregate of multiple transactions of a specific good or service over an accounting period (e.g. all sales of bread in one year) or an aggregate of multiple assets of a specific type at a balance sheet date (e.g. all trucks registered at 31 December). Further, accounting entries are recorded progressively over multiple accounting periods and balance sheet dates. In this way, time series of accounting entries based on exchange values are compiled for various goods and services and types of assets. All accounting entries are recorded at the respective points in time at their nominal values, that is, the prices applying at the time of the transaction or balance sheet entry.

8.2.2 Monetary valuation of ecosystem services

8.22 Chapter 2 above described the general ecosystem accounting framing in which ecosystem services are supplied by ecosystem assets and where ecosystem assets are established as additional units in a wider accounting system, distinct from standard economic units such as households and businesses. From a national accounting perspective, flows of ecosystem services from ecosystem assets can be conceptualized in two ways. First, ecosystem assets may be considered complex and interacting, producing units that supply outputs of ecosystem services to various users, which reflects the societal benefit perspective described in chapter 2. Alternatively, flows of ecosystem services may be considered analogous to flows of capital services supplied by produced and non-produced assets, as described in chapter 20 of the 2008 SNA (this reflects the asset value perspective described in chap. 2). These two perspectives are reconciled for the purposes of monetary valuation by treating the output of ecosystem assets as producing units as consisting solely of capital services.[84]

8.23 Thus, in concept, ecosystem services should be valued for accounting purposes in a manner aligned with the valuation of capital services in the SNA. This value is different from the rentals that would be charged following the definitions in the 2008

[84] It is to be noted for the purpose of clarification that the output associated with the use of ecosystem services (for example, rice production) is recorded in the accounting system distinctly as the output of an economic unit. This economic unit has intermediate, labour and capital costs that are deducted from output, resulting in measures of gross value added and gross operating surplus that are different from output.

SNA (para. 6.245). By way of example, the rentals paid by a tenant to a landlord cover the capital services provided by the dwelling[85] as well as the direct operating costs (e.g. management and maintenance costs). Output is therefore measured in terms of the rentals charged to the tenant and the direct costs must be deducted in order to determine the value of the capital services and, equivalently, the gross operating surplus.

8.24 Analogously, in ecosystem accounting, ecosystem services are distinguished from the benefits to which they contribute, and consequently the focus of valuation is on the contribution of the ecosystem asset (i.e. the input of ecosystem services) and not on the valuation of the benefits.[86] For example, in the valuation of ecosystem services associated with agricultural production, the direct operating and input costs associated with producing an agricultural output (e.g. rice), including fuel, fertilizer, labour and produced assets, must be deducted from the value of the output to isolate the value of the ecosystem services.

8.25 For each final ecosystem service, a single capital service flow between an ecosystem asset and an economic unit can be envisaged. Further, since there are multiple supply contexts (e.g. air filtration services may be supplied by different ecosystem assets) and different combinations of users (e.g. air filtration services may be used by both households and local building owners), it may be the case that a variety of different capital service flows would need to be recorded for the same type of ecosystem service. This would include, for example, the potential recording of imports and exports of ecosystem services.

8.26 More significantly, it is usual for a single ecosystem asset to supply a bundle of ecosystem services. Following the definitions and principles for measuring ecosystem services in physical terms set out in chapter 6, separate transactions should be recorded for each type of service supplied to each type of user. This approach therefore assumes the separability of ecosystem services. In practice, if bundles of services cannot be clearly separated, it is appropriate to value the bundle as a whole and then apply appropriate allocation methods, which would help to reduce the potential for double counting of services.

8.27 In applying national accounting principles to accounting for ecosystems, particularly in the context of the monetary valuation of ecosystem services, it must be recognized that ecosystem services lie outside the production boundary that defines the scope of measured GDP. Undertaking the valuation of ecosystem services using national accounting valuation principles thus complements but does not replace current national accounting estimates.[87] In this respect, the valuation of ecosystem services is analogous to the compilation of estimates of the value of unpaid household work where such estimates can be compared with but do not replace values from the standard national accounts.

8.28 Using a reference to the current production boundary of the SNA, two valuation contexts can be distinguished. First, in some cases, flows of ecosystem services are inputs to the production of goods and services within the SNA production boundary, i.e. SNA benefits. In these cases, the values of ecosystem services are implicitly embodied within values of goods and services recorded in the national accounts. Examples include ecosystem services that contribute to agricultural output, such as biomass provisioning services and pollination by wild bees. Monetary valuation therefore involves partitioning the values of the goods and services recorded in the national accounts to reveal the ecosystem contribution.[88] The ecosystem service is then recorded as an output of the ecosystem asset and an input of the economic unit that uses the ecosystem service. In a system-wide context, value added is unaffected by the recording of this transaction, but both total outputs and total inputs are increased.

85 These are commonly referred to as “user costs” and include both the consumption of fixed capital and the return on investment (opportunity cost) of the relevant asset.

86 The selection of terms to convey the meaning of the relevant concepts can be difficult. Here, the term “benefits” is used to reflect the concept of output (rentals) and it is not intended for this term to be considered within the context of a description of the outcomes or well-being associated with economic activity.

87 It is to be noted that the production boundary of the SNA may change in the future.

88 In these contexts, the ecosystem contribution may encompass both final ecosystem services and intermediate services, while it is recognized that the values of intermediate services will themselves be embodied in the value of the associated final ecosystem service.

8.29 Second, in other cases, ecosystem services contribute to benefits received by economic units, including households and governments that are not within the SNA production boundary, i.e. non-SNA benefits. For example, air filtration services of forests contribute to cleaner air whose value is not included in national accounts measures of output. In this case, estimating the accounting entries based on exchange values requires (a) determining the prices that would be charged on behalf of the ecosystem asset for the ecosystem services if a market existed; (b) estimating the costs of obtaining an ecosystem service that would need to be incurred by an economic unit to secure the benefits; or (c) assessing the loss of benefits to an economic unit that would be incurred if ecosystem services were lost.

8.30 In practice, the valuation methods used to estimate market prices in the national accounts, which were summarized in the previous section, can be applied to ecosystem services and assets. In particular, where there are links to SNA benefits, the market prices associated with those benefits provide a clear point of departure for valuation. For ecosystem services that contribute to non-SNA benefits, the market price equivalent and cost-based methods noted previously may also be used. Additional methods are available as well to address the range of ecosystem services and valuation contexts. Section 9.3 describes the appropriate valuation methods for estimating market price-based exchange values for the compilation of monetary ecosystem accounts.

8.31 Further, in the application of all valuation methods, it is necessary to consider the range of different contexts that may apply with respect to the supply and use of each ecosystem service across an EAA such as a country. Since market prices are unlikely to be estimated for all transactions in ecosystem services, it would be necessary to apply value transfer techniques that take into consideration variations across location, including institutional context and ecosystem type. Section 9.5 discusses the use of value transfer techniques for ecosystem accounting.

8.32 Since the monetary values of ecosystem services are estimated using the exchange value concept and are recorded in the same currency units, it is possible to sum across ecosystem services to derive aggregated measures. Such measures are described in section 9.2.

8.2.3 Monetary valuation of ecosystem assets

8.33 Ecosystem accounting also incorporates recording of entries for ecosystem assets based on their exchange values, together with associated changes in the value of ecosystem assets over an accounting period. These changes include ecosystem enhancement, ecosystem degradation and ecosystem conversions and revaluations. The present section provides a framing for the valuation of ecosystem assets in monetary terms for ecosystem accounting. Definitions of the terms for changes in ecosystem assets, including ecosystem degradation, are presented in chapter 10 and the approach to the valuation of those changes is outlined in appendix A10.1.

8.34 The ecosystem assets that are the focus of monetary valuation are delineated following the guidance on spatial units and measurement of ecosystem extent as provided in chapters 3 and 4, respectively. To explain the valuation of ecosystem assets, the initial focus is on a single ecosystem asset of a given ecosystem type (e.g. oceanic cool temperate rainforests (IUCN GET, class T2.3)). An ecosystem asset is considered to supply a number of ecosystem services (e.g. timber provisioning services, air filtration services and recreation-related services) to different users (e.g. businesses, households and government). Each ecosystem asset has its own distinct capacity to supply ecosystem services that is not only closely linked to its extent and condition but also linked to existing and expected patterns of ecosystem management and use, and to the influence of wider environmental factors such as climate change and extreme events.

8.35 An NPV approach to valuing ecosystem assets has been adopted for ecosystem accounting. ***NPV is the value of an asset determined by estimating the stream of income expected to be earned in the future and then discounting the future income back to the present accounting period*** (SEEA Central Framework, para. 5.110). In ecosystem accounting, this approach is applied by aggregating the NPV of expected future returns for each ecosystem service supplied by an ecosystem asset. The use of an NPV approach implies that the value of an ecosystem asset is related to its capacity to supply ecosystem services and how that capacity is expected to change in the future. Capacity and expected changes in capacity also provide information on the expected life of the ecosystem asset. If the use of ecosystem services derived from an ecosystem asset is considered sustainable (i.e. if there is no expected decline in condition), then the asset's life will be infinite.

8.36 Application of the NPV approach requires measurement of the expected future returns for each ecosystem service and application of a discount rate so that those future returns can be expressed in current period values. The selection of a discount rate can have a large effect on estimated monetary values (see chap. 10 for a dedicated discussion on this topic).

8.37 There are a number of factors to be considered in measuring expected future returns, which are described in more detail in chapter 10. These include (a) scope of the returns (i.e. the number of ecosystem services to be included); (b) future patterns of flows in physical terms of each ecosystem service, taking into consideration expected degradation and patterns of demand; (c) expected future prices for each ecosystem service; (d) expected institutional arrangements; and (e) expected asset life. Together with the discount rate, all of these factors are combined to yield an estimated NPV for each ecosystem service at a given point in time. The NPV of the ecosystem asset is equal to the sum of those estimated ecosystem services NPVs.

8.38 Description of the NPV approach at the level of an individual ecosystem asset assumes that data are available that can attribute the supply of ecosystem services to this level of detail and hence that variations in context and location can be taken into account. In practice, it may not be possible to undertake valuation at this scale and valuation by ecosystem type may be undertaken instead. While the same theory and approach applies at more aggregated scales, it is necessary to ensure that variations between contexts and location are considered, including changes in institutional context. Those variations may impact the appropriateness of valuation methods and assumptions and on the way in which value transfer techniques can be applied. For example, where measurement is undertaken for all woodlands within a country, the value of recreation-related services provided by those woodlands should take into consideration the variations in distance from population centres.

8.39 Further, as in the case of monetary valuation of ecosystem services, this approach assumes that the expected future returns for each ecosystem service are separable. Nonetheless, it is recognized that since there is a bundle of services from a single ecosystem asset, determining the expected future flows for each service requires consideration of the relationships among ecosystem services. Thus, factors influencing the future supply of one ecosystem service are linked to the future supply of other ecosystem services and expected patterns in the use of some ecosystem services will have direct implications for the potential availability of other ecosystem services. For example, regular use of a forest for harvesting timber will likely reduce the supply of global climate regulation services from the same forest. These considerations apply as well across ecosystem assets, which also have relationships with each other.

8.40 The application of the NPV approach does not require any assumption concerning the economic ownership of the ecosystem asset itself. Such an assumption is required only when monetary values are being integrated into the standard sequence of institutional sector accounts, a step described in chapter 11. Nonetheless, there is often interest in understanding the relationship between ecosystem asset values and economic ownership of associated spatial areas, particularly land. This relationship can be analysed through utilization of data from the ecosystem extent account and associated data on landownership and land tenure.

8.41 For some ecosystem assets, primarily anthropogenic ecosystem types such as cropland and urban areas, there are active property markets that reveal prices for these areas. Generally, those prices will not incorporate all ecosystem services supplied from that property and therefore they should not be used directly to value an ecosystem asset. At the same time, it is likely that for certain ecosystem services, particularly provisioning services, there is a correlation between the market prices of properties (or the associated rental prices) and the prices of the associated ecosystem services. Valuation methods that utilize this type of market information are described in chapter 9.

8.42 Besides offering guidance on the valuation of ecosystem assets at balance sheet dates, chapter 10 provides recommendations on valuing other ecosystem accounting entries such as ecosystem enhancement, ecosystem degradation, ecosystem conversions, other changes in the volume of ecosystem assets (including catastrophic losses) and revaluations.

8.43 While there are complexities associated with the measurement of ecosystem asset values and changes in values in monetary terms, the underlying accounting logic is consistent with that used in the SNA and the SEEA Central Framework with respect to the valuation of natural resources such as timber and mineral and energy resources. The general principles are also aligned with those used in the measurement of the capital stock of produced assets as described in the SNA. Consequently, compilers familiar with the valuation of natural resources and the implementation of perpetual inventory models should recognize many of the requirements in relation to the valuation of ecosystem assets.

8.2.4 Volume and price measures

8.44 The analysis of nominal values (i.e. estimates expressed in prices of the accounting period) can be of interest, for example, in understanding the relative structure of consumption or production, or in comparing levels of expenditure to budget and fiscal constraints. In addition, for many analytical purposes, it is standard practice to separate (or decompose) changes in accounting entries recorded at two points in time into changes associated with price and those associated with changes in volumes, reflecting both changes in quantity and quality.[89] Following decomposition, a time series is derived that excludes the effects of price changes, that is, a time series of changes in volumes. These estimates are commonly referred to as constant price measures.[90]

8.45 Since prices for most ecosystem services are not observable, standard practices for estimating price and volume measures, which rely on the use of price indexes, cannot be applied. A particular consideration may involve the extent of spatial variation in prices for ecosystem services. While other techniques might be considered, at this stage, it is not recommended that compilers aim towards developing volume estimates of ecosystem services and ecosystem assets that can be aligned with estimates in the national accounts.

[89] The term "volume" is used in accounting since for many goods, services and assets, changes may be due to changes in quality, in addition to changes in quantity and price. In accounting, volume reflects this combination of quantity and quality.

[90] There is an extensive literature on the theory of index numbers and their application to accounting. The core elements are described in chap. 15 of the 2008 SNA.

8.46 At the same time, since much economic analysis is undertaken using data that exclude price effects, it may be relevant to adjust the aggregate nominal values of ecosystem services and ecosystem assets using a general measure of economy-wide price change, such as the consumer price index or the GDP deflator. The resulting estimates are commonly referred to as “real measures” in the national accounting literature.

Chapter 9
Accounting for ecosystem services in monetary terms

9.1 Introduction

9.1 Recording monetary values for ecosystem services underpins the compilation of two of the ecosystem accounts: the ecosystem services flow account in monetary terms and the monetary ecosystem asset account. The present chapter describes the ecosystem services flow account in monetary terms as well as approaches to the valuation of ecosystem services for ecosystem accounting, applying the principles described in chapter 8.

9.2 The ecosystem services flow account in monetary terms records the monetary value of flows of ecosystem services based on their exchange values. The data from this account can be used to understand the relative economic significance of different ecosystem services (within the valuation framing of the national accounts); support aggregation of ecosystem services for the purpose of comparing the role of different ecosystem assets; understand changes in monetary value over time; underpin comparison of the inputs of different ecosystem services to different users; and support understanding of the role of ecosystem services in different locations, for example, across countries. In addition, the use of exchange values in an accounting context requires drawing clear links between the supply of ecosystem services and the users of ecosystem services. Establishing these links can highlight both the economic costs arising from the loss of ecosystem services and the role of government as a provider of public goods.

9.3 While the monetary values described in this chapter can fulfil a range of analytical needs, the valuation approach applied in ecosystem accounting does not provide a comprehensive measure of the value of nature. Further, the aggregate monetary values discussed here likely reflect a subset of all ecosystem services, since common practice is to commence work on valuation by compiling estimates for a limited number of ecosystem services. Further, as described in section 8.1.2, monetary values based on exchange values exclude measures of consumer surplus that may be of analytical interest in some contexts. Chapter 12 considers complementary approaches to valuation.

9.4 Entries in the ecosystem services flow account in monetary terms are recorded in line with the definitions, treatments and measurement boundaries for ecosystem services in physical terms described in chapters 6 and 7. Key features of those treatments are discussed in section 9.2. As noted in chapter 8, the monetary valuation of ecosystem services requires the use of various valuation methods since, in many cases, prices for ecosystem services cannot be observed on markets. There is a wide range of environmental valuation methods that have been developed, but not all are suitable for application in an accounting context. Section 9.3 summarizes and prioritizes the methods that can be applied and section 9.4 introduces the ways in which different methods can be applied for different types of services. Section 9.5 introduces the topic of value transfer, which constitutes an important step in the compilation of monetary values for ecosystem services at larger scales, since it is unlikely that prices for all ecosystem services in all locations can be estimated directly.

9.2 Ecosystem services flow account in monetary terms

9.5 Estimates of the monetary value of ecosystem services are recorded in the ecosystem services flow account in monetary terms. This account follows the structure of an SUT and has the same underlying structure as the ecosystem services flow account in physical terms described in chapter 7. An SUT format is used to record flows of different types of ecosystem services between ecosystem assets and economic units. The physical and the monetary accounts should exhibit consistency in terms of the structure, classification and labelling of the various components (e.g. of ecosystem services and ecosystem assets).

9.6 The set of ecosystem services included in the monetary ecosystem services flow account should generally align with the set of ecosystem services included in the physical ecosystem services flow account. However, as it is possible that some flows of ecosystem services are considered more difficult to value in monetary terms, the number of ecosystem services included in monetary terms may be smaller.

9.7 It is important that compilers document the scope of the ecosystem services included in the accounts and highlight ecosystem services that have been excluded from the scope of measurement and valuation. This is required so that users of the accounts can readily understand and interpret the aggregate measures of the monetary value of ecosystem services. Further, such documentation also reinforces that data on ecosystem services in physical terms remain relevant for decision-making.

9.8 The basic framing of a monetary ecosystem services flow account is illustrated in tables 9.1a and 9.1b. The primary scope of the account is determined by the set of ecosystem assets located within the EAA. Those assets are considered the suppliers of the ecosystem services. The set of users included in the account consists of different types of SNA economic units (i.e. businesses, governments, households) that are resident in the EAA. In addition, the use table allows for recording use by non-resident economic units (i.e. those economic units that are resident outside the EAA);[91] and use by other ecosystem assets (i.e. flows of intermediate services). This scope of users is required to ensure that the supply of ecosystem services by resident ecosystem assets can be fully allocated.

9.9 Flows of intermediate services must be recorded as part of a chain of flows that results in a final ecosystem service, following the guidance provided in chapter 7, namely, that intermediate services are inputs used by ecosystem assets to supply final ecosystem services. In monetary terms, the total supply of ecosystem services (recorded in table 9.1a) is increased through recording of flows of intermediate services. This is offset by recording use of ecosystem services by ecosystem assets (in table 9.1b) as distinct from entries pertaining to final ecosystem services that are used by economic units. There is no double counting that results from recording intermediate services in this way. It is to be noted that, in a given chain of flows, the ecosystem type recorded as using the intermediate service should also be the ecosystem type recorded as supplying the related final ecosystem service.

9.10 The supply and use framework also allows for the recording of the use of ecosystem services by resident economic units in cases where those services are supplied by ecosystem assets that are located outside the EAA. For example, members of resident household units may travel to other countries and receive cultural ecosystem services

[91] The definitions of "resident economic units" and "non-resident economic units" follow the definition and treatments in the SNA and the *Balance of Payments and International Investment Position Manual*, 6th ed. In broad terms, an economic unit is determined to have residency in a given economic territory if it has a centre of economic interest in that territory.

in those countries, and resident economic units may receive regulating services such as flood control services that reflect contributions from ecosystem assets outside their EAA. These are recorded in table 9.1a in the column with the heading "Supply from non-resident ecosystem assets – imports". Chapter 7 provides an extended discussion on treatments related to exports and imports of ecosystem services.

9.11 The entries recorded in the SUT should be based on the exchange value concept, apply a common currency unit and pertain to a single accounting period in which accounting entries are recorded in the prices of that period (i.e. nominal values). Separate SUTs can be compiled for different accounting periods for the purpose of recording a time series for ecosystem services flows.

9.12 Generally, entries recorded in the monetary ecosystem services flow account should correspond directly to those recorded in the physical ecosystem services flow account described in chapter 7. Thus:

- The definition and measurement scope of each ecosystem service is the same as in the PSUT, including the treatment and recording of intermediate services, imports and exports of ecosystem services, subsistence production of agricultural and related products and abiotic flows.
- The flow recorded in physical terms should be consistent with the entry in monetary terms; i.e. examination of the accounts in physical and monetary terms should support a coherent picture of supply and use of ecosystem services.
- Allocation of ecosystem services supply to the various users of ecosystem services should be consistent with allocation in the PSUT. It is to be noted that the user should not be determined on the basis of choice of valuation method.
- The accounting period should be the same as that for the PSUT.

9.13 Generally, accounting entries for each ecosystem service are obtained by multiplying a measure of the service flow in physical terms by a price estimated using an appropriate method chosen from among those described in section 9.3 below. However, since it is common for data not to be available for all transactions, it becomes necessary to estimate values for ecosystem services using value transfer techniques, which account for differences in environmental and socioeconomic contexts. The use of value transfer techniques involves a range of assumptions concerning the variation of prices of ecosystem services in different locations. Relevant issues concerning these techniques are discussed in section 9.5.

9.14 Where the accounting entry is measured directly rather than by using separate price and quantity estimates, an estimate of the corresponding flow in quantitative terms should still be included in the PSUT. This serves to maintain coherence in the accounting system and supports assessment of changes in the ecosystem asset, including, for example, ecosystem degradation.

9.15 Since entries in monetary terms are in a common currency and are measured using the common value concept of exchange values, it is possible to derive aggregate measures of ecosystem services, for example, for a bundle of ecosystem services supplied by an ecosystem type (e.g. all ecosystem services supplied by forests within an EAA) or for a bundle of ecosystem services used by an industry (e.g. ecosystem services used by the fishing industry). It is to be noted that the total value of all final ecosystem services supplied by ecosystems within an EAA includes exports of those services.

Table 9.1a
Ecosystem services supply and use account in monetary terms – supply table

SUPPLY		Economic units														Total supply by economic units	Ecosystem type (based on the EFG level 3 of IUCN GET)																		Total supply by resident ecosystem assets	Supply from non-resident ecosystem assets - Imports	Total supply by ecosystem assets	TOTAL SUPPLY
		Industries									Total industry	Government consumption	Household consumption	Total supply by resident economic units	Supply by non-resident economic units – Imports		Terrestrial												Freshwater			Marine						
																	T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
Ecosystem services (reference list)		Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries							T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	…	T2.6 Temperate pyric sclerophyll forests and woodlands	…	…	…	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	…	FM1.3 Intermittently closed and open lakes and lagoon	M1.1 Seagrass meadows	…	MFT1.3 Coastal saltmarshes and reedbeds				
Provisioning services																																						
Biomass provisioning	Crop provisioning																																					
	Grazed biomass provisioning																																					
	Livestock provisioning services																																					
	Aquaculture provisioning services																																					
	Wood provisioning services																																					
	Wild fish and other natural aquatic biomass provisioning services																																					
	Wild animals, plants and other biomass provisioning services																																					
Genetic material services																																						
Water supply																																						
Other provisioning services																																						
Regulating and maintenance services																																						
Global climate regulation services																																						
Rainfall pattern regulation services																																						
Local (micro and meso) climate regulation services																																						
Air filtration services																																						

Table 9.1a
Ecosystem services supply and use account in monetary terms – supply table (*continued*)

SUPPLY	Economic units														
	Industries														
Ecosystem services (reference list)	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	**Total industry**	Government consumption	Household consumption	**Total supply by resident economic units**	Supply by non-resident economic units – Imports	**Total supply by economic units**
Soil quality regulation services															
Soil and sediment retention services															
Solid waste remediation services															
Water purification services															
Water flow regulation services															
Flood control services															
Storm mitigation services															
Noise attenuation services															
Pollination services															
Biological control services															
Nursery population and habitat maintenance services															
Other regulating and maintenance services															
Cultural services															
Recreation-related services															
Visual amenity services															
Education, scientific and research services															
Spiritual, artistic and symbolic services															
Other cultural services															
TOTAL SUPPLY															

SUPPLY	Ecosystem type (based on the EFG level 3 of IUCN GET)																						
	Terrestrial												Freshwater			Marine							
	T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
Ecosystem services (reference list)	T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	…	T2.6 Temperate pyric sclerophyll forests and woodlands	…	…	…	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	…	FM1.3 Intermittently closed and open lakes and lagoon	M1.1 Seagrass meadows	…	MFT1.3 Coastal saltmarshes and reedbeds	**Total supply by resident ecosystem assets**	Supply from non-resident ecosystem assets - Imports	**Total supply by ecosystem assets**	TOTAL SUPPLY
Soil quality regulation services																						
Soil and sediment retention services																						
Solid waste remediation services																						
Water purification services																						
Water flow regulation services																						
Flood control services																						
Storm mitigation services																						
Noise attenuation services																						
Pollination services																						
Biological control services																						
Nursery population and habitat maintenance services																						
Other regulating and maintenance services																						
Cultural services																						
Recreation-related services																						
Visual amenity services																						
Education, scientific and research services																						
Spiritual, artistic and symbolic services																						
Other cultural services																						
TOTAL SUPPLY																						

Note: The list of ecosystem services presented is indicative only.

Table 9.1b
Ecosystem services supply and use account in monetary terms – use table

USE	Economic units															Ecosystem type (based on the EFG level 3 of IUCN GET)																					
	Industries															Terrestrial												Freshwater			Marine						
																T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
Ecosystem services (reference list)	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	Total industry	Government consumption	Household consumption	Total use by resident economic units	Exports - final ecosystem services	Total use by economic units	T1.1 Tropical-subtropicalowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	… …	T2.6 Temperate pyric sclerophyll forests and woodlands	… …	… …	… …	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	… …	FM1.3 Intermittently closed and open lakes and lagoons	M1.1 Seagrass meadows	… …	MFT1.3 Coastal saltmarshes and reedbeds	Total use by resident ecosystem assets	Exports – intermediate services	Total use by ecosystem assets	TOTAL USE
Provisioning services																																					
Biomass provisioning – Crop provisioning																																					
Grazed biomass provisioning																																					
Livestock provisioning services																																					
Aquaculture provisioning services																																					
Wood provisioning services																																					
Wild fish and other natural aquatic biomass provisioning services																																					
Wild animals, plants and other biomass provisioning services																																					
Genetic material services																																					
Water supply																																					
Other provisioning services																																					
Regulating and maintenance services																																					
Global climate regulation services																																					
Rainfall pattern regulation services																																					
Local (micro and meso) climate regulation services																																					

Table 9.1b
Ecosystem services supply and use account in monetary terms – use table (*continued*)

USE	Economic units															Ecosystem type (based on the EFG level 3 of IUCN GET)																					
	Industries															Terrestrial												Freshwater			Marine						
																T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
Ecosystem services (reference list)	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	Total industry	Government consumption	Household consumption	Total use by resident economic units	Exports - final ecosystem services	Total use by economic units	T1.1 Tropical-subtropicalowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	… …	T2.6 Temperate pyric sclerophyll forests and woodlands	… …	… …	… …	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	… …	FM1.3 Intermittently closed and open lakes and lagoons	M1.1 Seagrass meadows	… …	MFT1.3 Coastal saltmarshes and reedbeds	Total use by resident ecosystem assets	Exports – intermediate services	Total use by ecosystem assets	TOTAL USE
Air filtration services																																					
Soil quality regulation services																																					
Soil and sediment retention services																																					
Solid waste remediation services																																					
Water purification services																																					
Water flow regulation services																																					
Flood control services																																					
Storm mitigation services																																					
Noise attenuation services																																					
Pollination services																																					
Biological control services																																					
Nursery population and habitat maintenance services																																					
Other regulating and maintenance services																																					
Cultural services																																					
Recreation-related services																																					
Visual amenity services																																					
Education, scientific and research services																																					
Spiritual, artistic and symbolic services																																					
Other cultural services																																					
TOTAL USE																																					

Note: The list of ecosystem services presented is indicative only.

9.16 The structure of table 9.1a suggests that the supply of each ecosystem service is presented by ecosystem type. Most commonly in practice, as discussed in chapter 6, flows of several ecosystem services are measured spatially using ecosystem modelling and geospatial data techniques, as introduced in chapter 7. Consequently, the presentation in the supply table implies the attribution of ecosystem service flows to ecosystem type (e.g. by overlaying maps of individual ecosystem service supply with a map of extent by ecosystem type). Further, where a spatial approach is applied, it is possible to disseminate maps of different ecosystem services showing where they are supplied within an EAA as complementary outputs to the ecosystem services supply table. It should be noted that compilation of maps with data in monetary terms requires a clear articulation of the approach that is taken to estimating prices for ecosystem services across the EAA.

9.17 Aggregate measures of ecosystem services in monetary terms can be derived by summing across columns (i.e. to estimate total supply or use of a single service) and by summing downrows (i.e. to estimate total supply by an ecosystem type or total use by type of economic unit). Aggregate measures may be of particular interest when making comparisons to measures of output, intermediate consumption and value added in the standard national accounts, including at an industry level (e.g. for agriculture).

9.18 Using a focus on the total contribution of ecosystem assets within an EAA, such as a country, the aggregate measure ***gross ecosystem product (GEP) is equal to the sum of all final ecosystem services at their exchange value supplied by all ecosystem types located within an EAA over an accounting period less the net imports of intermediate services***.[92] In cases where net imports of intermediate services, that is, imports less exports of intermediate services (see sect. 7.2.6), are small, GEP may be assumed to be the sum of final ecosystem services supplied by the EAA.

9.19 The scope of GEP covers ecosystem services, including provisioning, regulating and maintenance and cultural services, and excludes the monetary value of abiotic flows, spatial functions and non-use values. More generally, the monetary value of abiotic flows and spatial functions should be excluded from monetary aggregates concerning ecosystem assets, for example, in the monetary ecosystem asset account. While they are excluded from monetary aggregates, abiotic flows and spatial functions can still be recorded in SUTs in both physical and monetary terms.

9.20 Completing the entries in the use table (table 9.1b) does not require recording the location of the user, that is to say, it is sufficient to record the type of economic unit, whether the unit is resident or non-resident, and the relevant class (e.g. type of industry). Nonetheless, the location of users relative to the location of the supplying ecosystem asset needs to be known so as to ensure that the estimation of prices is aligned with the spatial context.

[92] This definition of GEP reflects a production-based approach (i.e. outputs less inputs) to determining the contribution of the ecosystems of an EAA to benefits and well-being. It is also to be noted that (a) supply of final ecosystem services includes exports to non-resident economic units; and (b) imports of final ecosystem services are not included in this measure as they represent contributions by ecosystems located in other EAAs. The measure is "gross" in the sense that it does not deduct any associated ecosystem degradation arising in the supply of the services. Measurement of GEP has been actively pursued in China (see, for example, Ouyang and others (2020)).

9.3 Techniques for valuing transactions in ecosystem services

9.3.1 Introduction

9.21 Section 8.2 describes the conceptual basis for valuing ecosystem services for ecosystem accounting. Since prices for ecosystem services are not generally observed, a range of methods have been developed for estimating them. The present section describes methods that support the derivation of prices for ecosystem services that are consistent with exchange values and can therefore be used to provide estimates for entry into the accounts.

9.22 This section describes those methods in order of preference, indicating those that are considered to align most closely to the target valuation concept of market prices. For accounting purposes, there is a strong preference for using methods that translate observable and revealed prices and costs (i.e. for related or similar goods and services) into the values required for accounting purposes.

9.23 The general advice of the SNA (chap. 3) is that where directly observed market prices are not available, they may be estimated by using prices from similar or related markets or by using costs of production. Following a similar framing, it is recommended that choice of the type of valuation methods to be applied be made according to the following order, from highest to lowest preference.

(a) Methods where the price for the ecosystem service is directly observable;

(b) Methods where the price for the ecosystem service is obtained from markets for similar goods and services;

(c) Methods where the price for the ecosystem service is embodied in a market transaction;

(d) Methods where the price for the ecosystem services is based on revealed expenditures (costs) for related goods and services;

(e) Methods where the price for the ecosystem service is based on expected expenditures or expected markets.

9.24 The various methods across these five groups are described below. In addition, some other methods that have been applied in environmental valuation contexts are briefly summarized, but they are not recommended for use in an SEEA EA context without appropriate adjustment so as to align results with the exchange value concept. In all situations, the documentation of the data sources, methods and assumptions used should be made publicly available.

9.25 Some methods are more suited to the valuation of certain ecosystem services than others. For example, it is more likely that exchange values for provisioning services can be estimated based on observed market transactions. The matching of methods to different types of ecosystem services is considered further in section 9.4 and discussed in more detail in the Monetary Valuation of Ecosystem Services and assets for Ecosystem Accounting (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022b).

9.26 The valuation methods described in this section have been developed in the context of valuing final ecosystem services, that is, with a focus on the contribution of ecosystems to economic and human activity. Where intermediate services are recorded, the same valuation methods can be applied since the intent remains to measure the contribution of the ecosystem to economic and human activity. For example, where flows of pollination services are recorded as inputs to biomass provisioning services, both of these types of services can be valued in terms of their contribution to the associated agricultural output.

9.27 In an SEEA EA context, the aim is to record entries in the accounts for multiple ecosystem services across multiple ecosystem types. In principle, aggregation across ecosystem services and ecosystem types is possible even where different valuation methods are used, provided that the different methods are focused on applying the same target valuation concept. This principle is also applied in the national accounts to aggregate across market and non-market goods and services.

9.3.2 Methods where prices are directly observable

9.28 **Directly observed values**. The most direct method for measuring prices and estimating values for the accounts is based on the direct observation of exchanges in ecosystem services when they are available. For example, if a wetland provides services of water purification and the owners or managers of that wetland are able to charge the water company that abstracts the water for municipal uses, there occurs a transaction in ecosystem services provided by the ecosystem that can be recorded. Stumpage values charged to timber logging businesses are also an example of directly observed values. Land rental prices in agriculture where markets exist for renting land for crop production or grazing are another example of directly observed values. Those rental prices may be used to derive prices for accounting purposes for the relevant biomass provisioning services. In all of these examples, there is a direct link to SNA benefits.

9.29 While the use of directly observed values is the method that is most preferred, the resulting prices may provide accounting entries for the value of ecosystem services that might be considered low, i.e., where the monetary value of the contribution of the ecosystem is considered negligible. It is fundamental to recognize that this result is most likely a reflection of existing institutional arrangements and is a result that is well understood in the economic literature. For example, it is well documented that the resource rents for natural resources that are extracted in open-access contexts tend to zero (Hartwick and Olewiler, 1998).[93]

9.30 Nonetheless, provided that the prices reflect institutional arrangements that are sufficiently mature and large, the resulting prices should still be applied in ecosystem accounting since the core intent is to show accounting entries that reflect the established market context and hence support analysis of the prices relative to those of other services and assets. To the extent that the recorded values are considered low, there may then be an interest in estimating complementary values on the basis of alternative institutional contexts and market settings. These hypothetical values should not be recorded in ecosystem accounts but may be presented in complementary accounts (see chap. 12).

9.31 Prices may also be observed in relation to non-SNA benefits. For example, payments for ecosystem services may provide a direct measure of the value of those services. This is true in certain circumstances, and the payments made, for example, by a government agency to a land manager, would embody an appropriate price for a particular service for accounting purposes. However, most commonly, payments for ecosystem services and the associated institutional mechanisms are not designed to reveal prices for specific services. Instead, they are aimed at either supporting land managers in undertaking ecosystem restoration work or similar practices or implementing broader government social policies, for example, concerning income support. Generally, the advice is not to use data from payments for ecosystem services schemes in the estimation of prices for ecosystem services, unless there is clear evidence that the scheme targets a specific service.

9.32 Specific markets are associated with observed prices from emission trading systems, which may be used to estimate prices for global climate regulation services based on carbon retention. The number of countries with such trading systems is increasing, as is the quantity of carbon being traded, and therefore those markets may provide suitable price data.[94] If the trading system is considered to be insufficiently mature, an alternative is to use data on the marginal costs of abatement, which are more widely available,[95] or data on the social cost of carbon when derived from models that are consistent with the exchange value concept, that is, limited to assessment of the effects on measures of output.

93 An assumption made here is that there is an increasing scarcity of the underlying resource. Where there is no such scarcity, a low or zero price would be appropriate.

94 Ideally, the observed price from the emission trading system should be adjusted to take into account the impact that inclusion of removals of carbon by the forestry sector would have on price. The depth and maturity of those markets should also be considered in these contexts.

95 As these costs vary by sector, the highest cost should be taken as the overall marginal cost of abatement.

9.33 It is to be noted that the SNA does not require that prices originate from competitive markets; for example, transactions based on prices from monopolistic or oligopolistic markets are recorded in the national accounts without adjustment. However, where directly observed prices are considered not economically significant[96] (such cases may arise in the context of fees paid to enter a national park, for example), the observed price should not be used and alternative valuation methods should be applied. Further, care should be taken to understand the size of markets and their maturity. The use of prices from small or immature markets may not be sufficiently representative for use in ecosystem accounting.

9.3.3 Methods where prices are obtained from markets for similar goods and services

9.34 **Prices from similar markets.** When market prices for a specific ecosystem service are not observable, valuation according to market price equivalents may provide an approximation to market prices. Following the SNA (para. 3.123), "[g]enerally, market prices should be taken from the markets where the same or similar items are traded currently in sufficient numbers and in similar circumstances. If there is no appropriate market in which a particular good or service is currently traded, the valuation of a transaction involving that good or service may be derived from the market prices of similar goods and services by making adjustments for quality and other differences".

9.35 For example, when non-wood forest products (e.g. mushrooms) from one forest are marketed but those from a similar forest are not, the prices observed in the former case can be used to value the non-wood forest products in the latter case, allowing for differences between products and other factors. In applying this method, the price of the marketed product would need to be adjusted for any costs incurred in supplying that product in order to ensure that the derived price corresponds to the ecosystem service. It is assumed implicitly that the flows of (non-marketed) ecosystem services (in this example, harvest of mushrooms) are not significant enough to alter the observed price of and demand for the good or service from the similar market. It is to be noted that prices from similar markets reflect prices within the existing institutional context in the same way that they do when the directly observed values method is applied.

9.3.4 Methods where prices (and associated values) are embodied in market transactions

9.36 **Residual value and resource rent methods.** The residual value and resource rent methods[97] estimate a value for an ecosystem service by taking the gross value of the final marketed good to which the ecosystem service provides an input and deducting the cost of all other inputs, including labour, produced assets and intermediate inputs (see the formula below, taken from table 5.5 of the SEEA Central Framework). Depending on the scope of the data (whether pertaining, for example, to a specific location or to the activities of an industry as a whole), the estimated residual value provides a direct value that can be recorded in the accounts or used to derive a price that may be applied in other contexts. The relevant considerations in deriving a price are described in the Central Framework (appendix A5.1).

9.37 In practice, there can be a number of difficulties in applying these methods. First, as the residual may reflect a combination of other non-paid and indirect inputs, distinguishing the ecosystem service contribution may be difficult. Second, the estimates are subject to errors that arise in calculating the value of all of the "paid" inputs. Third, the size of the residual is directly affected by the institutional arrangements surrounding

96 Consideration of the relative significance of prices in the 2008 SNA is reflected in the following statement (para. 22.28): "Economically significant prices are prices that have a significant effect on the amounts that producers are willing to supply and on the amounts purchasers wish to buy."

97 While similar in intent, there is a distinction to be made between these methods. The resource rent method reflects an aggregate value of rent in a given circumstance, while the residual value method focuses on calculating the rental price, where the rent is determined in a market with a fixed supply and a competitive demand.

Output
less intermediate consumption
less compensation of employees
less other taxes on production
plus other subsidies on production
Equals gross operating surplus
less consumption of fixed capital (depreciation)
less return to produced assets
less labour of self-employed persons
Equals resource rent
= depletion + net return to environmental assets

the use of the ecosystem. Finally, it is to be noted that these methods are often most readily applied using broad, industry-level data and the resulting price estimates may lack the granularity required for developing location-specific monetary values. At the same time, since these methods are based on observed data, the values and prices estimated using these techniques will reflect the current institutional context and may provide a high-level framing for monetary values.

9.38 **Productivity change method.** In this method, the ecosystem service is considered an input in the production function of a marketed good. Thus, changes in the service will lead to changes in the output of the marketed good, holding other things equal. The value of the service is derived in three stages. First, the marginal product (contribution) of the ecosystem service is estimated as the change in the value of production consequent upon a marginal change in the supply of the ecosystem service. Second, the marginal product is multiplied by the price of the marketed good to derive a marginal value product for the ecosystem services. Third, this marginal value product is multiplied by the physical quantity of the provided ecosystem service to obtain the value of the ecosystem service. The relationships should be estimated for a single accounting period, recognizing that they may change over time.

9.39 The productivity change method has been used to price the services provided by water and other inputs in agriculture, for example, pollination, across locations where detailed data are available to estimate production functions. It is particularly well suited for the valuation of ecosystem services that are inputs to existing SNA outputs. However, where there are multiple goods and ecosystem services involved, it may be difficult to specify the production function and marginal product of an individual ecosystem service, since there are a range of factors that need to be factored in. Further, the method can be data-intensive and scaling up to a national level may be difficult.

9.40 **Hedonic pricing method.** The hedonic pricing method estimates the differential premium on property values or rental values (or other composite goods) that arises from the effect of an ecosystem characteristic (e.g. clean air, local parks) on those values. This method is commonly used to measure services related to the amenity provided to residents in particular locations. In order to obtain a measure of this effect, all other characteristics of the property (including size, number of rooms, central heating, garage space, etc.) are standardized and need to be included in the analysis. Consideration should also be given to the geographical, neighbourhood and ecosystem characteristics of the properties.

9.41 In the context of ecosystem accounting, the decomposition of these values into two parts – the part explained by the ecosystem characteristic and the part explained by the remaining characteristics of the property – can be used to estimate a value for the relevant ecosystem service (e.g. air filtration services or recreation-related services) for a specific property. Where the hedonic pricing method is applied to property values rather than rental values, the resulting prices need to be converted so as to relate to an annual service flow using a suitable rate of return.

9.42 Estimated prices for the ecosystem service can be applied in other locations, for example, by deriving prices per hectare. This method may also be considered for use in other property or rental value contexts such as those involving agriculture land sales or rentals in the context of biomass provisioning services.[98]

9.43 Hedonic pricing reveals a value for accounting purposes only in the case of a fully informed and fluid market where buyers are able to find properties with sets of characteristics that are an optimal fit with their preferences.

98 Triplett (2006) may be consulted for guidance on the use of hedonic pricing approaches in a statistical context.

9.3.5 Methods where prices are based on revealed expenditures in related goods and services

9.44 Where prices for ecosystem services cannot be estimated using the methods described above, it is possible to adopt methods using data on revealed expenditures on related goods and services, commonly referred to as cost-based methods.

9.45 **Averting behaviour method.** The averting behaviour method assumes that individuals and communities spend money on preventing or mitigating the negative effects and damages arising from adverse environmental impacts. The revealed expenditure demonstrates the value placed on the associated ecosystem services. This is the case, for example, with respect to the incurring of costs associated with extra filtration in order to purify polluted water and air conditioning to avoid air pollution.

9.46 The actual expenditures incurred are considered a lower-bound estimate of the benefits of mitigation, since it can be assumed that the benefits derived from avoiding damages are at least equal to the share of costs incurred to avoid them. An advantage of this method is that it is easier to estimate the expenses incurred than to estimate the avoided environmental damage. A disadvantage is that those expenditures may not be highly sensitive to the differences in environmental quality and so they may not be spatially sensitive in the way that damage functions could be. Also, care is needed (a) to align the expenditures to specific ecosystem services since they may reflect securing a bundle of services; and (b) to ensure that the expenditures reflect only the cost of avoiding environmental impacts rather than also reflecting taste and consumption preferences.

9.47 **Travel cost method.** The travel cost method is commonly used in economics to estimate the value of recreational areas based on the revealed preferences of visitors to a site. A demand function for recreation is estimated by observing the actual number of trips that take place at different costs of travelling to a recreational or cultural site and assuming that people hold similar preferences with respect to visiting the site. Data on costs of travelling include the expenditures incurred by households or individuals to reach a recreational site and entrance fees and may also include the opportunity cost of time spent travelling to and visiting the site. Travel cost data are ideally captured at a detailed level that considers the different features of the sites being visited and enjoyed. The area under the demand function provides a measure of the welfare value of the site, that is, including the consumer surplus.

9.48 For ecosystem accounting purposes, calculation is required of the exchange value of the associated ecosystem services, generally recreation-related services. An exchange value can be estimated on the basis of the demand function using the simulated exchange value method described below. In the absence of estimated demand functions, exchange values can be approximated based on aggregated travel cost data (e.g. data on fuel). Where travel cost data are not available, an alternative method for obtaining the exchange value of recreation-related services is to sum relevant consumption expenditures (e.g. using data from tourism satellite accounts).

9.3.6 Methods where prices are based on expected expenditures or markets

9.49 The final group of valuation methods that are available for accounting purposes are those based on estimating the expenditures that would be expected if the ecosystem service was no longer provided or was in fact sold on a market. Applying these methods is based on the following logic, namely, that a loss of ecosystem services would directly increase monetary costs (or reduce incomes) for economic units and that the presence of a market would reveal these effects.

9.50 **Replacement cost method.** The replacement cost method estimates the cost of replacing an ecosystem service by a substitute that provides the same contribution to benefits. It is also known as the substitute cost or alternative cost approach. The substitute can be either a consumption item (e.g. an air filtration unit for a household substituting for air filtration services of trees) or an input factor (e.g. sorghum substituting for non-priced forage in the case of a rangeland grazing ecosystem service) or a capital factor (e.g. a water treatment plant). In all cases, if the substitute provides an identical contribution, the price of the ecosystem service is the cost of using the substitute to provide the same benefits as provided by a single quantity unit of the ecosystem service (e.g. price of a ton of forage). If applied in a single context (e.g. the context of a single farm), a direct accounting entry may be estimated based on the total cost of using the substitute in that context.

9.51 The validity of the replacement cost method depends upon three conditions being upheld: (a) the substitute can perform exactly the same function as the ecosystem service being substituted for; (b) the substitute used is the least-cost alternative; and (c) there would be a willingness to pay for the substitute if the ecosystem service was no longer supplied. Thus, in the example of non-priced forage noted above, it should be evident that the sorghum is a good substitute for rangeland fodder, that it is cheaper than other substitutes (e.g. moving livestock elsewhere, using other types of fodder) and that livestock operations would be continued if the rangeland grazing activity was curtailed.

9.52 **Avoided damage costs method.** The avoided damage costs method estimates the value of ecosystem services based on the costs of the damages that would occur due to the loss of those services. The focus, similar to that of replacement costs, is generally on services provided by ecosystems that would be lost if an ecosystem was not present or was in sufficiently poor condition to cause the services not to be available. To obtain values and prices for accounting purposes, damages should be estimated using prices that are consistent with the exchange value concept. The validity of the avoided damage cost method depends on similar conditions to those noted above with respect to the replacement cost method. The avoided damage method is particularly useful for regulating the following services: soil erosion control, flood control, air filtration and global climate regulation, among others.

9.53 Estimation of avoided damage costs identifies certain economic units that are expected to avoid damage costs as a result of the supply of ecosystem services. For example, the value of air filtration services may be related to avoided health costs by governments. However, this should not be interpreted as meaning that those units are users of the services; rather estimation of avoided damage costs is solely a means of estimating the value of those services.

9.54 In some contexts, prices based on both replacement costs and avoided damage costs are capable of being estimated. If this is possible, the lower of the two estimated prices should be used. In most contexts, it is expected that this would be the prices based on the replacement costs method.

9.55 **Simulated exchange value method.**[99] The simulated exchange value method estimates the price and quantity that would prevail if the ecosystem service were to be traded in a hypothetical market. It thus provides a direct estimate of the value of the ecosystem service based on the required exchange value concept.[100] This method is applied by using results from demand functions for the relevant ecosystem service (for example, as estimated using the travel cost method, discussed above, or stated preference methods, discussed below). These are used to calculate the price for the ecosystem service that would obtain if it were actually marketed. This requires combining the information on the demand function with a supply function and an appropriate market structure (institutional context). Standard microeconomic methods are then applied to produce the simulated price, which can be used to estimate the value of the ecosystem service. This method can be applied at various levels of complexity and using alternative market structures, but it has not been as widely applied as the methods described above.

[99] Based on Caparrós and others (2017).

[100] Where the simulated quantity differs from the observed quantity (e.g. in terms of the number of visits), the simulated price can be adjusted in a subsequent step so that the simulated exchange value remains unchanged.

9.3.7 Other valuation methods

9.56 There is a range of other valuation methods that are found in the environmental economics and ecosystem services valuation literature. These methods should not be applied in preference to any of the types of methods described above. If data based on these other methods are considered for compilation purposes, then they should be checked for consistency with exchange value principles and adjusted as required before use in the accounts.

9.57 **Shadow project cost method.** This is a variant of the replacement cost method that focuses on the hypothetical costs of providing the same ecosystem service elsewhere. It is less suitable for the valuation of individual ecosystem services since it is not intended to capture individual flows. Possible alternatives to the design of a shadow project include asset reconstruction (e.g. providing an alternative habitat site for threatened wildlife); asset transplantation (e.g. moving the existing habitat to a new site); and asset restoration (e.g. enhancing an existing degraded habitat). The three conditions noted above for the replacement cost method also apply to this method, but it should be noted that the shadow project cost method is valid only if the shadow project is actually realized or planned to be realized.

9.58 This method is also linked to the restoration cost method, which may be applied to value ecosystem degradation by estimating the costs that would need to be incurred to restore an ecosystem to its condition at the beginning of the accounting period. The restoration cost method is discussed further in chapter 12.

9.59 **Opportunity costs of alternative uses.** This approach estimates values of ecosystem services by measuring the forgone benefits of not using the same ecosystem asset for alternative uses. For example, the value of ecosystem services arising from not harvesting trees for timber (e.g. to supply global climate regulation services) can be measured by using the forgone income from selling timber. This approach therefore measures what has to be given up for the sake of securing ecosystem services. The opportunity cost approach is most useful when considering the ecosystem services that can be linked to certain purposes such as protection of habitats or cultural or historical sites. The values obtained can be considered exchange values provided that (a) the valuation of the forgone benefits is based on exchange values; and (b) the institutional context considered is sufficiently realistic to permit the alternative scenario to be analysed. A primary difficulty with the opportunity cost approach concerns determining a realistic alternative use since, depending on the choice made, the value of the forgone benefits could vary substantially.

9.60 **Stated preference methods.** Stated preference methods do not utilize information on the behaviour of people in existing markets; rather they use information from questionnaires to elicit likely responses of people by asking them to state their preferences in hypothetical situations. Stated preference methods do not reveal exchange values directly and hence require adjustment for use in accounting. These are the primary methods for estimating non-use values and hence may be relevant in some applications described in chapter 12. Stated preference methods fall into two broad categories: contingent valuation and choice experiments.[101]

101 The pros and cons of different specifications of stated preference methods are discussed in various publications; see, in particular, Johnston and others, (2017) for state-of-the-art guidance on stated preference methods.

9.61 The contingent valuation method is a survey-based stated preference technique that elicits information on people's behaviour in constructed markets. In a contingent valuation questionnaire, a hypothetical market is described where the good in question can be traded. This contingent market defines the good itself, the institutional context in which it would be provided and the way in which it would be financed. Respondents are asked about their willingness to pay for, or willingness to accept, a hypothetical change in the level of provision of the good, usually by asking them if they would accept a particular scenario. Respondents are assumed to behave as though they were in a real market (Atkinson and others, 2018).

9.62 In choice experiments, an individual is offered a set of alternative levels of supply of goods or services (typically two or three), for which the characteristics vary according to defined dimensions of quality and cost. By analysing preferences across these different bundles of characteristics, it is possible to obtain the value placed by the individual on each of the characteristics, provided (a) the bundles include a cost variable; and (b) a baseline bundle is included that represents the status quo.

9.63 The information obtained from application of contingent valuation methods and from choice experiments is on WTP for an ecosystem service or WTA payment for its loss. This information is then used to assess changes in consumer and producer surplus and, as such, does not provide an estimate of the exchange value required for accounting purposes. However, by combining information on the WTP or the WTA of a range of recipients of the service, it is possible to derive a demand function for the ecosystem service and such a demand function may subsequently be utilized to derive an exchange value by using a simulated exchange value approach.

9.64 **Prices from economic modelling.** Conceptually, it is possible to derive prices for ecosystem services from economic models that encompass relevant information on environmental and economic variables. For example, ecosystem services prices (e.g. for biomass provisioning services) may be elicited from computable general equilibrium models that take into consideration a wide range of factors and connections among economic sectors and which can be extended to include environmental factors. While these models have the potential to yield prices generated in more dynamic market contexts, the data requirements for applying them indicate that they are not likely to be suitable for use in ecosystem accounting.

9.65 **Qualitative methods.** There is a range of qualitative methods, including deliberative and group methods, that can be used in assessing the value of ecosystem services. However, since these methods are generally not designed for the derivation of monetary values, they are not considered appropriate for use in ecosystem accounting.

9.4 Valuation methods for different ecosystem services

9.4.1 Introduction

9.66 For the compilation of the ecosystem services flow account in monetary terms, the different valuation methods described in section 9.3 must be applied to individual ecosystem services. Compilers should be guided by the order of preference for valuation methods outlined in section 9.3.1 when determining which valuation method to apply for a given ecosystem service. In practice, the method that is applied often depends on data availability. The following subsection provides general guidance on the issues to be considered in undertaking monetary valuation of different services. More detailed technical guidance on the implementation of valuation methods for individual services is available in the interim report on the monetary valuation of ecosystem services and assets for ecosystem accounting (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022b).

9.4.2 Valuation of different types of services

9.67 Provisioning services include living resources harvested from systems ranging from unmanaged terrestrial and aquatic natural systems (uncultivated biomass) to highly managed plantations and aquaculture and livestock systems (cultivated biomass). The valuation of provisioning services should deal only with estimating the value related to the physical flows (e.g. fish) that are harvested for non-recreational, consumptive use, commonly as inputs to wider supply chains. The relevant measurement boundaries for provisioning services are described in chapter 6.

9.68 All biomass harvested is within scope of the production boundary of the SNA and hence exchange values for the relevant products are included in current measures of economic production. The valuation of ecosystem services is therefore focused on identifying the contribution of the ecosystem to the biomass product values, which are themselves based on data on quantities traded, market prices and input costs.

9.69 There may be significant flows of ecosystem services associated with subsistence agriculture, forestry and fisheries in a number of situations, that is, when the outputs from growing and harvesting activities are not sold on markets but directly consumed by households. A broad range of products may be relevant in this regard, including all types of non-timber forest products. Following the conceptual scope of the SNA, the production associated with these activities should be included in national accounts estimates of output, with exchange values estimated on the basis of the prices of similar goods sold on markets.[102] There would then be an associated ecosystem services contribution to the recorded output. The methods described above for estimating the value of biomass provisioning services can be used for the valuation of the ecosystem services associated with subsistence production and consumption on the basis of the estimated market prices.

9.70 There is a wide range of regulating and maintenance services. In some cases, the contribution of these services is an input to SNA benefits. For example, the service of soil erosion control may be an input to agricultural production. In other cases, ser-

[102] The handbook on measuring the non-observed economy (Organisation for Economic Co-operation and Development, International Monetary Fund, International Labour Organization and Commonwealth of Independent States, 2002) provides guidance on measurement approaches in this area.

vices (e.g. water purification services) are contributions to non-SNA benefits, related especially to improvements in human health. In all cases, there are few, if any, distinct markets for these services and identifying their relative contribution within the context of existing market prices is likely to be challenging. Finally, most regulating and maintenance services exhibit considerable variation in their supply owing to their dependency on local contexts and, generally, the measurement of flows in biophysical terms requires biophysical modelling at relatively fine spatial scales.

9.71 Cost-based methods, such as the averting behaviour, replacement cost and avoided damages methods, are the methods most commonly used for monetary valuation of regulating and maintenance services. In some cases, those services can be valued based on observed market transactions, for example, through use of data from payments for ecosystem services schemes or emission trading schemes. However, depending on the institutional arrangements involved or the way in which services are quantified within the schemes (e.g. management actions are often used as a proxy for quantities), there will be limits with respect to where these methods can be used to estimate exchange values.

9.72 For some services, especially those related to mitigating the effects of extreme events, the flow of the service will depend on the likelihood of events, both natural events and those related to human activity. For example, in measuring coastal protection services, there needs to be a likelihood greater than zero that events that cause damage (e.g. a tidal surge) may occur. The role of the ecosystem can then be assessed in terms of the extent to which it reduces the impact of such events. It is also necessary to consider the likelihood of damage. Thus, even if an event is likely, the ecosystem service flow will be lower if there is little damage expected. In the extreme case, if there is no expected damage, then there will be no user of the mitigation service and hence no flow of ecosystem services to be recorded. Overall, the likelihood of occurrence, the potential for damages and the extent to which the relevant ecosystems can reduce those damages will affect the value of the service.

9.73 For cultural services, it is generally necessary to consider their monetary valuation from a demand or consumption perspective. The most common methods used for recreation-related services are revealed preference methods based on the travel cost method, including payments for entry or related services. Methods for estimating the value of other cultural services include hedonic pricing where, for example, the value of visual amenity services (and also local recreation services) may be determined from the assessment of local house prices.

9.74 By using residual value approaches, it is possible to estimate the value of ecosystem services as inputs to the businesses involved in facilitating people's interactions with nature, for example, island resorts or canoe hiring firms. In line with the recording in chapter 7, the flow of cultural ecosystem services is recorded as used by households and the values of any ecosystem services that may be a part of monetary payments to businesses are recorded as supplementary items in the SUT.

9.5 Spatial variation in values and value transfer for the purpose of ecosystem accounting

9.5.1 Introduction

9.75 Most commonly, the valuation of ecosystem services requires the recognition that there will be variation in their values depending on the location and context in which those services are supplied and used. The variation in ecosystem services values between locations occurs for a number of reasons. The physical level of service provision may vary spatially, for example, when the global climate regulation service supplied by a forest through carbon sequestration varies from one side of a hill to another as solar energy varies with the aspect of that hill. Similarly, the recreation-related services supplied by a lake or river may vary depending on proximity to human populations: for example, a lake located near a town may generate large recreational benefits, while an ecologically identical lake located in a remote area might never be visited from one year to the next. Indeed, "distance decay" in values over space is one of the most persistent and substantial determinants of ecosystem service valuation (Badura and others, 2020; Johnston, Besedin and Holland, 2019). In addition, there are likely to be differences in terms of access and property rights (institutional context) in different locations. Further, the value of an ecosystem service may vary owing to the underlying preference heterogeneity that occurs over space, that is to say, human populations in some areas may simply have preferences that are different from those of populations living in other areas. Overall, failure to account for the influence of location frequently leads to significant error (Bateman and others, 2006).

9.76 Generally, the discussion of monetary valuation for ecosystem accounting is focused on the compilation of estimates in monetary exchange value terms for large regions or countries, with the expectation that these values can support the development, implementation and/or monitoring of public policy. In contrast, much work on valuation has used economic welfare values and has focused on the valuation of ecosystems and ecosystem services for specific ecosystems; or in relation to the potential effects of policies and programmes (such as the introduction of a new tax or subsidy); or in relation to hypothetical events, for example, the damages caused by oil spills or the effects of ecosystem restoration. Consequently, much of the data on the monetary value of ecosystem services is fragmented, covering only specific services over a large area or multiple services in a more confined area or valuing changes in the flow of ecosystem services following a specific event.

9.77 Among the challenges for ecosystem accounting is how to reconcile and utilize the information from existing studies so as to obtain valid estimates of exchange value that may be applied consistently over large accounting areas and that account for the potential variations in ecosystem service values that occur over those areas. Indeed, while the consideration of larger areas might be thought of as reducing error, this is not necessarily a correct assumption if the averages estimated for such areas are calculated in ignorance of spatial variation. The extent to which spatial variation in values can be accounted for depends on data availability and the methodological considerations that have been introduced in the present publication. If spatial variation in values cannot be taken into consideration adequately, then some applications of accounting data may not be appropriate.

9.78 Beyond the need for supporting work on value transfer, there is a requirement for the ongoing expansion of work on estimating spatially explicit primary valuations to support the regular compilation of accounts. This requirement is especially important with respect to minimizing the use of primary data from other countries that have significantly different economic and institutional contexts. Although not discussed in this section, there is also a need to recognize that many primary valuations may not have been conducted with the intention of estimating exchange values as used in ecosystem accounting. In using primary valuations, there is therefore a need to consider the differences in valuation techniques and the relevant assumptions described in section 9.3 so as to ensure that estimates are fit for accounting purposes.

9.79 The present section provides a brief overview of relevant considerations and potential measurement approaches for ecosystem accounting as related to spatial variation in values. A key message is that there is an extensive body of research and applied practice that can be used. At the same time, consideration of the issues from an ecosystem accounting perspective highlights areas in which further research is required, including concerning exchange values and marketed ecosystem services. A more detailed discussion of relevant methods is available in technical guidance on valuation for ecosystem accounting.

9.5.2 Methods for incorporating spatial variation in prices

9.80 A set of techniques, collectively referred to as value transfer or benefit transfer techniques, can be applied to enable utilization of data from specific locations in the estimation of monetary values in other locations.[103] There are two main approaches among value transfer techniques: unit value transfers and value function transfers. Value function transfers may be further disaggregated into subgroups, including "meta-analysis" function transfers and other types of value function transfers (Johnston and others, eds., 2015, chap. 2). These techniques have been developed over many decades in the environmental economics community. Reviews of the relevant literature are provided in Boyle and others (2010); Johnston, Rolfe and Zawojska (2018); Johnston and others (2021); and Johnston and Rosenberger (2010).

[103] While much of the literature in this area uses the term "benefit transfer", the term "value transfer" is preferred in the present publication, reflecting a recognition of the focus on estimating exchange values and the distinctive use of the term *benefit* in the ecosystem accounting framework (see chap. 6).

9.81 A *unit value transfer* takes a single estimate of the monetary value of an ecosystem service (expressed in terms of a common measurement unit (e.g. hectares, tons, visits) or a measure of central tendency (e.g. mean, median) of several value estimates from different studies) to estimate the value of an ecosystem service in other locations. The validity of a unit value transfer approach is limited when there is a range of differences between the value from the observed location and those from the other locations. Unit value transfers typically provide little or no internal capacity to account for the differences. Examples of factors that can cause values to differ across locations may include:

- Physical characteristics of the sites that generate variation in the ecosystem services provided by the location, such as (in the case of a lake) differing opportunities for recreation in general and for angling in particular
- Socioeconomic and demographic characteristics, including income, educational attainment and age, of the relevant populations in the different locations
- Variation in the preferences of populations across different locations
- Variation in institutional context governing rights of access to, use of and duties towards biodiversity, ecosystems and their services
- Distance between the user of the ecosystem service and the supplying ecosystem asset, along with other geospatial differences that influence values in systematic ways (Glenk and others, 2020). It is to be noted that the effect of distance varies depending on the ecosystem service. For example, benefits of global climate regulation services emerge irrespective of distance, whereas benefits from water purification services accrue only to people located close to (or downstream of) the supplying ecosystem.
- Variation in the availability of substitutes and complements. For example, in the case of recreational locations such as lakes, two otherwise identical lakes might be characterized by different levels of alternative recreational opportunities. Other things being equal (by assumption in this example), the value of preventing the lowering of water quality at a lake where there are few substitutes should be greater than the value of averting the same water quality loss at a lake where there is an abundance of recreational

substitutes, the reason being that recreational opportunities are scarcer at the location of the former than at the location of the latter.

- Differences across countries reflected in spatial and temporal variation in purchasing power.

9.82 Failure to adjust for location-specific conditions affecting exchange value signifies that applying the unit value transfer approach would work as a simple scaling factor for the changes recorded in the PSUT. Thus, an unadjusted unit value provides no additional information when reflected in a monetary SUT. While such linear monetary scaling may still be useful in compiling the monetary asset account for purposes that require only low accuracy, care should nevertheless be taken to identify generalization errors and confidence ranges.

9.83 Since differences between locations such as those just described do exist, adjustments are generally made in order to take differences between locations into account. In the first instance, adjustments may be made to account for income per capita and income elasticities in order to derive an *adjusted unit value transfer*. Meta-studies (see, for example, Organisation for Economic Co-operation and Development (2014)) indicate that adjusting for income per capita is a significant factor in enabling application of values from one location to others. This adjustment is likely to be of most significance in the context of using primary data from another country. While data from other countries may be used in compiling accounts, it is advisable, wherever possible, to use primary data from the country for which the accounts are being compiled.

9.84 A more sophisticated technique is *value function transfer*. Value function transfers can be categorized in different ways. They can be grouped, for example, into four primary categories based on how the value functions are estimated. The first type of value function transfer estimates a value function using meta-analysis of prior valuation studies. The second type estimates a function concerning the relationship between value and the ecosystem and economic context from a primary research study in one location and uses that function in other locations. The third type uses primary data from multiple locations across a region to generate an "umbrella" function that can be applied to other locations within the region (see, for example, Bateman and others (2013)). This approach has the advantage of using data sets that encompass the locations of both the primary data site or sites and the transfer site or sites, thereby preventing "out of sample" problems. This approach is also referred to as value generalization. The fourth type is known as structural value transfer (also called preference calibration). This type of transfer combines information from multiple prior primary studies using a utility theoretic structure that is assumed to apply to the prior studies. These different types of value function may encompass factors such as the physical features of the location, differences in changes in population age structure between sites and differences in population density.

9.85 When used for value function transfer, *meta-analysis* (see, for example, Bateman and others (2000) and Boyle and Wooldridge (2018)) takes information from a range of existing primary studies and uses it to estimate a functional relationship that enables the values of ecosystem services to be predicted as a function of, inter alia, site and spatial characteristics, attributes and size of the population affected and the type of statistical methods used in the analysis of existing studies. The estimated functional relationship is then used in the new application through a procedure referred to as meta-regression value transfer, which gives a range of values for the new application, depending on the characteristics embedded in the meta-regression.

9.86 This approach is well suited to developing estimates for additional sites and can be used to provide estimates at larger scales, including at the national level (see, for example, Corona and others (2020) and Johnston, Besedin and Holland (2019)). Application of meta-analysis to the field of non-market valuation has expanded rapidly in recent years. Studies have been carried out on water quality, urban pollution, recreation, the ecological functions of wetlands, the values of statistical life, noise and congestion.

9.87 At the same time, as meta-analysis sometimes uses data from a variety of countries, variations between countries need to be recognized. Moreover, it is necessary to identify and select appropriately the studies to be used in the meta-analysis so as to ensure, for example, welfare consistency and commodity consistency (Johnston, Rolfe and Zawojska, 2018). Guidelines for the selection and coding of studies for economic meta-analysis are available (see, for example, Stanley and others (2013)). In meta-analytic transfers using valuation studies from other countries outside the EAA, care should be taken to adjust for particular differences in national jurisdiction affecting access and use rights.

9.88 The extent to which different value transfer methods can capture spatial variations in value and their general accuracy have constituted one area of extensive research. For discussions and a review of relevant work, see, for example, Bateman and others (2006); Johnston, Besedin and Holland (2019); Johnston, Besedin and Stapler (2017); and Schaafsma (2015). Further, guidelines are being developed to focus on improving more broadly the quality of estimates derived through the use of value transfer techniques (see Johnston and others (2020; 2021)). Fundamentally, the quality of value transfer approaches is influenced by the number, depth (in terms of number of data points) and quality of spatially explicit primary valuation studies, which in turn likely depend on the type of ecosystem and the type of ecosystem service being considered. For example, while there are many studies of recreational use of ecosystems, there are not as many on the value of wetlands. Moreover, since different valuation studies are often based on different assumptions and different valuation concepts and use different methods, there is a strong case to be made for using the SEEA EA framework and applying it through the practice of official statistics to develop consistently measured values across a variety of ecosystem services and locations. In developing these studies, coordination with the organization of data in physical terms on ecosystem extent and condition and ecosystem services flows is highly recommended since these data in physical terms on ecosystem extent and condition and ecosystem services flows can assist in consistently differentiating and classifying data for estimates derived through the use of value transfer techniques spatially and in ensuring consistent understanding of the supply and use context for ecosystem services.

9.89 When considering the direct applicability of existing value transfer research and findings to environmental accounting, it is important to consider the extent to which the types of values considered within the value transfer literature are consistent with those used within accounting applications. For example, much (although not all) of the available material in the value transfer literature is based on stated preference methods. Stated preference methods establish hypothetical markets to quantify welfare values of changes in non-marketed ecosystem condition and/or services. For accounting purposes, it is necessary to simulate exchange values by combining these stated preference functions with ecosystem services supply/cost functions. Since institutional regimes are specific to ecosystems and resource characteristics (Ostrom, 2010), simulating exchange values requires the definition of credible institutional conditions for a market for the ecosystem in question (Barton and others, 2019). Accounting principles state that accounting-compatible prices should reflect current or feasible market institutions. Compilers should therefore recognize that transferring or generalizing valuation estimates from actual or hypothetical markets to locations without markets may potentially contravene national accounting principles. In particular, care should be taken in cases where market simulation contradicts existing rights regimes. In these situations, simulated exchange values, and monetary accounts more generally, may be perceived as invalid by local rights holders. This is a particularly significant issue in ecosystems with open access or common property rights (e.g. community fisheries and forests, communal green spaces).

9.90 Location-based valuation of all ecosystem services is a clear-cut conceptual ideal. While implementing this concept has rarely been possible owing to resource constraints, rapid increases in the availability of spatial data and the ongoing advances in valuation methodologies will make this more of a possibility in the future. As introduced in this section, there are well-researched value transfer techniques available for use in ecosystem accounting that can utilize available primary valuation studies. Further testing and best practice guidelines on defining credible market exchange conditions for value transfers should be part of the SEEA EA research and development agenda. To support appropriate use and interpretation of monetary estimates and to provide a sound basis for further research and development of data, clear documentation will be required of data sources and of the methods and assumptions applied in forming aggregate values to be entered into the accounts.

Chapter 10
Accounting for ecosystem assets in monetary terms

10.1 Introduction

10.1 The series of ecosystem accounts is completed with the monetary ecosystem asset account. This account records a monetary value of ecosystem assets in terms of the NPV of the ecosystem services supplied by the asset. The estimates of monetary value are compiled following the NPV principles described in chapter 8 and using the exchange value concept. The estimates provide a measure of exchange value related to the scope of ecosystem services recorded in the ecosystem services flow account and cannot be interpreted as reflecting a complete or universal measure of the value of nature.

10.2 The monetary ecosystem asset account also records the changes in the monetary value of ecosystem assets over an accounting period including changes due to ecosystem degradation, ecosystem enhancement, ecosystem conversions and revaluations.

10.3 Estimates of ecosystem assets in monetary terms can support discussion of the relative significance of different ecosystem assets and ecosystem types and the monetary value of ecosystem assets can be combined with the monetary valuations of other types of assets, for example, produced assets, to provide broader assessments of net wealth, such as in wealth accounting (see UNEP (2018); World Bank (2018)). Measures of ecosystem assets in monetary terms may also be related to general socioeconomic drivers of change such as changes in economic activity and demographic trends. Together with information about assets in physical terms (e.g. measures of ecosystem condition), they may be used as part of an assessment of the sustainability of the flows of ecosystem services. Further, because there is a focus on future flows of ecosystem services, measures of the value of ecosystem assets can support project design and monitoring requirements.

10.4 At the same time, as noted in chapter 8, measures in monetary terms on their own are not sufficient for the analysis of non-marginal changes in ecosystems or issues of sustainability that concern ecological thresholds and boundaries. Consequently, there is significant advantage in using the ecosystem accounting system, which provides a clear line of sight between physical data on ecosystem extent and condition, measures of ecosystem service flows and ecosystem capacity, and monetary values. More generally, in analysing changes in value, there is a need to assess the effects of price change and to focus on the relevant changes in the volumes of assets and services.

10.5 Measures of ecosystem degradation in monetary terms are of particular interest in understanding changes in ecosystem assets relative to measures of economic activity such as industry value added. The derivation of degradation-adjusted income measures is explained in chapter 11, together with a description of extended balance sheets and extended institutional sector accounts.

10.6 Section 10.2 sets out the structure of the monetary ecosystem asset account and the associated accounting entries. Section 10.3 describes the key components in valuing ecosystem assets using the NPV approach, including the approach to valuing accounting entries for changes in ecosystem assets over an accounting period.

10.2 Monetary ecosystem asset account

10.2.1 Structure of the monetary ecosystem asset account

10.7 The monetary ecosystem asset account records the monetary values of all ecosystem assets within an EAA at the beginning (opening) and end (closing) of each accounting period, as well as changes in the value of those assets over the accounting period. Changes in the monetary value of ecosystem assets are separated into five broad types: ecosystem enhancement, ecosystem degradation, ecosystem conversions, other changes in the volume of ecosystem assets, and revaluations as a result of price changes.

10.8 The description provided in the present section reflects a framing in which an individual ecosystem asset is able to be valued as a single entity reflecting the NPV of the set of ecosystem services that it supplies as recorded in the ecosystem services flow accounts. Thus, the concepts concerning change in value such as ecosystem degradation and ecosystem enhancement are defined by viewing the ecosystem asset as a single entity in line with the framing for measurement of ecosystem extent and condition.

10.9 In practice, as explained in section 10.3, the value of an ecosystem asset is obtained by estimating the NPV of each ecosystem service supplied by the asset separately and taking into consideration key linkages among services and assets to the extent possible. The approach to reconciling ecosystem service-specific NPV estimates and changes in ecosystem asset values described in this section is explained in appendix A10.1. This reconciliation approach is pragmatic and suitable for accounting purposes. While improvements to the approach may be obtained through additional modelling that considers in greater depth the links between ecosystem condition, ecosystem capacity and ecosystem service flows, the accounting structure described in this section remains unaffected.

10.10 The basic accounting structure for the monetary ecosystem asset account is shown in table 10.1. The table presents an account for an EAA classified by ecosystem type using selected EFGs from IUCN GET (see chap. 3).

10.11 The opening and closing values are derived using the NPV of ecosystem services for a given ecosystem type based on the concepts described in chapter 8 and using the approach to estimating NPVs described in section 10.3. Data on the monetary value of ecosystem services by ecosystem type come from the ecosystem services flow account in monetary terms described in chapter 9. The opening and closing values are the first estimates compiled in compiling the monetary ecosystem asset account.

10.12 Entries for ecosystem degradation and enhancement involve assessing the change in NPV and comparing this with the change in condition for the ecosystem type as recorded in the ecosystem condition account described in chapter 5 and applying the definitions of ecosystem degradation and enhancement given below. Entries for ecosystem conversions will build on entries recorded in the ecosystem extent account (chap. 4). The additions and reductions shown in that account in physical terms align with the additions and reductions in monetary terms that are recorded under ecosystem conversions. Entries for other changes in the volume of ecosystem assets and revaluations are based on specific information concerning those changes as described below. Appendix A10.1 provides a worked example of how each of these accounting entries can be estimated in order to compile a monetary ecosystem asset account.

Table 10.1
Monetary ecosystem asset account (currency units)

	Ecosystem type (based on the EFG level 3 of IUCN GET)																		
	Terrestrial												Freshwater			Marine			
	T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1	
	Tropical-subtropical lowland rainforests	Tropical-subtropical dry forests and scrubs	Tropical-subtropical montane rainforests	Tropical heath forests	Boreal and temperate high montane forests and woodlands	Deciduous temperate forests	…	Temperate pyric sclerophyll forests and woodlands	…	…	…	Derived semi-natural pastures and old fields	Permanent upland streams	…	Intermittently closed and open lakes and lagoons	Seagrass meadows	…	Coastal saltmarshes and reedbeds	
	T1.1	T1.2	T1.3	T1.4	T2.1	T2.2	…	T2.6	…	…	…	T7.5	F1.1	…	FM1.3	M1.1	…	MFT1.3	TOTAL
Opening value																			
Ecosystem enhancement																			
Ecosystem degradation																			
Ecosystem conversions																			
Additions																			
Reductions																			
Other changes in volume of ecosystem assets																			
Catastrophic losses																			
Reappraisals																			
Revaluations																			
Net change in value																			
Closing value																			

10.13 As required and where data are available, asset accounts showing the same accounting entries can be compiled for individual ecosystem assets (e.g. a specific grassland), for all ecosystem assets of a single ecosystem type (e.g. all trophic savannas (T4.1)) or for various types of EAA (e.g. a country, a large administrative area or a catchment) that include multiple ecosystem assets of different ecosystem types.

10.14 Depending on data availability, it may be necessary to combine some accounting entries by netting the change in value. For example, net ecosystem conversions might be recorded rather than separately recorded additions and reductions. Further, in many contexts, there may be multiple potential entries over an accounting period reflecting a combination of enhancement, degradation and other types of changes. The present section outlines the conceptual ideal for distinguishing the various entries, recognizing that making such distinctions in practice commonly relies on the judgment of the compiler. At the same time, the measure of net change in ecosystem asset value should be well bounded by measures of the opening and closing values and the various changes can also be linked to measures in physical terms recorded in the ecosystem extent and condition accounts.

10.2.2 Ecosystem enhancement

10.15 ***Ecosystem enhancement is the increase in the value of an ecosystem asset over an accounting period that is associated with an improvement in the condition of the asset during that accounting period.*** The increase in value is demonstrated by a rise in the NPV of expected future returns of the ecosystem services supplied by that asset. Ecosystem enhancement incorporates the effects of activities, including those related to a reduction in harmful activities, that have improved the condition of an ecosystem asset by extending beyond activities that may simply maintain an ecosystem asset's condition. Ecosystem enhancement may also arise as the result of natural and unmanaged improvements in condition.[104] There is not a linear relationship between changes in condition and future flows of ecosystem services.

10.16 Not all increases in value should be recorded as ecosystem enhancement. The focus should be on recording increases in asset value resulting from improvements in ecosystem condition that can be reasonably expected to increase the future flows of ecosystem services in physical terms based on current and expected patterns of ecosystem management and use. Increases in value attributable to changes in the expected demand for ecosystem services should be recorded as upward reappraisals. Increases in value due solely to movements in the unit prices of ecosystem services should be recorded as revaluations.

10.17 Ecosystem enhancement is measured in relation to the extent of an ecosystem asset as recorded at the beginning of the accounting period. Where there are changes in the extent of an ecosystem asset – that is, where there is a change (conversion) from one ecosystem type to another during an accounting period, a separate recording of that change should be undertaken, and the change should be entered under the item "ecosystem conversions".

10.18 Three types of activities may be considered to be within the context of ecosystem enhancement: restoration, rehabilitation and reclamation. Each of these types of activities is expected to affect ecosystems to a different degree.[105] Restoration occurs where the aim is to re-establish pre-existing structure and function, including biotic integrity. Rehabilitation occurs where the aim is to reinstate ecosystem functionality with a focus on supplying a range of ecosystem services. Both restoration and rehabilitation activities may be achieved by reducing the degree of human impact, for example, by reducing stocking rates on grazing land, reducing the release of pollutants

[104] In a SEEA Central Framework context, this is related to the concept of natural growth of biological resources.

[105] Details are available at the website of the Land Degradation Neutrality conceptual framework under the United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification (www.unccd.int/actions/ldn-target-setting-programme).

or separating or rezoning areas that are the focus of restoration and rehabilitation. Reclamation occurs where the aim is to return degraded land (caused, e.g. by loss of topsoil due to poor land management practices) to a useful state (e.g. for agriculture). Where restoration, rehabilitation or reclamation activities result in a change in ecosystem type during the accounting period, increases in value due to such activities should be recorded under ecosystem conversions.

10.19 Measures of ecosystem enhancement are linked to activities undertaken in the landscape. Consequently, the recorded changes in ecosystem extent and condition and ecosystem asset value can be compared with estimates of expenditure and other measures of human input (e.g. volunteer hours) associated with those activities. However, there should be no prior expectations regarding the results of such a comparison. For example, it should not be expected that the changes in NPV of an ecosystem asset would be the same as the levels of expenditure on environmental protection or restoration activity. Hence, to support decision-making and analysis, data on ecosystem enhancement may be presented as a complement to measures of expenditure and may provide an indication of the broader future returns that may result from a given level of expenditure.

10.20 In this context, there is a connection to the measurement of land improvements as recorded as a component of gross fixed capital formation in the SNA and to the measurement of environmental protection and resource management expenditure as recorded in the SEEA Central Framework. There may also be interest in comparing changes in the value of ecosystem assets associated with these environmental activities with data on the ownership of ecosystem assets.

10.2.3 Ecosystem degradation

10.21 ***Ecosystem degradation is the decrease in the value of an ecosystem asset over an accounting period that is associated with a decline in the condition of the ecosystem asset during that accounting period.*** The decrease in value is demonstrated by a fall in the NPV of expected future returns of the ecosystem services supplied by that asset. Ecosystem degradation occurs as a result of both managed and unmanaged declines in condition.

10.22 Not all decreases in value should be recorded as ecosystem degradation. The focus should be on recording decreases in asset value resulting from declines in condition that can be reasonably expected to decrease the future flows of ecosystem services in physical terms, considering the current and expected patterns of ecosystem management and use and expected patterns of environmental variation.

10.23 Declines in condition may arise from a range of factors including extraction and harvest of natural resources and short- and long-term effects of pollution and emissions. Where there is harvesting or extraction of resources from an ecosystem (e.g. through grazing), the assessment of the decline in condition should be considered at an appropriate scale and over an appropriate time frame within which the level of harvesting or extraction can be assessed relative to a rate of regeneration of the resource. Only extraction at rates above the rates of regeneration should be regarded as contributing to degradation.[106]

10.24 Decreases in value due to large-scale, discrete and recognizable events that cause a significant loss in the condition of an ecosystem asset should be recorded as catastrophic losses. Decreases in value attributable to changes in the expected demand for ecosystem services should be recorded as downward reappraisals. Decreases in value due solely to movements in the unit prices of ecosystem services should be recorded as revaluations.

[106] This treatment is consistent with the definition of depletion provided in the SEEA Central Framework.

10.25 Ecosystem degradation is measured in relation to the extent of an ecosystem asset recorded at the beginning of the accounting period. Where there are changes in the extent of an ecosystem asset – that is, where there is change (conversion) from one ecosystem type to another during an accounting period, a separate recording of that change should be undertaken and entered under the item "ecosystem conversions".

10.26 In non-SEEA contexts, the scope of measures of ecosystem degradation may be broader than as defined here. For example, the effects of some conversions (e.g. from natural to cultivated ecosystem types) may be incorporated in measures of degradation.

10.27 The measurement of ecosystem degradation reveals the loss of future flows of ecosystems services but does not capture wider economic and social impacts of declines in ecosystem condition that may also arise. For example, degradation of cultivated land may lead to losses of farm incomes and employment opportunities in rural communities. Similar observations apply to entries concerning ecosystem enhancement, ecosystem conversion and catastrophic losses. The analysis of these wider impacts can be supported by data from the ecosystem accounts, together with other data from, for example, the national accounts and labour-force statistics.

10.28 The measurement of ecosystem degradation can be undertaken for an ecosystem asset without specific regard to the legal or economic ownership of the asset. However, for some analytical purposes and for integration of ecosystem accounts into the general sequence of institutional sector accounts of the SNA, it is necessary to attribute the cost of ecosystem degradation to an economic unit and institutional sector. Approaches to the attribution of ecosystem degradation to institutional sectors are discussed in chapters 11 and 12.

10.29 In section 5.4 of the SEEA Central Framework, ***depletion of natural resources, in physical terms, is defined as "the decrease in the quantity of the stock of a natural resource over an accounting period that is due to the extraction of the natural resource by economic units occurring at a level greater than that of regeneration"*** (Central Framework, para. 5.76). This definition can be seen as embedded within the definition of ecosystem degradation to the extent that the quantity of a stock of a natural resource is considered part of the structure and composition of an ecosystem asset. The term *depletion* is retained to refer solely to the cost of using up natural resources. This measure is narrower in scope than ecosystem degradation since it is related only to the loss of future provisioning services. However, an economy-wide measure of depletion is broader in scope to the extent that it includes declines due to extraction in the NPV of the stock of non-renewable resources, in particular mineral and energy resources, since those resources fall outside the scope of ecosystem assets.

10.2.4 Ecosystem conversions

10.30 Ecosystem conversions refer to situations in which, for a given location, there is a change in ecosystem type involving a distinct and persistent change in ecological structure, composition and function, which, in turn, is reflected in the supply of a different set of ecosystem services and different expected future returns.

10.31 In physical terms, an ecosystem conversion that occurs during the accounting period should be recorded as a change in ecosystem extent (e.g. a change from shrubland to cropland), following the guidance in chapter 4. In the ecosystem extent account, an increase in the area of one ecosystem type and a decrease in the area of another ecosystem type at a given location nets to zero. It should also be noted that an ecosystem conversion may commonly apply only to part of an existing ecosystem asset.

10.32 Consistent with the definition of ecosystem degradation, assessment of the change in ecosystem type should be undertaken at an appropriate scale and over an appropriate time frame to allow for assessing the effects of, for example, harvesting or extraction of natural resources or forest fires relative to rates of regeneration. More generally, it would be relevant to consider changes in ecosystem condition since those changes serve as an indicator of potential changes in ecosystem type.

10.33 In monetary terms, a decrease in value is recorded for the ecosystem type from which the area has been converted (e.g. shrubland) and an increase in value is recorded for the ecosystem type to which the area has been converted (e.g. cropland). Each of these entries should be recorded under the item "ecosystem conversions" either in the row for additions or the row for reductions.

10.34 However, across an EAA, there is no expectation that the value of expected future returns for additions and reductions will be offsetting. Thus, the net effect in monetary terms of ecosystem conversions may be positive or negative depending on the differences in the set of expected ecosystem services that are generated by the different ecosystem types.

10.35 It may be of interest to present data, depending on their availability, on ecosystem conversions according to the reason for the conversion, including agricultural expansion, increased urbanization, coastal mangrove destruction by hurricanes or reclamation of desert areas for use as grazing land.

10.2.5 Other changes in the volume of ecosystem assets

10.36 Other changes in volume is an SNA-defined accounting entry that provides the opportunity to record all other changes in the value of an asset between balance sheet dates that are not attributable to transactions or revaluations (see 2008 SNA, chap. 12). In the context of ecosystem accounting, ***other changes in the volume of ecosystem assets are changes in the value of an ecosystem asset, other than (a) those due to ecosystem enhancement, ecosystem degradation or ecosystem conversion and (b) those that are the result solely of changes in unit prices of ecosystem services.*** The two main types of other changes in the volume of ecosystem assets are catastrophic losses and reappraisals.

10.37 Decreases in the value of ecosystem assets due to catastrophic losses are identified separately to provide scope for compilers to record decreases due to large-scale, discrete and recognizable events that cause a significant decline in the condition of an ecosystem asset, that is, significant losses in structure, function or composition, and hence affect the future flows of ecosystem services in physical terms. Examples include earthquakes, bushfires, cyclones and industrial disasters. While these events may be anticipated in general terms, the precise timing, location and magnitude cannot be foreseen in the same way that expectations may be formed about patterns of ecosystem use by people.[107] The effects on future flows of ecosystem services may be temporary if the ecosystem quickly regains its previous condition or permanent if the changes are such that some ecosystem services can no longer be supplied or accessed (e.g. due to changes in regulations). Where the effects of large-scale events are significant enough for the ecosystem to be considered to have changed its type, this should be recorded as an ecosystem conversion.

[107] See also 2008 SNA, paras. 12.46 and 12.47; and SEEA Central Framework, para. 5.49.

10.38 Reappraisals should be recorded when updated information emerges that permits a reassessment of the expected condition of the ecosystem assets or the future demand for ecosystem services, with the result that the expected pattern of future returns at the end of the accounting period is different from the pattern that had been expected at the start of the accounting period. For example, the effects of changes in demographic projections that affect the future demand for ecosystem services should be recorded as reappraisals, as well as effects of changes in the future flows of services due to rezoning of land or changes in the risk of extreme events.

10.39 Reappraisals concern changes in expectations and are materially different from the use of updated information to improve the quality of compiled estimates. The incorporation of new information concerning expectations does not lead to revisions in previous estimates.

10.40 Where source data are improved or revised (e.g. through the use of more detailed ecological information or biophysical modelling) or where revised methods and classifications are adopted, the changes should be applied consistently across all relevant accounting entries, and, as appropriate, revisions to past accounting entries should be made. A separate accounting entry to distinguish revisions due to changes in source data is not required but for data quality assessment purposes documenting all revisions to accounts is strongly recommended.

10.2.6 Revaluations

10.41 ***Revaluations are changes in the value of ecosystem assets over an accounting period that are due solely to movements in the unit prices of ecosystem services that underpin the derivation of the NPV of those assets.*** Following the SEEA Central Framework (para. 5.61), a change in the value of an ecosystem asset in response to a change in the quantity or quality of future flows of ecosystem services is not considered a revaluation and should be recorded, as appropriate, as ecosystem enhancement, ecosystem degradation or ecosystem conversion or under other changes in volume.

10.42 Revaluations reflect nominal holding gains over an accounting period and there may be analytical interest in decomposing these gains into neutral holding gains – equivalent to the nominal gains associated with the general rate of inflation – and real holding gains. Holding gains may be positive or negative since the nominal gains may be greater or less than the general rate of inflation.

10.43 Revaluations should also incorporate changes in the value of ecosystem assets due to changes in the assumptions made with respect to the parameters that are used to estimate NPVs, such as the discount rate, to the extent that these effects can be isolated. Changes in estimated values that are due to changes in methods are treated as revisions.

10.3 Approaches to valuing ecosystem assets

10.3.1 General approach to valuing ecosystem assets

10.44 The NPV approach to the valuation of ecosystem assets was introduced in chapter 8. In mathematical terms, the value of a single ecosystem asset at the end of an accounting period is written as:

$$V_t(\boldsymbol{EA}) = \sum_{i=1}^{i=s} \sum_{j=t+1}^{j=t+N} \frac{ES_t^{ij}(\boldsymbol{EA}_t)}{(1 + r_j)^{(j-t)}},$$

where ES_t^{ij} is the value of ecosystem service i in year j as expected in period t (e.g. 2020) generated by a specific ecosystem asset $\boldsymbol{EA}_t$; S is the total number of ecosystem services; rj is the discount rate (in year j); and N is the lifetime of the asset, which may be infinite for some ecosystem assets if they are used sustainably.[108]

10.45 In ecosystem accounting, an ecosystem asset generates a bundle of ecosystem services, each valued separately. The NPV formula is applied at the level of individual ecosystem services and the resulting discounted values are aggregated to derive the monetary value of the ecosystem asset. Where the ecosystem service values are based on observed market prices for associated benefits (e.g. using the resource rent method), the costs incurred in supplying the ecosystem services are excluded so that the values used reflect only the contribution of the ecosystem. A discussion on the various components of the equation is presented below.

10.46 Each ecosystem service is considered separable given that (a) it can be measured distinctly, that is, in a mutually exclusive manner; and (b) it represents a distinct flow between an ecosystem asset and a user. At the same time, in measuring the NPV for each ecosystem service, it is necessary to recognize that, while each ecosystem service is generated from an ecosystem asset, different characteristics of that ecosystem asset would be relevant in the generation of each service. Thus, in this formulation, while there is a common location, there is not a single distinct stock, as is evident when using the NPV approach to value mineral, energy or timber resources, as presented in the SEEA Central Framework.

10.47 Consequently, while each ecosystem service flow and its associated NPV are considered separable, it is necessary for the inherent connections among ecosystem characteristics within an ecosystem asset in a given location to be considered jointly when the expected future returns of each ecosystem service are being determined. General proposals for providing a reasonable baseline for consistency in measurement are set out below, with the general aim of preventing contradictions within a set of accounts. This ambition provides a suitable basis for meaningful interpretation in monitoring and decision-making.[109]

10.48 Assuming that the expected future returns for each service are estimated based on the exchange value concept, the NPV for an ecosystem service provides an exchange value for the capitalized value of that service and the aggregate NPV will provide an exchange value for the ecosystem asset. In order to decompose the change in asset value from the beginning to the end of an accounting period, for example, in order to record the value of ecosystem degradation, the changes in price and quantity of future returns for each ecosystem service are analysed. Appendix A10.1 provides a description of the decomposition approach.

10.49 The general principles just outlined apply to the situation where ecosystem services are attributable to individual ecosystem assets. Commonly, the measurement and valuation of ecosystem services are undertaken using detailed spatial data, which in turn supports the potential to undertake measurement at this level of detail. The spatial attribution of ecosystem services to different ecosystem assets is discussed in chapter 7. Where ecosystem services are not attributed to a single ecosystem asset, it remains possible to estimate the NPV of each ecosystem service and aggregate to determine a total value of ecosystem assets for an EAA. Further, in practice, it may be necessary to undertake projections at a more aggregated scale (e.g. with respect

[108] The assumption made is that the returns accrue at the end of the accounting period, hence the first future period's flows are discounted. This assumption is used to simplify the explanation and the associated notation but has no impact on the underlying relationships described.

[109] It will likely be possible with advances in biophysical science and associated economic modelling to better estimate expected interactions within ecosystems with respect to the supply of ecosystem services. Indeed, advances in this direction are occurring, and an important area of future research will involve applying these advances to the task of improving the valuation of ecosystem assets (see, for example, Fenichel, Abbott and Yun (2018)).

to demography) rather than for individual ecosystem assets. Nonetheless, where possible, estimation should be undertaken for smaller, sub-EAA spatial areas to assist in recognizing variations in local contexts, including differences in ecosystem characteristics and in institutional arrangements (see also sect. 10.3.6).

10.50 As introduced in section 8.2, the measurement of expected future returns involves consideration of five key factors: (a) scope and definition of returns; (b) valuation of returns; (c) future flows of ecosystem services in physical terms; (d) asset lives; and (e) expected institutional arrangements. Each of these factors is considered in more detail below. In practice, all factors are interconnected and an iterative process would be needed to establish a clear and agreed basis for estimating expected future returns across multiple ecosystem services. Importantly, the integrated approach used in ecosystem accounting, especially the use of consistent classes of ecosystem types to underpin the organization of relevant data, provides the structure within which all of the relevant factors can be addressed consistently.

10.51 In addition to estimating expected future returns, the second key component of the NPV formula is the discounting of these returns to their present value, which, entails a mathematically straightforward calculation. The selection of an appropriate discount rate is a matter of considerable importance since it can have a significant effect on the resulting asset value and on its interpretation. The selection of discount rates is discussed in section 10.3.7.

10.52 To support the interpretation of estimates and comparison of results from different sets of accounts, it is necessary for all assumptions used to underpin the measures of the value of ecosystem assets and changes in value to be clearly documented.

10.53 It is standard practice to record single point estimates in the accounts. However, given the assumptions required to underpin valuation in monetary terms, it may be appropriate to provide a range of values that could be obtained under plausible alternative assumptions. For example, estimates of the value of ecosystem assets might be derived using different assumptions concerning the discount rate.

10.54 The description of the NPV approach in this chapter is aligned with the discussion in the SNA and the SEEA Central Framework. The key difference in application concerns the need to aggregate multiple future returns for a single asset value. The alignment in approach supports the compilation of extended balance sheets that incorporate ecosystem assets alongside other asset classes (see chap. 11). Because the approach described here involves the aggregation of individual ecosystem services, it should be possible to directly integrate estimates from the Central Framework for natural resources provided that they can be matched to the relevant provisioning service and ecosystem asset. This also means that alternative valuations for those services can be incorporated, potentially using directly observed data (for example, on land values) or variations on the NPV formulation presented above, such as the stumpage method for valuing timber resources.[110]

10.3.2 Scope and definition of returns

10.55 The scope of returns encompasses the set of ecosystem services that is included in the valuation of any given ecosystem asset. In practice, the set of ecosystem services included for asset valuation should align with the set of services recorded in the monetary ecosystem services flow account for each ecosystem type, as recorded in tables 9.1a and 9.1b, in turn building on the measurement of ecosystem services in physical terms as described in chapters 6 and 7. Compilers should include a comprehensive range of ecosystem services in order to best reflect the monetary value of the asset and its changes over time.

[110] The SEEA Central Framework describes alternative approaches to the valuation of timber resources (paras. 5.383 and 5.384), noting that they are NPV formulations under simplifying assumptions concerning the timber stock.

10.56 The returns included in the NPV calculation refer to the ecosystem services expected to be supplied by an ecosystem asset. As described in chapter 8, ecosystem services are the contributions of ecosystem assets to benefits and hence ecosystem services and benefits must be clearly distinguished. By way of example, in the case of timber provisioning services, the ecosystem services refer to the contribution of the ecosystem (e.g. valued using a stumpage value or resource rent) and are distinct from the benefits, namely, the harvested timber, commonly in the form of logs, which is sold by the forester.

10.57 Following the treatments of ecosystem services described in chapter 6, the scope of ecosystem services included in the NPV calculation may include flows of intermediate services. Thus, in principle, in the estimation of returns for a given ecosystem asset, the supply of intermediate services to other ecosystem assets should be included and the use of intermediate services from other ecosystem assets should be deducted. Intermediate services that are supplied and used within an ecosystem asset need not be included in the calculation since they will net out in the overall valuation.

10.58 With respect to marine ecosystems, attention should be paid to determining the appropriate measurement boundary for fish stocks and other aquatic resources since those stocks may migrate through or straddle the EAA boundary if it is defined following, for example, a country's EEZ. The measurement boundary for fish stocks defined in the SEEA Central Framework (sect. 5.9) should be applied for the relevant provisioning services.

10.59 The monetary value of abiotic flows, spatial functions and non-use values, defined following the treatments in chapter 6, should not be included in the valuation of ecosystem assets. However, the NPV of those flows may be separately calculated, for example, for renewable energy sources, and included as part of other environmental assets in the extended balance sheet described in chapter 11.

10.3.3 Valuation of returns

10.60 Returns for each ecosystem service are valued based on exchange values consistent with the guidance provided in chapters 8 and 9. The value of ecosystem services is focused only on the contribution of the ecosystem following the methods described in chapter 9. Where ecosystem services values are based on observed market prices for associated benefits (e.g. using the resource rent method), the costs incurred in supplying the ecosystem services will be excluded so that the value used considers only the contribution of the ecosystem. All of the other methods described in chapter 9 estimate the ecosystem contribution directly and exclude costs of supply.

10.61 To determine the present value of future returns, assumptions are required concerning the future prices for each ecosystem service. When valuing individual environmental assets, such as mineral and energy resources, it is common, for national accounting purposes, to assume that the current period price (or an average of prices in recent accounting periods) will apply in future periods. This is also an appropriate default approach for ecosystem accounting purposes.

10.62 Nonetheless, in valuing future returns of ecosystem services, assuming constant prices may not be valid in some situations in view of the wider interconnections and factors that influence an ecosystem asset and affect future returns. Therefore, future price changes should be taken into account when expected changes in markets are well understood and where sufficient information is available, such as on some aspects of climate change-related effects.

10.3.4 Future flows of services in physical terms

10.63 In estimating future flows of ecosystem services in an asset valuation context, it is necessary to allow for relationships among ecosystem services. While each ecosystem service is assumed to be measured separately from other ecosystem services and can be quantified separately in the current accounting period, estimation of future flows requires recognition that expectations regarding patterns of ecosystem management and wider environmental trends for a single ecosystem asset will affect different ecosystem services in different ways. Thus, for example, if global climate regulation services are estimated under the assumption that a forest can sequester carbon over an infinite time frame, while for the same ecosystem asset, rates of timber provisioning are estimated under the assumption that the forest's timber resources will be fully depleted within a limited time frame (e.g. 30 years) with no likelihood of regeneration, then the two estimates of expected service flows will be internally inconsistent.

10.64 More specifically, the future flow of services depends upon the condition and regeneration of the ecosystem and future demand for ecosystem services, it being understood that the supply and use of ecosystem services must align for accounting purposes. For example, the future flow of ecosystem services from a forest ecosystem in relation to air filtration services will depend in part on (a) the extent and condition of the forest; (b) the expected level of pollutants; and (c) the expected size and growth of the local population that benefits from air filtration services. There will be a set of factors to consider for each type of ecosystem service. It is to be noted that in estimating the expected future flow of services, it cannot necessarily be assumed that the flow will be ecologically sustainable, i.e. will involve no loss of ecosystem condition.

10.65 It is not anticipated that compilers will develop comprehensive models of future demand and supply considerations. However, it is reasonable to consider that some factors may be identifiable and quantifiable in certain contexts, for example, the effects of increases in population or consequences of the adoption of specific legislation that is expected to reduce pollution. In some cases there may be bioeconomic and similar models that can support the development of estimates. In these cases, such information should be considered in the estimation of future flows for a given ecosystem service. Over time, as a time series of ecosystem accounts is developed, insights should emerge with regard to the factors of most relevance. Indeed, a key application of the accounts is in the organization of past data to estimate future trends. Relevant considerations are outlined in the following points set out below.

10.66 Since ecosystem services require both the supply and use of services, the expected socioeconomic context must also be considered in estimating the future flows of ecosystem services. This context includes general socioeconomic factors (such as demography and incomes) and more specific factors, including those that are spatially relevant or relevant to individual ecosystem services. Examples include changes in the demand for recreation-related services following increases in accessibility of ecosystems; and changes to regulations that reduce the concentrations of pollutants and thus reduce the demand for air filtration services.

10.67 In considering both the future supply and demand of ecosystem services it is helpful to frame future flows in different ways depending on the type of service. Future flows of provisioning services are likely to be functions of natural resource and cultivated biological resource supply and demand considerations. On the other hand, future flows of regulating and maintenance services are more likely to be functions of changes in exposure to risks over time, for example, from pollution and emissions, floods and the effects of climate change. Cultural services are likely to be driven by demand considerations including demographic changes and specific factors such as urban design and trends in tourism and recreation. The information provided in the logic chains for ecosystem services in appendix A6.1 may provide a useful starting point in framing the relevant factors by type of ecosystem service.

10.68 Chapter 8 provided an introduction to the interactions among and within ecosystem assets that should be taken into account when considering the future flows of ecosystem services and their values. Assumptions concerning expected future degradation that would exert an impact on specific ecosystem services are of particular importance. For example, anticipated degradation of forests due to high levels of current ecosystem use would be expected to affect regeneration rates and consequently the flow of wood provisioning services would be expected to decline over time. In national accounting, similar assumptions are made when estimating the stock of produced assets.

10.69 In addition, in order to avoid internal contradictions in the measurement of asset values, it should be recognized that some patterns of use, primarily overexploitation of natural resources such as timber, soil and fish, will have detrimental impacts on the supply of other ecosystem services. Those impacts may not be apparent immediately, being subject to different environmental thresholds. The description of the measurement of ecosystem capacity contained in chapter 6 can provide valuable input to the consideration of these issues.

10.70 Moreover, it is relevant to consider wider environmental changes, such as expected changes in rainfall and temperature patterns or ocean acidification associated with climate change. Ideally, information from climate change-related models may be applied.

10.71 There are some contexts in which economic activity, including household consumption, has indirect and potentially delayed impacts on ecosystem condition. In an NPV framing, the fact that the impacts on ecosystem condition (and hence ecosystem services flows) may arise well into the future is conceptually straightforward to manage, if the timing and magnitude of the impacts are known and can be incorporated into the estimation process. However, under a common scenario, evidence of impacts might emerge gradually, with the result that expectations regarding future services flows change. From an accounting perspective, identifying such a change in expectations is possible. It is recommended that the change in value associated with these new expectations be recorded as a reappraisal of ecosystem asset value.

10.3.5 Ecosystem asset life

10.72 ***Ecosystem asset life is the period over which an ecosystem asset is expected to generate ecosystem services.*** Estimates of asset life should be based on consideration of the condition of the ecosystem asset and its capacity to supply the set of ecosystem services being considered in the valuation of the asset. It is possible to assume an infinite asset life when it is expected that the ecosystem asset will be used long into the future. An alternative is to apply a maximum asset life of 100 years. Unless there is strong evidence to the contrary, it is recommended that estimates of asset life be based on patterns of ecosystem use that have occurred in the recent past rather than on the utilization of general assumptions regarding future sustainability or intended or optimal management practices.

10.73 For use of the NPV formula, it is necessary to apply the same asset life for all ecosystem services supplied by an individual ecosystem asset, that is, the concept of asset life should be applied in relation to the asset rather than the service. For ease of application of this requirement, it is most likely appropriate to assume a single asset life for all ecosystem assets and hence all ecosystem services. An infinite asset life might be most appropriate for this purpose. Then, if there are some services for which the expectation is that services will no longer be supplied or used after a particular point in time (e.g. after 30 years), entries for subsequent time periods can be filled in with zeros.

10.3.6 Expected institutional arrangements

10.74 The fifth factor associated with establishing expected future returns is formulation of expectations regarding future institutional arrangements. The starting assumption for accounting purposes is that the current institutional arrangements will continue to apply. However, in cases where it is strongly expected that those arrangements will change in the future and the nature of the changes can be clearly understood, the effects of future changes in institutional arrangements and the expected timing of the changes should be factored in when estimating the future returns of ecosystem services. Examples of relevant institutional arrangements include natural resource management regimes, taxation arrangements, government environmental conservation programmes and markets for environmental services (e.g. carbon markets).

10.3.7 Discounting

10.75 A discounting process involving the selection of a discount rate is required to derive NPV estimates. Appendix 5.2 of the SEEA Central Framework ("Discount rates") summarizes key issues involved in the choice of discount rates and describes the mathematical and analytical implications of the choice of discount rates. In particular, that appendix takes note of the distinction between individual/private discount rates and social discount rates and the logic behind whether those rates are determined descriptively or prescriptively. Descriptively determined discount rates are those based on the prices (and other measurable factors) facing either individuals or governments, while prescriptively determined discount rates incorporate assumptions regarding the preferences of individuals and societies, particularly in respect of equity between and within generations.[111]

[111] See, in this regard, the SEEA Central Framework, annex A5.2, para. A5.52.

10.76 For individual ecosystem assets such as mineral and energy resources, and timber resources, the SEEA Central Framework concludes that for the purpose of alignment with the concept of exchange values as defined in the SNA, it is necessary to use marginal, private, market-based discount rates. This reflects that the discount rates are being applied in the context of the preferences of economic units operating from a private, market-based perspective. In SEEA EA, preferences relating to a wider range of economic units and goods and services need to be considered.

10.77 In this context, the following conceptual framing should be applied in selecting a discount rate.[112] Under this framing:

- Individual market-based discount rates should be applied in the valuation of ecosystem services whose users are private economic units
- Social discount rates should be applied in the valuation of ecosystem services that contribute to collective benefits, that is, benefits received by groups of people or society generally

[112] Under this framing, which is consistent with the concept of "dual discounting" (Baumgärtner and others, 2015; Weikard and Zhu, 2005), it is recognized that, ideally, this approach would also take into consideration substitution effects between types of services with different discount rates. These effects would generally be reflected in future prices.

10.78 The selection of a social discount rate for SEEA EA purposes should be based on rates as specified in relevant government guidelines; and further, rates should be in active use in government decision-making. Those rates are likely to embody some assumptions on preferences of individuals and societies. Where such rates are not available, compilers may consider using long-term government bond rates. It is not expected that all countries will use the same discount rate, given variations in economic context and institutional arrangements. However, the consistent application of the conceptual framing outlined above would support comparability across countries.

10.79 In applying discount rates, it is recommended that compilers use a constant rate over the asset's life. The primary alternative is to use declining discount rates including hyperbolic, gamma and geometrically declining rates. Declining rates may have some intuitive appeal in that they do not fix the relationship of preferences across generations and hence allow the preferences of future generations to be considered more explicitly. Declining rates also allow for increasing uncertainty, especially concerning future income growth. However, there are a range of challenges, theoretical (e.g. time inconsistencies) and practical; those rates are therefore not recommended for use in ecosystem accounting.

10.80 Care should be taken to ensure that the discount rate applied is consistent with the assumptions made in projecting future returns of ecosystem services. Specifically, if future returns are estimated in nominal prices, then the discount rate should include an allowance for expected inflation. Most commonly, future returns would be estimated in real terms and thus the discount rate applied should also be in real terms. Since the essential function of a discount rate is to reflect the time value of money, the appropriate measure of expected inflation is likely to be one that is economy-wide in scope, for example, the GDP deflator.

10.81 Compilers are encouraged to undertake an assessment of the sensitivity of monetary valuations to different assumptions, in particular through the application of alternative discount rates. Such assessments can be published as part of the general documentation of the accounts.

10.3.8 Measuring changes in the present value of ecosystem assets over an accounting period

10.82 Accounting for the change in the value of assets over an accounting period is a core part of asset accounting. Like the assessment of the value of an asset at the beginning and the end of an accounting period, the valuation of changes in asset value, such as those due to ecosystem enhancement, degradation and conversions, is also dependent on the impact exerted by those changes on expected future returns. Further, since the changes are not usually evidenced by transactions in the assets themselves, their valuation requires the use of the NPV approach to ensure alignment between opening and closing valuations and valuations of the changes.

10.83 A complete accounting for NPV and changes in NPV is presented in appendix A10.1. The appendix highlights the relationships between changes in the quantities of expected flows of ecosystem services, changes in the condition and extent of the ecosystem asset and changes in the prices of ecosystem assets with respect to each ecosystem service. A key conclusion drawn in the appendix is that it is incorrect to use the unit price of the ecosystem service in the current period to value the ecosystem assets and changes in those assets; rather the relevant asset prices are a function of the NPV formula on which expected future returns and discounting will have an effect. The relationship between unit prices for ecosystem services and ecosystem asset prices is also discussed in appendix A10.1.[113]

[113] This relationship is described in connection with the valuation of individual environmental assets in appendix A5.1 of the SEEA Central Framework.

Appendix A10.1

Application of the NPV method for valuing ecosystem assets and changes in ecosystem assets

Introduction

A10.1 The present appendix explains, in some detail, the steps involved in implementing an NPV approach for the valuation of ecosystem assets, with a view to deriving valuations of the opening and closing values of ecosystem assets and consistent measures of ecosystem enhancement, degradation, conversions, other changes in volume and revaluations. The conceptual framing for the approach described here is explained in chapter 10, which provides definitions of the relevant accounting entries.

A10.2 A simple stylized example is used to demonstrate the approach. It is recognized that the application of these principles will be more complex in practice and that some variations in application will be needed for ecosystem services other than the ones used. A more complete stylized example is presented in annex I to the present publication. It involves a larger number of ecosystem types and ecosystem services and incorporates a full range of ecosystem accounts including extent accounts, condition accounts, ecosystem services flow accounts and monetary ecosystem asset accounts. At the same time, the accounting principles described in the present appendix are also applied in that broader example. It is to be noted that there are some differences in terms of assumptions between appendix 10.1 and annex I; those differences are described in the appropriate sections below.

Stylized example

A10.3 In this simple example, the EAA covers 90 hectares (ha) consisting of two ecosystem assets: forest and cropland. At t_0,[114] the forest (EA1 – green) covers 50 ha and the cropland (EA2 – yellow) covers 40 ha (see figure A10.1.1). It is assumed that the extent of each ecosystem asset remains the same from t_0 to t_1; therefore, changes in ecosystem service flows are driven by changes in condition (degradation or enhancement) or changes in prices. The situation within which ecosystem conversion occurs is discussed further on in the present appendix.

A10.4 The forest is assumed to supply three types of ecosystem services: wood provisioning services (ES1), global climate regulation services (ES2) and recreation-related services (ES3); and the cropland supplies one type of ecosystem services: crop provisioning (ES4). It is also assumed that each of these services is supplied only from specific areas of each ecosystem asset so that the SPAs of each ecosystem service at time t (denoted by a_t) coincide with the areas of the respective ecosystem assets.

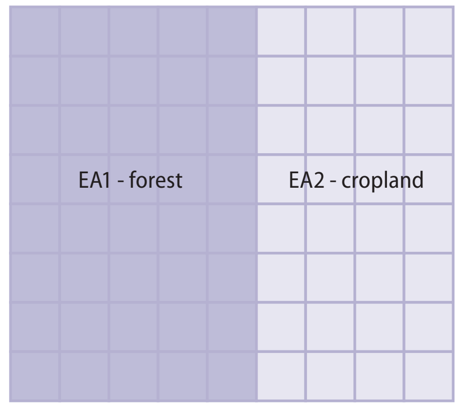
A10.5 As explained in section 10.3, the value V_t of each ecosystem asset is calculated as the NPV of the future flows of each ecosystem service supplied by that ecosystem asset. In this example, as shown in table A10.1.1, it is assumed that unit prices p and quantities of ecosystem services supplied Q are known and have been projected for each ecosystem service for a future period of five years.[115]

[114] Accounting periods are measured over time, where t_1 is the end of the first accounting period, t_2 is the end of the second accounting period and so on. t_0 is the start of the first accounting period and reflects the initial characteristics of the ecosystems and the initial expected prices and quantities of ecosystem services. Accounting periods are assumed to be years. To provide context, first accounting period year 1 could be 2020 (which would start at t_0 and end at t_1) and year 2 could be 2021 (which would start at t_1). Further, it is to be noted that in this example t_0 will also be the end of the accounting period for 2019.

[115] This example works with a moving asset life of five years (for illustrative purposes only), instead of assuming a fixed asset life end date, which has an effect on the results obtained. However, in more realistic applications, the asset life would be multiple decades (or infinite, as the examples utilizes renewable assets) and this effect would become minimal. In the stylized example in annex I, an asset life of 100 years is assumed.

Figure A10.1.1
Extent at t_0

Ecosystem asset	a_0
EA1 - forest	50 ha
EA2 - cropland	40 ha



A10.6 Table A10.1.1 depicts the set of unit prices and total quantities of ecosystem services supplied across the EAA as expected at t_0 (covering years 1 to 5) and table 10.1.2 depicts the prices and quantities as expected at t_1 (covering years 2 to 6). The expected prices and quantities shown in tables A10.1.1 and A10.1.2 for each of the four ecosystem services supplied across the EAA are different between t_0 and t_1, reflecting differences in expectations at these two points in time. Further, in this example, the pattern of expected prices and quantities shows changes over the five-year life of the asset. In the stylized example in annex I, the expected prices and quantities are assumed to be constant over the entire asset life.

A10.7 To simplify the presentation, the calculations are undertaken using discounted prices, assuming a 2 per cent discount rate. Discounted prices are obtained by multiplying the unit price in year *j* with the applicable discount factor for year *j* (as shown in table A10.1.1), which yields the ecosystem service values in the prices of the base year. For example, the value of wood provisioning in the amount of 723 currency units in year 3 is calculated as the number of cubic metres of wood (12 m^3) times the unit price (64 currency units per m^3) times the discount factor (0.9412). Table A.10.1.1 shows the discount factors obtained using a 2 per cent discount rate, assuming that the flows in the first year are discounted. This approach allows variations in the pattern of expected prices and quantities to be accounted for.

A10.8 For the derivation of the NPV using the equation provided in section 10.3, the value of the EAA, that is, the value of all ecosystem services across all ecosystem assets, can be expressed as

$$V_t = \sum_{i=1}^{i=4} \sum_{j=t+1}^{j=5} \frac{p_t^{ij}\, q_t^{ij}}{(1 + r_j)^{(j-t)}}. \qquad (1)$$

A10.9 In equation (1), *Vt* refers to the value at the end of accounting period *t* and is based on expectations regarding future prices and quantities at that point in time; i denotes the ecosystem service and j the year. It should be noted that it is assumed the value of each ecosystem service is separable and hence the overall asset value of the EAA can be obtained by summing over all ecosystem services.

A10.10 To explain the calculation for an individual ecosystem service, consider the global climate regulation service, ES2. In this case, quantities range from 140 to 148 tons per year over the five years from t_0 and the unit prices increase each year, from

Table A10.1.1

Input data and NPV calculations for three ecosystem services at time period t_0

Variable	Ecosystem services	Measure-ment unit	Year 1	Year 2	Year 3	Year 4	Year 5	Total flow (Q_0)	Total NPV (V_0)	Average prices (p_0)
ES quantity supplied (a)	ES1 Wood provisioning	m^3	12	12	12	12	12	60		
	ES2 Global climate regulation	tCO_2	140	142	144	146	148	720		
	ES3 Recreation-related	Visits	190	190	190	200	200	970		
	ES4 Crop provisioning	t	5	6	6	7	7	31		
Unit price (b)	ES1 Wood provisioning	$/m³	$60	$62	$64	$66	$70			
	ES2 Global climate regulation	$\$/tCO_2$	$25	$26	$27	$28	$29			
	ES3 Recreation-related	$/visit	$5	$5	$6	$6	$6			
	ES4 Crop provisioning	$/t	$75	$75	$75	$75	$75			
Exchange value (c) = (a) * (b)	ES1 Wood provisioning	$	$720	$744	$ 768	$792	$840			
	ES2 Global climate regulation	$	$3 500	$3 692	$3 888	$4 088	$4 292			
	ES3 Recreation-related	$	$950	$950	$1 140	$1 200	$1 200			
	ES4 Crop provisioning	$	$375	$450	$450	$525	$525			
Discount factor (d)	2 per cent discount rate		0.9800	0.9604	0.9412	0.9224	0.9039			
Net present value (e) = (c) * (d)	ES1 Wood provisioning	$	$706	$715	$723	$731	$759		$3 633	$61
	ES2 Global climate regulation	$	$3 430	$3 546	$3 659	$3 771	$3 880		$18 285	$25
	ES3 Recreation-related	$	$931	$912	$1 073	$1 107	$1 085		$5 108	$5
	Total forest	$							$27 026	
	ES4 Crop provisioning	$	$368	$432	$424	$484	$475		$2 182	$70
	Total cropland	$							$2 182	
	Total EAA	$							**$29 208**	

Abbreviations: ES, ecosystem service; m_3, cubic metres; tCO_2, tons of CO_2; t, tons.

Note: The symbol "$" signifies currency units.

Table A10.1.2
Input data and NPV calculations for three ecosystem services at time period t_1

Variable	Ecosystem services	Measurement unit	Year 2	Year 3	Year 4	Year 5	Year 6	Total flow (Q_1)	Total NPV (V_1)	Average prices (p_1)
ES quantity supplied (a)	ES1 Wood provisioning	m^3	10	10	10	10	10	50		
	ES2 Global climate regulation	tCO_2	130	132	134	136	138	670		
	ES3 Recreation-related	Visits	190	200	200	210	210	1 010		
	ES4 Crop provisioning	t	6	7	7	8	7	35		
Unit price (b)	ES1 Wood provisioning	$/m^3$	$65	$65	$67	$70	$72			
	ES2 Global climate regulation	$/tCO_2$	$26	$27	$28	$29	$30			
	ES3 Recreation-related	$/visit	$5	$6	$6	$6	$6			
	ES4 Crop provisioning	$/t	$75	$75	$75	$75	$75			
Exchange value (c) = (a) * (b)	ES1 Wood provisioning	$	$650	$650	$670	$700	$720			
	ES2 Global climate regulation	$	$3 380	$3 564	$3 752	$3 944	$4 140			
	ES3 Recreation-related	$	$950	$1 200	$1 200	$1 260	$1 260			
	ES4 Crop provisioning	$	$450	$525	$525	$600	$525			
Discount factor (d)	2 per cent discount rate		0.9800	0.9604	0.9412	0.9224	0.9039			
Net present value (e) = (c) * (d)	ES1 Wood provisioning	$	$637	$624	$631	$646	$651		$3 188	$64
	ES2 Global climate regulation	$	$3 312	$3 423	$3 531	$3 638	$3 742		$17 647	$26
	ES3 Recreation-related	$	$931	$1 152	$1 129	$1 162	$1 139		$5 514	$5
	Total forest	$							$26 349	
	ES4 Crop provisioning	$	$441	$504	$494	$553	$475		$2 467	$70
	Total cropland								$2 467	
	Total EAA	$							$28 816	
	Change in EAA value	$							**-$392**	

Abbreviations: ES, ecosystem service; m3, cubic metres; tCO_2, tons of CO_2; t, tons.
Note: The symbol "$" signifies currency units.

25 to 29 currency units per ton of CO_2 (e.g. as the marginal damages of carbon release increase). The NPV of this ecosystem service is derived by multiplying the quantity by the associated discounted unit price in each year (e.g. for t_0, year 1, 140 tons of CO_2 * 25 currency units per ton of CO_2 * 0.98 = 3,430 currency units). Summing over the five-year asset life yields the NPV for climate regulation at t_0 of 18,285 currency units.

A10.11 Using this approach across all ecosystem services and for both ecosystem assets, a total opening value at t_0 of 29,208 currency units is obtained. This decreases to 28,816 currency units, the value at t_0, that is, at the end of the accounting period. The change in asset value is -392 currency units. It should be noted that in the calculations, the NPV for each ecosystem service and each ecosystem type is also obtained.

Decomposition of the change in NPV

A10.12 In order to compile the entries in the ecosystem monetary asset account that records changes in NPV between opening and closing values, it is necessary to distinguish between changes due to prices and changes due to volumes (quantities). To distinguish these different changes, V_t^i (the value of the i^{th} ecosystem service) is defined as the product of (a) average (discounted) unit price over the asset life, denoted by $\bar{p}_t^i$ and (b) total flow (cumulative quantity) of ecosystem services supplied over the asset life, denoted by Q_t^i.[116]

A10.13 Table A10.1.1 details the various values of $\bar{p}_t^i$ and Q_t^i for each ecosystem service. To illustrate the derivation of $\bar{p}_t^i$ consider the global climate regulation service, ES2. NPV at t_0 is V_0^2 = 18,285 currency units and the cumulative quantity Q_0^2 over the five years from t_0 is 720 tons of CO_2. Dividing the NPV value by the total volume (V_0^2/Q_0^2) gives an average discounted unit price $\bar{p}_0^2$ for ES2 of 25.40 currency units per ton of CO_2.

A10.14 Using this framing, equation (1) can be re-expressed as:

$$V_t = \sum_{i=1}^{4} \bar{p}_t^i Q_t^i \qquad (2)$$

$$V_1^i - V_0^i = \bar{p}_1^i Q_1^i - \bar{p}_0^i Q_0^i = (\bar{p}_1^i - \bar{p}_0^i) Q_1^i + \bar{p}_0^i Q_1^i - \bar{p}_0^i Q_0^i$$

$$= \underbrace{(\bar{p}_1^i - \bar{p}_0^i) Q_1^i}_{\text{Price effect}} + \underbrace{\bar{p}_0^i (Q_1^i - Q_0^i)}_{\text{Volume effect}} \qquad (3)$$

A10.15 Equation (3) reflects the decomposition of the change in NPV for each ecosystem service i, into changes due to price (price effect) and changes due to volume/quantity (volume effect). The change in price $(\bar{p}_1^i - \bar{p}_0^i)$ is given a weight of Q_1^i and the change in volume $(Q_1^i - Q_0^i)$ is given a weight of $\bar{p}_0^i$. However, this weighting pattern (or decomposition form) is not unique and the change in value could have been decomposed into $(\bar{p}_1^i - \bar{p}_0^i)\, Q_1^i + \bar{p}_1^i (Q_1^i - Q_0^i)$. Thus, different weights for the price and volume effects are derived. As in appendix A5.1 of the SEEA Central Framework, and following standard index number practice, the average of the two decomposition forms is used to generate the results shown below.

A10.16 Using the various average unit prices $\bar{p}_t^i$ and total flows (Q_t^i) for each ecosystem service, the results using both decomposition forms can be calculated and averaged to derive average price and volume effects. Those average price and volume effects for each ecosystem service are shown in table A10.1.3. The key observation is that the total of both of the decomposition effects must equal the overall change in value (-392 currency units) shown in table A10.1.1 above. In other words, the decomposition is exact.

116 The manner in which this average discounted unit price is derived is similar to the approach taken in the SEEA Central Framework (annex A5.1) to derive estimates of depletion, where the *asset price in situ* for a subsoil asset was defined as the ratio of its NPV value *V* and the total stock *S*.

A10.17 Table A10.1.3 shows that the total value change of -392 currency units reflects the combination of a positive price effect (1,027 currency units) and a negative volume effect (-1,419 currency units). The decomposition thus provides additional insight into the nature of the change in total value. This type of analysis can also be undertaken for individual services. For example, there is a large reduction in the value of global climate regulation (-639 currency units), which is explainable mostly as a volume effect (Q_t^1 drops from 720 to 670 tons of CO_2 (see tables A10.1.1 and A10.1.2)). At the same time, there is an upward price effect due to the increasing price path of the service. It is to be noted as well that there is a minimal price effect for crop provisioning services, reflecting the fact that its expected price path does not change.

Ecosystem monetary asset account

Table A10.1.3
Results of the decomposition analysis for four ecosystem services (currency units)

	Price effect	Volume effect	Total
ES1 Wood provisioning	177	-622	-444
ES2 Global climate regulation	655	-1 293	-639
ES3 Recreation-related	192	215	406
ES4 Crop provisioning	4	282	285
Total	**1 027**	**-1 419**	**-392**

A10.18 The various decomposition elements can now be used to compile the ecosystem monetary asset account, as presented in table A10.1.4. The account is structured to show the opening and closing values for each ecosystem asset (equal to the sum of the NPVs of the ecosystem services relevant for that ecosystem asset)[117] and the various changes due to enhancement, degradation, conversions, revaluations or other changes. An explanation of the allocation of the accounting entries is provided in table A10.1.5.

A10.19 The estimates for the opening and closing values for each ecosystem asset can be readily obtained from tables A.10.1.1 and A.10.1.2. For forests, it is the sum of the NPVs for ES1, ES2 and ES3; and for cropland, it is NPV for ES4. To complete the other accounting entries, the first focus is estimation of the entry for revaluations, which is equal to the price effect shown in table A.10.1.3. This equality applies since the price effect measures the change in value that is due solely to the change in average (discounted) price (for each ecosystem service). The relationship between unit prices of ecosystem services and asset prices is discussed towards the end of the present appendix.

A10.20 The remaining change in value is associated with the volume effect, which measures changes in the total quantity of expected future ecosystem services (for each ecosystem service) due to changes that occur during the accounting period, excluding the effects of price changes. The volume effects can therefore be used to determine the relevant entries for ecosystem enhancement, degradation, reappraisals and catastrophic losses depending on the cause of the change, following the definitions provided in chapter 10.

A10.21 The process of establishing how a volume effect for a given ecosystem service is treated entails considering (a) whether the volume effect is positive or negative; (b) change in ecosystem condition over the accounting period; and (c) change in

117 In this example, the process of estimation of the entries into the asset account categories is made more straightforward since there is a one-to-one correspondence between the ecosystem assets and the areas providing ecosystem services. In more complex settings, the value of the individual ecosystem services would need to be apportioned to the underlying ecosystem assets (i.e. when an ecosystem service is supplied over a combination of ecosystem assets). This may be undertaken by prorating the aggregate supply of the ecosystem service using the share of areas of the relevant ecosystem assets, in which case there is an assumption of a homogeneous distribution of the supply of the ecosystem service across the SPA. More complex allocation methods might also be applied.

demand for ecosystem services.[118] Through consideration of the various combinations, the appropriate treatment of the measured volume effect can be carried out following the guidance in table A.10.1.5. For example, if the change in volume is positive and the change in condition is also positive, then the volume change is recorded as ecosystem enhancement. There are two combinations that are not possible: i.e. where condition and demand move in the same direction (either up or down), the volume cannot move in the opposite direction since this would imply that the future flow of ecosystem services in physical terms was not correlated with either the condition of the ecosystem or the demand for services.

Table A10.1.4
Ecosystem monetary asset account (currency units)

	Forest	Cropland	Total
Opening stocks at t_0	27 026	2 182	29 208
Ecosystem enhancement		282	282
Ecosystem degradation	-1 915		-1 915
Ecosystem conversions			
Additions		0	0
Reductions	0		0
Other changes in volume of ecosystem assets			
Catastrophic losses			
Reappraisals	215		215
Revaluation	1 023	4	1 027
Net change in value	-677	285	-392
Closing stocks at t_1	26 349	2 467	28 816

A10.22 In case of significant unexpected changes in quantities (e.g. due to uprooting of trees by a hurricane), negative changes in volume could be recorded as catastrophic losses rather than as degradation. In this way, all possible entries of the monetary asset account can be obtained in a manner that is aligned with and uses information from extent accounts, condition accounts and ecosystem service supply and use accounts.

A10.23 To apply the guidance from table A10.1.5 in this example, it is assumed that the associated condition account indicates that the condition of the forest ecosystem asset has declined during the accounting period but that the condition of the cropland ecosystem asset has increased. Considering each ecosystem service in turn:

- For wood provisioning services (ES1), table A10.1.3 shows a negative volume effect (-622 currency units). Since the condition also declines, this volume effect is recorded as degradation
- For global climate regulation services (ES2), table A10.1.3 shows a negative volume effect (-1,293 currency units). Since the condition also declines, this volume effect is recorded as degradation
- For recreation-related services (ES3), table A10.1.3 shows a positive volume effect (215 currency units). Since the condition declines, this is best explained as being due to an increase in demand (reflected in a slight increase in total expected visitor numbers) and is therefore recorded as an upward reappraisal.

[118] In projecting physical flows and unit prices (*p*'s and *Q*'s in table A10.1.1), it is reasonable to assume that ecosystem condition (and expectations on how it will develop within the current management regime) and expected demand are taken into account. During the accounting period, many changes occur (changes in demand but also changes in actual condition), with the final result being that at the end of the accounting period, there will be updated expectations regarding physical flows and unit prices.

- For crop provisioning services (ES4), table A10.1.3 shows a positive volume effect (282 currency units). Although demand is assumed to decline slightly, since condition improves, this volume effect is recorded as ecosystem enhancement.

Table A10.1.5
Treatment of ecosystem services volume effects based on condition and demand changes

Volume change	Condition change	Demand change	Accounting entry
Up	Up	Up	Enhancement
Up	Up	Down	Enhancement
Up	Down	Up	Upward reappraisal
Up	Down	Down	Not possible
Down	Up	Up	Not possible
Down	Up	Down	Downward reappraisal
Down	Down	Up	Degradation
Down	down	down	Degradation

A10.24 The broader interpretation is that the overall value of the forest ecosystem asset has declined, while the cropland ecosystem asset has increased in value. The net effect, however, is a loss of 392 currency units in the value of this EAA.

Decomposition of the change in NPV with ecosystem conversions

A10.25 In the above example, the areas of each ecosystem asset remained the same over the projection period. Consequently, there was no consideration of ecosystem conversions, that is, changes in ecosystem extent, where a particular location changes in ecosystem type during an accounting period. These changes are recorded in biophysical terms in the ecosystem extent account. The appropriate calculations for recording the monetary effects of conversions in the monetary ecosystem asset account are explained below.

A10.26 To demonstrate the relevant entries, the example is adapted so that forest extent during the accounting period is reduced by 2 ha, which are converted to cropland (see figure A10.1.1). To retain the connection with the previous context and data, a simplifying assumption is made, according to which all other details of expected quantities and unit prices remain the same and consequently NPV for each ecosystem service and the total NPV for the EAA remain the same.

A10.27 To indicate changes in the area of each ecosystem asset, the decomposition formula is altered so that the extent of the SPA of each ecosystem service, denoted by a_t^i is incorporated. This incorporation is shown in equation (4), which is a reworking of equation (2):

$$V_t^i = \bar{p}_t^i \frac{Q_t^i}{a_t^i} a_t^i = \bar{p}_t^i \bar{q}_t^i a_t^i \,. \tag{4}$$

A10.28 Total (expected) volume of ecosystem service i per hectare within the SPA is denoted by $\bar{q}_t^i$. Using this expansion, the difference between the opening and closing values for each ecosystem service can be expressed as

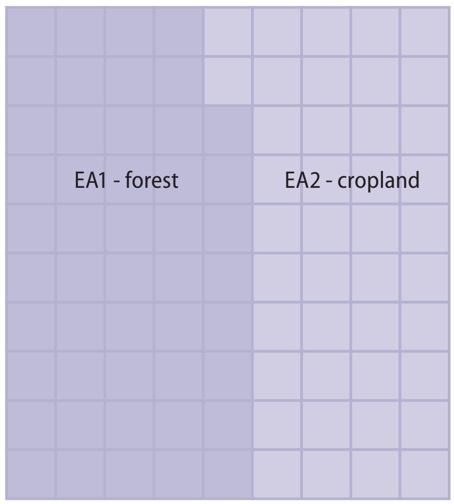
$$V_1^i - V_0^i = \bar{p}_1^i\bar{q}_1^i a_1^i - \bar{p}_0^i\bar{q}_0^i a_0^i = (\bar{p}_1^i - \bar{p}_0^i)\bar{q}_1^i a_1^i + \bar{p}_0^i\bar{q}_1^i a_1^i - \bar{p}_0^i\bar{q}_0^i a_0^i$$

$$= (\bar{p}_1^i - \bar{p}_0^i)\bar{q}_1^i a_1^i + \bar{p}_0^i(\bar{q}_1^i - \bar{q}_0^i)a_1^i + \bar{p}_0^i\bar{q}_0^i a_1^i - \bar{p}_0^i\bar{q}_0^i a_0^i$$

$$= \underbrace{(\bar{p}_1^i - \bar{p}_0^i)\bar{q}_1^i a_1^i}_{\text{Price effect}} + \underbrace{\bar{p}_0^i(\bar{q}_1^i - \bar{q}_0^i)a_1^i}_{\text{Volume effect}} + \underbrace{\bar{p}_0^i\bar{q}_0^i(a_1^i - a_0^i)}_{\text{Area effect}} \qquad (5)$$

Figure A10.1.2
Extent at t_1

Ecosystem asset	a_1
EA1 - forest	48 ha
EA2 - cropland	42 ha



A10.29 Formula (5) thus decomposes the change in NPV (of each ecosystem service *i*) into three effects: a price effect, a volume (intensity) effect and an area effect. As before, the price effect measures the change in average (discounted) unit prices that occurs during the accounting period. The volume (intensity) effect measures changes in the quantity of future ecosystem services per hectare to allow the effect of changes in area to be separately identified. The area effect measures changes in value due to changes in extent of assets.

A10.30 As was the case for the earlier decomposition into price and volume effects (equation (3)), the decomposition form shown in equation (5) is exact but not unique. In fact, there are six alternative exact formulations of equation (5), compared with two alternative formulations of equation (3).[119] The results shown below have been derived using a weighted average of each of the six forms of (a) the area effect, (b) the price effect and (c) the volume (intensity) effect. To derive the actual effects the changes in the relevant variable (e.g. area) are multiplied by these weights. In this example, the derivations of the three effects are expressed as follows:

Area effect: $[\frac{1}{3}\bar{p}_0^i\bar{q}_0^i + \frac{1}{6}\bar{p}_0^i\bar{q}_1^i + \frac{1}{6}\bar{p}_1^i\bar{q}_0^i + \frac{1}{3}\bar{p}_1^i\bar{q}_1^i] * a_1^i - a_0^i$

Price effect: $[\frac{1}{3}\bar{p}_0^i a_0^i + \frac{1}{6}\bar{p}_0^i a_1^i + \frac{1}{6}\bar{p}_1^i a_0^i + \frac{1}{3}\bar{p}_1^i a_1^i] * \bar{p}_1^i - \bar{p}_0^i$

Volume effect: $[\frac{1}{3}a_0^i\bar{q}_0^i + \frac{1}{6}a_0^i\bar{q}_1^i + \frac{1}{6}a_1^i\bar{q}_0^i + \frac{1}{3}a_1^i\bar{q}_1^i] * \bar{q}_1^i - \bar{q}_0^i$

A10.31 The values of $\bar{q}_0^i$ that are used to calculate this decomposition are obtained by dividing, for example, the total quantity of global climate regulation services at t_0, i.e. Q_0^2 (720 tons of CO_2) by the size of the SPA a_0^2 (50 ha), resulting in a $\bar{q}_0^i$ of 14.40 tons of

[119] This can be seen by noting that in equation (3), the starting point was (p_1-p_0) but the starting point could also have been (q_1-q_0). In equation (5), this is extended to allow for consider starting with (a_1-a_0). See Dietzenbacher and Los (1998) for a more general proof.

CO_2 per ha. Following the previous steps, but incorporating measurement of the area effect, the decomposition of the change in value can be calculated as shown in table A10.1.6.

A10.32 Again, the decomposition is exact, as the sum of the changes due to area, volume and price equals the total value change (of -392 currency units). As expected, the differences in NPV for each ecosystem service are the same (e.g. -444 currency units for ES1, as previously), but there are now three explanatory factors rather than two. Also as expected, the price effect is virtually the same as in the earlier decomposition, since the volume effect has essentially been split into a volume (intensity) effect and an area effect. The area effect can now be interpreted as providing the entries for ecosystem conversions (additions and reductions) in the ecosystem monetary asset account. It should be noted that the change in area used to derive the area effect is consistent with the information in the ecosystem extent account.[120]

A10.33 The structure of the ecosystem monetary asset account remains unchanged (see table A.10.1.7) but compared with the results shown in table A10.1.4, the entries for ecosystem conversions are now non-zero. The main change is that the previous entry for degradation of forests (-1,915 currency units) is reduced to -1,042 currency units. The difference is now recorded as a negative ecosystem conversion (-1,090 currency units) and a higher value of reappraisals (431 currency units). A similar partitioning occurs with cropland, with the previous entry for ecosystem enhancement reduced to 168 currency units and a positive ecosystem conversion of 113 currency units recorded. By including an additional factor in the decomposition form, the change in value that occurred during the accounting period can be better explained.

Unit prices and asset prices

A10.34 With regard to interpretation of prices: in this valuation and decomposition, discounted unit prices have been used for each ecosystem service. By multiplying the discounted unit prices (p_t^{ij}) by their expected quantities (q_t^{ij}) and summing over the life of the asset, the NPV of each ecosystem service is obtained and the value of each ecosystem asset at each point in time can then be determined.

A10.35 In this context, the NPV of the ecosystem asset (i.e. the sum over relevant services) is also the unit price of the asset. Thus, the basic measurement unit remains the individual ecosystem asset, characterized by its extent (which will generally be greater than 1 ha) and its condition. In this framing, the price of the ecosystem asset can be considered to reflect an average asset price over all hectares for that ecosystem asset.

A10.36 It may also be of interest to calculate the marginal asset price, defined as the change in the NPV of the ecosystem asset with respect to a marginal change in extent of the asset (e.g. a change of 1 ha).[121] In this framing, it may be reasonable to suppose intuitively for an asset that is large (in terms of extent) – say, a forest – that the mar-

[120] It is to be noted that there are some interactions between changes in volume and changes in price in a general equilibrium context but the effect of those interactions is likely to be minimal.

[121] Extent is just one among several options for assessing marginal price. It is also possible, for example, to consider ecosystem characteristics such as timber volume.

Table A10.1.6
Results of the decomposition analysis (three factors) (currency units)

	Area effect	Volume effect	Price effect	Total
ES1 Wood provisioning	-139	-482	177	-444
ES2 Global climate regulation	-733	-560	654	-639
ES3 Recreation-related services	-217	431	192	406
ES4 Crop provisioning	113	168	4	285
Total	**-976**	**-442**	**1 027**	**-392**

Table A10.1.7
Monetary ecosystem asset account (with conversions) (currency units)

	Forest	Cropland	Total
Opening stocks at t_0	27 026	2 182	29 208
Ecosystem enhancement		168	168
Ecosystem degradation	-1 042		-1 042
Ecosystem conversions			
Additions		113	113
Reductions	-1 090		-1 090
Other changes in volume of ecosystem assets			
Catastrophic losses			
Reappraisals	431		431
Revaluation	1 023	4	1 027
Net change in value	-677	285	-392
Closing stocks at t_1	26 349	2 467	28 816

ginal price of a hectare at the edge of the forest is different from the marginal price of a hectare at its centre, that is to say, that there are different asset prices for different parts of an ecosystem asset and those asset prices might change as the overall size of the asset changes. Put differently, losing 1 hectare when the extent is 100 hectares may be less problematic than losing 1 hectare when the extent is 5 hectares.

A10.37 In the example, it is assumed that the supply of ecosystem services is distributed homogeneously across the ecosystem asset, which implies that the marginal and average asset prices can be assumed to coincide. This is how it was possible to normalize ecosystem services using the area over which they were supplied in order to separate out the area effect in the decomposition.

A10.38 Of course, in practice, most ecosystem services are not supplied homogeneously across the ecosystem asset and therefore a difference would arise between the marginal and average asset prices. In such instances, it would be theoretically possible to break up the ecosystem asset into smaller units (e.g. units of one ha each) and, following the approach described in the present appendix, obtain for each an average asset price. Provided that each resulting smaller unit was itself homogeneous, an alignment would emerge between the average and marginal asset prices at that smaller scale.

A10.39 The example provided in the present appendix is framed in the context of individual ecosystem assets that provide ecosystem services. However, it is also possible to apply the same approach at an aggregate scale to value ecosystem types based on the bundles of ecosystem services that they provide.

Chapter 11
Integrated and extended accounting for ecosystem services and assets

11.1 Introduction

11.1 The discussion on combining ecosystem accounting data with standard economic data is increasingly relevant as countries, both nationally and multinationally, are recognizing the losses of some ecosystem services and are developing policy instruments to mitigate and reverse this trend. The combination of ecosystem and economic data supports a richer discussion of the connection between ecosystems and people; underpins the development of indicators concerning this relationship, such as the contribution of ecosystem services to measures of economic production; and allows the derivation of adjusted national accounting aggregates such as degradation-adjusted measures of net domestic product (NDP).

11.2 Building on the ecosystem accounts described in chapters 3 through 10, the present chapter describes principles and recommendations for the integration of ecosystem accounting data and data from the standard SNA accounts. Integration is considered with respect to the SUTs and the sequence of institutional sector accounts, including balance sheets. All of these accounts are labelled as extensions to the SNA accounts, which recognizes the intent to complement the data presented in the SNA.

11.3 Historically, approaches to more detailed integration of ecosystem-related information with the national accounts have focused on the valuation of degradation and the appropriate recording of this "cost of capital" in the accounts of different sectors. This is a characteristic of the previous approaches outlined by national accountants (see, for example, Nordhaus and Kokkelenberg, eds. (1999), A. Harrison (1993) and Vanoli (1995)). As explained in SEEA EEA and in some papers in the recent literature (e.g. Edens and Hein (2013) and Obst, Hein and Edens (2016)), the emergence and application of the concept of ecosystem services have enabled a reconceptualization of the integration of ecosystem-related data with the SNA. This basis for integration underpins much of the discussion in this chapter.

11.4 The monetary valuation of ecosystem services and ecosystem assets using exchange values is required for integration with the national accounts. However, as explained consistently through chapters 8 to 10, in many instances, data from the ecosystem extent and condition accounts and data concerning the physical flows of ecosystem services are required to better understand relevant ecological thresholds and limits. Also, coverage of the extended accounts is limited to the ecosystem services that are within scope of measurement. Finally, use of exchange values provides monetary values that are suitable for the compilation of extended accounts but in other contexts alternative valuation concepts and presentations may be more appropriate. Complementary approaches to monetary valuation that are considered to reflect applications and extensions of the SEEA EA accounting framework are discussed in chapter 12.

11.5 Data from the ecosystem accounts also complement data from the SEEA Central Framework, especially on environmental pressures (e.g. emissions) and policy responses (e.g. environmental protection expenditure, environmental taxes and subsidies). These types of data are needed for a complete assessment of the environmental-economic relationship. The potential to combine data from the SEEA Central Framework and SEEA EA is discussed in chapter 13 using selected policy themes as the entry point.

11.2 Extended SUTs

11.6 SUTs show the relationships between economic units (households, business, governments) in terms of flows of goods and services. Each type of good or service is recorded as supplied by an economic unit and used by another for final consumption, intermediate consumption, investment (capital formation) or export. Inherent in the design of an SUT is the ability to record supply chains through the economic system by showing gross outputs and intermediate inputs and how they are netted within each economic unit to derive measures of value added, i.e. income generated through the production of goods and services. SUT are commonly used to support the compilation of measures of GDP as SUT require a complete reconciliation between the supply of and demand for goods and services and hence reconciliation among the three different measures of GDP. Importantly, the scope of goods and services included in a standard SUT is limited to the production boundary of the SNA.

11.7 Compiling extended SUT involves combining data from the ecosystem services flow account in monetary terms described in chapter 9 with the standard SUT from the SNA as described in the previous paragraph. Extended SUT thus require explicit consideration of the measurement boundaries between the economy and ecosystems to ensure that there is an appropriate structure for the accounts and that recorded data do not imply double counting. Extended SUT thus present the data on the supply and use of ecosystem services as extensions to the standard SUT compiled following the SNA.

11.8 The compilation of extended SUT can support a range of purposes:

- To show the contribution of ecosystem services to the output and value added of different industries and the economy as a whole
- To identify the share of economy-wide value added that is dependent on ecosystem services
- To develop an understanding of the main users of ecosystem services and the relative contribution of ecosystem services to household and government final consumption expenditure
- To describe ecosystem services as inputs to economic supply chains and to develop an understanding of ecosystem services-dependent industries
- To integrate ecosystem services data into analytical and modelling tools – for example, input-output models and computable general equilibrium models – that use SUT as primary data sources

11.9 There are two key aspects to consider in extending the standard SUT to incorporate ecosystem services. First, since ecosystem accounting implies an extension to the standard production boundary, the set of goods and services within scope of the extended SUT is broader and in consequence the dimensions of the standard SUT must increase. Usually, this would be carried out through the addition of new rows (each additional row representing an additional ecosystem service).[122]

[122] SUT need not be square matrices, where the number of goods and services is equal to the number of supplying industries. The standard input-output (I-O) matrix algebra that underpins input-output analysis has been adapted to allow non-square SUT data to be used in I-O analysis and this can be applied in the case of extended SUT. It is to be noted that the resulting I-O tables are square matrices.

11.10 The accounting requirement is to ensure that the ecosystem services are distinguished clearly from the goods and services (products) that are already recorded within the standard SUT. For the products to which ecosystem services are direct inputs (i.e. SNA benefits), ecosystem services are recorded as the intermediate consumption of the associated user of the ecosystem service. For example, the ecosystem service of timber biomass provisioning is recorded as additional intermediate consumption by forestry units.

11.11 For ecosystem services that contribute to non-SNA benefits, there are no associated products with which the services can be connected and it is sufficient to record the supply of the relevant ecosystem service (e.g. air filtration services) and the use of that service by the relevant economic unit following the guidance in chapter 6.

11.12 It is possible to design an extended SUT that also incorporates intermediate services supplied by ecosystems. For example, where pollination services are of relevance, an additional row might be included to recognize these flows as inputs to the generation of associated final ecosystem services, e.g. biomass accumulation of crops. It should be noted that intermediate services must be recorded as used by ecosystem assets not as inputs to economic units.

11.13 The second key aspect of the extended SUT entails the requirement that columns be added to reflect the source of the supply of ecosystem services. Thus, ecosystem assets (grouped by ecosystem type) are treated as additional producing units alongside the current set of industries (agriculture, manufacturing, etc.). A simple example is presented in appendix A11.1 to demonstrate the steps involved in producing these extensions.

11.14 Tables 11.1a and 11.1b present an extended SUT incorporating a selected set of product groups and using the broad groups of ecosystem services listed in the monetary ecosystem services SUT found in chapter 9. It is to be noted that after including additional rows for ecosystem services and additional columns for ecosystem assets, the extended SUT is completed by incorporating the standard value added entries for industries and for ecosystem assets. Where ecosystem services are inputs to SNA benefits, this has the effect of partitioning the operating surplus of the using industry (e.g. agriculture or forestry) so that the contribution of ecosystem services is deducted from that industry and shown as the output and operating surplus of the supplying ecosystem asset.

11.15 Extended SUTs are different from environmentally extended input-output tables (EE-IOTs).[123] Those EE-IOTs can readily incorporate flows of individual ecosystem services following the same methods that would be applied to incorporating flows of, for example, GHG emissions, water use or solid waste. However, in an EE-IOT there is no inherent change in or extension of the SNA production boundary as is applied in the extended SUT and as a result, there is no inherent extension of supply chains that record the links between the economy and ecosystems.

[123] The connection between EE-IOTs and the SEEA Central Framework accounts is described in *System of Environmental-Economic Accounting 2012 – Applications and Extensions* (United Nations, European Commission, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development and World Bank, 2017).

11.3 Extended balance sheets

11.3.1 Introduction

11.16 Ecosystem accounting data can be used to augment the economic accounts of the SNA through the compilation of extended balance sheets. Extended balance sheets allow the comparison and integration of the values of ecosystem assets with values of produced assets, financial assets (and liabilities) and other assets.

Table 11.1a
Extended SUT with ecosystem services – supply table

SUPPLY	Economic units															Ecosystem type (based on the EFG level 3 of IUCN GET)																					
	Industries															Terrestrial												Freshwater			Marine						
																T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	Total industry				Imports	Total supply	T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	…	T2.6 Temperate pyric sclerophyll forests and woodlands	…	…	…	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	…	FM1.3 Intermittently closed and open lakes and lagoons	M1.1 Seagrass meadows	…	MFT1.3 Coastal saltmarshes and reedbeds	Total supply by resident ecosystem assets	Supply from non-resident ecosystem assets - Imports	Total supply by ecosystem assets	TOTAL SUPPLY
Products																																					
Agricultural products																																					
Fishery products																																					
Manufacturing products																																					
Electricity and gas products																																					
Water supply products																																					
Services																																					
Other products																																					
TOTAL																																					
Ecosystems services																																					
Provisioning services																																					
Regulating and maintenance services																																					
Cultural services																																					
TOTAL																																					
TOTAL SUPPLY																																					

Note: Dark grey cells are null by definition.

Table 11.1b
Extended SUT with ecosystem services – use table

USE	Economic units															Ecosystem type (based on the EFG level 3 of IUCN GET)																					
	Industries															Terrestrial												Freshwater			Marine						
																T1 Tropical-subtropical forests				T2 Temperate-boreal forests and woodlands				…		T7		F1	…	FM1	M1	…	MFT1				
	Agriculture	Forestry	Fisheries	Mining and quarrying	Manufacturing	Electricity, gas, steam and air-conditioning supply	Water supply; sewerage, waste management and remediation activities	Services	Other industries	Total industry	Government consumption	Household consumption	Gross capital formation	Exports	Total use	T1.1 Tropical-subtropical forests	T1.2 Tropical-subtropical dry forests and scrubs	T1.3 Tropical-subtropical montane rainforests	T1.4 Tropical heath forests	T2.1 Boreal and temperate high montane forests and woodlands	T2.2 Deciduous temperate forests	… …	T2.6 Temperate pyric sclerophyll forests and woodlands	… …	… …	… …	T7.5 Derived semi-natural pastures and old fields	F1.1 Permanent upland streams	… …	FM1.3 Intermittently closed and open lakes and lagoons	M1.1 Seagrass meadows	… …	MFT1.3 Coastal saltmarshes and reedbeds	Total use resident by resident ecosystem assets	Exports – ecosystem services	Total use by ecosystem assets	TOTAL USE
Products																																					
Agricultural products																																					
Fishery products																																					
Manufacturing products																																					
Electricity and gas products																																					
Water supply products																																					
Services																																					
Other products																																					
TOTAL																																					
Ecosystems services																																					
Provisioning services																																					
Regulating and maintenance services																																					
Cultural services																																					
TOTAL																																					
TOTAL USE																																					
Gross value added																																					
Compensation of employees																																					
Gross operating surplus																																					
Consumption of fixed capital																																					
Net value added																																					

Note: Dark grey cells are null by definition.

[124] A range of information on the World Bank Changing Wealth of Nations project and related outputs is available at.

[125] See the *Inclusive Wealth Report 2018* (United Nations Environment Programme, 2018). Available at www.unenvironment.org/resources/report/inclusive-wealth-report-2018.

11.17 The development of extended balance sheets aligns with the general intent in the compilation of wealth accounts, as driven forward by the World Bank[124] and the United Nations Environment Programme.[125] In general terms, there is a common desire to extend the valuation of natural capital to incorporate a wide range of ecosystem services beyond those that are incorporated in the valuation of natural resources according to the SNA. If the outputs of wealth accounting apply exchange value concepts in the valuation of different types of capital, then the values from the monetary ecosystem asset account are appropriate for inclusion in the extended balance sheet described here. It is to be noted that wealth accounts may also include measures of human capital (and, in some cases, social capital) in addition to produced and non-produced (natural) capital and hence those accounts extend beyond the scope of both SEEA EA and the SNA.

11.18 Extended balance sheets encompassing monetary values of ecosystem assets can be applied in a number of contexts where the focus is, for example, on understanding the changing composition of wealth, identifying imbalances in stocks of wealth, analysing productivity and assessing returns on investment.

11.19 A concern regarding extensions made to balance sheets containing the monetary values of economic and ecosystem assets is that presentation of the different assets side by side may be interpreted as meaning that all assets are substitutable. In theory, estimates of all asset prices should take into account the extent to which there are developing shortages in the availability of certain "critical" resources, where the effect should be that asset prices reflected in the accounts rise over time and the relative value of these assets becomes much higher. However, in practice, since future trends in the availability of various assets and their interactions cannot be well anticipated, the extent to which shortages and imbalances are reflected in estimated asset prices will be more limited.

11.20 Compiling extended balance sheets involves complementing the opening and closing values of ecosystem assets as described in chapter 10 with SNA balance sheet values described in the 2008 SNA (chap. 13). In some cases, there may be an overlap between the scope of SNA asset values and the scope of ecosystem assets, for example, with regard to the values of biological resources and land. To avoid double counting of asset values, clear treatments of different assets are required. Those treatments are discussed in section 11.3.3.

11.3.2 Structure of an extended balance sheet

11.21 Conceptually, an extension of the SNA balance sheet requires that the values of ecosystem assets over and above those currently recorded in the SNA balance sheets be included. However, since the value of ecosystem assets commonly includes the value of natural resources (such as timber resources) and components of land values, there is a range of ways in which the additional values might be combined and presented.

11.22 The approach adopted here, as presented in table 11.2, is to first distinguish environmental assets from produced assets, other non-produced (non-environmental) assets and financial assets and liabilities and to then distinguish within environmental assets (a) ecosystem asset values linked to each of the ecosystem types at the level of the main realms (terrestrial, freshwater, marine and subterranean) and (b) values of other environmental assets including land, renewable energy resources, cultivated biological resources, water resources, mineral and energy resources and atmospheric systems.

11.23 Ecosystem asset values align with those included in the monetary ecosystem asset account (table 10.1). The values of other environmental assets generally align with the values in the SNA for the relevant classes, taking into account the treatments in the SEEA Central Framework (chap. V). However, there may be some values of other environmental assets related to the values of abiotic flows and spatial functions – for example, values related to renewable energy resources – that may be outside the scope of SNA- and Central Framework-based valuations. These additional values should be recorded under other environmental assets, as appropriate.

11.24 For each ecosystem realm, the total monetary value including all ecosystem services is recorded, thus reflecting an aggregation of the monetary values compiled in the monetary ecosystem asset account. Following the advice in the SNA, values for other environmental assets will overlap in a number of cases with the values recorded against the various ecosystem types. For example, the value of cultivated land includes an ecosystem asset value. The relevant boundary cases are considered below, and conventions are described to support comparable measurement.

11.25 An extended balance sheet would most commonly be compiled at a national level, building from a country's national balance sheet from the SNA. Thus, the geographical scope of the extended balance sheet would be defined by the country's economic territory, which, in geographical terms, is broadly limited to its land area and marine areas within the EEZ. Conceptually, it would be possible to define extended balance sheets for alternative geographical scopes, for example, encompassing a wider coverage of marine ecosystems or focusing on subnational areas.

11.3.3 Aligning ecosystem asset values with the values of SNA assets

11.26 As highlighted in section 11.3.3, there are a number of potential overlaps between the measurement scope of SEEA for ecosystem assets and that of the SNA for economic assets (here labelled "SNA assets"). The appropriate starting point for articulating the overlaps and the differences is the definition of assets in the SNA. The SEEA Central Framework (sect. 5.2.3) provides a useful overview from an environmental-economic accounting perspective. The following clarification is presented:

> "In the Central Framework, consistent with the SNA, the scope of valuation is limited to the benefits that accrue to economic owners. An economic owner is the institutional unit entitled to claim the benefits associated with the use of an asset in the course of an economic activity by virtue of accepting the associated risks. Further, following the SNA, an asset is a store of value representing a benefit or series of benefits accruing to the economic owner by holding or using the entity over a period of time." (Central Framework, para. 5.32).

11.27 At an aggregate level – for example, for a country, where the aim is to convey information on the total stock of assets and their monetary value – the inclusion of assets in an extended balance sheet is not straightforward. In effect, the aggregate measures assume attribution of the environmental assets to the country of reference, which in turn implies that establishing a total value for environmental assets requires, in the first instance, the identification of a set of benefits. The focus in aligning the scope of valuation for various asset classes is thus on aligning the extended set of benefits with the relevant asset classes. Issues concerning the ownership of ecosystem assets are considered in section 11.3.4.

11.28 The concept of benefits formulated in the SNA is potentially broad, since they are considered to denote "a gain or positive utility arising from economic production, consumption or accumulation" (2008 SNA, para. 3.19). However, in practice, the scope of the SNA with respect to benefits from environmental assets is limited to those "(i) in the form of operating surplus from the sale of natural resources and cultivated biological resources, (ii) in the form of rent earned on permitting the use or extraction of an environmental asset or (iii) in the form of net receipts (i.e. excluding transaction costs) when an environmental asset (e.g. land) is sold" (Central Framework, para. 5.33).

Table 11.2
Structure of an extended balance sheet

		Monetary value	
		Opening	Closing
Assets			
Produced assets[a]	Fixed assets • Dwellings • Other buildings and structures • Machinery and equipment • Weapons systems • Intellectual property products		
	Inventories[b]		
	Valuables		
Environmental assets – ecosystems	Terrestrial ecosystems (IUCN GET EFG T1-T7) (includes SNA value of natural timber resources and other non-produced biota)		
	Freshwater ecosystems (IUCN GET EFG F1–FM1) (includes SNA value of natural aquatic resources and other non-produced biota) (excludes the value of water resources)		
	Marine ecosystems (IUCN GET EFG M1-MFT1) (includes SNA value of natural aquatic resources and other non-produced biota)		
	Subterranean ecosystems (IUCN GET S1-SM1)		
Environmental assets – other	Cultivated biological resources • Fixed assets • Work in progress (inventories)		
	Land (as provision of space) (includes SNA value of land under buildings)		
	Renewable energy resources[b]		
	Water resources[b]		
	Mineral and energy resources		
	Atmospheric systems (includes SNA value of the radio spectrum)		
Other non-produced assets	Contracts, leases and licences[c]		
	Goodwill and marketing assets		
Financial assets			
Financial liabilities			
Net worth			

Abbreviations: EFG, ecosystem functional group; IUCN GET, International Union for Conservation of Nature Global Ecosystem Typology.

[a] The scope of produced assets presented here is different from that of the SNA, as cultivated biological resources are included under other environmental assets.

[b] These entries are boundary cases for which specific measurement conventions apply, as discussed in section 11.3.3.

[c] The value of contracts, leases and licences concerning environmental assets that satisfy the requirements of the SNA (chap. 17, part 5) for consideration as distinct assets is not distinguished in this balance sheet but is included instead in the value of the underlying environmental asset.

11.29 In ecosystem accounting, a broader set of benefits is included through the recognition of ecosystem services that contribute to non-SNA benefits. The inclusion of the monetary value of ecosystem services that contribute to non-SNA benefits increases the value of environmental assets relative to the SNA and thereby extends the balance sheet relative to the scope of the SNA. Nonetheless, the inclusion of these additional monetary values does not provide a measure that encompasses all aspects of value or wealth.

11.30 To clarify the nature of the extensions to the SNA balance sheets motivated by considerations regarding the scope of benefits, the treatment of a range of SNA assets with respect to incorporating ecosystem assets is described directly below. In practice, since relatively few countries compile full SNA balance sheets of non-produced assets, the following considerations, taken in conjunction with guidance and treatments in the SEEA Central Framework, will be relevant in developing such balance sheets in the first instance or in refining initial estimates.

11.31 **Treatment of biological resources**. The value of all natural (non-cultivated) biological resources are in scope of both ecosystem assets and SNA non-produced assets. Thus, values of natural timber and aquatic and other biological resources (e.g. wild animals and non-wood forest products) are estimated in terms of the expected future rates of harvest and relevant prices for these provisioning services. In the extended balance sheet, the value of these natural biological resources is included within the value of the relevant ecosystem asset, for example, the value of natural timber resources is included within the broader value of forest ecosystems.

11.32 For cultivated biological resources, related to agriculture, forestry and fisheries, there is a range of types to be considered, including annual crops, plantations (e.g. timber, orchards, vineyards), livestock for slaughter, breeding or ongoing production (e.g. dairy cows, sheep for wool) and aquaculture. These resources, considered to be produced assets, are classified as either inventories (work in progress)[126] or fixed assets. The SNA value for these resources is included in the scope of environmental assets as defined in the SEEA Central Framework.

[126] Work in progress on cultivated biological resources consists of output that is not yet sufficiently mature to be in a state in which it is normally supplied to other institutional units (2008 SNA, para. 10.140).

11.33 The values of cultivated biological resources included in the SNA relate only to the stock of those resources that are present on the date of the balance sheet (e.g. they relate to the number of cattle or volume of standing timber on 31 December). Two separate cases are to be noted. In the case of crops and livestock, their balance sheet value is separable from the value of any associated land. Since the value of ecosystem services reflects the contribution of land to the growth of crops or livestock, in the extended balance sheet the value of cultivated crops and livestock are recorded under “other environmental assets” separately from the value of the associated ecosystem asset (e.g. pastures, cultivated land), which encompasses the NPV of the expected biomass provisioning services.

11.34 In the case of cultivated timber, the SNA balance sheet value concerns the value of standing timber, which is estimated as the discounted “future proceeds of selling the timber at current prices after deducting the expenses of bringing the timber to maturity” (2008 SNA, para. 13.41). The expenses should also incorporate capital costs associated with the inputs of produced assets and forest land (see SEEA Central Framework, sect. 5.8). This value overlaps with the NPV of wood provisioning services although the latter value will be higher since it includes: (a) the value of the contribution of land; and (b) the value of future timber harvests beyond the current rotation. Consequently, to ensure alignment between the values recorded in the extended balance sheet and the values recorded in the monetary ecosystem asset account, the work-in-progress value of cultivated timber resources should not be recorded as part of other environmental assets.

11.35 **Treatment of mineral and energy resources.** These natural resources, which include shallow mineral resources such as sand and gravel, are defined in the SNA and the SEEA Central Framework but are not considered a part of ecosystem assets since the benefits they provide are not the result of current ecosystem processes. They are recorded in the extended balance sheet under other environmental assets. By convention, this class excludes energy from renewable sources, as discussed directly below.

11.36 Special note should be taken of peat resources, which may be used as a form of fossil fuel. Peatlands are an important type of terrestrial ecosystem, supplying a range of ecosystem services, including global climate regulation and water purification services. In this balance sheet, the value of peatlands is partitioned, with the value of future flows of ecosystem services included as part of terrestrial ecosystems and the value associated with the use of peat as a fossil fuel resource included as part of mineral and energy resources.

11.37 **Treatment of energy from renewable sources.** Renewable sources of energy (such as wind and solar sources) cannot be exhausted in a manner akin to that which characterizes fossil energy resources and, unlike biological resources, they are not regenerated. Thus, in an accounting sense, there is no physical stock of renewable sources of energy that can be used up or sold.

11.38 The monetary value associated with the ongoing capture of energy from wind and solar sources can be considered to be embedded in the values of the associated area (e.g. land), reflecting the specific characteristics of the location in which the renewable energy is captured. In the extended balance sheet, by convention, the value of the location (including both terrestrial and marine locations) that is linked to the capture of, for example, wind and solar energy should be included in the value of land (as provision of space).

11.39 For energy generated through hydroelectric power, the monetary value associated with the capture of energy can be considered to be embedded in the values of the surrounding area that incorporates water resources and land formations. For energy generated from geothermal resources, relevant values should be included under deep geological systems. It is recommended that the value associated with energy from renewable sources be separately recorded in the extended balance sheet and calculated using the NPV of the associated abiotic flows.

11.40 **Treatment of inland water resources (i.e. excluding marine ecosystems).** The valuation of water resources is recognized in the SNA in cases where "surface and groundwater resources [are] used for extraction to the extent that their scarcity leads to the enforcement of ownership or use rights, market valuation and some measure of economic control" (2008 SNA, para. 10.184). It is recommended that this value should be recorded separately from the value of ecosystem services of freshwater ecosystems.

11.41 Water supply is treated as an abiotic flow, and its value is therefore recorded as part of other environmental assets, as water resources, rather than associated with the terrestrial or freshwater ecosystem asset to which it is most directly connected (e.g. based on the location of a bore or well). In this context, the value of water resources is limited to their use as input to economic activity and human consumption. It is to be noted that the valuation of water is an area of measurement that poses challenges and requires an alignment of methods and scope based on guidance derived from the SNA, the SEEA Central Framework and SEEA EA.

11.42 **Treatment of land.** A key function of land is to provide space. Land and the space it represents, define the locations within which economic and other activity is undertaken and within which assets are situated. This role of land is a fundamental input to economic activity and has significant value in many locations.

11.43 However, the provision of space is not considered an ecosystem service and consequently the value of ecosystem assets, particularly terrestrial ecosystems, excludes the value of the provision of space. Thus, depending on the location and ecosystem type, the total value of an area of land may be greater than the value of the aggregated ecosystem services. In this regard, particular note should be taken of urban ecosystems and cultivated land. For urban ecosystems, the value of the provision of space may be the predominant component of the total value of environmental assets. For cultivated land, the distinction may be less evident, that is, the value of provisioning ecosystem services may be closer to the total market value of the land as recorded in the SNA. However, the value of the ecosystem asset as a whole may be larger than the SNA-based land value, through the inclusion of the value of non-provisioning services (e.g. water regulation), which are supplied by cultivated land but are not recognized in the market value of land. For areas of government-owned or public land, it is likely that no value is recorded following the SNA and in this case the value associated with the relevant ecosystem assets reflects the total value of the area for accounting purposes.

11.44 In the extended balance sheet, in recognition of the fact that values of land likely differ from the value of ecosystem assets, the approach taken, following the guidance in chapter 10, is to record the aggregated NPV of ecosystem services against the relevant ecosystem type and then, where relevant, to record the additional value of land in terms of the provision of space as a separate asset class under other environmental assets. In a number of cases, most notably for urban ecosystems and cultivated land, it would be necessary to partition the value of land as recorded in the SNA so as to extract that component of value that is attributable to ecosystem services (that is related, for example, to amenity services embodied in land values).

11.45 **Treatment of the atmosphere and the high seas.** The scope of ecosystem assets excludes the atmosphere and generally for national-level accounting purposes marine areas beyond the EEZ would also be outside the EAA that defines the scope of the extended balance sheet. The values of these environmental assets are therefore not captured in the value of ecosystem assets. SNA values relevant to these environmental assets include the radio spectrum and fish stocks on the high seas over which ownership rights may exist. The value of the radio spectrum (as defined in the SNA) should be included under atmospheric systems in table 11.2 and the value of fish stocks on the high seas that satisfy the definition of economic assets in the SNA should be included under marine ecosystems.

11.46 As noted in the previous section, an extended balance sheet could be compiled with an alternative scope that incorporates a wider range of ecosystem assets such as marine areas beyond the EEZ and the atmosphere. Such accounts could recognize the importance of these ecosystems, for example, the role of the ozone layer and the role of marine ecosystems in regulating global climate.

11.47 **Treatment of permits and licences to use natural resources.** In the SNA, the value of permits and licences associated with the use of natural resources – including, for example, resource leases and transferable quotas – is recorded separately from the value of the underlying resource. In recording this value separately, the total value of the natural resource is considered to be partitioned, with the value of the permit or licence reducing the value of the resource that is recorded as part of natural resources. In the extended balance sheet, by convention, the total value of the natural resource is recorded as part of environmental assets and, if required, the value of the associated permit or licence should be recorded as an "of which" item.

11.4 Assigning economic ownership and allocation of degradation and enhancement

11.4.1 Considerations in assigning economic ownership

11.48 The compilation of the ecosystem accounts in physical and monetary terms does not necessarily require a statement or assumption concerning the ownership of ecosystem assets. This is important since it highlights the fact that accounting for ecosystem assets, their services and their links to the economy can be undertaken from a perspective that views ecosystems as distinct ecological entities. This neutrality with respect to ownership enables the set of ecosystem accounts to support a wide range of decision-making contexts.

11.49 This perspective on ecosystem assets is consistent with the wider definition of environmental assets found in the SEEA Central Framework (para. 2.17), in which environmental assets are defined as the components of the Earth that constitute the biophysical environment and with the potential to deliver benefits to humanity.

11.50 Nonetheless, understanding ecosystem assets in the context of legal and economic ownership is highly relevant to developing, enacting and monitoring policy on ecosystem management and use. Cross-classifying data from the ecosystem accounts with data on legal and economic ownership is therefore clearly policy-relevant. For example, data from ecosystem extent accounts may be cross-classified with data from cadastres to assess the connections between different ecosystem types and the types of economic units that manage them. The cross-classification of data on the supply of ecosystem services with data on economic ownership of land and other areas is similarly pertinent. Undertaking this type of work (i.e. cross-classification of data sets) using ecosystem accounting data expressed in spatial terms is likely to be of significant interest and benefit.

11.51 From a national accounting perspective, integration of the ecosystem accounts with the institutional sector accounts of the SNA requires the application of a treatment or appropriate convention that enables the relationship between ecosystem assets and economic units to be recorded consistently. A particular focus for SEEA EA is integration of the ecosystem accounts with the income, distribution of income, capital and financial accounts of the SNA that are compiled for institutional sectors and subsectors, including corporations, households and general government. To support integration with those accounts and to facilitate derivation of degradation-adjusted measures of income and saving, ecosystem assets must be assigned to an institutional sector.

11.4.2 Institutional sector for ecosystem assets

11.52 The SNA discussion on determination of ownership distinguishes between legal and economic ownership. The SNA defines the legal owner of entities (which include goods and services, financial assets and natural resources) as “the institutional unit entitled in law and sustainable under the law to claim the benefits associated with the entities” (2008 SNA, para. 10.5) The economic owner is “the institutional unit entitled to claim the benefits associated with the use of the entity in question in the course of an economic activity by virtue of accepting the associated risks” (ibid.).

11.53 Further, all buildings and structures and almost all land and marine areas within the economic territory of a country are deemed by convention to be owned by economic units that are considered resident in that territory.[127] Where a non-resident unit is the legal owner, a notional resident unit is created that is considered to own the relevant asset, and the non-resident unit then holds a financial asset equal to the value

[127] A small exception applies to the treatment of land and buildings of foreign Governments, such as embassies, which are treated as lying outside the economic territory of a country. As this matter is not considered material to the development of integrated environmental-economic accounts, it is not considered further here. As required, 2008 SNA treatments should be applied.

of the relevant assets owned by the notional resident unit. This treatment underpins the recording of flows between ecosystem assets and economic units that are resident in the rest of the world, including with respect to imports and exports of ecosystem services and the attribution of value in a balance sheet context.

11.54 In many cases, the legal and economic owners are the same but there are a range of situations in which there may be a lack of clarity. These include situations involving government ownership of entities such as public roads, national parks and natural resources; situations involving financial leases; and situations where assets are built under private finance initiatives. In these contexts, measurement approaches may be supported through use of the definitions under the Framework on Effective Land Administration.[128]

[128] United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), "Framework for Effective Land Administration" (E/C.20/2020/29/Add.2), May 2020. Available at https://ggim.un.org/meetings/GGIM-committee/10th-Session/documents/E-C.20-2020-29-Add_2-Framework-for-Effective-Land-Administration.pdf.

11.55 Using these national accounting principles of economic ownership, which are founded on the relationship between an institutional unit and the benefits from an asset (or entity), and solely for the purpose of integrating ecosystem accounts data with the standard sector accounts of the SNA, it is considered appropriate to partition the ownership of ecosystem assets using a focus on the users of different types of ecosystem services. In effect, this represents a partitioning of the benefits rather than a partitioning of the ecosystem asset in physical terms. Thus, where an ecosystem asset supplies ecosystem services that contribute to SNA benefits (i.e. primarily provisioning services), that part of the value of the asset is considered to be owned by the sector that uses those ecosystem services. Most commonly, this is the legal and economic owner of the land, which is using the ecosystem services as inputs to private returns (e.g. in agriculture or forestry).

11.56 At the same time, where an ecosystem asset supplies ecosystem services that contribute to non-SNA benefits (i.e. primarily regulating and maintenance services and cultural services), that part of the value of the asset is considered to be owned by a new subsector of general government entitled the "ecosystem trustee". In this treatment, the ecosystem trustee operates analogously to other institutional units, both receiving benefits through the supply of ecosystem services and incurring costs in relation to the supply of those services. The ecosystem trustee is therefore a separate entity from the ecosystem asset.

11.57 In a situation where an ecosystem asset does not contribute to non-SNA benefits, the treatment is aligned with the assignment of ownership in the SNA. Where an ecosystem asset does not contribute to any SNA benefits, the ecosystem trustee is assigned complete ownership. This situation may arise in remote areas of a country. Commonly, there is some partitioning of ownership, reflecting recognition of the fact that many ecosystem assets contribute to both SNA and non-SNA benefits. It is to be noted that there are areas that are under common ownership (e.g. for grazing livestock) or under government or public sector ownership and which contribute to SNA benefits. In these cases, ownership is not assigned solely to the ecosystem trustee but also to the economic units deemed to own those benefits, following the approach just described.

11.58 This approach to the allocation of ownership allows the resulting institutional accounts to align most closely to the existing understanding of the economic and financial situation of the current SNA institutional sectors. The main differences between the SNA and the approach outlined here concern the recognition of the use of ecosystem services as inputs to the production of SNA benefits and recognition of any costs of ecosystem degradation associated with such a use of those services.

11.59 Two alternative ownership allocation assumptions might be applied, under which all ecosystem assets are assigned to (a) an ecosystem trustee or (b) relevant economic units. While accounting entries and sequences of accounts can be developed under either of these assumptions, the partitioned asset approach aligns most closely to the accounting principles inherent in the SNA. Even if economy-wide measures of aggregates, such as gross value added (GVA) and degradation-adjusted value added, are unaffected by the approach taken to assigning ownership, different ownership assumptions will impact the relative sizes of those aggregates at the institutional sector level. The effects of different approaches are considered by La Notte and Marques (2019).

11.4.3 Allocation of degradation and enhancement to economic units

11.60 Chapter 10 described approaches to the valuation of ecosystem degradation and enhancement in the context of the monetary ecosystem asset account. In that account, the focus of measurement is on degradation and enhancement for individual ecosystem assets and ecosystem types within an EAA.

11.61 When integrating ecosystem accounts with economic accounts, the allocation of ecosystem degradation and enhancement to economic units is required. For both degradation and enhancement, this allocation is directly related to the approach applied to assigning ownership, as explained above. Thus, ecosystem degradation and enhancement of an ecosystem asset are partitioned and recorded in the accounts of either the economic unit that receives the SNA benefits or the new ecosystem trustee in relation to contributions to non-SNA benefits.

11.62 For integrated economic accounting in SEEA, a costs-borne approach for recording ecosystem degradation is followed, meaning that the cost of capital is attributed to the economic unit that is assigned ownership of the asset. This is consistent with general accounting practice. An alternative is to allocate degradation on the basis of costs caused (the polluter pays approach) by determining the appropriate "source", that is, the economic unit that has caused the degradation. This may be challenging owing, for example, to factors of distance (i.e. cases where impacts of causing economic units are felt in distant ecosystems) and time (i.e. cases where impacts become evident well after the causing activity has occurred). Nonetheless, it is recognized that there is likely to be substantial policy interest in providing estimates of an allocation of degradation that is attributable to causing or polluting economic units. Chapter 12 includes a discussion of the presentation of such complementary estimates. It is to be noted that the aggregate measure of degradation recorded in the ecosystem accounts is not affected by the choice of allocation approach.

11.5 Integrated sequence of institutional sector accounts

11.5.1 Introduction

11.63 As introduced in the previous section, ecosystem accounting data can be used to augment the economic accounts of the SNA through the compilation of an extended sequence of accounts for institutional sectors. The extended sequence of accounts shows how entries for the values of ecosystem services and changes in ecosystem assets (including ecosystem degradation and enhancement) can be combined with standard measures of production, income and consumption, and associated accounting aggregates such as saving and net lending.

11.64 One of the main functions of the sequence of accounts is to demonstrate the linkages among incomes, investments and balance sheets. In this regard, a key feature of the standard SNA sequence of accounts is the attribution of consumption of fixed capital (depreciation) to economic activities and institutional sectors as a cost against income. The equivalent outcome from an extended sequence of accounts is the attribution of ecosystem degradation as a cost against the income of institutional sectors. Thus, the extended sequence of accounts describes the relevant accounting entries for the derivation of adjusted measures of value added, domestic product, national income and net worth. Section 11.5.3 describes adjusted income measures.

11.5.2 Structure of the extended sequence of accounts

11.65 The design of an extended sequence of accounts reflects the ownership structure described in section 11.4. The extension thus requires the inclusion of the ecosystem trustee as a new subsector within, or next to, the general government sector.

11.66 This extended sequence of accounts is presented in table 11.3 where a simple example is used to illustrate the different accounting entries. The example shows a simplified economy consisting of a farm that produces wheat (with an output value of 200 currency units). The wheat is purchased and consumed by households. The cropland used by the farmer provides a mix of ecosystem services amounting to gross ecosystem services supply of 110 currency units, of which 80 currency units are used by the farmer as input to wheat production (i.e. crop provisioning services as inputs to SNA benefits) and 30 currency units represent recreation-related services, which are inputs to the non-SNA benefit of physical and mental health. For simplicity, all production of the farmer (200 currency units) is recorded as final consumption of households and no other production, intermediate consumption or final consumption is recorded. Furthermore, it is assumed that compensation of employees amounts to 50 currency units and that the farmer's consumption of the fixed capital of a tractor amounts to 10 currency units.

11.67 For the purpose of comparison, the accounting entries following the recording principles of the standard SNA are also shown. In this case, no transactions in ecosystem services are recorded, as such activity lies outside the production boundary. Following the SNA, the economy in this example has a value added (GDP) of 200 currency units and the farmer has a net saving of 140 currency units.

11.68 Following the partitioned ownership approach described in section 11.4 above, the ecosystem asset is partitioned so that flows of ecosystem services are shown (a) as supplied by the farmer in the case of the crop provisioning services (thus increasing the measure of the farmer's gross output); and (b) as supplied by the ecosystem trustee in the case of recreation-related services. The crop provisioning services are immediately deducted in the farmer's accounts as intermediate consumption.

11.69 The use of recreation-related services is shown in two steps. In the allocation/use of income accounts, an ecosystem services transfer in kind is recorded as payable by the ecosystem trustee and receivable by the subsequent recipient. In this example, the final recipient of recreation-related services is the household sector but in other cases multiple recipients may be recorded. In a second step, the use of the ecosystem services is shown as final consumption of the household sector.

11.70 As noted in section 11.4.2, the ecosystem trustee is a subsector related to general government that is regarded as managing the flow of ecosystem services contributing to non-SNA benefits. While the ecosystem asset itself does not incur costs, there may be expenditure undertaken to manage the ecosystem asset in supplying those services. In the institutional sector accounts, these costs should be recorded as intermediate consumption or capital formation of the ecosystem trustee. This would involve reallocating expenditures from other institutional sectors.

11.5.3 Adjusted income aggregates

11.71 A key focus in the development of the extended sequence of accounts is the derivation of various measures of economic activity, including valued added, operating surplus, disposable income and net saving, which take into account the cost of ecosystem degradation. Table 11.3 shows how these measures are derived and the relationships between them. Importantly, to retain accounting consistency, it is necessary that, in addition to deducting measures of ecosystem degradation, the income measures themselves be extended to incorporate the generation and use of ecosystem services (i.e. the flows that are not captured within the standard SNA production boundary).

11.72 Similar considerations apply to incorporating the effects of changes in ecosystem asset values other than ecosystem degradation, such as ecosystem enhancement and ecosystem conversion. However, the accounting entries required for these other changes in the value of ecosystem assets require further investigation and will be considered under the SEEA EA research and development agenda.

11.73 The discussion of adjusting measures of GDP and other SNA aggregates for environmental factors is much broader than the above description of degradation-adjusted measures. Some considerations on the theoretical relationship between national accounts and welfare are relevant, as discussed in appendix A12.1. There is also a range of approaches to measurement coverage and valuation that have led to the development of a variety of alternative and complementary measures of the environment-economy relationship. Chapter 12 provides an overview of those approaches and the relationship to the measures described in the ecosystem accounts and in the extended accounts presented in the present chapter.

Table 11.3
Models for including ecosystem services in the sequence of accounts (excluding financial account and change in balance sheet entries) (currency units)

		SNA treatment			Extended sequence of accounts			
		Sector			Sector			
		Agri-culture	House-hold	Total	Agricul-ture	House-hold	Ecosystem trustee	Total
Production and generation of income account								
Output	Products (wheat)	200		200	200			200
	Ecosystem services (crop provisioning)				80			80
	Ecosystem services (recreation)						30	30
Total output		200		200	280		30	310
Intermediate consumption	Products	0		0	0		0	0
	Ecosystem services (crop provisioning)				80		0	80
Gross value added		200		200	200		30	230
less Consumption of fixed capital (produced assets)		10		10	10		0	10
less Ecosystem degradation					10		5	15
Degradation-adjusted net value added		190		190	180		25	205
less Compensation of employees		50		50	50		0	50
Degradation-adjusted net operating surplus		140		140	130		25	155
Allocation/use of income accounts								
Degradation-adjusted net operating surplus		140		140	130		25	155
plus Compensation of employees			50	50		50		50
Ecosystem service transfer in kind payable							30	30
Ecosystem services transfer in kind receivable						30		30
Degradation-adjusted disposable income		140	50	190	130	80	-5	205
less Final consumption	Products (wheat)		200	200		200		200
	Ecosystem services (recreation)					30		30
Degradation-adjusted net saving		140	-150	-10	130	-150	-5	-25
Capital account								
Degradation-adjusted net saving		140	-150	-10	130	-150	-5	-25
plus Consumption of fixed capital (produced assets)		10		10	10			10
plus Ecosystem degradation					10		5	15
Net lending/borrowing		150	-150	0	150	-150	0	0

Appendix A11.1
Example of an extended SUT

A11.1 Table A11.1.1 presents a small, stylized series of SUTs using timber production as an example. Part A of the table presents the standard SUT recording of timber production for furniture purchased by households, that is, no ecosystem services are recorded. It shows the output of logged timber by the forestry industry (50 currency units), the use of that timber by the manufacturing industry and the ultimate sale of the furniture in the amount of 80 currency units to households. The total value added of 80 currency units that is recorded is equal to both (a) the sum of value added for forestry and value added for manufacturing and (b) total household final consumption expenditure.[129]

A11.2 Part B extends this recording to include the flow of wood provisioning services (30 currency units) from the ecosystem asset (a forest), which is recorded as an input to the forestry industry. There is thus an additional row and an additional column in the SUT relative to the standard SUT in part A. The main effect of this extension is to partition the value added of the forestry industry (previously 50 currency units) between the industry (value added now 20 currency units) and the ecosystem asset (value added now 30 currency units and equal to the supply of ecosystem services). Overall, value added through the inclusion of the ecosystem asset remains unchanged (at 80 currency units) even though the total supply has increased by 30 currency units. This reflects the extension of the production boundary.

A11.3 Part C introduces a second ecosystem service, air filtration, which is supplied by the same ecosystem asset (i.e. the forest). In this case, a second additional row is required but no additional columns. Total supply is further increased (by 15 currency units) but in this case, total value added also rises (to 95 currency units) because the additional output is not an input to existing products; rather, supply of air filtration services is recorded as an increase in final consumption of households.

A11.4 An important result of integrating the flows of ecosystem services in the extended SUT is that it becomes clear how the commonly discussed topic of double counting can be managed. Quite frequently, there is concern that integrating ecosystem services within the national accounts will result in double counting (in terms of the impacts on value added and GDP) if the final ecosystem services that contribute to SNA benefits are recorded. Recording on a gross basis (i.e. recording both supply and use of ecosystem services), which is applied in tables 11.1a, 11.1b and A11.1.1, is the most transparent means of dealing with double counting.

[129] The recording presented here ignores all other inputs and potentially relevant flows (e.g. labour costs, retail margins, taxes).

Table A11.1.1
Stylized example of an extended SUT (currency units)

	Ecosystem asset (forest)	Forestry industry	Manufacturing industry	Household final demand	Total
PART A: Standard SUT					
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: Extended SUT (SNA benefits)					
Supply					
Ecosystem service: wood provisioning	30				30
Logged timber		50			50
Furniture			80		80
Use					
Ecosystem service: wood provisioning		30			30
Logged timber			50		50
Furniture				80	80
Value added (supply less use)	30	20	30		80
PART C: Extended SUT (non-SNA benefits)					
Supply					
Ecosystem service: wood provisioning	30				30
Ecosystem service: air filtration	15				15
Logged timber		50			50
Furniture			80		80
Use					
Ecosystem service: wood provisioning		30			30
Ecosystem service: air filtration				15	15
Logged timber			50		50
Furniture				80	80
Value added (supply less use)	45	20	30		95

Section E

Applications and extensions of SEEA

Section overview

Section E, comprising chapters 12 to 14, describes applications and extensions of SEEA EA. It has been prepared to underpin a shared understanding among compilers and users of how data from the various ecosystem accounts may be applied to support analysis and decision-making.

Three different areas of application and extension are covered in the present section. Chapter 12 considers the area of complementary approaches to valuation. The measurement of monetary values based on exchange values as described in chapters 8 to 11 supports comparison with the accounting values of the national accounts and a range of other uses described in those chapters. However, there are limits to the range of economic values that can be included in such measures and there are a number of applications that exchange-based values cannot support directly. The discussion in chapter 12 recognizes that there are other approaches to monetary valuation and a number of other valuation concepts, such as welfare values and total economic values, which have been used extensively in decision-making for, inter alia, cost-benefit analysis, scenario assessments and the development of environmental markets.

Describing these complementary approaches to valuation aims towards providing support for account compilers in their efforts to understand the different ways in which valuation may be considered and how the compilation of ecosystem accounts relates to the complementary approaches. Further, for users of the accounts, this discussion is intended to place various valuation approaches in context and hence clarify the potential of ecosystem accounts to support analysis and decision-making. A body of research on complementary approaches to accounting for the environment is also emerging, for example, in work on advancing the complementary accounts network (Turner, Badura and Ferrini, 2019). Developing and enriching the relationship among different measurement approaches will support the supply of coherent data and underpin support for decision makers.

More broadly, the compilation of ecosystem accounts is of merit only when the data can be used to support analysis and monitoring of policy- and decision-making. In this context, chapter 13 examines the second area covered in section E by describing the potential for using SEEA EA and other data, including data from accounts under the SEEA Central Framework and the SNA, to support discussion of individual policy themes. Four high-profile environmental themes are considered, namely, biodiversity, climate change, oceans and urban areas, but the approach can be applied in other contexts as well. The discussion in chapter 13 also highlights the fact that accounting approaches can be used to organize data on specific variables (e.g. species and carbon) both to support the compilation of ecosystem accounts and to better describe the relationship between those variables and economic and human activity.

The third area of application and extension covered in section E encompasses indicators and combined presentations. The most common approach to monitoring entails the use of indicators. Chapter 14 describes how accounting principles can be used to underpin the derivation of more coherent indicators, particularly where data are combined across the economic and environmental domains. There is a range of indicator-related initiatives at local, national and global scales and across various ecosystem realms. Chapter 14 provides an introduction to the potential role of SEEA EA in supporting those initiatives, taking note in particular of the links to reporting on the 2030 Agenda for Sustainable Development and the Kunming-Montreal Global Biodiversity Framework.

Chapter 12
Complementary approaches to valuation

12.1 Introduction

12.1 The primary purpose of ecosystem accounting is to integrate information on ecosystems with measures of economic activity. To align with SNA principles, the ecosystem accounts in monetary terms, as described in chapters 8 to 11, record entries based on the exchange value concept. While this approach supports alignment with the accounting values of the national accounts and hence with macroeconomic policy, there are other monetary approaches and valuation concepts involving welfare values, willingness to pay (WTP) and total economic values that have been extensively used in other decision-making contexts related, for example, to cost-benefit analysis and project appraisal.

12.2 SEEA EA alignment with SNA principles implies that the monetary values recorded in the ecosystem accounts reflect the current use of ecosystems, that is to say, that they are based on existing management regimes and institutional arrangements, regardless of the extent to which the associated patterns of use may be considered sustainable or efficient. However, in many contexts, it is important to assess scenarios reflecting alternative management regimes or institutional arrangements for ecosystems. For example, it may be relevant to analyse how certain negative externalities (e.g. pollution) might best be internalized in the decisions of economic units. The monetary values of the ecosystem accounts support, but do not incorporate, such alternative valuations.

12.3 In this context, the present chapter considers how the monetary ecosystem accounts presented in chapters 8 to 11 can be related to and support other approaches and applications in monetary terms. Section 12.2 describes a set of complementary tables that can be compiled when taking a welfare-based approach to valuation and explains the links between these approaches and ecosystem accounts. Section 12.3 describes alternative measures of income, wealth and degradation that can be derived when making different assumptions regarding the attribution of costs or the institutional arrangements underlying valuation. Section 12.4 describes linkages with corporate assessments of natural capital. The appendix to the present chapter examines the conceptual connection between exchange and welfare values.

12.2 Building connections with welfare values

12.2.1 Introduction

12.4 The relationship between measures of national income and measures of social welfare has long been a discussion point among prominent economists.[130] Some of them, for example, Pigou and Hicks, sought to relate observed market values to the framework of utility theory but this approach proved difficult (Hicks, 1975). An alternative approach, following Kuznets, considered the final objectives of economic activity and hence looked to adjusted measures of aggregate economic activity,

130 See, for example, the summaries in Obst, Hein and Edens (2016) and Vanoli (2005).

most commonly GDP. This approach, pioneered by Nordhaus and Tobin (1972), was reflected in their macroeconomic welfare index. However, application of this approach has proved challenging owing to the difficulties of selecting and measuring the range of possible adjustments for all aspects of social welfare, as demonstrated by the range of alternative indicators that were proposed subsequently.

12.5 In light of these integration challenges, the 2008 SNA (para. 1.75) warns against a welfare-based interpretation of the accounts and notes that "GDP is often taken as a measure of welfare, but the SNA makes no claim that this is so and indeed there are several conventions in the SNA that argue against the welfare interpretation of the accounts". Indeed, as stated, the main objective of the SNA is to "compile measures of economic activity in accordance with strict accounting conventions based on economic principles" (2008 SNA, para. 1.1). This is not to say, however, that connections do not exist between entries in the national accounts and measures of welfare (see appendix A12.1 for a more detailed discussion of the topic).

12.6 In the course of its development, the relationship of the System of Environmental-Economic Accounting with welfare measures has frequently been touched upon, mostly in the context of assessing the cost of degradation, which, when estimated, would provide the means to adjust GDP and other national accounts measures of income and wealth along the lines initiated by Nordhaus and Tobin. For instance, the *Handbook of National Accounting: Integrated Environmental and Economic Accounting* (1993 SEEA) (United Nations, 1993) contained various extensions, including one in which the costs associated with the repercussions of a deteriorated environment on households could be assessed using contingent valuation (chap. IV.D). The *Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003* (SEEA 2003) (United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank, 2007) contained both cost-based and damage-based methods for assessing degradation, concluding that adjusting macro-aggregates for the latter "is the furthest removed from the normal SNA conventions and impinges on the realm of welfare measurement" (para. 1.96).

12.7 The approach taken in SEEA EA (as explained in chap. 8) is to align the ecosystem accounts with the valuation basis of the SNA. In the present section, complementary tables that support welfare analysis are discussed, namely, a bridge table linking accounting values to welfare values and tables that make negative externalities and ecosystem disservices visible.

12.2.2 Bridge table between accounting and welfare values

12.8 Table 12.1, a bridge table, has been compiled to support understanding of the links between accounting and welfare values in the context of ecosystem services. The table lists the various additions/subtractions to be made in moving from one value concept to the other, for selected ecosystem services. It also serves to illustrate why accounting values are smaller than welfare-based values.

12.9 The example presented in table 12.1 is underpinned by the following details:

- An area of land provides crop provisioning services (in the amount of 10 currency units) to a farmer engaged in the production of crops. This value is derived net of input costs such as labour and fuel.
- The same land area also offers some recreational opportunities for people living nearby. While there is no charge for using the area, individuals must travel some distance to reach it. The valuation methods described in chap-

ter 9 can be used to estimate the accounting value of the recreation-related services (5 currency units). However, the users of the recreation site obtain a consumer surplus, as they would be willing to pay more. The amount of the surplus is assumed to be 20 units. This results in a total welfare use value of 25 units for recreation-related services.

- People who do not visit the site assign a non-use value to it (300 currency units). This value, which is not an individual ecosystem service, is attributed to the ecosystem asset as a whole.
- Asset values are the NPVs of the value of a constant flow of services over an indefinite future at an assumed discount rate of 5 per cent. No changes in prices of inputs or outputs are expected. The corresponding asset values are: (a) 300 currency units, based on accounting values (this is the value that would be included in the extended SNA balance sheet (chap. 11)); (b) 700 units, based on welfare use values; and (c) 1,000 units, based on use and non-use values. The last-mentioned amount is the value that would be included during compilation of wealth accounts on a welfare basis.

Table 12.1
Bridge table between accounting and welfare values of ecosystem services (currency units)

	Crop provisioning services	Recreation-related services	Total flow	Asset
1. Accounting value	10	5	15	300
2. Consumer surplus	0	20		
3. Welfare use value	10	25	35	700
4. Welfare non-use value				300
Total welfare value				**1 000**

12.10 The table highlights some differences between accounting values and welfare values. In addition, it is noted that welfare values are sometimes estimated for benefits rather than for the ecosystem contribution to the benefits. In this example, the benefit would be valued using the market price of the crop when sold by the farmer.

12.11 In certain applications, the difference in values between accounting and welfare-based valuations may provide relevant information on so-called unrealized values. These may be obtained when comparing the current situation with a situation with changed economic institutions or management regimes for ecosystem assets. For instance, the current management of an ecosystem (e.g. an open access ecosystem) may result in low exchange values, whereas the welfare value (measured by people's WTP for the same ecosystem services) may be very high. Large unrealized values may provide a rationale for policy intervention.

12.12 From a measurement perspective, in order to populate the table, it may be reasonable to assume, for the provisioning services and (most of) the regulating and maintenance services, that no consumer surplus exists, i.e. that the final consumer would be willing to pay only the final price (of, say, the crops) and nothing more. For cultural services, the non-market valuation techniques applied (as described in chap. 9) are commonly used to estimate welfare values. Non-use values (which can be highly significant) need to be assessed using stated preference approaches.

12.2.3 Assessing externalities, ecosystem disservices and health outcomes

12.13 Perhaps the most commonly discussed framing for examining the link between the environment and the economy involves externalities. Frequently, there is a call for frameworks and information that allow decision makers to "internalize environmental externalities". This is a general demand to ensure that the negative impacts of business, government and people on the environment are taken into account.

12.14 ***Externalities are impacts that "arise when the actions of an individual, firm or community affect the welfare of other individuals, firms or communities [and the] agent responsible for the action does not take full account of the effect"*** (Markandya and others, 2001). Externalities may be positive or negative, although much of the focus in environmental economics is on negative externalities, such as the effects of pollution or emissions. They are measured in terms of the social costs and benefits affecting other economic units.

12.15 Accounting approaches do not explicitly account for externalities, at least not directly. Accounting, as a transaction-based system, focuses on recording actual exchanges between units. In contrast, and as discussed in section 6.3.5, the measurement of externalities considers the magnitude of effects as a comparison between two alternative contexts, one in which the externality is present and the other in which the externality is absent. In this framing, accounting is designed to record trends in stocks and flows for the context in which the externality is present. Indeed, the estimates recorded in the accounts reveal any actual costs or changes in income that may be associated with externalities, such as increased costs incurred with respect to pollution.

12.16 A common focus in externality assessment is cost-benefit analysis, entailing the measurement of the expected effects, both positive and negative, of a particular project, activity or policy change. This type of analysis, when undertaken in the context of decision-making in the public sphere, requires a comparison of the wider social costs and benefits of a given project, activity, or policy.

12.17 From a measurement perspective, a key feature of assessment of externalities is assessing the effect on welfare arising from specific activities. In this analysis, welfare is generally measured in terms of effects on consumer and producer surplus. Thus, negative externalities have a negative effect on the total surplus of other economic units. As discussed in appendix A12.1, there are conceptual links between measures of welfare based on total surplus and the exchange values recorded in accounting but the concepts of value are not equivalent.

12.18 While both the analytical framing and the valuation concept are different in externality assessments compared with ecosystem accounting, data from the ecosystem accounts can provide inputs to such assessments through its recording of changes in ecosystem condition and changes in ecosystem services flows that arise as a result of a particular activity (e.g. impacts of the use of fertilizer and pesticides on water bodies and biodiversity). Thus, the accounts can provide baseline information for the derivation of total surplus measures.

12.19 **Positive externalities.** With respect to positive externalities, there is a conceptually simple extension to the ecosystem services flow account in monetary terms that entails valuing the flows of services in terms of their total surplus, i.e. producer plus consumer surplus, rather than using exchanges values as described in chapter 9. For example, the exchange value of pollination services can be identified through analysis of market values of pollinated agricultural outputs, while the full economic value of pollination, potentially measured in the context of a change in the pollinator population, can be measured in welfare terms. These complementary valuations may be presented alongside estimates in exchange value terms. The bridge table presented in table 12.1 is an example of such an application.

12.20 **Negative externalities and ecosystem disservices.** While the accounts do not directly adjust or measure negative externalities as a distinct concept, the data in any set of accounts can track the effects of externalities over time, to the extent that those effects are within the prescribed accounting boundaries. Further, it is possible to record the effects, for example, on ecosystem condition and changes in flows of ecosystem services for individual ecosystem assets. In addition, in the related economic accounts, additional costs incurred by affected economic units can be recorded and changed patterns of income of affected economic units can be assessed. Finally, the accounts can record the net effect of any mitigation action that is undertaken by the economic unit that generates the externality. Thus, if the mitigation action occurs, the effects on measures of ecosystem condition, services, costs and revenue will be offset to some degree.

12.21 By way of example, additional costs associated with water purification resulting from excess fertilizer use are recorded in the accounts of the water supply and distribution company; and degradation in soil quality through overcropping is reflected in reduced ecosystem condition and the affected farmer's reduced output.

12.22 The primary differences between the estimates recorded in accounts and those measured using an externalities-based framing are that (a) the accounts themselves do not record the reason for the changes in ecosystem condition, value of output of the sectors or associated attribution of costs; and (b) the accounts do not aim towards measuring what might have happened under an alternative set of circumstances. At the same time, it is clear that the data from the accounts can underpin such assessments and, in particular, can be used to associate externalities to specific locations and affected ecosystem assets.

12.23 Ecosystem disservices fall into a category similar to that of negative externalities in that there are negative effects on people and economic units. A useful distinguishing feature is that disservices may be characterized as caused by environmental factors (e.g. mosquitoes causing malaria), whereas negative externalities are caused by the activities of economic units (e.g. land clearing spreading zoonotic diseases). The appropriate framing of disservices from an accounting point of view, as described in section 6.3.5, is to capture the wider effects of ecosystem disservices implicitly as a reduction in the flows of ecosystem services (e.g. reduction of biomass provisioning services due to destruction of crops by pests; reduction of opportunities for recreational activities related to lakes due to algal bloom).

12.24 The following tables demonstrate the potential to provide alternative recordings (using an accounting structure) that highlight ecosystem disservices and negative externalities. Table 12.2 illustrates how a disservice can be recorded. It is supposed that there is an economy with two activities: agriculture (ISIC, sect. A); and manufacturing (ISIC, sect. C), producing two products, X (crops) and Y (canned goods), respectively. In addition, it is assumed that ecosystem service A is being provided to ISIC, sect. A. Further, it is supposed that disservice B is introduced (e.g. elephants' trampling of agricultural produce and thus reducing the output of crops).

12.25 Table 12.2 recognizes both the ecosystem services of biomass provisioning and the disservice. The disservice effectively causes a reduction of 20 currency units in the value of the ecosystem service, which is why it is introduced as a negative. The net value of the crop provisioning service, which is used by ISIC A, then becomes 50. An income transfer is also recorded so that the same disposable income is recorded as in the situation where there is not a recording of the disservice (as in the SNA). The advantage of this table compared with the extended SUT (tables 11.1a and 11.1b) is that the same outputs are recorded but the value of the disservice is made explicit. This accounting treatment can be applied also where there is no offsetting ecosystem service; for instance, GHG emissions could be recorded as a negative output of an ecosystem and used by households, thereby reducing their final consumption.

12.26 Table 12.3 adjusts the example displaying the ecosystem disservice to show a recording of negative externalities. It is supposed that the farmer disposes of the agricultural wastes in a river, causing costs to downstream users (in this example, a water supply company (under ISIC, sect. E (water supply; sewerage, waste management and remediation activities)). The externality can be recorded as a negative output of the farmer (ISIC, sect. A) (-20 currency units), thereby reducing the farmer's output (and value added). In the use table, the externality can be recorded as (negative) intermediate consumption (-20 currency units) by the ecosystem, reflecting that in this situation, the ecosystem suffers the externality. This has the effect of showing the value added of the ecosystem in the absence of the externality (i.e. 75 currency units) while still exhibiting the actual ecosystem services supplied (55 currency units) and used (25 units by ISIC, sect. A, and 30 units by ISIC, sect. E). The income transfer (75 currency units) ensures, as in the previous recording of disservices, that the ecosystem has no disposable income and that the activities have the same value added as they would have without the ecosystem service and the externality.

12.27 In many situations, the discussion of negative externalities and ecosystem disservices is related to the effects on human and population health. It has long been established that the national accounts do not place a direct value on health outcomes and that, instead, the focus is placed on measuring the inputs to human health, for example, outputs related to doctors and hospitals. Similarly, in ecosystem accounting, there is measurement of ecosystems' contribution to health outcomes (e.g. through air filtration services) but not of the health outcomes themselves.

Table 12.2
Complementary recording of an ecosystem disservice in the SUT (currency units)

	Ecosystem assets	ISIC section A: Agriculture	ISIC section C: Manufac-turing	Households	Total
Supply					
Ecosystem service A	70				70
Ecosystem disservice B	-20				-20
Product X: crops		200			200
Product Y: canned goods			80		80
Use					
Ecosystem service A		70			70
Ecosystem disservice	0	-20			-20
Product X: crops			25	175	200
Product Y: canned goods				80	80
Value added (supply less use)	50	150	55		255
Transfer	-50	50			0
Disposable income	0	200	55	255	255

Table 12.3
Complementary table with an externality in the SUT (currency units)

	Ecosystem assets	ISIC section A: Agriculture	ISIC section E: Water supply	Households	Total
Supply					
Ecosystem service A	55				75
Externality		-20			-20
Product X: crops		200			200
Product Z: water			300		300
Use					
Ecosystem service A		25	30		70
Externality	-20				-20
Product X: crops				200	200
Product Z: water				300	300
Value added (supply less use)	75	155	270		500
Transfer	-75	45	30		0
Disposable income	0	200	300		500

12.28 Consequently, an important area of analysis extending beyond the ecosystem accounts lies in direct measurement of those outcomes. This work has been undertaken, for example, by the World Bank and the Organisation for Economic Co-operation and Development, among other organizations, under the generic heading of measuring the costs of environmental degradation.[131] Such work involves some form of monetary valuation but may also involve the measurement of dose-response functions that track the changes in population health in relation to changes in, for example, ecosystem condition (e.g. involving measures of water quality). It should be apparent that the structure of ecosystem extent and condition accounts, together with the biophysical modelling required for measuring many ecosystem services, may be applied usefully to derivation of health-related metrics and the related analysis.

131 See, for example, the World Bank *Changing Wealth of Nations* reports; the OCED database on those costs; and Muller, Mendelsohn and Nordhaus (2011).

12.29 There are also a range of approaches within the private sector through which the monetary value of externalities is added or subtracted from an existing measure of financial income or profit. These approaches are commonly labelled as environmental profit and loss statements. In general, they seek to assess the overall (or net) cost or benefit that a company contributes to society, for example, by deducting the social cost of carbon associated with its emissions from its measure of financial profit.

12.3 Alternative measures of income, wealth and degradation

12.3.1 Introduction

12.30 Chapter 11 described the SEEA EA approach to the measurement of income and wealth, which is adjusted for ecosystem degradation. In summary, the approach involves measuring the value of degradation in terms of loss in future value of ecosystem services due to a decline in ecosystem condition and deducting this cost of capital from the relevant aggregate measure of income (e.g. GDP) or wealth. At an industry or institutional sector level, the cost of ecosystem degradation is attributed to the economic units that suffer the loss of future ecosystem services.

12.31 Other approaches to accounting for the effects of degradation on income and wealth have been developed. They vary in the ways in which they estimate the cost of ecosystem degradation and in their definitions of income and wealth. The general ambitions of these measures are similar, but there are conceptual and practical differences compared with the estimates derived using the SEEA EA approach. In most cases, the data contained in the ecosystem accounts or data from the SEEA Central Framework can be used to support the derivation of alternative measures, but usually additional assumptions and alternative valuation concepts are applied.

12.3.2 Restoration cost-based approaches to measuring degradation

12.32 Earlier iterations of SEEA focused not on valuing ecosystem (or environmental) assets per se (in terms of the future value of ecosystem services) but rather on measuring the cost of degradation directly. This was carried out in the context of the environmental cost associated with recorded levels of economic activity. SEEA 1993 recommended use of the so-called restoration cost (or maintenance cost) approach to value degradation, i.e. an approach focused on the costs required to restore the environment to a previous or agreed condition. Further, as explained more fully in SEEA 2003 (chap. 9), the conceptual perspective assumed that environmental assets – air, water, soil – were effectively fixed in quantity and that the focus should therefore be placed either on the costs involved in combating declines in the quality of those assets (restoration costs) or on the damages incurred as a result of declines in quality.

12.33 In terms of monetary valuation, there are a number of considerations that emerge from this framing. First, in a situation where environmental quality meets or exceeds a suitable threshold – e.g. a situation where there is sufficient clean air – it is posited that there is no additional cost that needs to be considered in accounting for degradation.

12.34 Second, the non-market benefits that people obtain from nature are not considered exchanges with economic actors and therefore there is no rationale for extending the production boundary to record ecosystem services as described in the SEEA EA framework. Indeed, the distinct focus of the restoration-cost approach is not on articulating the contribution that ecosystems make to well-being but on highlighting the direct costs of reducing ecosystem condition below acceptable thresholds.

12.35 Third, it is considered that there is no market or institutional mechanism through which the restoration costs are confronted with the benefits (reductions in damages) associated with the change in environmental quality. The consequence of this is that SEEA 2003 described both cost-based methods and damage-based methods for estimating the monetary value of degradation. The damage-based methods described in SEEA 2003 have much in common with the measurement of welfare values as applied in the measurement of negative externalities and they are not further discussed here. In an environmental accounting context, most of the focus has been kept on cost-based approaches.

12.36 Following SEEA 2003, costs in relation to environmental degradation can either be preventative (avoidance and abatement costs) or aim towards reversing the effects of degradation (restoration costs). In the context of accounting for the cost of degradation in any given period, as described in SEEA 2003 (chap. 10), the avoidance and abatement costs may have been incurred in which case the quantity of degradation will have been reduced, ceteris paribus, and, further, they will have already been recorded in the accounts. (The framework for identifying these costs and recording them in environmental protection expenditure accounts is described in chapter IV of the SEEA Central Framework.)

12.37 Placing a value on the actual change in environmental quality must therefore focus on restoration costs, the expenditure required to return the environment to a given condition. This condition could be the condition in a previous (or sustainable) state or a condition defined as a societally desired state (e.g. as expressed in multilateral environmental agreements). This focus thus captures any degradation not included in measures of actual avoidance and abatement costs.

12.38 Measuring restoration costs may be challenging for two reasons. First, they are estimates of future expenditure, which require the use of appropriate assumptions concerning prices and quantities of necessary inputs. The core assumptions are that the estimate of costs will reflect the least cost and that there is broad agreement that the expenditures are justified. In some cases, highly extensive information on future restoration costs may be available, for example, mining companies may be required to estimate the cost of rehabilitating mine sites. However, it must be recognized that restoration may take up a considerable period of time. Measurement in this area is related to an issue emerging within the context of the SNA concerning the recording of provisions wherein liabilities may be recognized in relation to potential future costs. While provisions are a common feature of corporate accounting, they are not recorded in the national accounts.[132] To the extent that some of those costs are actually incurred, an accounting-based data set may be maintained to support estimation of such costs for future periods.

12.39 Second, it is necessary to assume an appropriate environmental quality to which the condition of the environment should be restored. Ideally, determining this level of quality should involve (a) an understanding of the benefits obtained from the ecosystem (e.g. ecosystem services, intrinsic values); (b) an understanding of relevant ecological thresholds and boundaries; (c) identification of the socially desired state; and (d) connections to relevant environmental regulations, standards and policy that can be used as indicators of social preferences. The determination should also entail recognition of the fact that in many cases ecosystems cannot be fully restored to a natural state. Based on the assumptions concerning the socially desired state, the estimated costs would reflect a social WTP for a specific level of environmental quality.

12.40 A simplifying assumption – that degradation is the estimated cost associated with restoring the ecosystem to its condition at the beginning of the accounting period – might be applied. In all cases, there is a clear-cut role for the ecosystem condition account in supporting the assessment of degradation and the associated restoration costs. It should be noted that, if those costs were actually paid during an accounting period, then, in theory, condition should be unchanged and no degradation should be recorded. Taking such a cost-based approach may therefore be better understood as an example of applying the accounts for scenario analysis.

12.41 In general, the estimate of the monetary value of degradation obtained using this approach could be integrated into the accounts as a macro adjustment. Recognizing the nature of these costs, Vanoli (2015) proposed adding the monetary value of degradation of ecosystems to the final expenditure categories as "unpaid ecological costs", through which final consumption and gross fixed capital formation would then be recorded on a "total costs" basis. Further, where the costs accrued remain unpaid in subsequent periods, they would be recorded as a negative with respect to saving and consequently recorded as an increase within a new liability category, namely, "eco-

[132] However, there is an area of active research in an SNA context that reflects a recognition of the significance of potential future costs.

logical debt of the economy". Table 12.4 below shows how unpaid ecological costs and ecological debt may be incorporated in a sequence of accounts.

12.42 As noted, this approach can provide a means to estimate cost of degradation but it cannot be easily combined with direct measures of the value of ecosystem services and associated values of ecosystem assets as presented in the ecosystem accounts, since there is no particular reason to expect that the estimated restoration costs will either align with the estimated loss of future flows of ecosystem services or reflect the social WTP for future ecosystem services. One option may be to apply this approach in cases (e.g. involving the atmosphere or fisheries on the high seas) where no underlying ecosystem asset is recognized. Restoration costs for these environmental assets could be recorded as unpaid ecological costs alongside measures of degradation for ecosystem assets as shown in the core ecosystem accounts.

12.3.3 Polluter pays presentation of degradation

12.43 Recording in SEEA EA is based on the cost-borne perspective in which the cost of degradation is allocated to the economic unit considered to own the ecosystem asset since this is the unit that suffers from the loss. An alternative perspective is to allocate the costs of degradation to the economic unit that is considered to have caused the degradation (e.g. costs may be assigned to a polluter) (La Notte and Marques, 2019).

12.44 To support this alternative presentation, table 12.4 illustrates how it is possible to include both costs-caused and costs-borne presentations in the sequence of accounts, as compared with the sequence of accounts displayed in table 11.3. This is done by allocating degradation on the basis of costs caused in the production account and then transferring degradation costs between sectors in the allocation of income account by including two additional rows – for degradation transfer in kind payable and degradation transfer in kind receivable. The transfer ensures that degradation-adjusted disposable income is the same as that obtained in table 11.3. In table 12.4, it is assumed that the farmer is responsible for all of the degradation.

12.45 This presentation has the following advantages: (a) the ecosystem asset value underpinning the supply of services reflects the costs-borne perspective (i.e. it reflects the value of the asset to the economic owner); and (b) the entries for production and value added provide a measure of net value added, reflecting a costs-caused perspective.

12.46 These allocations to causing units may be difficult to assign in practice, for example, in cases where the effects of degradation arise at some distance from the cause; where there are multiple economic units contributing to the degradation; or when there is a significant time lag between the activities causing the degradation and the incurrence of costs by other economic units.

12.3.4 Defensive expenditures

12.47 Another long-standing framing in the economics literature entails adjusting aggregate measures of income for expenditures incurred to avoid bad or negative outcomes. This includes, for example, the purchase of equipment to filter polluted air. These so-called defensive expenditures add to measures of national income following the SNA (i.e. there is increased production and consumption of relevant goods and services) but may be considered to not enhance overall welfare. Thus, defensive expenditures may be deducted to provide a more appropriate measure of national income in terms of welfare. A challenge in adopting this approach is defining the measurement boundary for defensive expenditures.

Table 12.4
Alternative recording of degradation costs in the sequence of accounts, excluding the financial account (currency units)

		Extended sequence of accounts			
		Sector			
		Agriculture	Household	Ecosystem trustee	Total
Production and generation of income account					
Output	Products (wheat)	200			200
	Ecosystem services (crop provisioning)	80			80
	Ecosystem services (air filtration)			30	30
Total output		280		30	310
Intermediate consumption	Products	0		0	0
	Ecosystem services (crop provisioning)	80		0	80
Gross value added		200		30	230
less Consumption of fixed capital (produced assets)		10		0	10
less Ecosystem degradation (polluter pays)		15		0	15
Degradation-adjusted net value added		175		30	205
less Compensation of employees		50		0	50
Degradation-adjusted net operating surplus		125		30	155
Allocation /use of income accounts					
Degradation-adjusted net operating surplus		125		30	155
plus Compensation of employees			50		50
Ecosystem service transfer in kind payable				30	30
Ecosystem services transfer in kind receivable			30		30
Degradation transfer in kind payable				5	5
Degradation transfer in kind receivable		5			5
Degradation-adjusted disposable income		130	80	-5	205
less Final consumption	Products (wheat)		200		200
	Ecosystem services (air filtration)		30		30
	Unpaid ecological costs		25		25
Degradation-adjusted net saving		130	-175	-5	-50
Capital account					
Degradation-adjusted net saving		130	-175	-5	-50
plus Consumption of fixed capital (produced assets)		10			10
plus Ecosystem degradation		10		5	15
Net lending/borrowing		150	-175	0	-25
Changes in balance sheet					
Changes in fixed capital (SNA)		10			10
Changes in ecosystem assets (non-SNA)		10		5	15
Changes in ecological debt (non-SNA)			25		25

Note: ■ Cells changed/added in a polluter pays recording in which ecosystem degradation of 15 currency units is allocated to the polluter. ■ Cells changed/added when including unpaid ecological costs, where those costs are assumed to be related to environmental assets outside the scope of the included sectors' balance sheets (e.g. the atmosphere or fisheries on the high seas). The unpaid ecological costs are therefore additional to the recorded ecosystem degradation.

12.3.5 Alternative measures of environmental income

12.48 The ecosystem accounts involve treating the monetary value of flows of ecosystem services as output and hence as income. Consequently, expectations of future income flows will affect the monetary value and changes in value of ecosystem assets. As described in chapter 10, there is a range of entries for recording the change in value of ecosystem assets including changes in value due to ecosystem enhancement, ecosystem degradation, ecosystem conversions and other changes. These other changes in asset values are accounted for following national accounting treatments as either other changes in volume (resulting, for example, from catastrophic losses) or revaluations. Importantly, these entries are not considered part of income in a national accounting context.

12.49 An alternative framing[133] entails defining income so that it includes all changes in asset values, including other changes in volume and revaluations. Such an approach has many similarities to the ecosystem accounting approach described in SEEA EA. The primary difference lies in the use of a Hicksian measure of income that explicitly incorporates all changes in asset values in a manner that is not aligned with the SNA. However, all of the underlying accounting entries and valuations – including the use of the exchange value concept – are aligned.

[133] See Caparrós, Campos and Montero (2003).

12.3.6 Alternative approaches to asset valuation

12.50 The recording of the monetary value of ecosystem services and the consequential extension of the monetary value of environmental assets relative to the SNA is consistent with the central logic of wealth accounting as described in, for example, Barbier (2013). At the same time, there are a range of assumptions, alternative to those associated with the treatments and boundaries of the ecosystem accounts, that can be applied in implementing the central logic of wealth accounting. The following considerations are particularly noteworthy:

- For some biological resources, especially fish stocks, where there is limited regulation and open access fishing is possible, the resource rent that reflects the price of the asset will fall to very low levels. In these contexts, it may be of interest to estimate the value of the fish stocks and the associated ecosystem asset using an alternative institutional context to evaluate the effects of making such a change. These values might be considered unrealized values
- Also for biological resources – indeed, for all ecosystem services – it may be of interest to estimate the present value of future returns using alternative institutional arrangements, for example, assuming some optimal management of the resources. These values might also be considered unrealized values. A specific case would entail estimating values of assets under an assumption of long-term sustainable use of the ecosystem and those values might be considered sustainability-based values
- Alternative valuation concepts may be applied whereby estimates of consumer surplus are included in the value of future flows of ecosystem services
- When valuing individual ecosystem assets, there may be interest in deducting the value of ecosystem disservices to the extent that those disservices are understood to have a negative overall effect on the value of the asset in terms of its contribution to society

- When defining future income flows, alternative treatments and interpretations of capital gains and depreciation (compared with standard national accounting principles) may be applied

12.51 In the context of these various assumptions and treatments for wealth accounting, the values obtained from the ecosystem accounts can be considered one alternative to asset valuation. In all contexts, it would be relevant to describe carefully the selected assumptions and treatments so that the differences between various wealth accounting estimates can be clearly understood. This documentation should also extend to including a clear articulation of the set of ecosystem services used to measure natural capital in the wealth accounts, as well as information on, for example, the selected discount rate and asset lives.

12.3.7 Extended modelling/greened economy modelling

12.52 A general concern for all measures and aggregates in monetary terms when an extended income framing is used is that the values of the environmental variables reflect the current imperfect institutions and regulations for managing the environmental-economic system. In this context, one alternative approach is to undertake extended modelling to estimate an alternative GDP (and other income measures) under the assumption that alternative environmental constraints (e.g. restrictions on pollution) are in existence. Greened economy modelling thus derives a measure of income for an alternative economy rather than an alternative measure of income for the existing economy (SEEA 2003, sect. 11.F.4).

12.53 More generally, there are a range of possible applications of the accounts in scenario analysis, which are considered in a technical report *Policy Scenario Analysis Using SEEA Ecosystem Accounting* (United Nations, Department of Economic and Social Affairs, Statistics Division, and UNEP, 2021).

12.4 Corporate natural capital assessments

12.54 In parallel with the advances in environmental-economic accounting in the public sector, in recent years there have been strong advances in natural capital accounting in the corporate sector. In general, these approaches have tended to focus on considering the impact of corporate activities on the environment, with a particular emphasis on GHG emissions and other pollutants, but there is an increasing shift towards efforts to understand dependencies on water and towards ecosystems and biodiversity.[134]

12.55 This has been taken forward most commonly using an externalities-based framing as described in the section above, particularly in the compilation of environmental profit and loss accounts. These approaches have been used as well in a range of applications, which have included undertaking risk analysis, identifying operational efficiencies and securing access to sustainable finance.

12.56 There are a number of approaches being used at the corporate level that reflect the spatially based approach under the ecosystem accounting framework (e.g. corporate natural capital accounting, Biological Diversity Protocol, Natural Capital Accounting for Organizations (United Kingdom)).[135] However, there are also differences between these approaches and SEEA-based accounting. The differences arise in particular with respect to the type of analytical questions posed. In a corporate context, those questions often reflect reporting requirements focused on business impacts on society. Corporate approaches therefore tend to apply welfare-based rather than exchange value-based methods to valuation. There are also questions that arise

[134] See https://seea.un.org/sites/seea.un.org/files/background_paper_release_for_unseeaforum.pdf.

[135] See Eftec, RSPB and PwC (2015); and the information available at the British Standards Institute (BSI) website (www.bsigroup.com/en-GB/our-services/events/webinars/2020/bs-8632/). The Biological Diversity Protocol is available at https://sustainableflows.com/biological-diversity-protocol/.

in this regard concerning the extent to which the data underpinning the compilation of SEEA-based accounts are sufficiently detailed for the purposes of corporate-scale measurement and analysis.

12.57 With respect to corporate sector engagement, and more broadly, given the potential for collating consistent and spatially detailed physical and monetary data using the ecosystem accounting approach, there is likely considerable potential for cross-fertilization of efforts in collating environmental data that support shared measurement of ecosystem extent and condition and ecosystem services flows. Shared measurement should encompass sharing of data, use of agreed classifications and application of coherent definitions. It is likely that issues of monetary valuation will continue to be an area of discussion, but this is equally true in the context of public sector accounting and analysis. Importantly, there needs to be further engagement regarding the development of accounting principles and their harmonization at the national and corporate levels, as well as regarding the potential for the development of rich data sets to underpin accounting at all scales.

Appendix A12.1

Exchange and welfare values in an accounting context

A12.1 The present appendix provides a technical summary of the relationship between exchange value-based accounting and monetary values focused on the measurement of welfare.

Monetary valuation of individual goods and services

A12.2 To establish the concepts, the initial focus is on the valuation of a single marketed good and a single consumer and producer. The basis of monetary valuation in neoclassical economics is the assumption that people and businesses have preferences that can be represented in quantitative terms using money values as a common unit or numeraire. The preferences are based on individuals' WTP for a given good or service or on individuals', firms' or resource owners' WTA for giving up a good or service.

A12.3 The WTP for a good or service or the WTA for giving up a good or service can be represented by a demand curve for the good or service under consideration. In figure A12.1.1, quantities of the good are displayed along the horizontal axis and prices are displayed along the vertical axis. For most goods, an individual's WTP decreases with each additional unit obtained by that individual; or, conversely, the quantity demanded by an individual decreases as the price increases. Line AB is referred to as the individual's demand curve because it illustrates the quantity demanded relative to price. The total WTP for quantity Q_0 is represented by the area under the demand curve. If the good or service was sold in a market at price P, the individual would purchase quantity Q_0, as that individual is willing to pay more than P for all quantity units before Q_0 but the WTP for an additional unit (Q_0+1) is less than P, with the result that the individual will not purchase another unit at that price.

A12.4 In this case, the sum of money exchanged is represented by the yellow area and is referred to as the *accounting value*, reflecting the value that is recorded in the accounts. The blue area represents the benefit that individuals who obtain the good or service enjoy over and above what is paid. This is called the *consumer surplus* (for further details on consumer surplus, WTP and WTA, see Markandya and others (2002)).[136] If the good is provided for free and there are no costs associated with supplying the service, then the consumer surplus is equal to the whole area under the demand curve (i.e. triangle AB0).[137]

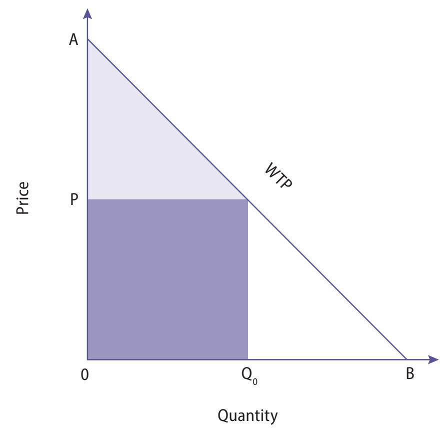
A12.5 To complete the picture of the market for a single good – again in terms of a combination of prices and quantities – a supply curve (figure A12.1.2) can be incorporated that reflects the preferences of the producer in providing the good for sale. Since the producer will be willing to supply more of a good as prices rise, the supply curve will be upward sloping. The nature of the supply curve will be affected by the costs of supply, i.e. a producer will be willing to accept only a price for its goods that covers the costs.

A12.6 The transactions in ordinary goods and services are based on prices, with the price being determined by the point at which the marginal WTP is equal to the

[136] Economic theory distinguishes between the Hicksian and Marshallian approaches to estimating demand curves, with the former approach aligning demand and preference to the concept of utility and the latter aligning them to the concept of income. While, ideally, Hicksian demand curves based on utility would be measured, in practice income is the more measurable concept. Consumer surplus is thus an approximation to the ideal.

[137] For essential goods like water, the consumer surplus can be very high (arguably infinite) as a person´s WTP for the amount needed for survival will be very large. (This state of affairs illustrates what is known as the zero problem (Nordhaus, 2006).) This is one of the reasons why welfare analysis usually focuses on assessing changes in welfare, for example, between q1 and q2 rather than between q1 and 0.

Figure A12.1.1
WTP, exchange values and consumer surplus



marginal cost of producing the good or service. This is the point of intersection of the supply and demand curves, denoted in figure A12.1.2 by point A, which exhibits both the exchange price and the quantity of the good exchanged. Data concerning these transactions form the foundation of all SNA accounts.

A12.7 Area Z reflects the costs of supply. The *producer surplus* (area Y) is the additional benefit that a producer receives from selling quantity X_0 at price P given costs Z.

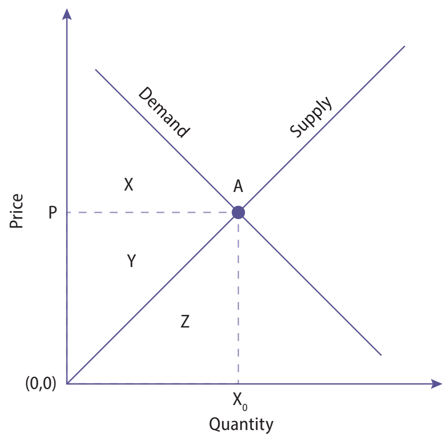
A12.8 The welfare value or total surplus, as understood in welfare economics, is equal to areas X + Y, i.e. the sum of consumer surplus and producer surplus. It represents the total benefit accruing to consumers and producers in this one-good market from exchanging the quantity of the good at price P. If preferences, costs or incomes change, then the measured total surplus will change. Commonly, welfare analysis involves assessment of the change in total surplus that would arise within a different context, for example, as the result of a policy change (e.g. related to tax rates).

A12.9 The relationships between areas X, Y and Z depend on the slopes of the supply and demand curves. For example, if the demand curve is horizontal then the consumer surplus (X) will be zero and the total surplus will equal the producer surplus. If the supply curve is vertical, then costs (Z) will be zero and the accounting value will equal producer surplus (Y). While there are a range of different combinations that can be envisaged for the relationship between accounting values and total surplus, the nature of those combinations is not critical to the present discussion.

A12.10 There are two key implications of figure A12.1.2 to be considered. The first concerns the link between price and accounting value. The price of a good is what is paid for it, and this needs to be multiplied by the quantity of the good to establish the accounting value. If there is no rationing involved, people will continue buying goods until their WTP equals the price at which the goods are offered. The price can therefore also be referred to as the marginal value of the good. A similar logic can be applied reflecting the situation of the producer of the good, that is, the price reflects the good's marginal cost to the producer.

A12.11 Second, the discussion in the present section indicates that the welfare derived from a good or service is equal to the total WTP for that good or service, which includes the payment made and the consumer surplus. As is well understood in the

Figure A12.1.2
Static one-good market



national accounts literature, accounts do not include the consumer surplus but record accounting values instead. A link with welfare can nonetheless be posited because the price is also the marginal value of a unit, which is the welfare that that unit provides. Thus, a small increase in the availability of a good will generate a change in welfare approximately equal to the change in the accounting value. This insight is the basis of a formal proof in the literature demonstrating that variations in material well-being in society are reasonably well represented by changes in NDP (see Weitzman (1976)), which are measured as the change in GDP less any change in depreciation.

A12.12 This conclusion depends on a restrictive set of assumptions. While the restrictiveness of those assumptions has been partially relaxed in subsequent studies (see Harberger (1971) for a previous, similar result and Löfgren (2010) for a survey of this literature and a discussion of the assumptions needed), the link between changes in GDP/NDP and changes in societal welfare still needs to be the subject of careful reflection. Of particular note is the fact that the result obtained assumes the absence of externalities and that all goods and services are provided through competitive markets. Moreover, there are connections to wealth distribution and relative poverty that are important in determining individual well-being but that are not captured in aggregate measures. More broadly, making the connection between accounting values and well-being should include recognizing that accounting values reflect an instrumental perspective on value and that other value perspectives (introduced in sect. 2.4) should also be considered.

A12.13 From an ecosystem accounting perspective, an important assumption associated with Weitzman's proof is that the products included in the income measure (i.e. GDP) all correlate positively with well-being. This in turn suggests the need for a focus on the scope of goods and services applied (i.e. the choice of production boundary) and on whether this scope includes some factors that have a negative link to well-being or whether there are goods and services that contribute positively to well-being that have been excluded. Indeed, one of the motivations for the development of ecosystem accounting is its potential for considering (a) some of the goods and services excluded from GDP; and (b) the effects of losing access to those goods and services as a result of ecosystem degradation.

Extension to non-market values

A12.14 The focus in the present appendix has been on supply and demand curves for a single consumer and producer. The demand curves for all individuals in a given market can be combined to construct a total demand or market demand curve. The summation is carried out horizontally in the case of a private good. Thus, for any given WTP, the quantity demanded by each individual based on that WTP is summed together to obtain the total quantity under the WTP for that good. For (quasi) public goods, such as recreation-related services, aggregate demand is obtained not through a horizontal summation (as in the case of private goods) but through a vertical one. That is, for any given quantity of a good, the WTP of each individual is summed together to obtain the total WTP. This applies to a situation where the supply is (relatively) inelastic. For example, in the case of a protected area supplying cultural services, it may take time to increase the supply of lodgings, parking or access roads in response to an increase in demand.

A12.15 The average cost of producing a good or service is not directly related to its value to the consumer (for example, average cost will exclude measures of consumer surplus), although the more expensive it is to produce that good or service, the higher its price is likely to be, making the marginal value higher. In the SNA, a number of goods are valued at their cost of production because there is no market for them and hence no observed price. This is the case with public goods provided by the government and other authorities, such as defence or public health. However, the use of cost data in this context does not signify that levels of provision are unrelated to values: the link can be formed through the political process that determines the level of provision. Thus, a given level of spending on health, education or transport, for example, reflects society's collective WTP for these services through taxes and user charges. That having been said, the relationship between public expenditure data and the true value of goods and services is subject to ongoing discussion.

A12.16 A key characteristic of ecosystem services involves the frequent lack of an accompanying exchange of money that can be used to quantify the preferences for the services applying the same approach adopted for marketed goods, as described directly above. As a result (as discussed in chap. 9), to support the valuation of ecosystem services and many other non-market goods and services, a wide range of valuation techniques have been developed for use in pricing ecosystem services in cases where market prices are not available.

A12.17 While these techniques may commonly be applied to estimate changes in welfare values, they all involve the estimation of the marginal WTP for a good or service. Consequently, using the framing described above, these techniques can also be applied to estimating prices for accounting purposes, that is, an accounting value can be estimated by multiplying a marginal WTP by a revealed quantity exchanged.

A12.18 An important issue related to understanding the potential to use marginal prices concerns assumptions regarding institutional arrangements or market structure. Generally, with respect to ecosystem services, it is expected that prices will be estimated assuming that the current institutional arrangements are related to the transaction involving those services. Hence, prices used to estimate accounting values need not align with estimates of marginal WTP made utilizing theoretically preferred institutional arrangements or market structures, such as perfect competition.

A12.19 Where there is a close connection of the ecosystem service to a marketed good or service, the potential to infer preferences and hence a marginal WTP will be relatively high. Further, in these cases, it is likely to be reasonable to assume that the institutional arrangements pertaining to the observed price of the related good or service can be applied in estimating the marginal WTP (provided that the context (e.g. ecosystem type, location) is sufficiently similar). However, there are other situations where there is no close connection of the ecosystem service to a marketed good or service, in which case establishing preferences and determining the appropriate institutional arrangements would be difficult. Different techniques have been developed to consider these different contexts, as discussed in chapter 9.

Chapter 13
Accounting for specific environmental themes

13.1 Introduction

13.1 The framing provided by ecosystem accounting is systematic and comprehensive with respect to ecosystem extent, ecosystem condition and ecosystem services and offers one perspective on monetary values of ecosystem services and ecosystem assets. Collectively, this data set allows for broad-scale measurement of trends in ecosystems and their services and supports the incorporation of ecosystem-related data into standard economic reporting and analysis. These applications emerge from the set of five ecosystem accounts, and the extended accounts and complementary valuations described in chapters 3 to 12. However, policy and analysis related to the environment and human connection to it can be framed in many ways. Often, it requires consideration of specific environmental themes, such as biodiversity, climate change, oceans and urban areas, among many others.

13.2 The present chapter introduces ways in which data from the ecosystem accounts, together with data from accounts of the SEEA Central Framework and the SNA, and data from other sources can be used to support discussion and analysis from a thematic perspective, i.e. when considering specific themes. Use of accounts in this way is collectively referred to as thematic accounting. The benefit of thematic accounting is ensuring consistency with additional data sets that can then be used to underpin reporting and decision-making for a given theme. While securing this benefit may require additional spatial disaggregation of data (e.g. economic data) and the use of consistent classifications, these challenges are common in implementation of ecosystem accounting and SEEA generally.

13.3 Section 13.2 describes the general principles involved in combining accounts, including accounts of the SEEA Central Framework. Data from those accounts – for example, accounts for water and land[138] – complement and support compilation of ecosystem accounts and thematic accounting. Sections 13.3 to 13.6 present examples of four types of thematic accounting, for biodiversity, climate change, oceans and urban areas. Each of these themes has been of widespread policy interest. Using the same general principles, thematic accounting may also be considered for other themes such as protected areas, wetlands, mangroves and forests.

[138] This work is also complemented by guidance from documents such as *System of Environmental-Economic Accounting for Water (SEEA-Water*) (United Nations, 2012); *System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries* (*SEEA AFF*) (FAO and United Nations, 2020); and *Forest Accounting Sourcebook: Policy Applications and Basic Compilation* (World Bank, 2017).

13.2 General principles of thematic accounting

13.4 All SEEA accounts build from the accounting principles described in the SNA. Much of the focus in thematic accounting is on the consistent approach to valuation concepts applied across these accounting frameworks. However, of greater importance in the organization and integration of data is the consistent application of rules and treatments concerning measurement boundaries and the use of consistent classifications. Such rules and treatments allow accounts to be adapted to suit specific purposes and hence place relevant data in context. They further support the development of broad and coherent links with additional information systems for each theme. The present section describes the three types of rules and treatments that are of most relevance in thematic accounting.

13.5 First, there needs to be a clearly agreed geographical area. In ecosystem accounting, it is referred to as the EAA. At a national level, this aligns closely with the SNA concept of economic territory. For thematic accounting, a focus on more targeted areas, (e.g. coastal and marine ecosystems in ocean accounting) may be appropriate. Delineating this area allows for the relevant set of ecosystem assets, economic units and other accounting entities to be appropriately delineated and also allows the measurement focus of the accounts to be clearly defined and aligned across different accounts.

13.6 Second, it is necessary to have a set of entities that are the focus of accounting. In ecosystem accounting, the focus is on ecosystems, in the SNA the focus is on economic units and in the SEEA Central Framework the focus is on individual stocks and flows. In thematic accounting, a number of different types of entities are integrated. Once the entities have been selected, it then becomes appropriate to choose relevant classifications. In ecosystem accounting, the relevant classifications concern ecosystem types and ecosystem services. In the SNA, the relevant classifications concern the classification of economic units by economic activity and institutional sector as well as the classification of products. In the Central Framework, the classifications are related to details of specific individual stocks and flows (e.g. land, soil, mineral and energy resources, and air pollutants). The selection of entities and their classification enables accounts to be structured to organize and present the information relevant to the theme.

13.7 Third, in accounting for a single theme, multiple accounts are required. It is evident from the SEEA and SNA frameworks that multiple accounts are required to organize the relevant information, i.e. there is no single ecosystem account or economic account. The same consideration applies in thematic accounting. The number of accounts developed to support discussion of a given theme vary depending on the analytical questions to be addressed and data availability. While a number of accounts are required, each account has relevance and merit in its own right by reflecting relevant accounting principles. For example, asset accounts provide an opening and closing position and a full description of changes in the relevant stock, and SUTs balance supply and use by entities.

13.8 Links between the various accounts for a theme are possible because of the use of a clearly delineated and consistently applied geographical boundary and consistent application of classifications for agreed entities. This allows the accounts for one theme to convey a coherent narrative. These features also allow for the derivation of consistent indicators and support the integration of data into models and other analytical tools.

13.9 For any given thematic accounting exercise, there is no a priori restriction on the geographical area, type of entity or classification that must be applied. However, it is likely to be advantageous to link the selection of geographical areas, definition of entities and choice of classifications to existing data and decision-making processes. Thus, for example, a geographical scope that aligns with administrative boundaries may be most useful. This allows existing data to be more readily incorporated and, more importantly, facilitates the use of data from the accounts in decision-making. Further, common classifications that can be used for data from different sources (e.g. classifications of ecosystem types, economic units) would support (a) comparison of information across themes; and (b) improved and streamlined data collection and reuse.

13.10 Accounting principles are themselves equally applicable across different spatial scales and entities and are unaffected by the choice of classification. These choices should therefore be made with a focus on the use of the accounts, including the potential to compare results over time and in different locations.

13.11 In practice, thematic accounting is most likely to be applied in one of the following ways:

- To extend or adapt an existing account from SEEA to provide additional detail or to use alternative classifications. For example, for the theme of forests it may be appropriate to compile adapted extent and condition accounts at the level of forest species and to make distinctions between different types of land-use and management arrangements
- To focus on a specific entity or group of entities and build associated accounts. For example, in accounting for the theme of climate change, the likely core focus would be on accounts for stocks and flows of carbon; and in accounting for the theme of biodiversity, it would likely be relevant to compile accounts for a target group of species or taxa
- To focus on a type of area that has specific management and policy relevance. Examples include protected areas, urban areas and coastal and marine areas. Often, there is a link to specific ecosystem types but the framing of thematic accounting looks beyond the ecosystem accounts to consider the relevance of other SEEA and SNA accounts in supporting the design of a more comprehensive data set

13.12 Under each of these approaches, which may be combined, there remains a need to specify the relevant geographical area for the set of thematic accounts. Thus, thematic accounts can be compiled at a national level, for large administrative regions within a country or at relatively detailed landscape and catchment scales. Further, for some themes (for example, climate change or assessment of environmental and economic outcomes on the high seas beyond national jurisdiction), compilation of global-scale accounts may be of relevance., Whatever geographical area and scale are chosen, accounting designs based on the principles of SEEA can be developed.

13.13 While the development of thematic accounting has emerged through the development of ecosystem accounts, there are many relevant accounts in the SEEA Central Framework that should be used in combination with ecosystem accounts to support accounting for any given theme. The relevant Central Framework accounts for the four themes selected for consideration in this chapter are described in the sections that follow. A more general introduction to the relevant Central Framework accounts is provided in appendix A13.1. It is to be noted that, in some cases, the data from the Central Framework accounts provide input to the compilation of ecosystem accounts. For example, data from the water resources asset account and the carbon stock account can support the measurement of ecosystem service flows and the derivation of ecosystem condition indicators.

13.3 Accounting for biodiversity

13.3.1 Introduction

13.14 Biodiversity comprises three levels – ecosystems, species and genes – as reflected in the definition of biodiversity under the Convention on Biological Diversity. According to that definition, biodiversity is ***"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and***

the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”.[139]

[139] See Convention on Biological Diversity, article 2, entitled “Use of terms”, available at www.cbd.int/convention/articles/?a=cbd-02.

13.15 The ecosystem accounts illustrate how accounting principles can be used to organize a wide range of data concerning ecosystems in a manner that supports an understanding of the connection between ecosystems and economic activity and human well-being. The present section describes the potential for using ecosystem accounts and other accounting data to support decision-making on biodiversity more broadly, with one particular aim being to mainstream the use of data on biodiversity in planning and decision-making. This use of accounting is referred to collectively as accounting for biodiversity. The ambition to support the mainstreaming of biodiversity into national policy and related decision-making is reflected in the IUCN World Conservation Congress resolution 057 (2020) entitled “Accounting for biodiversity: encompassing ecosystems, species and genetic diversity”.[140]

[140] See https://portals.iucn.org/library/node/49196.

13.16 The purpose of accounting for biodiversity includes informing conservation actions and enhancing biodiversity as an environmental management objective in its own right, as well as facilitating discussion on securing ecosystem services supply and on the various policy responses that may be relevant, such as biodiversity finance. Accounting for biodiversity recognizes the definition of biodiversity under the Convention on Biological Diversity, the different components of biodiversity and the links between economic activity and changes in biodiversity.

13.17 This section summarizes the connections between biodiversity assessments and SEEA EA; describes one particular type of accounts, namely, species accounts, which complement the suite of ecosystem accounts; notes the relevance of measures concerning the genetic level of biodiversity; and lists the types of accounts that are relevant in accounting for biodiversity. The present discussion reflects the current state of play in accounting for biodiversity, recognizing that a broader and richer discussion is required on the coverage and application of accounting in relation to biodiversity. A future output of these discussions may be an SEEA for biodiversity.

13.3.2 Biodiversity assessments and SEEA EA

13.18 There is a wide array of primary data on ecosystems, species and genes that is used to support the measurement and assessment of biodiversity. The focus of biodiversity assessments may be regional, national or global in scale or may consider individual species or ecosystem types. Work on assessing biodiversity is the focus of a range of global and national measurement initiatives and assessment frameworks, including the IUCN Red List of Threatened Species, the IUCN Red List of Ecosystems and the IUCN Global Standard for the Identification of Key Biodiversity Areas; the IPBES; the Biodiversity Indicators Partnership; and the Global Biodiversity Information Facility. The GEO BON approach to essential biodiversity variables, while not itself providing assessments or data, does provide an organizing framework for primary data.

13.19 Given this rich and long-standing body of information, accounting for biodiversity is not intended to replace or duplicate existing initiatives in biodiversity assessment or to generate indicators of diversity at ecosystem, species or genetic levels. Further, there is no single “biodiversity account”.

13.20 In addition to these assessment frameworks, there are global monitoring initiatives, principally under the Convention on Biological Diversity and the 2030 Agenda for Sustainable Development. The Kunming-Montreal Global Biodiversity Framework, for example, has five pillars. These represent the three levels of biodiversity – comprising ecosystems, species and genetic material – that are embodied in the Convention definition of biodiversity, and two levels of interactions with people and the economy, through ecosystem services and biodiversity finance. Data and methods related to all of these pillars are relevant in supporting a complete monitoring of and support for biodiversity-related policy- and decision-making.

13.21 There are three main connections between SEEA EA and biodiversity assessment and monitoring frameworks. First, data collected for use in biodiversity assessments can also support the compilation of ecosystem condition accounts and may provide input to the measurement of ecosystem services. For example, data on species abundance and diversity for specific ecosystem types can support measurement of the composition, structure and function of those ecosystems.

13.22 Second, data from various SEEA EA accounts may constitute an input to these assessment frameworks and global monitoring initiatives (e.g. under the Convention on Biological Diversity) where the focus is on measures pertaining to ecosystems. For example, where data are needed concerning ecosystem extent, ecosystem condition or ecosystem services flows, output data from the ecosystem accounts can provide a relevant source of information.

13.23 Third, data from the ecosystem accounts particularly concerning ecosystem services and data from the SEEA Central Framework concerning environmental protection expenditure and environmental taxes and subsidies can support discussion of the interactions between biodiversity, people and the economy.

13.24 The use of data from the ecosystem accounts for use in the monitoring of biodiversity does not imply that the accounts provide direct measures of ecosystem diversity. Rather, information on ecosystem extent and condition can be used to support an understanding of the status of and trends in biodiversity. The potential of ecosystem accounts data to support the derivation of measures of ecosystem diversity is an area for research in the context of advancing accounting for biodiversity.

13.25 Given these various connections, advancing accounting for biodiversity requires developing coherence with existing national biodiversity objectives and associated international commitments. This being the case, ministries responsible for the development of national biodiversity strategies and action plans, multilateral environmental agreements and similar policies that deliver on various national and global biodiversity objectives, including commitments under the Convention on Biological Diversity, should be involved at an early stage in work in the area of accounting for biodiversity.

13.3.3 Accounting for species

13.26 Environmental-economic accounting has the potential to create a structured link between the environment and economic activity and human well-being. Consequently, it is relevant to consider the links between selected species and economic activity and human well-being. This motivation can advance the compilation of species accounts to support decision-making.

13.27 Species accounts measure changes in (a) species "status" in terms of extinction risk over an accounting period; (b) species stocks (e.g. in terms of presence or abundance); and (c) species distribution.[141] All species accounts have the same general structure, comprising an opening and a closing entry and changes over the accounting period. While data within a species account do not generate a measure of species diversity directly, those data may support the assessment of species diversity and may provide input for indicators of species diversity.

[141] Species assemblages are a defining characteristic of ecosystems and there is also a relationship between species and ecosystem extent accounts.

13.28 For each type of account, species are selected as the focus of accounting. Four high-level groups for species accounting can be identified: (a) species of concern (e.g. threatened species); (b) species important for ecosystem services; (c) species of social or cultural significance; and (d) species important for maintaining ecosystem condition (or functioning). A species account may focus on a single species within these groups or a selection of species or taxa relevant to the accounting's purpose.

13.29 The rationale for accounting for the abundance and/or persistence of the species important for ecosystem services is well established in the context of provisioning services (as related, for example, to harvest of fish and timber) as attested in SEEA AFF (FAO and United Nations, 2020). For species to be harvested on a sustainable basis, their stocks need to be quantified and assessed in the context of supply and use of the services. Commercial fishery species are a relevant example here. There are also some regulating services where recording the stocks of particular species groups is important for understanding the sustainability of ecosystem services supply. Populations of pollinator species constitute an important example in this regard.

13.30 Species accounts may also organize data to support measurement of some cultural ecosystem services, for example, data on services involving relationships with sacred plants, iconic animals or other species linked to spiritual and symbolic services. Species accounts can also provide useful data on elements of biodiversity to whose existence people assign non-use value or bequest values (recorded using the label "ecosystem and species appreciation").

13.31 The compilation of species accounts is commonly based on existing data and monitoring programmes. Of particular note is the IUCN Red List of Threatened Species, which is underpinned by a comprehensive set of data on species for which Red List assessments have been undertaken. More generally, two approaches to measurement can be described, both of which are used in Red List assessments. The "direct observation" approach may be informed by large sample surveys (such as national surveys), stock assessments for commercially valuable species or more focused efforts (e.g. censuses of protected areas and nature reserves). Where sampling densities are sufficient and spatially referenced, species accounts can be aligned to ecosystem types and, potentially, ecosystem assets and integrated with information in the ecosystem accounts.

13.32 Where direct observation data on species are limited, as is typically the case, inferred approaches may be used. One particular habitat-based inferred approach uses observations of changes in spatial extent (expressed in terms of area) and changes in configuration of habitat required by individual species or communities of species (UNEP-WCMC, 2016). Inferred approaches underlie a large proportion of Red List assessments. More sophisticated measures can also be applied to estimate species persistence or proportions of species expected to be retained in communities. Data compiled for ecosystem extent and condition accounts represent a potentially valuable source of information for assessing the spatial configuration and condition of remaining habitat for species. In this way, the relationship can be made explicit between changes in ecosystem extent and ecosystem condition and changes in the suitable habitat available for individual species or in species extinction risk.

13.33 The general structure for a species account is shown in table 13.1. The structure, which reflects that of a typical asset account, is similar to the ecosystem extent account. The scale at which the species account is compiled is flexible. However, in practice, it is likely that species accounts will be compiled at the scale of EAAs, either in aggregate or by ecosystem type. The columns in table 13.1 organize information on selected species (e.g. lions, elephants) or species groups (e.g. taxa, functional groups such as pollinators). An opening measure and a closing measure for each column is recorded for the accounting period. Where possible, additions and reductions to those measures, whether due to unmanaged or managed changes, are also recorded. Additions could be due, for example, to species population growth, reintroductions or translocations.

13.34 A range of species accounts have been developed following the general principles outlined here, including accounts for cycads and rhinoceros in South Africa (Statistics South Africa, 2021a; 2021b), accounts for butterflies in the Australian Capital Territory; and species accounts in the Kingdom of the Netherlands (Bogaart and others, 2020).

13.35 There are a range of possible species accounts and associated extensions and species accounts can be linked to other accounting data through the use of aligned geographical boundaries, classifications and accounting treatments. Species accounts can therefore readily complement that other information, especially concerning economic activity and human well-being, in accounting for biodiversity.

13.3.4 Accounting for habitats and spatial scale

13.36 As noted above, a common approach to the assessment of species in the absence of data on individual populations is to use data on the area and spatial configuration of the habitat for species. Given that a relationship exists between habitat and ecosystem types, there is the potential to use data on ecosystem extent and ecosystem condition from the ecosystem accounts to support the derivation of habitat-based information both for individual species and in the context of assessing multi-species diversity. Examples of this type of work include accounting for chimpanzees and shea trees in Uganda (UNEP-WCMC and IDEEA, 2017) and accounting for multi-species plant, vertebrate and invertebrate diversity in the San Martin region of Peru (Alam and others, 2016). Further examination of the potential connection between SEEA EA and habitat-based biodiversity assessment constitutes one area of research in accounting for biodiversity. A background paper, already cited above, that discusses relevant issues in this regard, in particular with respect to spatial scale in deriving and aggregating biodiversity metrics, provides an appropriate framing for this area of research (Larsen and others, 2021).[142]

[142] The background paper, entitled "Addressing spatial scale in deriving and aggregating biodiversity metrics for ecosystem accounting", is available at https://seea.un.org/content/accounting-biodiversity.

Table 13.1
Species account for an EAA

	Species or species group 1	Species or species group 2	Species or species group 3	Species or species group 4	Species or species group 5	Species or species group 6	Species or species group 7	Species or species group 8	Species or species group 9	Species or species group 10
Measurement unit										
Opening measure										
Additions										
Unmanaged										
Managed										
Reductions										
Unmanaged										
Managed										
Net change										
Closing measure										

13.37 In deriving complex measures of multi-species diversity, data on the abundance and trends of a selected species in individual locations are relevant, but for measuring species diversity it is also useful to understand species assemblages, i.e. where different local populations of multiple species exist and how they are connected to other local populations and to different ecosystem types. Different species and species assemblages perform different functional roles and have varying degrees of resilience to different pressures. Thus, understanding the complementarity of species assemblages must be recognized as a key long-term goal if ambitions for establishing resilient multifunctional landscapes are to be realized. This includes the maintenance of capacity for future ecosystem services delivery at landscape (rather than ecosystem asset) scale.

13.38 These types of considerations of spatial scale in providing such complex measures of multi-species diversity are beyond the scope of ecosystem extent and condition accounts directly. In particular, since the focus of ecosystem accounts is on accounting for individual ecosystem assets, the information set would not capture to any degree the effects of spatial variation and complementarity in species composition across whole regions (i.e. beta and gamma diversity) or the effects of spatial configuration of habitat (e.g. connectivity) on biodiversity persistence. These aspects of biodiversity may be considered in accounting for biodiversity. An introduction to concepts and methods relevant to the relationship between ecosystem accounts and issues of spatial scale in the measurement of biodiversity is provided in the technical note by Larsen and others (2021) cited in paragraph 13.36.

13.3.5 Accounting for the genetic level of biodiversity

13.39 Genetic diversity concerns the variety of genes between and within species populations. Genetic diversity within species populations is linked to the condition of those populations. As meta-populations become fragmented and individual populations become isolated, exchanges of genetic material within species are restricted. Further, as identified by IPBES, maintaining phylogenetic diversity[143] is important for maintaining options concerning genetic diversity overall (i.e. gene pools). Maintaining gene pools is also important for various commercial activities – for example, for the further development of crops or livestock that are well adapted to respond to different and changing conditions (e.g. climate change) – and with respect to biosafety and biosecurity. There are also option values linked to gene pools associated with future medical applications or other biomimicry technologies and their development.

[143] Phylogenetic diversity reflects genetic differences between species with different evolutionary histories.

13.40 The basic framing of a species account shown in table 13.1 could be adapted to support discussion of these issues by recording, for example, the extinction risk of phylogenetically diverse species or species groups. In addition, if the results can be presented with appropriate spatial detail, species accounts could be used to help to track translocations of selected species where meta-populations become isolated (e.g. transfers of iconic species between protected areas).

13.41 While recognizing the importance of genes and their diversity in underpinning ecosystem function and the flow of ecosystem services, there have not yet been advances in the development of accounts for the genetic level of biodiversity. However, as data on genetic material for selected species become more widely available, the use of accounting to frame the connection of genetic biodiversity to economic and human activity and well-being may be of relevance.

13.3.6 Using accounting data to support decision-making on biodiversity

13.42 SEEA EA supports discussion of the link between biodiversity and economic activity and human well-being by providing a description of the relationships between ecosystems, the species that compose them and the SNA and non-SNA benefits that ecosystems provide. Description of these relationships can be complemented by data from the SEEA Central Framework, where the focus is on tangible material and financial flows about the environment and the economy (e.g. provisioning ecosystem services, pollutant emissions, environmental protection expenditure). Data on economic activity related to specific locations of interest may also be integrated using national accounting principles. Accordingly, across the suite of SEEA EA accounts, many aggregates and indicators are relevant to biodiversity at the ecosystem level, as well as to biodiversity at levels other than that of ecosystems. A non-exhaustive set of relevant indicators and aggregates are summarized in table 13.2.

13.43 Assuming that these various accounts can be compiled using aligned geographical areas, classifications and accounting treatments, a wide variety of cross-cutting indicators and analyses can be derived from a coherent information set. For example, relationships between expenditure on biodiversity and changes in ecosystem condition might be analysed and changes in condition in relation to changes in land use and emissions might be assessed.

13.44 Accounts showing the extent of ecologically important areas that support significant biodiversity also provide useful information that can supplement the information presented in table 13.1. Such areas include those determined by, for example, policy designations (e.g. wetlands designated pursuant to the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) or the areas established pursuant to Council of the European Union directive 92/43/EEC of 21 May 1992 (Habitats directive)); scientific determinations (e.g. Key Biodiversity Areas (KBAs) identified under the IUCN Global Standard, including Alliance for Zero Extinction sites); broad-scale regional prioritizations (e.g. of biodiversity hotspots identified by Conservation International); and national and subnational government prioritizations and regulations. Similarly, compiling accounts showing the extent of important ecosystems for biodiversity within and surrounding protected areas is a relatively straightforward step in identifying where biodiversity is most at risk and where the risk of biodiversity loss should be managed. Ecosystem condition accounts record changes in several biodiversity-related indicators that can also be used to understand trends in biodiversity.

13.45 The physical and monetary values presented in ecosystem services flow accounts can reveal to decision makers the importance of species and their diversity, particularly in relation to provisioning services,[144] and of ecosystems to economic activity (e.g. tourism) and well-being. Data on ecosystem services may therefore support the case for investment in biodiversity conservation and restoration. Publicly available information on the multiple ways in which ecosystems support well-being can inform more holistic planning approaches. Encouragement of nature-based solutions, which, for example, benefit multiple sectors can lead to delivery of better social outcomes and achievement of conservation objectives.

[144] See, for example, FAO (2019).

13.46 One approach to the presentation of these different types of data is to use combined presentations following the principles outlined in the SEEA Central Framework. Such presentations provide a means of bringing together information from various accounts to describe connections between the different components of biodiversity and wider economic and social statistics. In this way, those presentations can be a useful tool for mainstreaming discussion of biodiversity. In particular, detailing trends related to extent and condition of ecosystems of high biodiversity value and their economic context can assist in promoting informed decision-making for biodiversity conservation. For example, it may be useful to present the opportunity costs of conserving mangrove forests and their biodiversity in terms of the forgone income from establishing shrimp farms in those forests' locations. Through these initiatives, multiple stakeholders in the domain of biodiversity can be mobilized and more cost-efficient solutions for delivering on economic and environmental objectives can be realized.

Table 13.2
Linking SEEA accounts to biodiversity at levels other than that of ecosystems

Framework	Account	Aggregate	Relevance
SEEA EA	Extent	Extent of ecosystems	Trends in the extent of ecosystems important for biodiversity can be used to infer implications for species and species loss.[a] They also provide an insight into habitat loss, a key driver of biodiversity loss
SEEA EA	Condition	Biotic characteristics	These characteristics can be used to distinguish ecosystem assets in which biodiversity is more intact, for example, to identify areas of grassland with high values for species-based indicators or patches of forest with "good" structural characteristics. They can also provide information on where biodiversity is threatened, based on trends of poor condition (e.g. invasive species abundance)
SEEA EA	Condition	Abiotic characteristics	These characteristics can track where pressures on biodiversity may be manifesting themselves (e.g. where pollutant concentrations are increasing). They can help to highlight and quantify potential relationships between ecosystem degradation and species loss, including through the use of habitat-based biodiversity assessment techniques
SEEA EA	Services	Physical supply and use	Aggregates for provisioning services can identify where overexploitation of individual species is occurring (e.g. where sustainable yields are being exceeded). This can also include illegal use, such as poaching, where sustainable yield may be zero
SEEA Central Framework	Land use and land cover	Areas of biodiversity impacting or enhancing activities	Data on land use, land-use change and land cover allow information on spatial biodiversity loss to be linked to different sectors and economic activities
SEEA Central Framework	Emissions	Spatially disaggregated emission flows	Emission flows can identify where pollutant pressures on biodiversity are likely to manifest themselves. These insights are enhanced by (potential) linkage to spatially disaggregated accounts
SEEA Central Framework	Environmental protection expenditure	Expenditure on biodiversity conservation and enhancement	Where these financial transactions can be linked to changes in ecosystem and species status or indicators of biodiversity at scale, they can have significant policy implications. In particular, they can be useful for understanding the ecological and economic benefits from public and private expenditure on the environment and biodiversity
SNA	Production and consumption	Monetary transactions involving biodiversity- related goods and services	A number of monetary aggregates relevant to biodiversity exist in the SNA (e.g. provisioning services, wildlife tourism, recreational activities in nature). These aggregates can be linked to the elements of biodiversity supporting their supply through SEEA EA. They can also inform consideration of the opportunity costs for biodiversity conservation (e.g. revenues forgone) and monetary trade-offs/opportunity costs associated with different management approaches for biodiversity

[a] Even without ongoing species monitoring, the species-area curve can reasonably estimate species loss based only on change in ecosystem extent.

13.47 Some aspects of biodiversity that are essential for development to proceed in balance with nature may not be well reflected in ecosystem services flow accounts. In general terms, those aspects concern the role that biodiversity plays in supporting the supply of ecosystem services, as discussed in section 6.3.3. Two particular aspects are related to insurance and option values.

13.48 Further, as noted in chapter 6, society places significant value on the continued existence of biodiversity for spiritual or religious reasons or reasons related to non-use values, including existence and bequest values. Thus, biophysical indicators need to be used to reflect changes in the elements of biodiversity relevant to these types of values (e.g. extent of natural ecosystems, recorded non-use flows concerning ecosystems and species appreciation). Indicators from the species accounts are also highly relevant.

13.4 Accounting for climate change

13.4.1 Introduction

13.49 Climate change is one of the major global challenges of our time. Ecosystem accounting can provide data through which to understand the key role that ecosystems play in GHG cycling on global, national and regional scales, which underpins the atmosphere's carbon concentration. In addition, data from the ecosystem accounts can help to facilitate an understanding of the impact that climate change is having on ecosystems and biodiversity. This connection among ecosystems, climate change and biodiversity and the need to consider them jointly is recognized in decision 1/CP.25, entitled "Chile Madrid Time for Action", adopted by the Conference of the Parties to the United Nations Framework Convention on Climate Change at its twenty-fifth session, held in Madrid from 2 to 15 December 2019, in which the Conference of the Parties underlined "the essential contribution of nature to addressing climate change and its impacts and the need to address biodiversity loss and climate change in an integrated manner" (para. 15).[145] As an integrated statistical framework SEEA can therefore play an important role in supporting international and national policy discussions related to climate change. Furthermore, it can provide the underlying data that link climate change to other environmental topics, for example, biodiversity and the circular economy.

[145] See FCCC/CP/2019/13/Add.1, available at https://unfccc.int/sites/default/files/resource/cp2019_13a01E.pdf.

13.50 SEEA EA accounts in combination with accounts from the SEEA Central Framework and the SNA can support various facets of climate change policy. These include carbon mitigation and adaptation policies, carbon markets and financing mechanisms, carbon stock assessment and management, linking of air emissions and economic activity, recording and modelling of climate change outcomes related to ecosystems, ecosystem services and economic activity, sector-based assessments (e.g. for agriculture), ecosystem-focused planning (e.g. for peatlands), co-benefits of carbon projects and policies, and impacts of mitigation responses.

13.51 Thematic accounting for climate change complements existing measurement approaches described in the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006) in the following two ways. First, carbon emissions from terrestrial ecosystems result from two processes: human activities (management) and environmental change but the IPCC guidelines for GHG accounting have been developed to account for net emissions due to human activities, whereas SEEA EA is more comprehensive and includes both managed and unmanaged areas. Second, SEEA allows connection with economic activities to be made.

13.52 The present section introduces the subject of how accounting can provide information that supports decision-making related to climate change. Three areas are considered: (a) potential of data from the ecosystem accounts to inform decision-making; (b) accounting for stocks and changes in stocks of carbon; and (c) other accounting connections and indicators. As for thematic accounting generally, the aim in this section is to introduce a range of connections that offer insight into the potential of accounting approaches.

13.4.2 Applying SEEA EA to inform climate policies

13.53 Several of the ecosystem accounts provide data that support monitoring and analysis of climate change policies. In general, this connection emerges because of the impact exerted by climate change on the extent and condition of ecosystem assets and flows of ecosystem services. That is, the ecosystem accounts are a framework for recording a range of climate change effects on the environment and exhibiting the links to economic and other human activity. Use of a common framework for recording those effects makes comparison of the effectiveness of different policies aimed at mitigation or adaptation to climate change a straightforward undertaking.

13.54 The extent account shows the managed and unmanaged conversions in ecosystem types that directly underpin changes in carbon removal by and carbon emission from ecosystems. Data from extent accounts can therefore be linked to the assessment of GHG emissions arising from land use, land-use change and forestry LULUCF as used in IPCC measurements. The link between accounting and land LULUCF is described in detail in SEEA AFF.

13.55 The condition account includes ecosystem characteristics and indicators that are highly relevant for climate change. Relevant physical state characteristics that are related to carbon stored in ecosystems include soil organic carbon and dry matter productivity. Carbon stock indicators for biomass provide a direct link to the carbon stock account described below. Condition indicators should also capture the local impacts of climate change on ecosystem condition. The effects, for example, on local temperatures and rainfall patterns will be relevant in assessing condition in some contexts. It should be noted, however, that ecosystem accounts do not incorporate direct measurement of climate per se, in terms of, for example, data on atmospheric and ocean concentrations of GHGs or comprehensive data on temperatures and rainfall.

13.56 The reference list of selected ecosystem services (table 6.3) includes several ecosystem services that are particularly relevant for climate change policies. Global climate regulation services are ecosystem contributions to the regulation of the concentrations of gases in the atmosphere that exert an impact on global climate, primarily through the sequestration and retention of carbon in ecosystems. The physical and monetary ecosystem services flow accounts (chaps. 6, 7 and 9) show which ecosystem types play an important role in carbon sequestration and retention and how they change over time. Physical data on carbon retention and sequestration by ecosystem type are embodied in the carbon stock account described below.

13.57 Furthermore, there are several regulating ecosystem services that mitigate the effects of climate change. Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions. Examples include the evaporative cooling provided by urban trees and the contribution of trees to providing shade for livestock. Rainfall pattern regulation services are the ecosystem contributions of vegetation at the subcontinental scale, in particular forests, in maintaining rainfall patterns through evapotranspiration. Flood mitigation services, including both tidal surge and river flood mitigation, are the ecosystem contributions that mitigate the impacts of floods on local communities. Storm mitigation services are the ecosystem contributions of vegetation, especially linear elements in the landscape, to mitigating the impacts of windstorms, sandstorms and other types of storms (other than water-related events) on local communities. The accounts indicate not only what ecosystem types are the main contributors to reducing the effects of climate change but also who are the main beneficiaries of these ecosystem services.

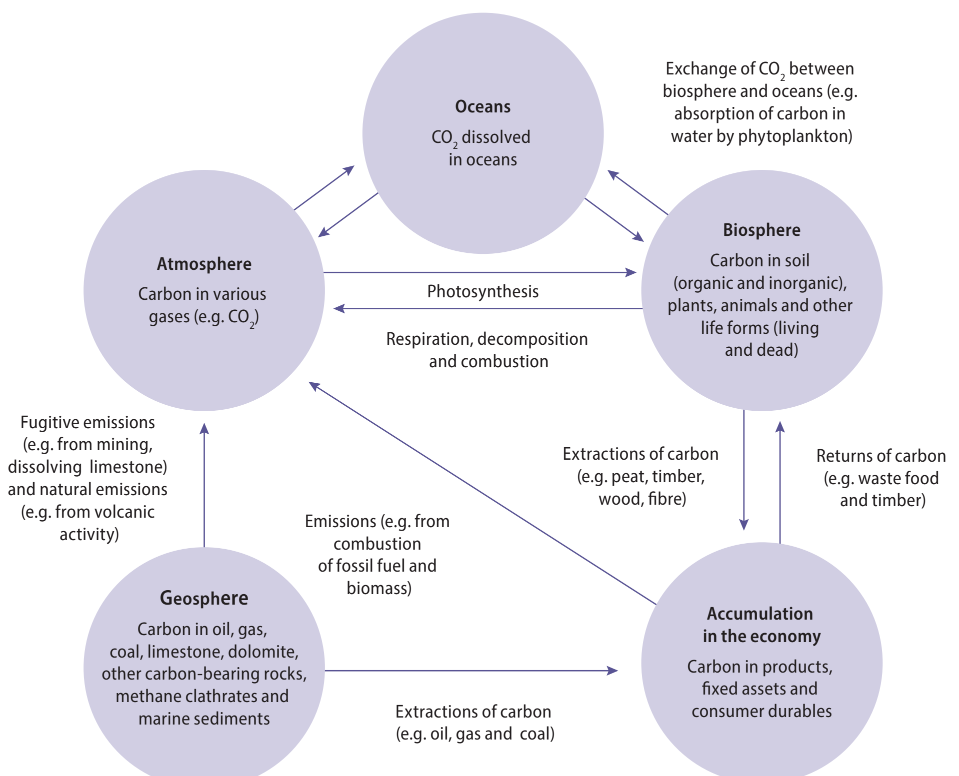
13.58 Finally, flows of several ecosystem services, including provisioning and cultural services (e.g. water supply, biomass provision and recreation-related services) are impacted by climate change, although isolating the precise contribution of climate change to the flows of ecosystem services is not an ambition of the accounts.

13.4.3 Accounting for carbon

13.59 Carbon has a central place in ecosystem and other environmental processes and hence accounting for carbon stocks and transfers between them is an important aspect of environmental-economic accounting. The carbon stock account provides comprehensive coverage of all relevant carbon stocks and changes in stocks across all stores of carbon at a national or subnational level covering both managed and unmanaged areas.

13.60 The fact that carbon plays an extensive role in the environment and the economy calls for a comprehensive approach to its measurement. Accounting for carbon must therefore consider stocks and changes in stocks of carbon in the geosphere, the biosphere, the atmosphere, the oceans and the economy. Figure 13.1 presents the main components of the carbon cycle. It is these stocks and flows that provide the context for carbon accounting. The same principles can be applied to accounting for other GHGs, including NOx.

Figure 13.1
Main components of the carbon cycle



13.61 The structure of a carbon stock account is presented in table 13.3. It provides a complete and ecologically grounded articulation of carbon accounting based on the carbon cycle and, in particular, the differences in the nature of particular carbon reservoirs. Opening and closing stocks of carbon are recorded, with the various changes between the beginning and end of the accounting period recorded as either additions to or reductions in the stock. A more detailed description of the carbon account is provided in appendix A13.2.

13.62 Carbon stocks are disaggregated into geocarbon (carbon stored in the geosphere), biocarbon (carbon stored in the biosphere, in living and dead biomass), carbon in the oceans (carbon dissolved in seawater (carbon in sediments is part of biocarbon or geocarbon)), carbon in the atmosphere and carbon accumulated in the economy.

13.63 The row entries in the account follow the basic form of the asset account in the SEEA Central Framework: opening stock, additions, reductions and closing stock. Additions to and reductions in stock can be attributed between managed and unmanaged expansion and contraction. The net carbon balance equals addition to stock less reductions in stock.

13.64 All values in the carbon stock account should be in equivalent carbon weights (e.g. ton carbon). Accordingly, methane (CH_4) and carbon dioxide (CO_2) emissions should be expressed in ton carbon, not in actual mass of CH_4 and CO_2. Similarly, for products such as recycled plastic or paper, the equivalent carbon content should be determined using the average composition of these materials to determine the carbon content. For emissions to the atmosphere, a bridge table may be compiled both in ton carbon and in CO_2 equivalents, as the latter are linked to the SEEA Central Framework air emission accounts.

13.65 The carbon stock account complements other SEEA accounts. Although broader in coverage through its inclusion of carbon stocks beyond ecosystems, carbon stock accounts are closely linked to SEEA EA accounts. Carbon accounts can provide information to support measures of the ecosystem services of carbon sequestration and carbon retention and are closely linked to accounts of the SEEA Central Framework (e.g. for physical assets of fossil fuels and minerals, carbon emissions to air, physical product flows to and from the rest of the world). SEEA AFF provides a detailed description of the links between these economic activities and emissions of carbon, with a particular focus on the effects of emissions related to land, land-use change and forestry.

13.66 The measurement of stocks and flows of carbon can support discussion of many policy-relevant issues. These issues include analysis of GHG emissions, sources of energy, deforestation and land-use change, loss of productivity and biomass, and sources and sinks of carbon emissions. For example, carbon stock accounts can complement the existing flow inventories developed under the United Nations Framework Convention on Climate Change, including the Paris Agreement adopted under the Convention. Since carbon is also a common focus of policy response (as reflected in, for example, carbon taxes), its direct measurement is of high relevance.

13.67 Further, carbon stock accounts can provide consistent and comparable information for policies aimed at, for example, protecting and restoring natural ecosystems, that is, maintaining carbon stocks in the biosphere. Combined with measures of carbon carrying capacity and land-use history, biosphere carbon stock accounts can be used to:

- Record the depletion of carbon stocks and the resulting CO_2 emissions due to conversion of natural ecosystems to other land uses

- Prioritize use of land for restoration of biological carbon stocks through reforestation, afforestation, revegetation ecosystem restoration and improved land management, taking into account differing trade-offs in respect of ecosystem services, biodiversity, food, fibre and wood production
- Identify land uses that result in carbon removal or retention

Table 13.3
Carbon stock account structure

	Geocarbon					Biocarbon			Carbon in the economy			Carbon in the oceans	Carbon in the atmosphere	Total
	Oil	Gas	Coal	Limestone and marl	Other	Terrestrial	Freshwaters and saline wetlands	Marine	Inventories	Fixed assets, consumer durables	Waste	Total	Total	
Opening stock														
Additions to stock														
Unmanaged expansion														
Managed expansion														
Discoveries														
Reclassifications														
Imports														
Reductions in stock														
Unmanaged contraction														
Managed contraction														
Reclassifications														
Exports														
Catastrophic losses														
Net carbon balance														
Closing stock														

13.4.4 Other climate change-related accounts and indicators

13.68 Besides ecosystem accounts and carbon stock accounts, both of which provide relevant information, there are two other types of accounts that should be highlighted. The SEEA Central Framework air emission account records the generation of air emissions by resident economic units by type of substance. These include the GHGs, CO_2, CH_4 and N_2O, and the fluorinated gases (F-gases). All emissions by establishments and households as a result of production, consumption and accumulation processes are included.

13.69 GHG emissions from economic activities, as recorded in SEEA, differ from the total emissions on a national territory or the emissions calculated according to the compilation guidelines of IPCC. This is because different concepts and calculation methods underlie the different emissions data. For instance, SEEA air emission accounts include emissions due to international transport based on the residence of the economic units involved. Bridge tables provide insight into the relationships between the different emission concepts.[146]

[146] See, for example, tables 5.2.1 and 5.2.2 in Lof and others (2017).

13.70 As included in the scope of the SEEA Central Framework, air emission accounts are emissions from cultivated livestock resulting from digestion (primarily of methane) and emissions from soil as a consequence of cultivation and other land-use practices that affect soils or other soil disturbances such as those caused by construction or land clearance. Emissions stemming from natural processes such as unintended forest and grassland fires, emissions from peatland and emissions from human metabolic processes are excluded. However, emissions from these sources are included in the carbon stock accounts.

13.71 In order to permit effective linking of physical flow data to monetary data, the physical flows of emissions are classified using the same activity and industry classifications used in the SNA. The emissions recorded for CO_2 and CH_4 in the SEEA Central Framework air emission account are directly linked to the removal (managed expansion) of carbon from the atmosphere and the emission (managed contraction) of carbon by the economy as recorded in the carbon stock account.

13.72 The SEEA Central Framework environmental activity accounts record transactions in monetary terms between economic units that may be considered environmental. Generally, these transactions concern activity undertaken to preserve and protect the environment. Transactions in environmental activity accounts are classified under the Classification of Environmental Activities (Central Framework, annex I, sect. A). Two classes are particularly relevant for climate change: Environmental protection (1: Protection of ambient air and climate), which includes activities aimed at the control of emissions of GHGs; and Resource management (10: Management of mineral and energy resources), which includes activities related to energy saving and renewable energy production. Using data on these classes from the accounts supports analysis of the mitigation costs for climate change and the economic benefits that result from the energy transition with regard to labour and the contribution to GDP.

13.73 In addition, there are a range of transactions, as related, for example, to taxes and subsidies, that reflect efforts by Governments, on behalf of society, to influence the behaviour of producers and consumers with respect to the environment. Payments and financial transactions related to carbon taxes and emission permits are recorded in the SNA.

13.74 There is a wide range of indicators concerning climate change that may be derived from the various SEEA accounts. Examples include indicators of energy and emission intensity, indicators concerning carbon taxes and emission permits and indicators of expenditure on climate change-related responses. *System of Environmental-Economic Accounting 2012 – Applications and Extensions* (United Nations, European Commission, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development and World Bank (2017)) provides a range of guidance in this area, in particular concerning the potential to undertake relevant structural decomposition analysis and footprinting. This provides estimates of the emissions embodied in goods and services that are imported (and exported) from production and consumption perspectives. There is also the potential for data from the accounts to support climate change modelling focused on implications of projected climate change scenarios on economic activity.

13.75 Various indicators can be derived directly from carbon stock accounts or in combination with other information, for example, on land cover, land use, population and industry value added. The suite of indicators can provide a rich information source for policymakers, researchers and the public. There are also links that can be established to support the measurement of Sustainable Development Goal 13: "Take urgent action to combat climate change and its impacts".

13.76 One of the indicators that can be derived from the carbon stock account is net ecosystem carbon balance, which can be used as a metric for measuring carbon sequestration. This indicator is related to the change in the stock of carbon in selected reservoirs over an accounting period. Commonly, the focus of net carbon balance measures is on biocarbon but depending on the analysis, the scope of the measure may also include parts of geocarbon, carbon in the economy and carbon in other reservoirs. Also, in some contexts and subject to appropriate assumptions, carbon carrying capacities may be estimated to support land-use decision-making where there are significant competing uses of land for food and fibre.[147]

[147] See, for example, Heather Keith and others (2010).

13.5 Accounting for the ocean

13.5.1 Introduction

13.77 The Earth's coastal and marine areas are an essential source of resources that support economic and other human activity while also being critical for the climate and health of global ecosystems. However, demand for ocean space and resources and associated anthropogenic pressures on ocean systems are rapidly increasing. In recent years, a growing number of countries have established ambitious policies and programmes designed to accelerate both ocean-based development and conservation. Decision makers are thus increasingly confronted with complex challenges and pressures with respect to balancing the social, environmental and economic interests of present and future generations. In this context, an integrated and standardized set of accounts that record ocean-related measures of economic activity, social context and ecosystem condition can support balanced decisions for near-term policy and long-term sustainability.

Table 13.4
Examples of potential core ocean statistics for biogeochemical cycling

Ecosystem type					
Coral reef (M1.3: photic coral reefs)	Mangrove (MFT1.2: intertidal forests and shrublands)	Kelp forests (M1.2)	Salt marshes and estuaries (FM1: semi-confined transitional waters)	Sediment (M1: marine shelfs; and M3: deep-sea floors)	Open ocean (M2: pelagic ocean waters)
Nitrate concentration	Soil nitrogen	Nitrate concentration	Sediment redox potential	Nitrate concentration	Thermocline
Total alkalinity	Turbidity	Ammonium concentration	Hypersalinity	Sulfate concentration	Pycnocline
Offshore: inshore dissolved inorganic carbon (DIC) ratio	Sediment accumulation: sea level rise ratio	Kelp growth rate	Inundation depth	Sediment redox potential	Vertical profile: oxygen
Aragonite saturation state	Particulate/dissolved organic C:N	DIC	C:N sediment ratios	Particulate/dissolved organic C:N	Vertical profile: nitrate
Dissolved oxygen	Dissolved oxygen	C13 stable isotopes	Submerged plant growth form	Dissolved oxygen	Vertical profile: pH
pH (total scale)	Soil and water pH	N15 stable isotopes		pH (total scale)	Vertical profile: DIC

Abbreviations: C, carbon; DIC, dissolved inorganic carbon; N, nitrogen.

13.78 At the global level, 2021 marked the beginning of the Decade of Ocean Science for Sustainable Development (2021–2030),[148] as proclaimed by the General Assembly in its resolution 72/73 of 5 December 2017. In that resolution, the Assembly called upon the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO) to prepare an implementation plan for the Decade. Further, UN-Oceans is in the process of updating the First Global Integrated Marine Assessment: World Ocean Assessment I;[149] Organisation for Economic Co-operation and Development (OECD) is continuing to support the assessment of the ocean economy;[150] and the High-level Panel for a Sustainable Ocean Economy[151] has developed an action agenda, including ocean accounts, for transitioning to a sustainable ocean economy. Moreover, IPCC has recently focused specifically on oceans, releasing an assessment of the ocean and cryosphere in a changing climate (IPCC, 2019).[152] All of these initiatives have in common the need to integrate fragmented data and the objective of advising national Governments on sustainable use of the ocean.

13.79 Conceptually, areas of the ocean encompassing coastal and marine areas are included in the SNA, the SEEA Central Framework and SEEA EA. However, different measurement boundaries are applied across these frameworks. Further, data on the ocean is more fragmented than data for terrestrial and freshwater ecosystems and the understanding of the ecological and economic connections among marine ecosystems, coastal ecosystems and other ecosystems is less advanced, although the relationship is expected to be highly non-linear. This requires a special focus to strengthen understanding of ocean-related areas, governance of human activities that exert an impact on them and coordination of ocean data within and outside national territories.

13.80 The present section introduces the design of a set of ocean accounts that follows the general principles of thematic accounting in linking data from different accounts. It is assumed in this section that the various contributing accounts – for example, extent and condition accounts for coastal and marine ecosystems (following the principles in chap. 5) and accounts on the flows of ecosystem services (following the principles in chaps. 6, 7 and 9) – can be compiled in their own right.

13.5.2 A set of ocean accounts

13.81 A comprehensive set of ocean accounts enables decision makers to monitor several critical trends: (a) changes in ocean ecosystem extent and condition and in associated flows of ecosystem services; (b) changes in ocean wealth, including produced assets (e.g. ports) and non-produced assets (e.g. mangroves, coral reefs); (c) ocean-related income and welfare for different groups of people (e.g. income from fisheries for local communities); (d) ocean-based economic production (e.g. GDP from sectors deemed to be ocean-related); (e) changes in how oceans are governed and managed (involving e.g. ocean zoning, regulatory rules and responsibilities, social circumstances).

13.82 These are important inputs into a range of ocean governance processes including marine spatial planning, integrated coastal zone management, development planning for ocean sectors, and collaborative resource management.

13.83 Building on SEEA EA ecosystem extent, ecosystem condition and ecosystem services flow accounts, the ocean accounts framework (figure 13.2) adds accounts for natural resources and physical flows that place pressure on ocean condition from the SEEA Central Framework and accounts concerning the ocean economy as well as governance, management and technology.

[148] See https://en.unesco.org/ocean-decade.

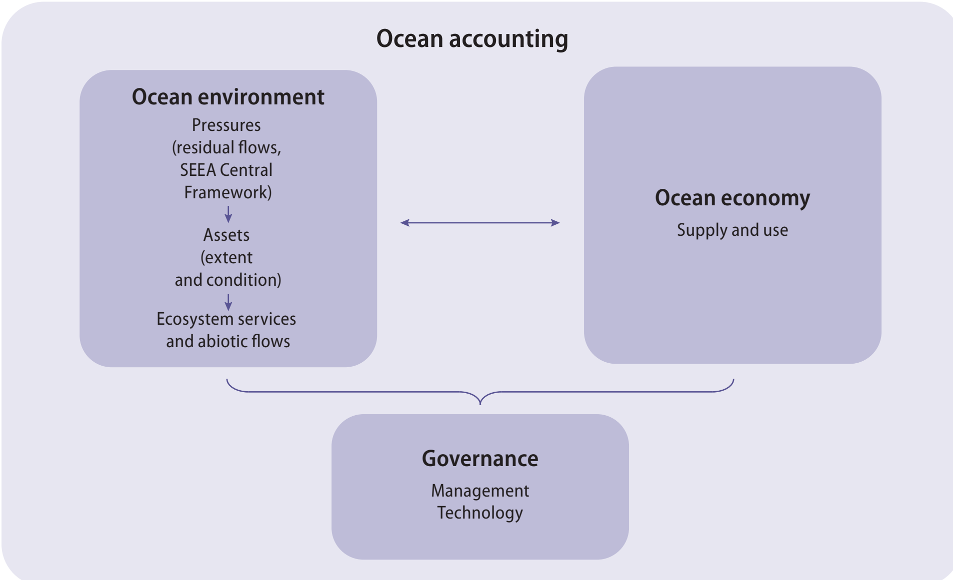
[149] See www.unenvironment.org/resources/report/first-global-integrated-marine-assessment-world-ocean-assessment-i.

[150] See www.oecd.org/ocean/topics/ocean-economy/.

[151] See www.oceanpanel.org/about-the-panel

[152] "Cryosphere" refers to areas of water that are frozen for at least part of the year. See www.ipcc.ch/srocc/.

Figure 13.2
Coverage of the ocean accounts framework



13.84 Ocean assets are recorded in a combination of accounts for individual environmental assets (minerals, energy and aquatic resources (e.g. fish stocks)) from the SEEA Central Framework and for ecosystem assets from SEEA EA. Spatially located individual environmental assets in the terrestrial realm are distinguished from those in the marine realm. In developing ocean accounts for these assets, a particular focus is needed on the treatment of migrating fish stocks and those assets beyond the EEZ whose management may not be captured in the accounts of the Central Framework or the SNA.

13.85 Coastal and marine ecosystems are treated in accordance with SEEA EA. Extent and condition accounts describe these ecosystems and for transitional ecosystems, such as estuaries and tidal flats, applying IUCN GET provides a link to terrestrial and freshwater ecosystem accounts. In developing ocean accounts for these various ecosystem assets, challenges may lie in appropriately reflecting the three dimensions of marine areas (i.e. depth in addition to area) and accurately capturing changes in condition. Commonly, it is beneficial to link measures of pressures on oceans (e.g. pollution) with direct measures of ecosystem condition. While data on pressures are important for understanding the connection to economic and human activity, direct monitoring of ocean condition is still required.

13.86 Ocean services include ecosystem services and abiotic flows (e.g. mineral extraction and energy capture). There are many ocean ecosystem services including provision of biomass (through wild fish and aquaculture), coastal protection and tidal surge mitigation, water purification, nursery population and habitat maintenance, recreation-related services and visual amenity services. These services supplied by coastal and marine ecosystems should be recorded in the ecosystem services flow accounts in physical and monetary terms.

13.87 The SEEA Central Framework provides guidance on measuring pressures on the ocean, particularly from air emissions, water emissions and solid wastes. For ocean accounts, these are spatially detailed by catchment area to estimate the quantities flowing to the ocean.

13.88 The ocean economy is measured in terms of the contribution of the main ocean-related activities (e.g. marine transportation, coastal tourism, marine fishing, offshore mineral and gas extraction) to the national economy. Following SNA guidance, the ocean economy can be accounted for using satellite accounting principles. At the core of ocean economy satellite accounts is measurement of the contribution to GDP and GVA of the sectors already considered in the SNA. More detail is added from estimates of the contributions of activities (e.g. shipping, boatbuilding) that are partially related to the ocean. Potentially, the economic value of ecosystem services not counted in these sectors (e.g. coastal protection services) could be added following the supply and use principles described in chapters 7, 9 and 11.

13.89 The objective of the ocean governance accounts is to provide spatially explicit location-based information so that decision makers and planners can make the most effective decisions with respect to ensuring the sustainable use of the ocean. Governance accounts include not only combined presentations of the elements mentioned above but also explicit consideration of institutional and legal frameworks such as zoning, rules and decision-making institutions, social circumstances of affected populations, and measures of ocean-related risks and resilience to them. One way in which these data may be combined is to overlay spatial data on different topics for a given marine or coastal area. This can show, for example, which ecosystem types are under which types of ocean management.

13.90 Much of the information required to compile ocean accounts is common to other communities of practice including those for marine spatial planning, disaster risk and climate change. One objective of the ocean accounting community of practice[153] is to ensure that these common data are standardized and shared.

13.91 Terrestrial and freshwater ecosystems are largely within national jurisdictions. However, the ocean is mostly an area beyond national jurisdiction (ABNJ). This introduces the opportunity to compile global ocean accounts, where much of the data are already collected by international agencies. A Global Ocean Data Inventory[154] compiled by the Economic and Social Commission for Asia and the Pacific is organized using the components of the ocean accounts framework. It shows that substantial data for compiling ecosystem extent and condition accounts are available on areas beyond national jurisdiction, but data on pressures, services and beneficiaries are underrepresented and hence additional data and monitoring are required. Adjacent coastal countries may also compile comparable ocean accounts to better understand transboundary impacts, including flows to and from areas beyond national jurisdiction.

13.92 The ocean accounts framework has proved effective in supporting several pilot studies, each of which has aimed towards answering policy-relevant questions. The pilot studies in Samoa, Thailand and Viet Nam, which were centred on sustainable tourism, linked tourism income, natural resources use, land-based pollution and ecosystem impacts. China's pilot focused on developing harmonized mangrove maps as well as improving the understanding of environmental assets of the mangrove ecosystems in Beihai Bay, one of China's important marine ecological sites. Malaysia examined food security risk (i.e. concerning fish) along the Straits of Malacca under expected future climate variability. All pilots depended on available data that were often limited.[155] One important function of the ocean accounts framework has been to guide the search for and integration of data.

13.5.3 Indicators derived from ocean accounts

13.93 Beyond sets of accounts, input to decision-making may be best facilitated through the derivation of indicators. While this general topic is discussed at length

153 See https://stat-confluence.escap.un.org/display/RPOES/Regional+Ocean+Accounts+Platform.

154 See https://stat-confluence.escap.un.org/display/RPOES/Regional+Ocean+Accounts+Platform.

155 Pilot study reports can be found at https://stat-confluence.escap.un.org/display/RPOES/Regional+Ocean+Accounts+Platform.

in chapter 14, a summary of relevant considerations from an ocean perspective is provided directly below.

13.94 In the context of ecosystems, the ocean may be viewed as a set of marine, coastal and transitional ecosystem types and any indictors derivable from SEEA EA can also be derived from the ocean accounts. Nonetheless, with their specific focus, ocean accounts can provide specific indicators for ocean conditions such as acidification and concentrations of marine debris, as well as indicators for ocean-related beneficiaries, (e.g. on income of small-scale fishers).

13.95 Linkage to the SEEA Central Framework allows for inclusion of indicators of subnational sources of pressures (such as solid waste supply and use by catchment area), separate accounts for individual environmental assets for the ocean (such as marine fish and offshore oil and gas) and accounts tracking environmental protection and other expenditures on the ocean.

13.96 The ocean economy satellite accounting component provides means of calculating the contribution of ocean-related sectors to national economies. Moreover, the focus on governance results in the addition of indicators on actors/institutions, norms and behavioural relationships. For example, through knowing the location of ocean assets, the extent to which they are used and the designated use of the area concerned, useful information for the management of that area can be obtained. A list of indicators derived from ocean accounts is presented in appendix A13.3.

13.97 Scientifically supported statistics of ocean ecosystem condition are of relevance in ecosystem accounting. Relevant characteristics are measured using different metrics in different ecosystems for such categories as biodiversity, ecosystem fitness, biogeochemical cycling, physiochemical quality and GHG retention (table 13.4). The Global Ocean Accounts Partnership has been working with several ocean-related communities of practice, including oceanographers and ocean ecologists, to produce a draft set of core ocean statistics. The Global Ocean Observing System (GOOS) is developing essential ocean variables (EOVs) for biology, including biodiversity, and from which a number of essential biodiversity variables could be derived for several groups of organisms and habitats (including those listed in table 13.4). Examples of such variables can be found in Moltmann and others (2019) and Muller-Karger and others (2018).

13.6 Accounting for urban areas

13.6.1 Introduction

13.98 Urban areas can be found in most terrestrial settings, whether highland or lowland, in forest, grassland, desert, tropical or tundra regions. They are defined chiefly by the presence of people and by their alteration of the underlying environment. They consist of a wide array of heterogeneous materials. Combinations of buildings (e.g. low-rise/high-rise buildings), impervious surface covers (e.g. roads, parking lots), vegetation (e.g. parks, sports fields), bare soil (e.g. empty lots, unattended garden plots) and water (e.g. wetlands, streams) are fundamental components of the urban ecosystem.

13.99 Accounting for ecosystem assets and services in urban areas is of increasing importance considering the large and growing proportion of the world population living in cities. Further, the high density of economic actors with varying perspectives on the use of the environment can create significant local challenges for decision makers. In this context, the regular and integrated information organized within the SEEA framework provides the basis for a transparent approach to informing the type of green urban development that delivers better outcomes for people and improves the ecological quality of urban environments.

13.100 Depending on the scale of underlying data sets and the aggregation level at which the accounts are compiled, urban ecosystem accounts can support various facets of international, national, subnational and municipal-level policy on urban areas such as strategic planning and policy-setting; communication and awareness-raising; economic accounting; and urban planning including peri-urban and coastal development. The application of accounting could extend further to include consideration of management of water resources, water treatment, regulating and maintenance services (e.g. local climate regulation, air filtration, flood mitigation), renewable energy sources and management of recreational opportunities.

13.101 Different motivations exist for accounting at different scales. For example, accounts covering all urban areas across a country focus on drawing out common features and ecosystem service flows, while accounts for a single urban area may focus on specific local issues and perhaps also encompass complementary valuations. A general benefit of applying accounting principles, particularly at local scale, results from the intent to integrate data on a consistent basis over time. This can help to bring together the data that are commonly available in various one-off reports to better support decision-making.

13.102 Urban ecosystem accounts with sufficient spatial detail (potentially extending down to property-level resolutions) can provide data to support trade-off analysis or benefit-cost analysis for spatial planning and design of policy instruments such as ecosystem services user charges. If ecosystem asset and condition mapping have sufficient resolution (e.g. to capture individual tree canopy size and height), ecosystem accounts can also provide support for compliance monitoring and litigation of environmental damages (e.g. resulting from illegal tree felling).

13.103 The present section introduces the subject of development of urban accounts building on the general framing of ecosystem accounts and taking into consideration some specific factors of relevance to the measurement of urban areas.

13.6.2 A set of urban ecosystem accounts

13.104 Urban ecosystem accounts could encompass measures of extent and include data on associated condition variables and indicators (e.g. urban tree canopy cover, urban air quality) and related ecosystem services (e.g. local climate regulation, water regulation, recreation-related services).

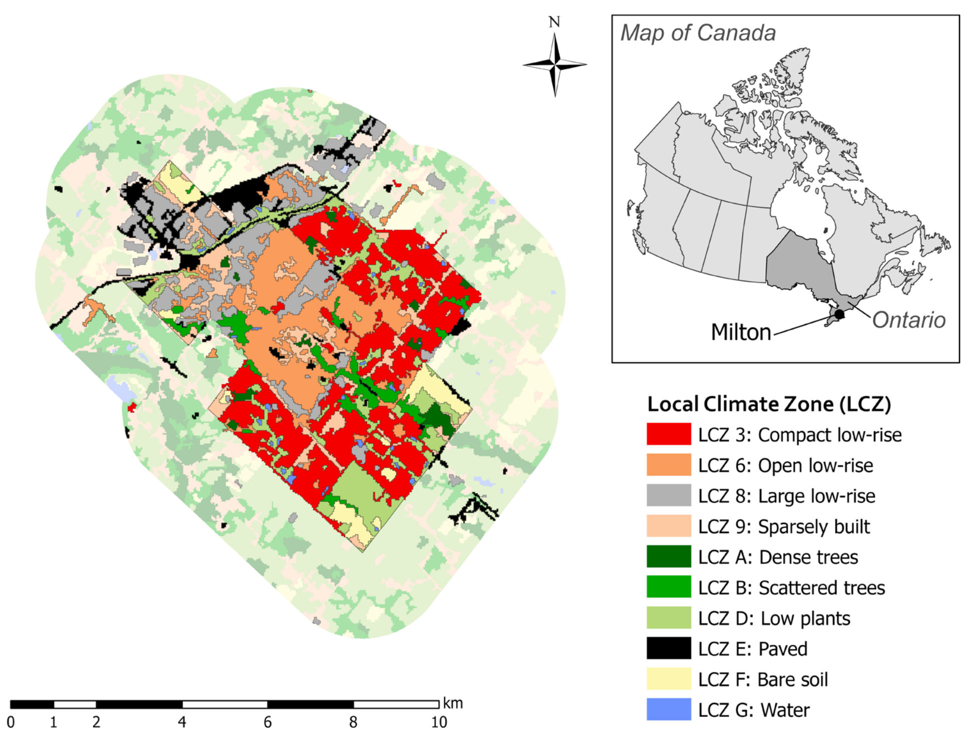
13.105 While urban ecosystems constitute an ecosystem type included in the SEEA EA ecosystem type classification, the compilation of urban ecosystem accounts provides the opportunity for a more detailed accounting for urban area subtypes, including, for example, highlighting of urban green and blue spaces, within the broader framing provided by IUCN GET, which defines a broad EFG covering urban and industrial ecosystems (class T7.4). Further, different boundaries and spatial resolutions of basic statistical and reporting units could also be considered with a view to addressing different concerns.

13.106 There are several approaches for defining the EAA for urban ecosystem accounts. Accounts can be compiled for cities based on administrative boundaries (i.e. a local government boundary), functional boundaries (e.g. based on commuting flows as defined by census data) or morphological criteria, such as the extent of the built-up area plus a buffer zone. Selection of criteria would depend on the anticipated purpose and the anticipated users of the urban accounts being compiled.

13.107 Urban areas often follow a gradient from less developed or even rural peripheral areas into a more developed urban core. Even areas with a higher degree of built-up area may contain significant areas of urban green cover, such as yards, parks, cemeteries, areas of street trees and green roofs. The two main approaches for the classification of urban areas according to subtypes are (a) the landscape approach; and (b) the individual asset approach.

13.108 **Landscape approach.** Under this approach, the entire urban area is disaggregated and larger patches with common characteristics are classified in different urban subtype categories. For example, a classification of urban subtypes could break down the variety of built-up and semi-natural types within the city into contiguous areas with common shared characteristics (e.g. compact high-rise, compact low-rise, open low-rise, sparsely built, paved, as illustrated in figures 13.3 and 13.4). Following the landscape approach, information on condition characteristics (e.g. percentage of impervious/pervious surfaces, soil contaminant concentrations) could be included in the condition accounts as measures of landscape-level characteristics in these subclasses. A landscape approach tends to support municipal planning and zoning integration across sector concerns.

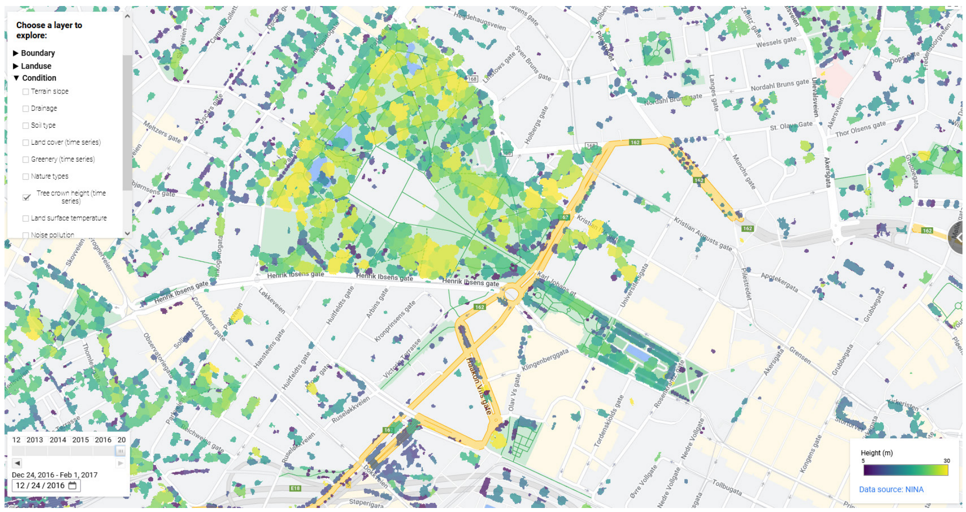
Figure 13.3
Applying the landscape approach for classifying urban ecosystems using the local climate zone classification of Stewart and Oke (2009)



Source: Grenier and others (2020).

13.109 **Individual asset approach.** This approach tracks various individual asset types at as fine a scale as possible (e.g. lines of street trees, playgrounds, allotment gardens, green roofs, drainage and storage systems) based on available very high resolution (10 metres or less) satellite imagery or other spatial data sets. In this case, ecosystem assets in urban accounts can be defined as areas of green and blue infrastructure that provide ecosystem services. This approach also permits reporting on the condition of these green and blue assets in the associated condition accounts. An asset approach tends to support thematic and sector policies specific to municipal sector agencies, such as urban forestry, urban agriculture, stormwater management.

Figure 13.4
High-resolution thematic focus mapping of urban tree canopy asset extent and height (condition)



Source: Urban Nature Atlas Oslo (Norwegian Institute for Nature Research (NINA) (2021)).

13.110 The classification approach and level of aggregation determine the distinction between extent accounts and condition accounts. Condition indicators that are predictors of urban ecosystem services should be selected. This does not prevent users from compiling thematic environmental quality and biodiversity indicators for other purposes. Extent table and condition table options following the landscape approach are presented in tables 13.5 and 13.6, while table 13.7 provides an example of the individual asset approach.

13.111 In some contexts, it may be appropriate to distinguish the urban airshed as a separate asset.[156] This may support a distinct recording of air quality data as an overall condition indicator. Generally, however, it is most appropriate to allocate measures of air quality to locations and areas within the wider urban area and therefore a separate asset would not be required. Allocation to ecosystem assets within the urban area can also support measurement and modelling of flows of ecosystem services (e.g. recreation-related and amenity-related services).

13.112 Urban ecosystem services supply and use accounts may focus on a different basket of ecosystem services, given the differing functions and conditions of urban ecosystems as the physical place where people live and work. Some key ecosystem services that would likely be considered include water regulation, local climate regulation, air filtration and noise attenuation, as well as recreation-related services and visual amenity services (table 13.8).

[156] An airshed is a geographical area within which the air is frequently confined or channelled, with all parts of that area thus being subject to similar conditions of air quality.

13.113 There are a range of issues and limitations that should be considered in the measurement of urban ecosystem services that differ from issues associated with ecosystem services involving other ecosystem types. For example, accurate detection of change at the small spatial scales inherent in urban areas are particularly important given that the scale for areas of change can be finer than the level of precision of the land cover classification used as input to ecosystem services models. Possibilities of substitution between ecosystem and man-made services are more apparent in urban areas. Moreover, spatial patterns in urban ecosystem services supply are driven by biophysical variation in ecosystem conditions, while spatial variation in demand (e.g. due to changes in the location and movement of the population) may not be detectable at the same resolution. Heterogeneous use factors – related to population density and socioeconomic and cultural diversity in cities, as well as substitution possibilities, qualitative values and non-linear distance decay of benefits – can result in variations in respect of beneficiaries and valuation results, particularly for recreational and amenity services.

13.114 For applications at municipal levels, urban ecosystem accounts need to align closely with the manner in which the municipal environmental administration is organized in order to address both integrated and sector-specific municipal policy and planning needs. For this reason, a combined landscape and asset approach is often required.

13.115 In some situations, for example, cost-benefit analysis of zoning and user charges, monetary valuation of ecosystem services supply and use by landscape types and calculation of asset values are undertaken. Monetary accounts compiled using exchange values may also provide support for municipal budget allocation to asset investment and maintenance, for example in relation to green and blue infrastructure and nature-based solutions. In addition, it may be necessary to consider the application of complementary values in providing a wider assessment of social benefits arising from different policies.

13.116 Where monetary valuation is undertaken for municipal-level applications, higher temporal and spatial resolutions and improved change detection, compared with the requirements for national-level accounts, are required. This may be addressed using different methods, for example, by pooling data across a large number of decision-making units. In this context, monetary urban ecosystem accounts therefore often need to be thematic and policy purpose-specific (Gómez-Baggethun and Barton, 2013).

Table 13.5
Example: extent account presentation using the landscape approach

	Example of ecosystem types in urban areas													
	Urban/built-up types and example sub-classes						Natural and semi-natural types							
	Compact high-rise	Open high-rise	Compact low-rise	Open low-rise	Sparsely built	Paved	Cropland	Grassland	Shrubland	Forest	Barren	Wetland	Inland water	Total EEA
Opening extent (km^2)														
Additions to extent														
Reductions in extent														
Net change in extent														
Closing extent (km^2)														

Table 13.6
Example: condition account presentation using the landscape approach

Example condition variables		Example of ecosystem types in urban areas																									
		Compact high-rise		Open high-rise		Compact low-rise		Open low-rise		Sparsely built		Paved		Cropland		Grassland		Shrubland		Forest		Barren		Wetland		Inland water	
Variables	Measurement unit	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock	Opening stock	Closing stock
Water quality	g/l																										
Air pollutant concentrations	ppm																										
Soil contaminant concentrations	g/kg																										
Soil sealing/ imperviousness	%																										
Greenness	%																										
Canopy cover	m^2																										
Street trees	km																										

Abbreviations: g/l, grams per litre; ppm, parts per million; g/kg, grams per kilogram; m^2, square metres; km, kilometres.

Table 13.7
Example: extent account presentation using the individual asset approach

	Example of ecosystem types and assets in urban areas																	
	Example of urban ecosystem assets								Natural and semi-natural types									
	Allotment garden	Street trees	Sports field	Playground	Cemetery or religious grounds	Public park or garden	Green roof	Private green space (e.g. yards)	Beach	Cropland	Grassland	Shrubland	Forest	Barren	Wetland	Inland water	Total	Total EEA
Opening extent (km^2)																		
Additions to extent																		
Reductions in extent																		
Net change in extent																		
Closing extent (km^2)																		

Table 13.8
Example service account presentation using the landscape approach

Examples of services	Measurement unit	Urban/built-up types and example sub-classes: Compact high-rise	Open high-rise	Compact low-rise	Open low-rise	Sparsely built	Paved	Natural and semi-natural types: Cropland	Grassland	Shrubland	Forest	Barren	Wetland	Inland water	Total EEA
Provisioning services															
Crops															
Regulating services															
Water regulation															
Climate regulation															
Air filtration															
Noise regulation															
Cultural services															
Recreation															
Amenity services															

13.6.3 Potential indicators for urban ecosystems

13.117 Certain indicators can provide useful summary-level information on the state and condition of urban areas. For example, change in extent of areas converted from natural or semi-natural ecosystem types to residential areas with associated infrastructures, tracked over time, provides a snapshot of urban expansion and loss of natural and semi-natural areas. Other related indicators could focus on the concept of land degradation (e.g. percentage of contaminated or brownfield areas and reclaimed areas). Indicators drawn from these accounts can also track the role that urban green and blue spaces play in providing ecosystem services, including by moderating air and water pollution and mitigating heat islands, and can support the measurement of accessibility to green and blue spaces.

13.118 Urban ecosystem accounts therefore provide information that is relevant at many levels, including for reporting internationally, nationally and at subnational levels. For example, the change in extent and condition of lands converted to residential areas with associated infrastructure is relevant for Sustainable Development Goal indicator 15.3.1: Proportion of land that is degraded over total land area. Further, ecosystem accounting for urban areas is particularly relevant for Sustainable Development Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable, including for the following indicators:[157]

[157] See United Nations Human Settlements Programme (UN-Habitat) (n.d.); and United Nations, Department of Economic and Social Affairs, Statistics Division, and United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) (2019).

- Indicator 11.3.1: Ratio of land consumption rate to population growth rate
- Indicator 11.4.1: Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional and local/municipal)
- Indicator 11.6.2: Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population-weighted)
- Indicator 11.7.1: Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities

13.119 The use of ecosystem accounts extends beyond the broad indicator framework for the Sustainable Development Goals and targets to encompass support for municipal planning and policy analysis, for example, as related to the equitable distribution of municipal (ecosystem) services. This requires disaggregation of statistics to different administrative areas such as districts, councils, boroughs and census tracts.

Appendix A13.1
SEEA Central Framework accounts for individual stocks and flows

Introduction

A13.1 The SEEA Central Framework describes a range of different accounts for recording individual stocks and flows. There are two main types of account structures that are used: physical flow accounts (in the form of SUTs) and asset accounts, both of which may be compiled in physical and monetary terms. The present appendix provides a brief summary of these accounts and describes how they can be adapted to support compilation of ecosystem accounts and thematic accounts.

Physical flow accounts

A13.2 The general principles underpinning physical flow accounts are described in chapter III of the SEEA Central Framework. Account structures for five physical flows are provided: water, energy, air emissions, emissions to water and solid waste. Depending on the type of substance, these accounts describe flows from the environment to the economy, within the economy and from the economy to the environment. They are primarily designed to record the connections between each type of substance and various economic units and hence are well aligned with objectives such as footprinting, where the use of specific substances can be traced through economic activities and products.

A13.3 In concept, the principles of physical flow accounting can be used to record flows for all elements, substances and materials. Examples include flows of nitrogen, phosphorus, heavy metals and carbon at an elemental level, and economy-wide material flows (all measured in mass) at a macro scale. The main requirement in applying accounting principles is that the same measurement unit (e.g. tons, cubic metres) be applied within a single account.

A13.4 For SEEA Central Framework purposes, the description focuses on measuring flows for each substance at a national level and thus on integrating with national-level measures of economic activity. Macro indicators concerning issues such as water use in agriculture, energy use in manufacturing and air emissions from the transport industry are therefore readily derivable.

A13.5 For their use in ecosystem and thematic accounting, there is a need for the scope of the accounts described in the SEEA Central Framework to align with requirements related to geographical area, spatial detail and economic units. For example, if there is interest in ocean accounting for understanding emissions to marine areas, an adjusted flow account would follow the same general framing as that of the physical flow account for emissions to water but would also be required to provide additional detail concerning the location of those emissions, i.e. a breakdown of the Central Framework entry for flows to the environment by location, for example, by catchment (see Central Framework, table 3.8). Additional detail might be incorporated on the industries generating the release of emissions to water and on the types of those emissions.

Asset accounts

A13.6 Asset accounts are described in chapter V of the SEEA Central Framework. They are presented for land use and land cover and for a range of natural resources including mineral and energy resources, soil resources, timber resources, fish and other aquatic resources and water resources. The general logic is to record, in physical or monetary terms, the opening and closing stocks of the relevant individual resource and then the various additions and reductions in stock, including from regeneration and depletion. Under the relevant accounting identity, the opening stock plus additions less reductions must be equal to the closing stock.

A13.7 For thematic accounting, the principles of asset accounting were applied in the preceding description of species accounts and carbon accounts. The same principles can be applied to any individual stock to support both thematic and core ecosystem accounting. For example, an asset account for key fish species by location might be used to support compilation of ecosystem services flow accounts.

A13.8 As for the physical flow accounts, once a single type of stock has been selected, the key requirement in applying asset accounting principles is to establish the geographical area to which the account is related. Whether the area is small or large, it needs to be clearly defined so that the focus of measurement is clear and linkages can be made to other data. It may be relevant to cross-classify data on the opening and closing stocks by types of area within the wider accounting area. Stocks of carbon, for example, might be cross-classified by ecosystem type.

A13.9 Along with carbon and species accounts, the asset account for water resources, which is described in section 5.11 of the SEEA Central Framework, is the most relevant for ecosystem accounting purposes. This account records the opening and closing stocks of water for various types of inland water bodies including lakes, rivers and streams and groundwater and goes on to record additions to the stock of water through precipitation, inflows and transfers between other water bodies and returns from the economy and reductions in stock due to abstraction by economic units, evaporation and outflows (e.g. to the sea) and transfers to other water bodies.

A13.10 The stocks and flows recorded in the water resources asset account comprehensively document the hydrological cycle as it pertains to inland water resources. Flows related to wastewater are also captured. Since stocks and flows of water are items of importance for understanding ecosystem condition and ecosystem services, compilation of water resources asset accounts is likely to be of significant relevance in supporting the compilation of ecosystem accounts.

A13.11 Compilation of data at a relatively high level of spatial detail for ecosystem accounting presents a measurement challenge that needs to be overcome. This is possible through standard hydrological modelling, which is commonly used to underpin the measurement of a range of ecosystem services, including water regulation, flood mitigation and soil erosion control. The task is therefore to adapt the framing provided in the SEEA Central Framework to accommodate a higher level of spatial detail, including, in particular, the incorporation of more detail on transfers of water between different parts of a catchment or water body. Ecosystem account compilers are encouraged to work with hydrological modellers on compiling detailed water resources asset accounts, in part because the accounts can be a useful tool in ensuring coherence in water modelling between opening and closing stock positions.

Appendix A13.2
Additional detail concerning accounting for carbon

A13.12 The rationale for carbon stock accounting in the context of ecosystem accounting was discussed in section 13.4. The present appendix provides some additional details on the structure and accounting entries related to the carbon stock account as presented in table 13.3. The carbon stock account presented in that table provides a complete and ecologically grounded articulation of carbon accounting based on the carbon cycle and, in particular, the differences in the nature of specific carbon reservoirs. Opening and closing stocks of carbon are recorded, together with the various changes – additions to or reductions in stock – occurring between the beginning and the end of the accounting period.[158]

A13.13 Carbon stocks are disaggregated into geocarbon, biocarbon, carbon accumulated in the economy, carbon in the oceans (inorganic only) and carbon in the atmosphere.

A13.14 All of the carbon stored in the Earth's lithosphere, excluding all organic carbon stored in dead biomass, is considered geocarbon (or geological carbon, i.e. carbon that is present in the Earth's bedrock and sediments, derived primarily from marine sediment deposits).[159] Carbon originally formed in the Earth's biosphere millions of years ago – which, after geological metamorphosis resulting from high pressure and temperatures in the Earth's crust, was transformed into, for example, oil and gas (organic geocarbon) – is also considered geocarbon. Organic carbon in soils and in peat deposits is included in the category of biocarbon.[160] Where the information generated from the accounts is policy-focused, the priority should be given to reporting those stocks that are being impacted by human activity (e.g. involving fossil fuels).

A13.15 Biocarbon includes all of the organic carbon in the biosphere, i.e. carbon in living biomass (plants and animals) and dead biomass (soil organic matter and sedimentary organic matter).[161] Further, biocarbon includes the biomass in crops and in grass in meadows, which is consequently not considered to be part of carbon accumulated in the economy. Carbon stored in livestock, however, is considered to be part of carbon in the economy, as is carbon stored in timber products, including timber used for construction.

A13.16 Biocarbon is classified by type of ecosystem according to the three main realms at the highest level of IUCN GET (marine, freshwater and saline wetlands, terrestrial). These high-level classes can be further broken down applying the EFG level 3 of GET. It is recommended that carbon in agricultural and other anthropogenic systems be separately recorded to enable the distinction to be made between natural and semi-natural ecosystems and anthropogenic ecosystems with regard to carbon removal and emissions.

A13.17 The stability of the carbon stocks in the biosphere depends significantly on ecosystem characteristics. In natural ecosystems, biodiversity underpins the stability of carbon stocks by bestowing resilience and the capacity to adapt and self-regenerate

[158] For examples of carbon stock accounts, see, for example, Heather Keith and others (2021) and Lof and others (2017).

[159] Geocarbon is further disaggregated into oil, gas, coal resources, rocks (primarily limestone and marls) and minerals, e.g. carbonate rocks used in cement production, methane clathrates and inorganic carbon in marine sediments.

[160] Soil is the layer of fine material covering the Earth's land surface impacted by and impacting plants and soil organisms.

[161] With respect to biocarbon in soils, for practical reasons, only the top 30 centimetres are considered in this study. This results in a significant underestimation, in particular for peat and peaty soils, of the total stock of biocarbon in soils. This limitation in the current models may also affect measurement of carbon flows in cases where there are changes in the water table below this depth.

(Thompson and others, 2009). Stability confers longevity and by extension the capacity for natural ecosystems to accumulate large amounts of carbon over periods ranging from centuries to millenniums in, for example, the woody stems of old trees and soil. As semi-modified and highly modified ecosystems are generally less resilient and less stable (ibid.), those ecosystems accumulate smaller carbon stocks, particularly if the land is used for agricultural activity where the plants are harvested or grazed regularly.

A13.18 The atmosphere contains carbon, in the form mainly of CO_2, and methane. The atmosphere is a receiving environment for carbon from the primary reservoirs of geocarbon and biocarbon, as well as for carbon emissions from the economy, while carbon removal from the atmosphere may occur through carbon sequestration in biocarbon. As CO_2 and methane act as GHGs in the atmosphere, accounting for these flows is highly policy-relevant.

A13.19 The oceans are receiving environments for carbon released from primary reservoirs and carbon released from its accumulations in the economy. Carbon in oceans includes only inorganic carbon, i.e. carbonates dissolved in seawater. Living and non-living organic carbon in oceans is part of biocarbon. Carbonate particulates (e.g. shells) in sediments are part of geocarbon.

A13.20 Accumulations in the economy, which are the stocks of carbon in anthropogenic products, are further disaggregated into the following SNA components: fixed assets (e.g. concrete in buildings, bitumen in roads, livestock); inventories (e.g. petroleum products in storage, excluding those included in cultivated ecosystems); consumer durables (e.g. wood and plastic products); and waste. These main asset categories can in turn be further disaggregated into biobased (i.e. derived from plants or animals) and non-biobased (i.e. fossil fuels, mineral (inorganic) products and synthetic materials (plastics)). Accounting for waste follows the conventions of the SEEA Central Framework, where waste products (e.g. disposed plastic and wood and paper products) stored in controlled landfill sites are treated as part of the economy.

A13.21 The flows of carbon that occur within the economy are highly significant and essential for understanding the interaction between the economy and the environment. The level at which geocarbon and biocarbon stock changes can be linked to the economy determines the policy usefulness of the carbon stock account. This is particularly relevant in cases where raw materials can be extracted from different ecosystem types (e.g. biomass fuel from natural or cultivated ecosystems) or from geocarbon reservoirs with different carbon contents and emissions profiles.

A13.22 Carbon stored through geo-sequestration (i.e. the managed injecting of gaseous CO_2 into the surface of the Earth) is treated similarly, i.e., as a flow within the economy (resulting in an increase in accumulations). Any subsequent release of carbon to the environment is treated as a residual flow with a reduction in accumulations in the economy matched by a corresponding increase in carbon in the atmosphere.

A13.23 The presentation of the row entries in the account follows the basic form of the asset account in the SEEA Central Framework, the entries being opening stock, additions, reductions and closing stock. Additions to and reductions in stock are split between managed and unmanaged expansion and contraction. Additional rows for imports and exports have been included, thus making the table a stock account, as distinct from an asset account.

A13.24 There are five types of additions in the carbon stock account:

- Unmanaged expansion, which reflects increases in the stock of carbon over an accounting period due to natural growth or the indirect effects of human activities. Effectively, this is recorded only for biocarbon and may arise from climatic variation, ecological factors such as reduction in grazing pressure, and indirect human impacts such as the CO_2 fertilization effect (where higher atmospheric CO_2 concentrations cause faster plant growth).

- Managed expansion, which reflects increases in the stock of carbon over an accounting period due to direct human activities. This is recorded for biocarbon in ecosystems and accumulations in the economy and in inventories, consumer durables, fixed assets and waste stored in controlled landfill sites. Also included are GHGs injected into the Earth. Basically, these reflect all increases in carbon stock due to carbon input flows from other reservoirs that are directly related to human activities. All emissions related to land use, LULUCF are included here (or in managed contractions, depending on the carbon stock).
- Discoveries of new stock, encompassing the emergence of new resources added to a stock, which commonly arise through exploration and evaluation. This applies exclusively to geocarbon.
- Reclassifications of carbon stocks, which generally occur in situations where an ecosystem asset is used for a purpose that is different from a previous one. For example, increases in carbon in semi-natural ecosystems following the establishment of a national park on an area previously used for agriculture would be offset by an equivalent decrease in cultivated ecosystems. In this case, it is only the particular land use that has changed, that is, reclassifications may have no impact on the total physical quantity of carbon during the period in which they occur.
- Imports recorded to enable accounting for imports of produced goods (e.g. petroleum products) that contain carbon.

A13.25 There are five types of reductions recorded in the carbon stock account:

- Unmanaged contractions, which reflect natural losses of stock during the course of an accounting period. They may be due to changing distribution of ecosystems (e.g. a contraction of natural ecosystems) or biocarbon losses that might reasonably be expected to occur based on past experience. Unmanaged contraction includes losses from episodic events including drought, some types of fires and floods, and pest attacks and disease outbreaks, as well as losses due to volcanic eruptions, tidal waves and hurricanes.
- Managed contractions, which are reductions in stock due to direct human activities and include the removal or harvest of carbon through a process of production. This includes mining of fossil fuels and felling of timber. Extraction from ecosystems includes (a) those quantities that continue to flow through the economy as products (including waste products) and (b) those quantities of stock that are immediately returned to the environment after extraction because they are unwanted, for example, felling residues. Managed contraction also includes losses as a result of war, riots or other political events and technological accidents such as major toxic releases. All emissions related to LULUCF are included here (or in managed expansions, depending on the carbon stock).
- Reclassifications of carbon stocks, which generally occur in situations where an ecosystem asset is used for a different purpose. For example, decreases in carbon in cultivated ecosystems following the establishment of a national park on an area used for agriculture would be offset by an

equivalent increase in semi-natural ecosystems. In this case, it is only the particular land use that has changed, that is, reclassifications have no impact on the total physical quantity of carbon during the period in which they occur.

- Exports recorded to enable accounting for exports of produced goods (e.g. petroleum products) that contain carbon.
- Catastrophic losses, which are not shown as a single entry but are allocated between managed contraction and unmanaged contraction. Catastrophic losses in managed contraction would include fires deliberately lit to reduce the risk of uncontrolled fires. For the purposes of accounting, reductions due to human accidents, such as rupture of oil wells, would also be included under managed contraction. However, catastrophic losses could be separately identified.

Appendix A13.3
Variables and indicators from ocean accounts

	Ocean-related biomes[h]										
	SM1 Subterranean tidal biome	FM1 Transitional waters biome (Freshwater-Marine)	M1 Marine shelfs biome	M2 Pelagic ocean waters biome	M3 Deep-sea floors biome	M4 Anthropogenic marine systems biome	MT1 Shorelines biome	MT2 Supralittoral coastal systems biome	MT3 Anthropogenic shorelines biome	MFT1 Brackish tidal biome	Total
Physical ocean assets											
Ecosystem assets											
Area (ha)											
Change in area from previous accounting period (%)											
Individual environmental assets											
Minerals (tons)											
Energy (PJ)											
Fish (tons)											
Timber (e.g. mangrove) (m^3)											
Other flora available for harvesting (e.g. seaweed) (tons dry weight)											
Monetary ocean assets (NPV of expected flow of services) (currency units)											
Ecosystem assets											
Value (currency units)											
Change in value from previous accounting period (%)											
Individual environmental assets											
Minerals											
Energy											
Fish											
Timber (e.g. mangrove)											
Other flora available for harvesting (e.g. seaweed)											
Condition of ocean assets[a]											
For marine and coastal ecosystems											
Acidification (pH)											
Eutrophication (BOD, COD, chlorophyll a concentrations)											
Temperature (°C)											

(*Continued*)

	Ocean-related biomes[h]										
	SM1 Subterranean tidal biome	FM1 Transitional waters biome (Freshwater-Marine)	M1 Marine shelfs biome	M2 Pelagic ocean waters biome	M3 Deep-sea floors biome	M4 Anthropogenic marine systems biome	MT1 Shorelines biome	MT2 Supralittoral coastal systems biome	MT3 Anthropogenic shorelines biome	MFT1 Brackish tidal biome	Total
Plastics density (g/m^3)											
Biodiversity (Shannon index)											
Health (index)											
For individual environmental assets											
Minerals (quality, accessibility)											
Energy (quality, accessibility)											
Fish (quality in terms of size, age, health)											
Timber (e.g. mangrove) (quality, accessibility)											
Other flora available for harvesting (e.g. seaweed) (quality, health)											
Physical ocean services											
Ocean ecosystem services											
As in SEEA EA ecosystem services list (specific units)											
Other ocean services (examples)											
Seawater for cooling (m^3)											
Sand (tons)											
Petroleum (megalitres, PJ)											
Monetary ocean services											
Ocean ecosystem services											
As in SEEA EA ecosystem services list (appropriate valuation techniques)											
Other ocean services (examples)											
Seawater for cooling (market or equivalent value)											
Sand (market or equivalent value)											
Petroleum (market or equivalent value)											
Pressures (flows to the environment)[b]											
Water emissions flows to the ocean											
BOD/COD (tons)											
Suspended solids (tons)											
Bilge (m^3)											
Heavy metals (tons)											
Solid waste flows to the ocean											
Chemical and health-care waste (tons)											

(*Continued*)

	Ocean-related biomes[h]										
	SM1 Subterranean tidal biome	FM1 Transitional waters biome (Freshwater-Marine)	M1 Marine shelfs biome	M2 Pelagic ocean waters biome	M3 Deep-sea floors biome	M4 Anthropogenic marine systems biome	MT1 Shorelines biome	MT2 Supralittoral coastal systems biome	MT3 Anthropogenic shorelines biome	MFT1 Brackish tidal biome	Total
Metallic waste (tons)											
Mineral waste and soil (tons)											
Mixed residential and commercial waste (tons)											
Plastics (tons)											
Radioactive waste (tons)											
Other waste (tons)											
Wastewater flows to the ocean (m^3)											
Air emissions flows to the ocean (examples)[c]											
CO_2 (tons)											
Methane (tons)											
Ocean economy											
Contribution of ocean sectors to national economy (GVA, % GDP)[d]											
By sector (fishing/aquaculture, offshore oil and gas, boat- and shipbuilding, etc.)											
Contribution of ocean sectors to national employment (FTE, %)											
By sector (fishing/aquaculture, offshore oil and gas, boat- and shipbuilding, etc.)											
Ocean governance											
Zoning											
Jurisdictional zone: internal waters, territorial sea, EEZ (area)											
Management or planning zone: protected area, private property, use designation (area)[e]											
Rules- and decision-making institutions											
By activity: fishing, wind farm development, marine spatial planning (institution)											
Social circumstances of resident populations (examples)[f]											
Health (index), economic equity (GINI), poverty (% below low income)											
Risk and resilience (examples)											
Flood/storm surge, sea level rise, coastal storm risk (vulnerability, occurrence)											
Resilience: disaster plan in place, adequate supplies and facilities (yes/no)											
Environmental protection expenditures ($)											

(*Continued*)

	Ocean-related biomes[h]										
	SM1 Subterranean tidal biome	FM1 Transitional waters biome (Freshwater-Marine)	M1 Marine shelfs biome	M2 Pelagic ocean waters biome	M3 Deep-sea floors biome	M4 Anthropogenic marine systems biome	MT1 Shorelines biome	MT2 Supralittoral coastal systems biome	MT3 Anthropogenic shorelines biome	MFT1 Brackish tidal biome	Total
Value of environmental goods and services sector ($) (see "Ocean economy" above)[g]											
Environmental taxes less subsidies ($)											

Abbreviations: BOD, biological oxygen demand; COD, chemical oxygen demand; EEZ, exclusive economic zone; FTE, full-time equivalent; g, gram; GDP, gross domestic product; GVA, gross value added; ha, hectare; m3, cubic metre; NPV, net present value; PJ, petajoule.

[a] Specific condition indicators for each ecosystem type are provided in *Technical Guidance on Ocean Accounting for Sustainable Development*, a background document prepared by the Economic and Social Commission for Asia and the Pacific for the fifty-first session of the Statistical Commission, held from 3 to 6 March 2020. Available at https://unstats.un.org/unsd/statcom/51st-session/documents/BG-item-3h-TG_Ocean%20accounting_ESCAP-E.pdf.

[b] Flows should include (a) those generated by terrestrial catchment areas, (b) those from marine sources, (c) inflows from other territories and (d) outflows to other territories (including international waters).

[c] Air emissions should be estimates of quantities deposited in the ocean, distinguishing between national and international territory.

[d] The ocean accounts framework provides a comprehensive list of ocean-related sectors. The location of economic activities could be classified by ecosystem type.

[e] Other examples of use designation include aquaculture, energy development, submarine cable corridor, locally managed marine area.

[f] Resident population includes those dependent on the ocean economy and those living near the ocean.

[g] The environmental goods and services sector may be embedded in the ocean economy as ocean-dependent sectors.

[h] Indicators may be presented for larger groupings or in more detail by ocean-related EFGs. It is to be noted that there may be vertical overlap of some of the biomes (e.g. subterranean tidal biomes with shoreline systems biomes). In this case, ideally, indicators would be presented separately for the intersection of those biomes (e.g. subterranean below shoreline).

Chapter 14
Indicators and combined presentations

14.1 Introduction

14.1 Indicators are used to summarize data and convey trends on topics of specific policy relevance. Examples of indicators include GDP, the human development index and water use. Indicators provide the most common entry point into accounting data since they summarize the detail that is present in accounts. There is a large and increasing demand for indicators on topics related to environment and sustainability. In response, there is a wide array of indicators that, in most cases, are not based on data that have been filtered through an accounting framework. This, in turn, has led to challenges concerning comparability and consistency, which affect the potential of indicators to be regularly incorporated in decision-making processes. Indeed, an indicator can be only as robust as its underlying data. Since a feature of accounting frameworks is their organization of data from multiple sources, SEEA EA has the potential to support the derivation of indicators that are more coherent and consistent.

14.2 Moreover, given the variety of analytical and policy contexts that exist worldwide, it is to be expected that people would consider combining accounts in different ways or, more commonly, focus on combining a subset of accounts that are most relevant for their specific needs. This is perfectly appropriate and such combinations of accounting information for different applications or policy framings should not be labelled as inferior to others or as irrelevant. In all cases, there is a need to ensure fitness for purpose in terms of both accounting integration and the quality of the data required. Further, the development of indicators is commonly a dynamic process involving multiple stakeholders and responses to emerging policy issues. This having been said, the discussion in the present chapter must therefore be viewed as reflecting an ongoing evolution encompassing both the development of indicator-related processes and advances in measurement of ecosystem accounts.

14.3 The present chapter describes a range of ways in which data from the ecosystem accounts can be used to derive indicators and can be combined with other environmental-economic accounting and national accounting data to demonstrate the links between the economy and the environment and to compare trends over time. Section 14.2 summarizes the roles and functions of SEEA EA-based indicators and gives examples of those indicators. Section 14.3 focuses on links of SEEA to reporting on progress towards various global environmental goals. Section 14.4 provides a general introduction to the development of combined presentations in which data from different accounts are presented alongside each other. These presentations may be particularly relevant to the derivation of indicators.

14.4 The discussion on indicators and combined presentations in this chapter complements the discussion found in chapter VI of the SEEA Central Framework, which summarizes a range of approaches to integrating and presenting accounting data. Additional insight on the types of indicators and analysis that can be supported by accounts is contained in *System of Environmental-Economic Accounting*

2012 – Applications and Extensions (United Nations, European Commission, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development and World Bank (2017).

14.2 Indicators derived from SEEA EA

14.2.1 Introduction

14.5 A clear understanding of the environment-economy nexus is critical in responding to a wide range of policy questions, often with regard to informing synergies and trade-offs in policy formulation. At a global policy level, relevant initiatives include the 2030 Agenda for Sustainable Development, the Kunming-Montreal Global Biodiversity Framework, the Paris Agreement adopted under the United Nations Framework Convention on Climate Change and the United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa. Further, current policy questions require an understanding of the relationship between the environment and the economy that goes beyond provision of information on individual environmental assets (e.g. timber, energy). Increasingly, policymakers are defining sustainability in ways that also incorporate ecosystems and the services that they provide to humanity.

14.6 The discussion below describes how information from ecosystem accounts can be organized and integrated to provide policy-relevant indicators and aggregates. The discussion focuses initially on the roles and functions of indicators with respect to accounting frameworks before providing examples of indicators derived from SEEA EA.

14.2.2 Roles and functions of SEEA EA indicators

14.7 An indicator is the representation of data for a specified time, place or any other relevant characteristic, corrected for at least one dimension (usually size) so as to allow for meaningful comparisons. It is a summary measure related to a key issue or phenomenon and derived from a series of observed facts.

14.8 The following three main types of indicators are considered:

- Aggregates, which are statistics that are grouped together or aggregated in order to provide a broader picture. Thus, an aggregate involves the combination of related categories, usually within a common branch of a hierarchy, for the purpose of providing information at a broader level than that at which detailed observations are taken. In accounting, aggregation is usually completed through simple addition, for example, by summing the areas of ecosystem types across an EAA
- Composite indices, which are those in which different variables are combined using a weighting pattern or aggregation rule to communicate an overall movement or trend. An example of a composite index in SEEA EA is the measure of ecosystem condition that involves weighting together relevant ecosystem condition indicators
- Ratio indicators, which are derived by combining data from different accounts, for example, data on flows of ecosystem services per hectare from different ecosystem types

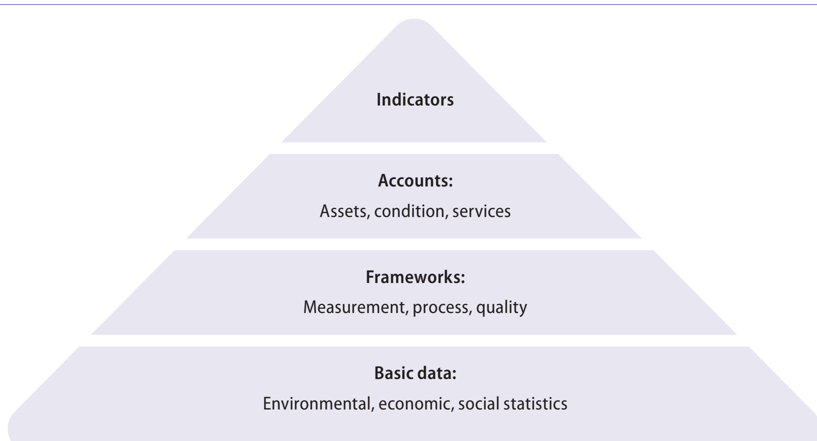
14.9 Indicators can be used to reveal relative positions or show positive or negative change over a regular interval and are usually a direct input into national and global policies. In strategic policy fields, indicators are important for setting targets and monitoring their achievement. While indicators by themselves do not necessarily encompass all aspects of development or change, they greatly contribute to explaining those processes. If a consistent methodology is employed, indicators allow comparisons over time and between, for instance, countries and regions and in this way they assist in gathering "evidence" for decision-making. Indicators can also be used to aggregate fine-level geospatial data to exhibit trends at subnational or national scale.

14.10 Indicators can serve many purposes, depending on the scale at which they are applied, the target audience and the quality of the underlying data. Indicators derived from SEEA EA are useful tools for tracking progress with regard to ecosystems and biodiversity and for mainstreaming the relevant issues into public policy. Applied in this manner, those indicators can help to promote the sustainable use of ecosystems and ecosystem services. More broadly, indicators can play an important role in supporting the communication of narratives regarding the environment and its connection to the economy and to people.

14.11 The target audience for SEEA EA indicators usually comprises decision makers and policy- makers in business and government, non-governmental organizations, environmental economists, ecologists, academia and the general public. The benefit of deriving indicators from SEEA EA is that they are consistent and coherent and synthesize accurately the underlying data. Moreover, they can be understood by and can be meaningful to non-statisticians. SEEA EA indicators are therefore capable of being statistically accurate as well as straightforward and user-friendly. They should consequently be viewed as summary measures which are fit for purpose and embedded within larger information systems (e.g. accounting frameworks, databases, monitoring systems, models) following consistent methodologies and workflows.

14.12 The relationship between different types of information within the context of SEEA EA is illustrated by the pyramid in figure 14.1. The base of the pyramid represents various sources of a full range of basic statistics and data including surveys, scientific measurements, geospatial data, administrative data and censuses. Generally, as these data are collected for various purposes, they utilize different scopes, frequencies, definitions and classifications.

Figure 14.1
Information pyramid



Source: United Nations, European Commission, FAO, OECD and World Bank (2017), figure 2.1.

14.13 The role of SEEA EA is to integrate those data so as to enable a coherent and unified understanding of ecosystems and their relationship to the economy. This means that compilers of SEEA EA accounts must reconcile and merge data from disparate sources, taking into account differences in scope, frequency, definition and classification, as appropriate. Once the data have been integrated within a single framework, indicators can be derived that provide insights into changes in composition or structure of the specific concept of interest, changes in relationships between ecosystem stocks and flows and other features, while taking advantage of underlying relationships between the accounts.

14.14 Just as a myriad of indicators such as GDP, national saving and national wealth emerge from a single national accounts framework so, too, can a wide range of indicators be derived from SEEA EA. Moreover, the use of an accounting framework such as SEEA EA produces significant benefits in the derivation of the resulting indicators. These benefits include:

- Provision of a stable conceptual framework that allows for new indicators to be developed, using a coherent source, to respond to new policy demands while allowing for improvements in data collection and methods
- Provision of a broad framework enabling different indicators to be seen in context; and, as necessary, summary information conveyed by the indicator can be disaggregated to enable a better understanding of the reasons for change
- Enabling analysis, including forecasting and projections, to build from the same coherent source data that were used for derivation of the indicators
- Support for the derivation of early estimates using various assumptions based on benchmark data from the accounting system

14.15 While indicators can be sourced directly from basic statistics, using an accounting framework necessitates reconciling and harmonizing the underlying data, which results in the derivation of coherent and consistent indicators. This has the potential to better clarify demand and priority needs for data and by extension to better link policy needs to data generation and thereby to decision structure. Further, the alignment of SEEA EA with the SNA facilitates a consistency between economic and environmental information that ensures the wider relevance of the indicators sourced from the accounts.

14.2.3 Indicators from ecosystem accounts

14.16 Information from ecosystem accounts can be organized and integrated to provide policy-relevant indicators. The present section provides an overview of indicators that can be derived from the ecosystem accounts.

14.17 The majority of the indicators presented in this section are output indicators that can be generated directly from SEEA EA accounts for tracking national and global progress. Also presented are indicators that have been developed and implemented by the scientific community but which nevertheless can be derived from ecosystem or thematic accounts using additional compilation and analysis.

14.18 Considering the underpinning spatial framework of SEEA EA and its integration with the SNA, indicators from each ecosystem account have the potential to be crosswalked with data from other accounts and socioeconomic measures. This could then provide integrated measures on interconnectedness and linkages for a range of topics, such as adjusted macroeconomic measures, costs of restoration and ecosystem capacity. Indicators from SEEA EA could also be designed to address distributional and environmental justice issues, for example, through aggregation and disaggregation to administrative units.

14.19 **Indicators from ecosystem extent accounts.** The ecosystem extent account describes the extent of the various ecosystem types presented in an accounting area and how the extent changes within an accounting period. The ecosystem types are based on IUCN GET, which provides a top level of four realms, a second level of 24 biomes and a third level of 98 EFGs. Depending on the application, alternative aggregations may be developed to align with the reporting requirements at national and international levels. In other contexts, it would be necessary to provide detail below the IUCN GET level to identify compositional differences at finer scales, for example, within urban areas, that may affect the interpretation of aggregate-level data.

14.20 Table 14.1 provides a selection of potential indicators that may be derived from the ecosystem extent account. Another possibility is to include an indicator of changes in the area of natural ecosystems compared with changes in anthropogenic and semi-natural ecosystems. Derivation of this indicator requires further definition of natural and semi-natural ecosystems in the context of IUCN GET (or other classifications of ecosystem types). It is also possible to establish a reference extent that reflects the composition of ecosystem types in a country at a given point in time and thus provides a common baseline for the assessment of change.

14.21 **Indicators from ecosystem condition accounts.** The ecosystem condition account records data on the state and functioning of ecosystem assets within an EAA using a combination of relevant variables and indicators. The selected variables and indicators reflect changes over time in the key characteristics of each ecosystem asset. Ecosystem condition accounts are compiled in physical terms. Ecosystem condition indexes and subindexes (as shown in table 14.2) are composite indicators that are aggregated from ecosystem condition indicators. The use of compatible reference levels (e.g. through a common reference condition) underpins the aggregation process. Many condition indicators that are developed and implemented by scientific communities can be integrated into SEEA EA condition accounts for further aggregation.

Table 14.1
Potential indicators on ecosystem extent

Extent indicators	Spatial unit	Disaggregation	Measurement unit
EAA covered by specific types or areas of interest including:			
Urban areas (IUCN GET T7.4) Cultivated areas (IUCN GET T7.1, T7.2, T7.3) Forests (IUCN GET T1, T2) Wetlands (IUCN GET F1, F2, TF1, FM1, MFT1) Coastal areas (IUCN GET M1, MT1, MT2, MT3, MFT1)	EAA	Ecosystem type	Hectares; % of total EAA; % of opening
Change of area covered by specific ecosystem types or areas of interest during an accounting period including:			
Urban areas (IUCN GET T7.4) Cultivated areas (IUCN GET T7.1, T7.2, T7.3) Forests (IUCN GET T1, T2) Wetlands (IUCN GET F1, F2, TF1, FM1, MFT1) Coastal areas (IUCN GET M1, MT1, MT2, MT3, MFT1)	EAA	Ecosystem type	% of opening
Percentage of area unchanged (opening stock – reduction)	EAA	Ecosystem type	% of opening

14.22 **Indicators from the physical ecosystem services flow account.** The physical ecosystem services flow accounts describe the ecosystem services generated by an ecosystem asset in volume terms. Ecosystem services are grouped under provisioning, regulating and maintenance, and cultural services. Indicators from the accounts, such as those shown in table 14.3, commonly focus on the ecological supply side of ecosystem service flows in physical units such as cubic metres and tons but indicators linked to ecosystem contributions for human benefit can also focus on the use of ecosystem services. Where measures of ecosystem services are available by detailed type of user, for example, by level of household income, it is possible to consider the relative dependence of different groups of people on ecosystem services. Many of these indicators may also be expressed in monetary terms where valuation is also undertaken, or may be linked to other, related economic data, such as data on value added and employment of relevant industries.

Table 14.2
Potential indicators on ecosystem condition

Ecosystem condition indicators	Further description	Spatial unit	Disaggregation	Measurement unit
Overall ecosystem condition index		EAA	Ecosystem type, ecosystem condition classes	Index
Physical state indicator	Overall physical state characteristics of an ecosystem asset (including soil structure, water availability, ocean temperature)	Ecosystem type	Ecosystem condition subclasses	Index
Chemical state indicator	Overall chemical state characteristics of an ecosystem asset (including soil nutrient levels, water quality, biogeochemistry, air pollutant concentrations)	Ecosystem type	Ecosystem condition subclasses	Index
Compositional state indicator	Overall compositional state characteristics of an ecosystem asset (including species diversity)	Ecosystem type	Ecosystem condition subclasses	Index
Structural state indicator	Overall structural state characteristics of an ecosystem asset (including vegetation (and biotic structure), biomass, food chains)	Ecosystem type	Ecosystem condition subclasses	Index
Functional state indicator	Overall functional state characteristics of an ecosystem asset (including ecosystem process, disturbances regimes)	Ecosystem type	Ecosystem condition subclasses	Index
Landscape/ seascape indicator	Overall characteristics of landscape/seascape (including landscape diversity, connectivity fragmentation, embedded semi-natural elements in farmland, coastal engineering)	Ecosystem type	Ecosystem condition subclasses	Index

14.23 **Indicators from the monetary ecosystem services flow account and the ecosystem asset account.** The monetary ecosystem services flow accounts describe the ecosystem services generated by an ecosystem asset in monetary terms. The monetary ecosystem asset account describes the opening and closing exchange value of ecosystem assets over an accounting period based on the NPV of the bundles of ecosystem services under their current use/institutional regime. When compiled for multiple years, the asset account records the cost of degradation and/or enhancement (e.g. restoration) of ecosystem assets that can be identified by exchange value.

14.24 Many SEEA EA indicators in monetary terms are aggregates derived from adding and subtracting relevant entries in individual monetary accounts such as the ecosystem services flow account and the monetary ecosystem asset account. Aggregates can be defined in different ways by determining different types of inclusions and exclusions. Other monetary indicators can be derived by comparing aggregates with other economic data such as total value of other assets, expected ecosystem restoration costs or value added of industries dependent on ecosystem services or at risk if ecosystem services are lost.

Table 14.3
Potential indicators on physical ecosystem services flows

Physical ecosystem services flow indicators	Further description	Spatial unit	Disaggregation	Measurement unit
Amount of biomass harvested, including crops, grazed biomass, livestock, wood, non-wood forest products and fish	Biomass provisioning services	EAA	Ecosystem type; type of biomass	Tons
Water abstracted for use by households and industry (proxy measure)	Water supply services	EAA	Ecosystem type	Cubic metres
Quantity of carbon retained (captured and stored/ trend in carbon sequestered)	Global climate regulation services	EAA	Ecosystem type	Tons
Quantity of airborne pollutants captured (e.g. PM10; PM2.5)	Air filtration services	EAA	Ecosystem type; type of pollutant	Tons
Quantity of waterborne pollutants removed (e.g. chemical oxygen demand) from wastewater	Water purification services	EAA	Ecosystem type; type of pollutant	Tons
Number of properties/km of coast/shoreline/riparian zone protected; change in degree of risk	Flood mitigation services	EAA	Ecosystem type	Count/km
Number of tourist/recreational visits	Recreation-related services	EAA	Ecosystem type	Count

14.25 Finally, because the data on different ecosystem services and ecosystem types are expressed using a common metric (i.e. currency units), comparisons and ratios can be estimated, for example, showing the relative shares of provisioning, regulating and maintenance, and cultural services. Table 14.4 includes a subset of possible monetary aggregates and other indicators. It is relevant to analyse indicators in monetary terms in combination with data in physical terms, for example, in relation to flows of ecosystem services in physical terms or in relation to extent and condition of different ecosystem types.

14.2.4 Indicators from thematic accounts

14.26 In chapter 13, a range of thematic accounts was introduced covering biodiversity, climate change, oceans and urban areas. For each of these themes, various data are brought together under an accounting umbrella, demonstrating the potential of the suite of SEEA accounts, including those of the SEEA Central Framework, to provide a broad range of data, which, together with data from other sources including the SNA, can support discussion of these and other themes. Indicators for each theme can be derived based on the considerations outlined in the present chapter.

14.3 Indicator frameworks and SEEA EA

14.3.1 SEEA EA and global indicator monitoring frameworks

14.27 SEEA enables countries to adopt a holistic and integrated approach to developing sets of indicators to support implementation, monitoring and reporting related to the 2030 Agenda for Sustainable Development and the Kunming-Montreal Global Biodiversity Framework. At its fifty-first session, in March 2020, the Statistical Commission "welcomed the background document on interlinkages…and stressed the importance of the System of Environmental-Economic Accounting for monitoring the [Sustainable Development] Goals".[162] At its fifty-second session, in March 2021, the Commission "welcomed the progress of the Committee [of Experts on Environmental-Economic Accounting] in mainstreaming the use of SEEA in policy, includ-

[162] See *Official Records of the Economic and Social Council, 2020, Supplement No. 4* (E/2020/24), chap. I, sect. C, decision 51/101, para. (g). Available at https://unstats.un.org/unsd/statcom/51st-session/documents/2020-37-Final-Report-E.pdf.

ing climate change, circular economy, sustainable finance and biodiversity policy, and particularly encouraged the Committee to engage in the monitoring framework of the post-2020 global biodiversity agenda and participate in the proposed expert group under the auspices of the secretariat of the Convention on Biological Diversity to provide the connection between the biodiversity and official statistical communities".[163]

[163] Ibid., *2021, Supplement No. 4* (E/2021/24), chap. I, sect. B, decision 52/108, para. (g). Available at https://unstats.un.org/unsd/statcom/52nd-session/documents/2021-30-FinalReport-E.pdf.

Table 14.4
Potential indicators for monetary ecosystem services flow accounts and ecosystem asset accounts

Monetary indicators	Further description	Spatial unit	Disaggregation	Measurement unit
Gross ecosystem product (GEP)	GEP is equal to the sum of all ES at their exchange value supplied by all ecosystem types located within an EAA over an accounting period less the net imports of intermediate services (for additional details, see para. 9.18 above)	EAA	Ecosystem type; ecosystem services classes	Local currency
Industry value added linked to ecosystem services	Value added of industries with direct inputs of ecosystem services reflecting extent to which economic activities are dependent on ecosystem services	EAA	Ecosystem type	Local currency
Monetary ecosystem asset value	End-of-year monetary ecosystem asset value	EAA	Ecosystem type	Local currency
Cost of degradation	Reduction in monetary ecosystem asset value attributable to ecosystem degradation	EAA	Ecosystem type per capita for administrative areas, planning areas	Local currency

14.28 SEEA provides two general advantages in relation to indicator monitoring frameworks. First, broad coverage by SEEA of environmental and economic topics, inherent connections between stocks and flows and use of physical and monetary data enables those designing and selecting indicators to place different indicators in context. Thus, SEEA can allow connections between indicators to be made evident in the development of monitoring frameworks and can be used to support appropriate coverage of indicators across relevant themes. Second, SEEA enables countries to use a single, coherent database for reporting to multiple monitoring frameworks. This has the potential to streamline data collection and organization and build more robust and consistent indicator derivations across reporting commitments.

14.29 In discussing the potential of SEEA to support the design and derivation of indicators in different contexts, it must be understood that monitoring frameworks continue to evolve in response to emerging policy demands and as a reflection of wider engagement processes. The present discussion therefore points to potential relationships and applications of SEEA. Specific guidance on the links between SEEA and individual monitoring frameworks is being developed progressively.

14.30 **Kunming-Montreal Global Biodiversity Framework.** The Kunming-Montreal Global Biodiversity Framework builds on the Strategic Plan for Biodiversity 2011–2020[164] and sets out an ambitious plan for implementing broad-based action to bring about a transformation in society's relationship with biodiversity and to ensure that, by 2050, the shared vision of living in harmony with nature is fulfilled. The framework has four long-term goals for 2050 related to the 2050 Vision for Biodiversity and each of those goals has an associated outcome for 2030. The framework also has 21 action-oriented targets for 2030 that will contribute to the achievement of the outcome-

[164] United Nations Environment Programme, document UNEP/CBD/COP/10/27, annex, decision X/2, annex.

oriented goals for 2030 and 2050. Under each goal and target, there is a set of components and elements to be monitored in assessing progress towards the achievement of those goals and targets.

14.31 SEEA can support the Kunming-Montreal Global Biodiversity Framework where it concerns measuring ecosystems' extent, condition and services while also helping to make the case for protecting and conserving biodiversity by providing a full picture of its connection to the economy. In particular, the information generated by SEEA can be used to inform biodiversity policies in an integrated and holistic manner and develop indicators for monitoring progress towards the achievement of biodiversity goals and targets. As described in section 13.3, this can include the use of data from ecosystem extent and condition accounts as inputs into derivation of habitat-based indicators of change in species-level biodiversity. SEEA can also play an important role in streamlining the reporting requirements of countries through the adoption of a common framework. This can in turn facilitate better integration of national and global target tracking.

14.32 Appendix A14.1 contains the 2050 goals and 2030 targets of the Kunming-Montreal Global Biodiversity Framework. SEEA-based accounts can be used to support the monitoring of the framework and to inform policy.

14.33 **Sustainable Development Goals.** In its resolution 70/1 of 25 September 2015, the General Assembly adopted the 2030 Agenda for Sustainable Development, in which Heads of State and Government of all of the States Members of the United Nations set out 17 Sustainable Development Goals with 169 associated targets. Those Goals and targets underpin an ambitious plan for achieving sustainable development and serve as the basis for the shaping by countries of their national policies and priorities. At the heart of the 2030 Agenda is the recognition that true development must combine economic growth and poverty alleviation with strategies that improve health and education and reduce inequality, while also addressing climate change and protecting nature. The interlinked nature of the Sustainable Development Goals calls for an integrated approach to decision-making on policy. As the international statistical standard for describing the relationship between the environment and the economy, SEEA is well positioned to support integrated policies based on a better understanding of the interactions, trade-offs and co-benefits that emerge in evaluating the link between the environment and the economy.

14.3.2 Other indicators and applications

14.34 **National indicator initiatives**. In addition to supporting global indicator initiatives, SEEA EA enables countries to adopt a holistic and integrated approach to developing sets of indicators that can support reporting on progress towards implementing national commitments, policies or strategy. The spatially explicit information generated using SEEA EA enables the effective targeting of policy efforts at both the national and the subnational levels and across terrestrial, freshwater and marine areas. This flexible modular approach allows countries to compile SEEA EA indicators on the basis of national priorities and data availability.

14.35 The connectivity and coherence of information sourced from accounts under the SEEA EA framework and its flexible approach are particularly important when those indicators are designed to support national policies related to sustainable development and the conservation of ecosystems and biodiversity.

14.36 National indicators that benefit most from having their foundation in SEEA EA include those related to:

- Contribution of ecosystems and their services to the economy, social well-being, jobs and livelihoods
- Changes in the condition and health of ecosystems and biodiversity over time and the main locations of degradation and enhancement
- Management of natural resources and ecosystems to ensure continued services and benefits such as energy, food supply, water supply, flood control, carbon storage and recreational opportunities
- Progress in efforts towards targeted conservation
- Expenditures and the development of economic instruments for conservation of nature
- Estimation of a nation's wealth, including natural capital and economic potential, once the state of nature is considered
- Assessment of government performance on sustainable development

14.37 The design and implementation of SEEA EA indicators to support national policy require strategic planning and the establishment of appropriate institutional mechanisms and arrangements for the ongoing compilation of accounts and subsequent calculation of indicators. Ultimately, the implementation of SEEA EA should support a coordinated long-term national programme of work involving a range of users of the accounts and a number of different source data agencies. The national statistical office (NSO) has a fundamental role to play in coordinating this process.

14.38 **Land degradation neutrality (LDN).** The structure of SEEA EA, with its emphasis on spatial analysis of ecosystems in terms of their extent and condition and ecosystem services, accords well with data requirements for monitoring LDN. The three global LDN indicators (land cover, land productivity and carbon stocks) that are used to derive Sustainable Development Goal indicator 15.3.1 (proportion of land that is degraded over total land area) can all be derived from existing core SEEA accounts, namely:

- SEEA land accounts, which present detailed spatial data on land cover
- SEEA ecosystem condition accounts, which measure the overall quality of an ecosystem asset with a range of variables including soil organic carbon, annual net primary productivity and changes in above- and belowground carbon stores
- SEEA ecosystem services accounts, which measure the global climate regulation services provided by an ecosystem

14.39 The United Nations Convention to Combat Desertification encourages countries to supplement their monitoring with additional indicators for ecosystem services and social outcomes that address their national or subnational priorities. SEEA alignment with the SNA means that data organized under the SEEA framework can be integrated and used with existing economic accounts relatively easily. The principle of neutrality usually involves offsetting degradation in some areas with improvements in others, and in this regard information is provided under the comprehensive SEEA framework that can help to identify key trade-offs and to facilitate the spatial targeting of restoration efforts.

14.40 **IPBES.** The overall objective of the IPBES is to provide policy-relevant knowledge on biodiversity and ecosystem services to inform decision-making through four agreed functions: assessment, development of policy support tools, capacity-building and knowledge development. A conceptual framework has been developed to support the analytical work of the Platform; to guide the development, implementation and evolution of its work programme; and to catalyse a positive transformation of the elements and interlinkages that are the causes of detrimental changes in biodiversity and ecosystems and subsequent loss of their benefits to present and future generations. The conceptual framework includes six interlinked elements constituting a social-ecological system that operates at various scales in time and space. As the SEEA EA ecosystem accounting framework captures many of the elements of the IPBES framework, the potential exists for SEEA EA-based indicators to inform IPBES assessments and related work.

14.41 **Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention).** At its ninth meeting, held in Kampala from 8 to 15 November 2005, the Conference of the Parties to the Convention on Wetlands adopted resolution IX.1, in which it welcomed an initial set of eight ecological outcome-oriented indicators for assessing the effectiveness of aspects of the Convention's implementation (presented in annex D to that resolution). The eight indicators, which were available during the 2006–2008 triennium, covered wetland resource status and threats; Ramsar sites – status; Ramsar sites – threats; water quality and quantity status; wetland management; species/biogeographic population status; threatened species; and Ramsar site designation progress. An additional two subindicators were developed to further examine the status of wetlands: status and trends in ecosystem extent, and trends in conservation status.

14.42 A total of 19 targets are specified across the four strategic goals of the Ramsar Convention in the Fourth Strategic Plan of the Convention for the period 2016–2024. In order to track progress towards achievement of the strategic targets of the Convention, a series of indicator-related questions are posed to countries in section 3 of the national report template for the Ramsar Convention, which should be completed for each conference of the contracting parties. A number of indicators have been identified as capable of being supported by SEEA-based accounts:

- Change in the extent of wetland ecosystems
- Trend in wetland condition
- Number of households linked to sewage system
- Percentage of sewerage coverage in the country
- Number of wastewater treatment plants

14.43 **Group on Earth Observations Biodiversity Observation Network (GEO BON).** GEO BON is a global network working to improve the acquisition, coordination and delivery of biodiversity observations for decision-making. In representing key biodiversity data providers operating at local, national, regional and global scales and through its efforts to design and implement structured and interoperable national biodiversity observation networks, the GEO BON network is of direct utility for the implementation of the SEEA EA process as a whole, in particular with regard to the production of natural capital accounts and related indicators.

14.44 Of particular relevance is the establishment of a scalable and interoperable framework for biodiversity observations, using the concept of essential biodiversity variables (EBVs). The EBVs cover the key dimensions of biodiversity spanning six classes (species populations, species traits, genetic composition, community composition, ecosystem structure and ecosystem function). EBVs optimize the use of in situ and remote sensing data, predictive models and repeated measures at the same locations for trend detection and attribution of ecosystem change. In addition, a new framework is being developed for essential ecosystem services variables (EESVs) that provides a flexible means of measuring change in a wide range of material, non-material and cultural services provided by biodiversity and ecosystems. The interactions and dynamics within and across biodiversity, ecosystem functions and ecosystem services – involving ecological as well as socioecological feedbacks – can be assessed using relevant sets of EBVs and EESVs.

14.45 The EBVs and EESVs are being implemented through structured and repeatable workflows that can be applied at multiple scales that connect primary observation data to multiple biodiversity information products. Those workflows are being utilized to develop a new suite of time-series indicators for tracking status of and trends in key dimensions of biodiversity change and patterns. Therefore, both the EBVs themselves and their integrated outputs (e.g. indicators) are of direct relevance to many of the indicators associated with the SEEA EA indicators initiative. Through the SEEA EA framework, which supports open, standardized and interoperable indicator development, EBVs and EESVs can provide underlying data products to inform a wide range of policy frameworks, including the Convention on Biological Diversity, the Sustainable Development Goals and multilateral environmental agreements. Continuous interactions and exchange between biodiversity data developers and a range of statistics authorities, extending from the national to the global level, will be instrumental in generating demand-driven, science-based and timely SEEA EA indicators in a coherent and consistent manner across scales and sectors. Kim and others (forthcoming) provide a detailed assessment of the potential connections between SEEA EA and GEO BON.

14.46 **Global Ocean Observing System.** The Global Ocean Observing System (GOOS) was established in 1991 by States members of the Intergovernmental Oceanographic Commission (United Nations Educational, Scientific and Cultural Organization (UNESCO)). It is co-sponsored by the World Meteorological Organization, the United Nations Environment Programme (UNEP) and the International Science Council. The GOOS community and its partners have coordinated development of global ocean climate observing and information products. Over the last decade, GOOS has been developing an integrated global observing system incorporating biology, ecosystems and ocean health.

14.47 GOOS is responsible for developing and expanding the set of essential ocean variables (EOVs) and the marine essential climate variables (ECVs). The physical and biogeochemical EOVs measure the physical and chemical condition of marine ecosystems and can support potential indicators on the condition of marine and coastal ecosystems following table 14.2. Biological EOVs measure the extent and condition of marine ecosystems of particular relevance to countries reporting to global environmental conventions. Both EOVs and ECVs can align to classifications under IUCN GET. They support global carbon modelling, investments in blue carbon and selection of natural ecosystems for derivation of headline indicators for the Kunming-Montreal Global Biodiversity Framework. They can also serve as potential indicators on ecosystem extent and condition and ecosystem services flows for SEEA EA (tables 14.1, 14.2 and 14.3). GOOS works closely with the Marine Biodiversity Observation Network of GEO BON, as biological EOVs provide the underlying data from which marine EBVs will be computed.

14.48 **Biodiversity Finance Initiative (BIOFIN).** BIOFIN has adopted an innovative approach that enables countries to measure their current biodiversity expenditures, assess their financial needs in the medium term and identify the most suitable finance solutions for bridging their national biodiversity finance gaps. BIOFIN, which is currently active in 30 countries, has produced intermediate guidance on the categorization of biodiversity expenditures based on nine categories.

14.49 Work is under way to harmonize the classification system for biodiversity expenditures between BIOFIN, the Environmental Expenditure Accounts of the SEEA Central Framework and the Sustainable Development Goal indicators related to expenditure on conservation and sustainable use of biodiversity and ecosystems.

14.50 **Inclusive wealth.** The inclusive wealth index is a sustainability index that measures wealth using countries' natural, manufactured, human and social capital. This can be used to complement existing national accounts including measures of GDP. The inclusive wealth index incorporates natural capital, human capital (e.g. education, wealth) and produced capital (e.g. equipment, machineries, roads), while also recognizing changing factors such as carbon damage, oil capital gains and total factor productivity. These factors are measured within countries and therefore show rates at national levels. The monetary value of ecosystem assets derived from the SEEA EA monetary ecosystem asset account can support measures of the natural capital component of inclusive wealth, reflecting the recognition that monetary values based on shadow prices may be appropriate depending on the analytical context (see chap. 12).

14.51 **Biophysical modelling**. Modelling for SEEA EA is important, as there are several challenges in assembling ecosystem accounts in order to derive indicators. First, the data needed to assemble ecosystem accounts are not typically captured in data sources that are relied on by statistical offices, such as surveys, administrative data and censuses. The second challenge is that SEEA EA is a spatially explicit framework, which ultimately requires mapping of both ecosystems and ecosystem services. Consequently, even measurements of ecosystem services that are regularly collected through household or agricultural surveys need to be spatially explicit. Finally, reporting environmental data in a way that can be integrated into accounting frameworks without oversimplifying complex ecological and socioeconomic processes underpinning ecosystem services presents a challenge. SEEA EA represents an attempt to merge disciplinary perspectives from ecology, economics and accounting by providing a spatially explicit accounting framework for ecosystem services, while at the same time avoiding double counting of the economic contributions of ecosystem benefits.

14.52 Biophysical modelling can fill gaps where information is not readily available, as well as spatially allocate data that are not regularly spatially explicit. Diverse models and tools for estimating the physical supply of ecosystem services have proliferated over the past decade and are quickly evolving, which means compilation of ecosystem accounts by statistical agencies is becoming increasingly feasible. While most biophysical models were not developed specifically for accounting, many models produce results that can be used directly in SEEA EA or modified for use in SEEA EA. Identifying which tools and modelling platforms produce results that align with SEEA EA can facilitate faster adoption of ecosystem accounts.

14.53 **Scenario analysis.** SEEA EA can be deployed in the application of scenario analysis to support policymaking. The increasing interconnectedness among the natural environment, human societies and their economies implies new challenges and opportunities for policymakers. To take adequate account of such complexities, policymakers require new sources of data and indicators, based on coherent statistical frameworks, that can be transformed into decision-relevant information through the application of innovative, sophisticated modelling techniques.

14.54 The creation and quantification of various scenarios with mathematical simulation models allow for the creation of quantitative estimates under those scenarios (e.g. for implementing or not implementing a proposed policy) that can be used to inform the policymaking process. This type of exercise is known as policy scenario analysis, which is aimed at informing decision-making by utilizing scenarios to assess the outcomes and effectiveness of various policy intervention options. A technical report on *Policy Scenario Analysis Using SEEA Ecosystem Accounting* (United Nations, Department of Economic and Social Affairs, Statistics Division, and United Nations Environment Programme, 2021)[165] and an IPBES report on scenario analysis (2016) are sources of further details on this area of work.

[165] See https://seea.un.org/content/policy-scenario-analysis-using-seea-ecosystem-accounting.

14.55 By providing a standardized approach using consistent and coherent data and by targeting policy relevance and the involvement of local stakeholders in policy analysis, SEEA EA can support use of accounts, further development of modelling approaches and creation of new models, all with the ultimate goal of informing policy decisions. This can be achieved through:

- Creation of new knowledge regarding ecosystems and how through their extent and quality they provide services that benefit communities and human well-being. This allows for the incorporation of ecosystems in social and economic assessments
- Creation of coherent and harmonized accounts, allowing for the development of new models that can make use of such a data framework
- Promotion of the use of a systemic approach that assesses (a) the impact of human activity on ecosystems and (b) models that determine the extent to which ecosystems influence human health and human activity
- Application of standard approaches to valuation of ecosystem services and ecosystem assets based on exchange values
- Improvement in the analysis performed with sectoral models by introducing physical indicators on ecosystem extent and condition and ecosystem services
- Generation of knowledge on how existing models could be interconnected so as to better represent the relations between society, the economy and the environment
- Use of simulations extending the analysis provided by SEEA through forecasting or back-casting scenarios
- Making explicit the importance of site-specific drivers of change, system responses and impacts, using a spatially explicit analysis that allows users to determine the value of ecosystem services based on the location at which they are used and thereby assess more explicitly demand and supply

14.4 Combined presentations for ecosystem accounting

14.4.1 Introduction

14.56 The presentation of data in a format that combines both physical and monetary data is one of the strongest features of SEEA. In chapter VI of the SEEA Central Framework, combined presentations are introduced as a means of summarizing data from various accounts and linking those data to other relevant data, for example, on population or employment. In the context of SEEA EA, combined presentations are intended to show changes in stocks and flows of ecosystems in terms of standard measures of economic activity, without necessarily undertaking the valuation of ecosystem services and ecosystem assets in monetary terms. Further, there is room for considerable flexibility in the design of combined presentations. The descriptions given below focus on common areas of interest rather than on providing an exhaustive list.

14.57 While they do not encompass a full integration of information in accounting terms, combined presentations can support a more informed discussion of the relationship between ecosystems and economic activity in a manner that takes into account spatial and environmental contexts. Further, they may help to support the presentation of indicators for monitoring trends in ecosystem-related outcomes.

14.58 In the present section, specific topics are introduced that might be the focus of a combined presentation. In selecting the relevant variables to be included in a combined presentation, it is necessary to keep in mind a specific question or focus of analysis such that the variables selected can be shown to be contributing to a broader narrative, which thereby contextualizes those variables. For this purpose, it may be relevant to apply indicator frameworks such as the long-standing driving forces-pressure-state-impact-response (DPSIR) framework (European Environment Agency, 1999) or more recently developed frameworks, such as the environmental sustainability gap framework or the natural capital indicator framework. The links between the DPSIR framework and SEEA are considered in this section to provide examples of the possibilities for applying an indicator framework. It should be noted that SEEA does not advocate for any specific indicator framework.

14.4.2 Information on environmental activities

14.59 There may be particular interest in combining information on ecosystem services and ecosystem assets with information on expenditure on environmental protection or resource management. If the information on relevant activities is organized so as to refer to the same spatial areas and/or ecosystem types, this would facilitate the monitoring of the effect of expenditures on changes in ecosystems.[166] For example, information showing expenditure to restore coastal wetlands may be combined with information on associated changes in ecosystem condition and in associated ecosystem services linked to improved ecosystem condition.

14.60 As defined in the SEEA Central Framework, environmental activities are economic activities that have as their primary purpose either environmental protection (prevention, reduction and elimination of pollution and other forms of degradation) or resource management (preserving and maintaining the stock of natural resources).[167]

14.61 Information gathered on actual expenditure on restoring ecosystem assets might be complemented over time by information on flows of ecosystem services, through which a more complete picture of the relationships between ecosystem condition and ecosystem services could emerge. Further, links may be established with analysis of positive and negative externalities, ecosystem disservices and the extent to which expenditures and other policy responses reduce any negative effects. Indeed, one of the key roles of the ecosystem accounting model is to facilitate the organization of these types of data and thereby furnish support for more detailed analyses.

14.62 The compilation of targeted statistics on the production of ecosystem-related environmental goods and services, using the framework of environmental goods and services sector (EGSS), may also be of interest. These statistics would provide information, for example, on the share of overall value added contributed to the economy through the production of goods and services related to ecosystems and biodiversity (sometimes referred to as the biodiversity economy).

[166] It may be difficult to allocate survey data collected at national level to specific ecosystem assets. Therefore, it may be necessary to consider alternative approaches to collecting information on site-specific expenditures, for example, through administrative sources.

[167] For further details, see chap. IV of the SEEA Central Framework.

14.4.3 Economic dependence on ecosystems

14.63 Although the focus of ecosystem accounting is on the services provided by ecosystems, there is also interest in understanding the significance of the relationship between ecosystems and standard measures of economic activity, such as GDP. For example, it may be of interest to understand the dependency of current measures of agricultural production on ecosystem services such as pollination. While such dependency measures could be focused on direct impact (e.g. GDP "at risk" in the absence of the pollination service), they might also take indirect (or supply chain) effects into account by measuring multiplier effects within the economy, using the extended SUT described in chapter 11. In situations where the total contribution of ecosystem services (expressed as percentage of GDP) is low, it is possible that economic dependency could still be very high.

14.64 It should be accepted that the allocation of economic activity to subnational spatial areas (such as administrative regions or catchments) can involve conceptual difficulties. Therefore, it may be most useful to commence with identification of measures of economic activity for those industries and activities – for example, agriculture, forestry, fishing and tourism – for which a clear link can be established between an ecosystem and the location of production. Further economic connections may be identified by tracing supply chains.

14.4.4 Information on policy instruments

14.65 Where links between economic units and particular ecosystems can be established, it is possible to consider integrating information on a range of other transactions that may occur in relation to economic activity. For example, data on payments of certain environmental taxes, payments of rent on natural resources, payments of environmental subsidies and similar transfers may be presented alongside standard economic indicators and indicators of ecosystem services and assets to provide a more complete picture of the relationships between a given ecosystem and the economy. From a general environmental management perspective, a comparison of environmental expenditures and environmentally related revenues may also be of interest.

14.4.5 Using the DPSIR framework

14.66 A number of indicators for the analysis of various topics can be described using the DPSIR framework (European Environment Agency, 1999), which describes a stepwise causal chain linking economic activity and impacts on nature. The DPSIR indicators that are most improved as a result of being derived from SEEA EA accounts are for the most part those indicators characterized as state or impact indicators in the DPSIR framework. By extending the scope of analysis and by integrating statistics and indicators from the SEEA Central Framework and other socioeconomic dimensions with SEEA EA, SEEA lends itself to the derivation of a wide range of important indicators that are considered to be policy-relevant and that can also be communicated using the DPSIR framework.

14.67 **Driving forces indicators.** Driving forces are anthropogenic activities that exert pressure on ecosystems. Indicators for driving forces describe social, demographic and economic developments in societies and the corresponding changes in consumption and production patterns. Primary driving forces are population growth and developments in the demand and consumption/production activities of economic agents. Such changes exert pressure on ecosystems. Examples of indicators of driving forces acting on ecosystems within the general context of SEEA are presented in table 14.5.

Table 14.5
Possible SEEA-based driving forces indicators

Type	Indicators	Spatial unit	Related SEEA accounts, and statistics from other dimensions
Combined presentation	Population per hectare of ecosystem type	Ecosystem type	Ecosystem extent account; population statistics disaggregated by ecosystem type
Combined presentation	Resource intensity in an EAA (i.e. ratio of natural resources such as water used to an economic variable such as output, income or value added)	EAA	Ecosystem extent account; SEEA Central Framework physical flow accounts; economic statistics

14.68 **Pressure indicators.** Pressures are direct stresses to ecosystems arising from anthropogenic activities such as emissions to air, water and waste and the release of excessive nutrients. The pressures exerted by the driving forces are transformed in a variety of biophysical and ecological processes so as to manifest themselves in changes in ecosystem conditions. Example of indicators for pressure exerted on ecosystems within the general context of SEEA are presented in table 14.6.

14.69 **State indicators.** State indicators give a description of the quantity and quality of physical, biological or chemical phenomena in a certain area. In the context of SEEA EA, they refer to the state of ecosystems in terms of extent, condition and capacity to provide services to humanity and conditions in the environment. Indicators derived from the ecosystem extent and condition accounts of SEEA EA are considered state indicators.

Table 14.6
Possible SEEA-based pressure indicators

Type	Indicators	Spatial unit	Related SEEA accounts, and statistics from other dimensions
Combined presentation	Hazardous waste generated per industry sector	Ecosystem type	Ecosystem extent account; SEEA solid waste accounts
Combined presentation	GHG emission per industry sector	Ecosystem type	Ecosystem extent account; SEEA CF air emission account
Combined presentation	Water emission (biological oxygen demand/chemical oxygen demand, phosphorus, nitrogen, etc.) per industry sector	Ecosystem type	Ecosystem extent account; SEEA CF water emission account

14.70 **Impact indicators.** Changes in the state of environment due to natural changes, pressures on the environment or human intervention have impacts on the social and economic functions of the environment. Impact indicators from SEEA EA include measures of changes in ecosystems and human systems, for example, with respect to provision of ecosystem services and degradation of ecosystems. Indicators derived from the physical and monetary ecosystem services flow account as well as the monetary ecosystem asset account of SEEA EA are considered impact indicators. Some examples are shown in table 14.7. Other types of impact indicators within the general context of SEEA include:

- Indicators derived from integrated and extended accounting (chap. 11 of SEEA EA)
- Indicators derived from the combination of physical and monetary accounts
- Indicators measuring economic dependence on ecosystems
- Indicators derived from analytical models using SEEA data for the analysis of consumption and production pattern (e.g. footprint-type indicators)

14.71 **Response indicators.** Responses are management actions aimed at addressing environmental problems in order to prevent, compensate for, ameliorate or adapt to changes in the state of the environment. Possible SEEA-based response indicators are presented in table 14.8. Types of potential response indicators within the SEEA context would cover the following areas:

- Environmental activities and EGSS
- Tax and expenditure, encompassing, for example, environmental protection and resource management expenditures and environmental taxes
- Policy instruments designed to safeguard ecosystem condition

Table 14.7
Possible SEEA-based impact indicators

Type	Indicators	Spatial unit	Related SEEA accounts, and statistics from other dimensions
Integrated and extended accounting	NDP adjusted for cost of degradation	EAA	Extended sequence of accounts
Combined presentation	Area of ecosystem that has seen an increase in condition	Ecosystem type	Ecosystem extent account; ecosystem condition account
Combined presentation	GEP per hectare of ecosystem type	Ecosystem type	Ecosystem extent account; monetary ecosystem services flow account
Combined presentation	Ratio of ecosystem asset value to service value	Ecosystem type	Monetary ecosystem services flow account; monetary ecosystem asset account;
Economic dependence on ecosystem	Economic activity dependent on nature (e.g. value of ecosystem services linked to industry value added)	EAA	Monetary ecosystem services flow accounts; SNA; industrial statistics
Environmentally extended multi-regional input-output analysis	Ecosystem footprints (e.g. flows of carbon, water or ecosystem services embodied in a country's imports and exports of goods and services)	EAA	Monetary ecosystem services flow accounts; Input-output analysis

Table 14.8
Possible SEEA-based response indicators

Type	Indicators	Spatial unit	Related SEEA accounts, and statistics from other dimensions
Environmental activities	Value added and employment generation by the EGSS per eco-system type	Ecosystem type	EGSS; SNA; economic statistics
Tax and expenditure	Return on biodiversity expenditure (change in ecosystem condition index per dollar spent)	EAA	Ecosystem condition account; environmental protection and expenditure account
Tax and expenditure	Biodiversity-related environmental tax	EAA	Accounting for environmental taxes
Policy instrument	Integration of biodiversity into national accounting and reporting systems, defined as implementation of SEEA		

Appendix A14.1
SEEA EA and the post-2020 global biodiversity framework[168]

A14.1 The role of the official statistical community and the value of SEEA in monitoring the post-2020 global biodiversity framework and mainstreaming biodiversity in national statistical systems are recognized at a political level. At its twenty-fourth meeting, the Subsidiary Body on Scientific, Technical and Technological Advice under the Convention on Biological Diversity reviewed the following documents: "Post-2020 global biodiversity framework: scientific and technical information to support the review of the updated goals and targets, and related indicators and baselines" (CBD/SBSTTA/24/3)[169] and "Proposed indicators and monitoring approach for the post-2020 global biodiversity framework" (CBD/SBSTTA/24/3/Add.1).[170] Document CBD/SBSTTA/24/3 included a recommendation that, at its fifteenth meeting, the Conference of the Parties to the Convention adopt a decision in which it would:

- Adopt the monitoring framework for the post-2020 global biodiversity framework
- Welcome the work of the Statistics Division of the United Nations Secretariat on developing statistical standards for measuring biodiversity, the environment and their relationship with socioeconomic development, as well as its support to NSOs engaging in the process for monitoring biodiversity
- Invite the United Nations Statistical Commission to support the operationalization of the monitoring framework for the post-2020 global biodiversity framework
- Recognize the value of aligning national monitoring with the United Nations System of Environmental-Economic Accounting statistical standard in order to mainstream biodiversity in national statistical systems and to strengthen national monitoring systems and reporting

A14.2 A monitoring framework composed of the following three groups of indicators is proposed for monitoring the implementation of the post-2020 global biodiversity framework:

- **Group 1: headline indicators.** A minimum set of high-level indicators that capture the overall scope of the goals and targets of the post-2020 global biodiversity framework to be used for tracking national progress as well as regional and global progress. These indicators could also be used for communication purposes. In addition, some countries may wish to use a subset of these indicators or only the goal-level headline indicators for high-level communication and outreach
- **Group 2: component indicators.** A set of indicators for monitoring each component of each goal and target of the post-2020 global biodiversity

[168] The present appendix is based on a possible set of headline indicators as of July 2021, which are still under consideration by the Conference of the Parties to the Convention on Biological Diversity. The post-2020 global biodiversity framework was formerly known as the Kunming-Montreal Global Biodiversity Framework.

[169] Available at www.cbd.int/doc/c/705d/6b4b/a1a463c1b19392bde6fa08f3/sbstta-24-03-en.pdf.

[170] Available at www.cbd.int/doc/c/ddf4/06ce/f004afa32d48740b6c21ab98/sbstta-24-03-add1-en.pdf.

framework at the national level as well as for tracking regional and global progress

- **Group 3: complementary indicators.** A set of indicators for thematic or in-depth analysis of each goal and target and which are less relevant for a majority of countries; have significant methodological or data-collection gaps; are highly specific and do not cover the scope of a goal or target component; or can be applied only at the global and regional levels

A14.3 Within these three groups, different types of indicators are proposed for the goals and targets of the post-2020 global biodiversity framework. The indicators proposed for the goals focus on the status and trends in biodiversity, including the benefits provided by biodiversity to people and the conditions necessary for achieving the framework. The indicators proposed for the targets aim towards monitoring the actions taken to reach those targets and their impacts.

A14.4 With regard to the selection of headline indicators, priority has been given to indicators that have been agreed through an established scientific or intergovernmental process and where there is an existing body that will continue to review the indicator. An effort was made to align with the intergovernmental processes under the United Nations Statistical Commission, including the Sustainable Development Goals or SEEA.[171]

A14.5 The discussion on the headline indicators for the post-2020 global biodiversity framework is ongoing. It is to be noted that SEEA is recognized as the methodological basis for the headline indicators on at least six goals and targets in the monitoring framework (goals A and B; and targets 9, 11, 14 and 19). Selected proposed headline indicators that can be derived from SEEA accounts are listed directly below:[172]

- Extent of selected natural and modified ecosystem (i.e. forest, savannas and grasslands, wetlands, mangroves, salt marshes, coral reefs, seagrass, macroalgae and intertidal habitats)
- National environmental-economic accounts of ecosystem services
- National GHG inventories from land use and land-use change
- National environmental-economic accounts of benefits from use of wild species
- National environmental-economic accounts of regulation of air quality, quality and quantity of water, and protection from hazards and extreme events for all people, from ecosystems
- Average share of the built-up area of cities that is green/blue space for public use for all
- Integration of biodiversity into national accounting and reporting systems, defined as implementation of SEEA
- Material footprint per capita
- Public expenditure and private expenditure on conservation and sustainable use of biodiversity and ecosystems

A14.6 Building on this discussion, tables A14.1.1 and A14.1.2 list, respectively, the 2050 goals and 2030 targets under the post-2020 global biodiversity framework that may be informed by the use of SEEA-based accounts.

[171] See the note by the Executive Secretary of the Convention on Biological Diversity entitled "Proposed headline indicators of the monitoring framework for the ost-2020 global biodiversity framework" (CBD/WG2020/3/3/Add.1). Available at www.cbd.int/doc/c/ d716/da69/5e81c8e0faca1db1dd145a59/wg2020-03-03-add1-en.pdf.

[172] Ibid.

Table A14.1.1
Potential indicators for the 2050 goals (including links to related Sustainable Development Goal indicators)

Goal	Relevant SEEA accounts
A. The integrity, connectivity and resilience of all ecosystems are maintained, enhanced, or restored, substantially increasing the area of natural ecosystems by 2050; Human induced extinction of known threatened species is halted, and, by 2050, the extinction rate and risk of all species are reduced tenfold and the abundance of native wild species is increased to healthy and resilient levels; The genetic diversity within populations of wild and domesticated species, is maintained, safeguarding their adaptive potential.	Goal A, which monitors the size of natural ecosystems and condition of ecosystems in terms of their connectivity and integrity as well as the status and trends of threatened species, can be informed by indicators from ecosystem extent accounts, ecosystem condition accounts and species accounts of SEEA EA
B. Biodiversity is sustainably used and managed and nature's contributions to people, including ecosystem functions and services, are valued, maintained and enhanced, with those currently in decline being restored, supporting the achievement of sustainable development for the benefit of present and future generations by 2050.	Goal B, which monitors nature's contribution to people and benefits from ecosystems and biodiversity and their sustainable use, can be informed by indicators from physical and monetary ecosystem services flow accounts of SEEA EA
D. Adequate means of implementation, including financial resources, capacity-building, technical and scientific cooperation, and access to and transfer of technology to fully implement the Kunming-Montreal Global Biodiversity Framework are secured and equitably accessible to all Parties, especially developing country Parties, in particular the least developed countries and small island developing States, as well as countries with economies in transition, progressively closing the biodiversity finance gap of $700 billion per year, and aligning financial flows with the Kunming-Montreal Global Biodiversity Framework and the 2050 Vision for biodiversity.	Goal D, which monitors the means of implementation for the post-2020 framework, can be informed by indicators from the environmental protection expenditure accounts of the SEEA Central Framework

Table A14.1.2
Connecting SEEA accounts to the 2030 targets

Target	Relevant SEEA accounts
2. Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and marine and coastal ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.	Target 2, which monitors the area of degraded ecosystems under ecosystem restoration, can be informed by indicators deriving from a combination of ecosystem extent accounts and ecosystem condition accounts of SEEA EA
3. Ensure and enable that by 2030 at least 30 per cent of terrestrial and inland water areas, and of marine and coastal areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures, recognizing indigenous and traditional territories, where applicable, and integrated into wider landscapes, seascapes and the ocean, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local communities, including over their traditional territories.	Target 3, which monitors the extent and condition of protected areas, can be informed by indicators from protected area accounts based on SEEA EA
4. Ensure urgent management actions to halt human induced extinction of known threatened species and for the recovery and conservation of species, in particular threatened species, to significantly reduce extinction risk, as well as to maintain and restore the genetic diversity within and between populations of native, wild and domesticated species to maintain their adaptive potential, including through in situ and ex situ conservation and sustainable management practices, and effectively manage human-wildlife interactions to minimize human-wildlife conflict for coexistence.	Target 4, which monitors management actions for the recovery and conservation of wild species of fauna and flora, can be informed by indicators from the species accounts of SEEA EA. Indicators that measure the status and trend of species can also be integrated into ecosystem condition accounts of SEEA EA to derive broader measures of sustainability

Table A14.1.2
Connecting SEEA accounts to the 2030 targets (*Continued*)

Target	Relevant SEEA accounts
5. Ensure that the use, harvesting and trade of wild species is sustainable, safe and legal, preventing overexploitation, minimizing impacts on non-target species and ecosystems, and reducing the risk of pathogen spillover, applying the ecosystem approach, while respecting and protecting customary sustainable use by indigenous peoples and local communities.	Target 5, which monitors the sustainable and safe harvesting and use of wild species of fauna, can be informed by indicators from physical ecosystem services flow account of SEEA EA
6. Eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority invasive alien species, reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 per cent by 2030, and eradicating or controlling invasive alien species, especially in priority sites, such as islands.	Target 6, which monitors the rate of introduction of invasive alien species can be integrated into the ecosystem condition accounts of SEEA EA to derive broader measures of sustainability
7. Reduce pollution risks and the negative impact of pollution from all sources by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services, considering cumulative effects, including: (a) by reducing excess nutrients lost to the environment by at least half, including through more efficient nutrient cycling and use; (b) by reducing the overall risk from pesticides and highly hazardous chemicals by at least half, including through integrated pest management, based on science, taking into account food security and livelihoods; and (c) by preventing, reducing, and working towards eliminating plastic pollution.	Target 7, which monitors the effects of levels of pollution on ecosystems and biodiversity, can be informed by indicators deriving from a combination of ecosystem condition accounts of SEEA EA and residual flow accounts of the SEEA Central Framework
8. Minimize the impact of climate change and ocean acidification on biodiversity and increase its resilience through mitigation, adaptation, and disaster risk reduction actions, including through nature-based solutions and/or ecosystem-based approaches, while minimizing negative and fostering positive impacts of climate action on biodiversity.	Target 8, which monitors climate change mitigation and adaptation through nature-based solutions and ecosystems-based approaches, can be informed by indicators from physical ecosystem services flow accounts of SEEA EA
9. Ensure that the management and use of wild species are sustainable, thereby providing social, economic and environmental benefits for people, especially those in vulnerable situations and those most dependent on biodiversity, including through sustainable biodiversity-based activities, products and services that enhance biodiversity, and protecting and encouraging customary sustainable use by indigenous peoples and local communities.	Target 9, which monitors the benefits from ecosystem and biodiversity for people, can be informed by indicators from a combination of physical and monetary ecosystem services flow accounts for SEEA EA and socioeconomic statistics
10. Ensure that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably, in particular through the sustainable use of biodiversity, including through a substantial increase of the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches, contributing to the resilience and long-term efficiency and productivity of these production systems, and to food security, conserving and restoring biodiversity and maintaining nature's contributions to people, including ecosystem functions and services.	Target 10, which monitors the productivity, sustainability and resilience of ecosystems and biodiversity in agricultural and other managed ecosystems, can be informed by indicators from a combination of ecosystem condition and physical and monetary ecosystem services flow accounts for cultivated/managed ecosystems of SEEA EA
11. Restore, maintain and enhance nature's contributions to people, including ecosystem functions and services, such as the regulation of air, water and climate, soil health, pollination and reduction of disease risk, as well as protection from natural hazards and disasters, through nature-based solutions and/or ecosystem-based approaches for the benefit of all people and nature.	Target 11, which monitors the regulation of air and water flows and the mitigation of extreme events by ecosystems, can be informed by indicators from physical ecosystem services flow accounts of SEEA EA
12. Significantly increase the area and quality, and connectivity of, access to, and benefits from green and blue spaces in urban and densely populated areas sustainably, by mainstreaming the conservation and sustainable use of biodiversity, and ensure biodiversity-inclusive urban planning, enhancing native biodiversity, ecological connectivity and integrity, and improving human health and well-being and connection to nature, and contributing to inclusive and sustainable urbanization and to the provision of ecosystem functions and services.	Target 12, which monitors the benefits from biodiversity and green/blue spaces for human health and well-being, can be informed by a combination of urban accounts, ecosystem condition accounts and physical ecosystem services flow accounts of SEEA EA

Table A14.1.2
Connecting SEEA accounts to the 2030 targets (*Continued*)

Target	Relevant SEEA accounts
14. Ensure the full integration of biodiversity and its multiple values into policies, regulations, planningand development processes, poverty eradication strategies, strategic environmental assessments, environmental impact assessments and, as appropriate, national accounting, within and across all levelsof government and across all sectors, in particular those with significant impacts on biodiversity, progressively aligning all relevant public and private activities, and fiscal and financial flows with the goals and targetsof this framework.	Target 14, which monitors the status of integration and mainstreaming of biodiversity, can be informed by the global assessment of SEEA that measures the integration of biodiversity into national accounting and reporting systems, defined as implementation of SEEA
16. Ensure that people are encouraged and enabled to make sustainable consumption choices, including by establishing supportive policy, legislative or regulatory frameworks, improving education and access to relevant and accurate information and alternatives, and by 2030, reduce the global footprint of consumption in an equitable manner, including through halving global food waste, significantly reducing overconsumption and substantially reducing waste generation, in order for all people to live well in harmony with Mother Earth.	Target 16, which monitors unsustainable consumption patterns, can be informed by footprint indicators deriving from environmentally extended input-output analysis using indicators from SEEA as the input data
19. Substantially and progressively increase the level of financial resources from all sources, in an effective, timely and easily accessible manner, including domestic, international, public and private resources, in accordance with Article 20 of the Convention, to implement national biodiversity strategies and action plans, mobilizing at least $200 billion per year by 2030, including by: (a) Increasing total biodiversity related international financial resources from developed countries, including official development assistance, and from countries that voluntarily assume obligations of developed country Parties, to developing countries, in particular the least developed countries and small island developing States, as well as countries with economies in transition, to at least $20 billion per year by 2025, and to at least $30 billion per year by 2030; (b) Significantly increasing domestic resource mobilization, facilitated by the preparation and implementation of national biodiversity finance plans or similar instruments according to national needs, priorities and circumstances; (c) Leveraging private finance, promoting blended finance, implementing strategies for raising new and additional resources, and encouraging the private sector to invest in biodiversity, including through impact funds and other instruments; (d) Stimulating innovative schemes such as payment for ecosystem services, green bonds, biodiversity offsets and credits, and benefit-sharing mechanisms, with environmental and social safeguards; (e) Optimizing co-benefits and synergies of finance targeting the biodiversity and climate crises; (f) Enhancing the role of collective actions, including by indigenous peoples and local communities, Mother Earth centric actions[1] and non-market-based approaches including community based natural resource management and civil society cooperation and solidarity aimed at the conservation of biodiversity; (g) Enhancing the effectiveness, efficiency and transparency of resource provision and use.	Target 19, which monitors financial resources for the implementation of the post-2020 framework, can be informed by indicators from the environmental protection expenditure accounts of the SEEA Central Framework

Annex I
SEEALand – a stylized example of ecosystem accounting

Background

The stylized example described in the present annex is intended to support the understanding and interpretation of the concepts described in System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA). Since there are a wide variety of combinations of ecosystem types and ecosystem services that are present in different locations, there is no attempt in this annex to provide an example that might be considered universally applicable. Consequently, this example demonstrates accounting for a limited set of ecosystem types and ecosystem services. It is expected, however, that the principles underpinning this limited example can be generalized to apply to more complex situations at the national level or to other EAAs.

In addition to the example provided here, there is a complementary online spreadsheet available, together with the present publication, on the SEEA website.[a] The spreadsheet demonstrates the accounting relationships and relevant calculations more explicitly. It is expected that over time this spreadsheet will be further developed to encompass a wider range of accounting contexts.

[a] See https://seea.un.org/ecosystem-accounting.

With respect to the estimates provided for the accounts in this example, there is no direct or implied connection made to specific data sources, that is, it is assumed in the presentation that account-ready data are available for incorporation into the accounts. Of course, generally, this will not be the case in practice and significant work is likely to be needed in collecting and organizing relevant data for use in accounting, some of which is outlined in the *Guidelines on Biophysical Modelling for Ecosystem Accounting* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022a) and the *Monetary Valuation of Ecosystem Services and Ecosystem Assets for Ecosystem Accounting. Interim Report* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022b).

Finally, this example does not extend to the description of the range of accounts that could be compiled to complement the five main ecosystem accounts. For example, thematic accounts, such as those for carbon, water or species, are not included. The development of such accounts to complement these ecosystem accounts may be developed in the online spreadsheet at a later stage.

General context and assumptions for the stylized example

The following ecosystem accounts have been compiled for the EAA of "*SEEALand*". The opening of the accounting period for the accounts is 1 January 2020 and the closing of the accounting period is 31 December 2020.

There are six ecosystem types in *SEEALand* that are classified following the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET) biomes and ecosystem functional groups (EFGs). For ease of explanation, short labels for each ecosystem type have been assigned, as shown in table AI.1 below.

Table AI.1
List of ecosystem types for *SEEALand*

Reference number	IUCN GET biome/EFG	Short label used in this example
1	T2 Temperate-boreal forests and woodlands/T2.2 Deciduous temperate forests	Forest
2	F2 Lakes/F2.1 Large permanent freshwater lakes	Lake
3	T7 Intensive land use/T7.1 Annual croplands	Cropland
4	T7 Intensive land use/T7.4 Urban and industrial ecosystems	Urban area
5	TF1 Palustrine wetlands/TF1.3 Permanent marshes	Wetland
6	M1 Marine shelf/M1.1 Seagrass meadows	Seagrass

In terms of the changing ecological context, it is assumed that in *SEEALand*, natural ecosystems have experienced increasing pressures reflected in (managed) conversions from forest to cropland and general intensification of ecosystem use. This has had a negative impact on condition of forest and wetland, for example, because of edge effects impacting on the ecological functioning of the forest. Further, policies to improve the condition of cropland have had mixed outcomes and urban intensification is driving a loss of urban green spaces. In contrast, long-term efforts to improve lake's water quality have resulted in improvement in its condition. Finally, sewerage overflow from urban area has negatively influenced the condition of seagrass beds.

These changes in condition also exert an impact on changes in the future expected flows of ecosystem services and in consequence on recorded measures of ecosystem degradation, ecosystem enhancement and reappraisals. Changes in future prices are also expected for some ecosystem services. For wood and wild fish provisioning services, increases in prices are driven by both increased demand and increased regulation of the sustainability of those industries, which has resulted in a decreased supply of ecosystem services. It is also expected that the price of global climate regulation services will increase, reflecting increases in the marginal damages incurred through carbon release.

Ecosystem extent

At the opening of the accounting period, there are six distinct ecosystem assets. The configuration of those ecosystem assets is shown in figure AI.1. The total area of *SEEALand* is 250 hectares (each grid cell represents 10 hectares).[b]

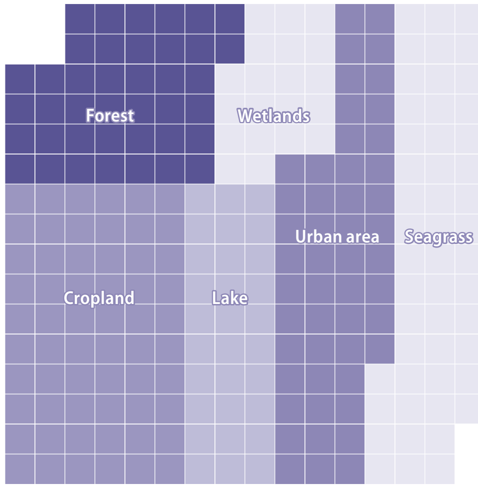
Over the accounting period, there is one change in the extent of the ecosystem assets. It entails the replacement of two hectares of forest by two hectares of cropland. This ecosystem conversion is considered a managed expansion of cropland and a managed reduction in forest.

The following ecosystem extent account can be compiled based on the information in figures AI.1 and AI.2. Entries concerning expansions and reductions are based on the changes in the maps of ecosystem extent and the context for those changes. Where there is no information available for determining whether a change is managed or unmanaged, it is appropriate to record only the total expansion or reduction.

An ecosystem extent change matrix can also be compiled, as presented in table AI.3. It is designed to record which ecosystem types have been converted to which other ecosystem types. The matrix is compiled in four steps. In step 1, the opening extent for each ecosystem type is recorded in the right-hand column. In step 2, the closing extent for each ecosystem type is recorded in the bottom row. In step 3, the

b In practice, data on ecosystem extent are likely to be calculated for a period of time (e.g. for the year 2020) rather than for specific days at the beginning and end of the accounting period. Given this situation, it is necessary to select the point in time to which the data should relate. For example, extent data for 2020 may be assumed to reflect the opening extent for the accounts of 2020 and extent data for 2021 may be assumed to reflect the closing extent for the accounts of 2020 (and the opening extent for the accounts of 2021).

Figure AI.1
Opening extent of ecosystem assets in *SEEALand*, 1 January 2020



areas of an ecosystem type that have not been converted to another ecosystem type over the accounting period are recorded along the diagonal. In this example, only one ecosystem type, namely, forest, has had a reduction in area; for all of the other ecosystem types, the unchanged extent is equal to the opening extent.

In step 4, entries are made for changes in extent, with one entry being made for each change. The entries are made by considering the closing extent (i.e. the column) of the ecosystem type that increased in area. In this example, since the area of cropland increased by 2 hectares, an entry is made in the cropland column corresponding to the ecosystem type that changed, in this case forest. With regard to this conversion, the interpretation is that for forests (reading along the first row) 38 hectares are unchanged but 2 hectares are now cropland. Also, for cropland (reading down the fourth column), 60 hectares are unchanged and an additional 2 hectares have been added that were formerly forest

Figure AI.2
Closing extent of ecosystem assets in *SEEALand*, 31 December 2020

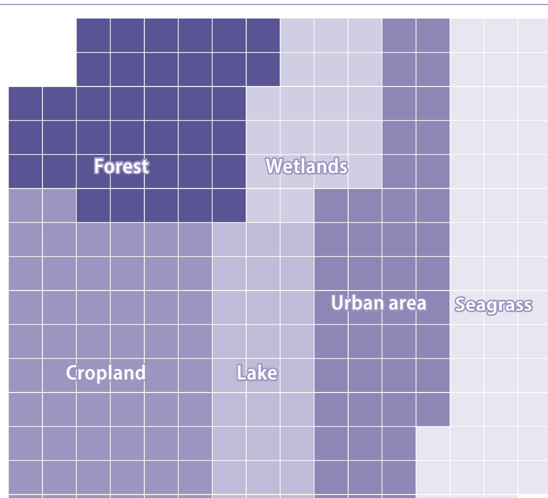


Table AI.2
Ecosystem extent account, 2020 (hectares)

Accounting entries	Forest	Lake	Crop-land	Urban area	Wetland	Seagrass	Total
	Ecosystem types						
Opening extent	**40**	**30**	**60**	**50**	**20**	**50**	**250**
Additions to extent							
Managed expansions			2				2
Unmanaged expansions							
Reductions to extent							
Managed reductions	2						2
Unmanaged reductions							
Net change in extent	-2	0	+2	0	0	0	0
Closing extent	**38**	**30**	**62**	**50**	**20**	**50**	**250**

Ecosystem condition

To measure the condition of each ecosystem asset, the ecosystem condition typology (ECT) is used to structure the relevant characteristics and variables, following the approach described in chapter 5. The intent in the selection of characteristics and variables is to measure each ecosystem's integrity, which is carried out by identifying relevant abiotic, biotic and landscape/seascape characteristics. These characteristics encompass information on biodiversity and are linked as well to the ecosystem's capacity to supply ecosystem services.

Abiotic characteristics of forest, for example, are assessed using three variables: vegetation water content, soil organic carbon stock and foliar nitrogen concentration, each of which describes the physical and chemical state of the ecosystem. The biotic characteristics of the forest are assessed using the following variables: trees species richness, tree cover and the normalized difference vegetation index (NDVI), each of which describes the composition, structure and function of the ecosystem. Forest area density is used to assess landscape characteristics. Collectively, these seven variables provide a good assessment of forest ecosystem integrity.

Table AI.3
Ecosystem type change matrix, 2020 (hectares)

		Ecosystem types – closing						
		Forest	Lake	Cropland	Urban areas	Wetland	Seagrass	Opening extent
Ecosystem types – Opening	Forest	38		2				**40**
	Lake		30					**30**
	Cropland			60				**60**
	Urban areas				50			**50**
	Wetland					20		**20**
	Seagrass						50	**50**
	Closing extent	**38**	**30**	**62**	**50**	**20**	**50**	**250**

The characteristics are structured following the SEEA ECT and following the selection criteria described in appendix A5.1. Relevant condition characteristics, variables, indicators and reference levels for each ecosystem type and associated stylized values are presented in the "Condition accounts by ecosystem type" sheet of the complementary spreadsheet, including a short discussion on the selection of characteristics and indicators in the context of this stylized example.

As an example, tables AI.4a, AI.4b and AI.4c present the three ecosystem condition accounts for forest, namely, the ecosystem condition variable account (table AI.4a), the ecosystem condition indicator account (table AI.4b) and the ecosystem condition indices account (table AI.4c). Columns 1 and 2 of each account exhibit the structure of the SEEA ECT, which is the same for all ecosystem types. Column 3 in each account shows the selected variables for each ECT class. One or more variables may be included for each class following the general advice provided in chapter 5. Column 4 in the variable and indicator accounts shows the measurement unit for each selected variable.

In the ecosystem variable account, columns 5 and 6 record the observed variable values at the opening and closing of the accounting period. Column 7 shows the change over the accounting period.

Table AI.4a
Ecosystem condition variable account for forests, 2020

SEEA ECT class		Variable descriptor	Measurement unit	Variable values (observed)		
				Opening	Closing	Change
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Abiotic characteristics	Physical state	Vegetation water content (NDWI)	Index (-1 to 1)	0.31	0.29	-0.02
	Chemical state	Soil organic carbon stock	tC/ha	100	95	-5
		Foliar or litter nitrogen concentration	mg N/g dry weight	18	17	-1
Biotic characteristics	Compositional state	Tree species richness	Number	6	5	-1
	Structural state	Tree cover	%	81	75	-6
	Functional state	Vegetation index (NDVI)	Index (-1 to 1)	0.65	0.63	-0.02
Landscape/seascape characteristics		Forest area density	%	74	59	-15

Abbreviations: NDWI, normalized difference water index; NDVI, normalized difference vegetation index; tC/ha, tons of carbon per hectare; N, nitrogen; mg, milligrams; g, grams.

In the ecosystem indicator account, columns 5 and 6 show the variable values from the ecosystem variable account and columns 7 and 8 record the lower and upper reference-level values for each variable, which are determined on the basis of the agreed reference condition (see appendix A5.2). In this example, forest, lake, wetland and seagrass are assessed in relation to natural reference conditions, while cropland and urban area are assessed in relation to anthropogenic reference conditions. The entries in columns 9 and 10 are the opening and closing values for the condition indicators derived after normalizing variable values based on the reference levels. Column 11 shows the change in indicator value between opening and closing of the accounting period.

Table AI.4b
Ecosystem condition indicator account for forests, 2020

SEEA ECT class		Variable descriptor	Measurement unit	Variable values (observed)		Reference-level values		Indicator values (rescaled)		
				Opening	Closing	Lower level	Upper level	Opening	Closing	Change
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Abiotic characteristics	Physical state	Vegetation water content (NDWI)	Index (-1 to 1)	0.31	0.29	-1	1	0.66	0.65	-0.01
	Chemical state	Soil organic carbon stock	tC/ha	100	95	0	250	0.40	0.38	-0.02
		Foliar or litter nitrogen concentration	mg N/g dry weight	18	17	4	40	0.39	0.36	-0.03
Biotic characteristics	Compositional state	Tree species richness	Number	6	5	0	10	0.60	0.50	-0.10
	Structural state	Tree cover	%	81	75	0	100	0.81	0.75	-0.06
	Functional state	Vegetation index (NDVI)	Index (-1 to 1)	0.65	0.63	-1	1	0.83	0.82	-0.01
Landscape/seascape characteristics		Forest area density	%	74	59	0	100	0.74	0.59	-0.15

Abbreviations: NDWI, normalized difference water index; NDVI, normalized difference vegetation index; tC/ha, tons of carbon per hectare; N, nitrogen; mg, milligrams; g, grams.

Table AI.4c
Ecosystem condition indices account for forests, 2020

SEEA ecosystem condition typology class		Variable descriptor	Indicator values (0 - 1)		Indicator weight	Index values		
			Opening	Closing		Opening	Closing	Change[a]
(1)	(2)	(3)	(9)	(10)	(12)	(13)	(14)	(15)
Abiotic characteristics	Physical state	Vegetation water content (NDWI)	0.66	0.65	0.17	0.11	0.11	0.00
	Chemical state	Soil organic carbon stock	0.40	0.38	0.08	0.03	0.03	0.00
		Foliar or litter nitrogen concentration	0.39	0.36	0.08	0.03	0.03	0.00
	Total abiotic				0.33	**0.17**	**0.17**	**-0.01**
Biotic characteristics	Compositional state	Tree species richness	0.60	0.50	0.17	0.10	0.08	-0.02
	Structural state	Tree cover	0.81	0.75	0.17	0.14	0.13	-0.01
	Functional state	Vegetation index (NDVI)	0.83	0.82	0.17	0.14	0.14	0.00
	Total biotic				0.50	**0.37**	**0.34**	**-0.03**
Landscape/ seascape characteristics		Forest area density	0.74	0.59	0.17	0.12	0.10	-0.03
	Total landscape/ seascape					**0.12**	**0.10**	**-0.03**
Total					1.00	**0.67**	**0.16**	**-0.06**

Abbreviations: NDWI, normalized difference water index; NDVI, normalized difference vegetation index.

[a] Changes in index values are derived as the difference between opening and closing index values. Owing to rounding, the results may differ from those obtained through weighting the change in indicator values to rounding, this may differ from the result obtained from weighting the change in indicator values.

In the ecosystem index account, columns 9 and 10 exhibit indicator values from the ecosystem indicator account. Column 12 records the weight for each indicator in the overall index for the ecosystem. In this example, derivation of the overall condition index is based on equal weighting of each of the ECT classes used to compile the index.[c] Usually, six ECT classes are measured and the weight for each class is therefore 0.17. Where there is more than one variable in an ECT class, each variable is equally weighted within that class to derive the subindex. Thus, for forest, the subindex for chemical state is derived using equal weights of the two component variables. Columns 13 and 14 record the derived opening and closing index values for each characteristic and the associated subindices and for the total index. Column 15 records the changes in index values.

[c] Section 5.4.2 provides a discussion on potential aggregation functions and weights. It is to be noted that an area-weighted approach has been used here, meaning that the overall index is invariant with respect to whether the data are collated at finer resolutions (e.g. pixels) or at larger resolutions (e.g. for the ecosystem asset).

The complementary spreadsheet shows how these three condition accounts can be combined into a single table. This alternative presentation may be useful in some contexts.

Table AI.5 shows the ecosystem condition indices and subindices for each of the six ecosystem types in this example, using the opening and closing index values and associated changes in those values as derived in the spreadsheet. An average measure of ecosystem condition across all ecosystem types has not been derived, as this would imply aggregation across different reference conditions, which is not recommended.

As noted above, additional detail for each of the condition accounts is provided in the complementary spreadsheet. The spreadsheet also provides a short discussion on the selection of characteristics for each ecosystem type. In summary, and within the general ecological context for *SEEALand* introduced above, changes in condition for each ET recorded in table AI.5 reflect the following:

- **Forest**: a substantial area of forest has been cleared previously for cropland and there has been a further small conversion in this accounting period. This results in a large decrease in forest area density, a proxy for forest connectivity. Tree cover has declined as well. Other condition variables exhibit smaller changes.
- **Lake**: a long-term action plan on nutrient management leads to a further improvement in lake condition, starting from what is already good quality.
- **Wetland**: sewerage overflow from urban wastewater treatment plants and intensive land use continue to affect wetland water quality.
- **Cropland**: cropland is slowly degrading through intensive use although there is a policy aimed at increasing organic farming practices.
- **Urban ecosystem**: as shown in the account, there has been a slight decline in condition of urban ecosystem over the accounting period related to a loss of urban green area
- **Seagrass**: seagrass beds are under pressure from sewerage overflow from urban area and the associated organic pollution

Table AI.5
Ecosystem condition indices account by ecosystem type

	Ecosystem types					
Accounting entries	Forest	Lake	Crop-land	Urban area	Wet-land	Sea-grass
Opening condition value	**0.67**	**0.63**	**0.47**	**0.50**	**0.59**	**0.45**
Change in abiotic ecosystem characteristics	-0.01	0.02	0.00	0.01	-0.02	-0.03
Change in biotic ecosystem characteristics	-0.03	0.03	0.01	-0.02	0.00	-0.03
Change in landscape-level characteristics	-0.03	0.00	0.00	-0.01	-0.01	-0.02
Net change in condition	**-0.06**	**0.05**	**0.00**	**-0.02**	**-0.04**	**-0.08**
Closing condition value	**0.61**	**0.67**	**0.47**	**0.49**	**0.56**	**0.37**

In this example, there has been one conversion during the accounting period, from forest to cropland. Following the guidance provided in chapter 5, the measurement of condition at the opening and closing of the accounting period should relate to the area of the ecosystem at that point in time. Consequently, in this example, the measure of closing condition for forest will relate to a smaller area of forest than the area related to the measure of opening condition. The opposite is true for cropland.

Accepting that conversions will occur, an approach is needed to accommodate the effect of the change in extent and to make the opening and closing measures of condition comparable. The general approach (and the approach applied in this example) when (a) accounting at relatively large scales (e.g. at catchment scale or larger) and (b) conversions are relatively small (e.g. < 5 per cent of total area), is to incorporate characteristics for the measurement of condition that are sensitive to changes in extent, for example, tree cover and share of lake shoreline covered by natural vegetation.

At the same time, where there are significant conversions among ecosystem types during an accounting period or where accounting is undertaken for small areas, it is likely to be necessary to explicitly distinguish changes in ecosystem extent and to assess changes in ecosystem condition more carefully. Where data are available, a useful approach is to measure the condition of the area of the ET that has remained unchanged over the accounting period separately from the condition of the area that has been converted. This approach may be most readily applied when data are used that are mapped to individual pixels, enabling the condition of unconverted areas to be distinguished from the condition of converted areas.

Ecosystem services

The ecosystem services supplied by the various ecosystem types are shown in table AI.6. The corresponding use of these ecosystem services is shown in table AI.7. All flows are treated as final ecosystem services, that is to say, they are recorded as flowing from ecosystem assets directly to economic units. There are no imports or exports of services to be recorded or intermediate services flowing between ecosystem assets to be recorded.

Ecosystem services flows in monetary terms are estimated by multiplying the physical flow of the service recorded in tables AI.6 and AI.7 by the relevant price for each service reflecting their exchange values. The estimates are recorded in tables AI.8 and AI.9, which present SUTs in monetary terms.

The following prices have been assumed in deriving the monetary supply and use entries:

Wood provisioning	60 currency units/m^3
Crop provisioning	75 currency units/ton
Wild fish biomass provisioning	350 currency units/ton
Global climate regulation	25 currency units/ton of CO_2
Water purification	100 currency units/ton of nitrogen removed
Recreation-related	5 currency units/visit

Table AI.6
Ecosystem services supply and use account in physical terms – supply table, 2020

SUPPLY		**UNITS**	Agriculture	Forestry	Fisheries	Electricity, gas, steam and air-conditioning supply	**Total Industry**	Government consumption	Household consumption	**Total supply by resident economic units**	Supply from non-resident economic units - imports	**Total supply by economic units**	Forest	Lake	Cropland	Urban area	Wetland	Seagrass	**Total supply resident ecosystem assets**	Supply from non-resident ecosystem assets - Imports		**TOTAL SUPPLY**
																				Final	Inter-medi-ate	
Selected ecosystem services																						
Provisioning services																						
Biomass provisioning	Crop provisioning	Tons													150				150	0	0	150
	Wood provisioning services	m^3											140						140	0	0	140
	Wild fish and other natural aquatic biomass provisioning services	Tons												3				6	9	0	0	9
Regulating and maintenance services																						
Global climate regulation services		Tons CO_2											150			5	20	250	425	0	0	425
Water purification services		Tons N removed															7		7	0	0	7
Cultural services																						
Recreation-related services		Number of visits											1 500	5 000		2 500		800	9 800	0	0	9 800

Abbreviations: N, nitrogen; m^3, cubic metres.

Note: Resident ecosystem assets are those ecosystem assets that are located within the EAA, while non-resident ecosystem assets are those located outside the ecosystem EAA.

Table AI.7
Ecosystem services supply and use account in physical terms – use table, 2020

USE		UNITS	Agriculture	Forestry	Fisheries	Electricity, gas, steam and air-conditioning supply	**Total industry**	Government consumption	Household consumption	**Total use by resident economic units**	Exports - final ecosystem services	**Total use by economic units**	Forest	Lake	Cropland	Urban area	Wetland	Seagrass	**Total use resident ecosystem assets**	Exports - intermediate services	**Total use by ecosystem assets**	**TOTAL USE**
Selected ecosystem services																						
Provisioning services																						
Biomass provisioning	Crop provisioning	Tons	150				150			150		150							0	0	0	150
	Wood provisioning services	m^3		140			140			140		140							0	0	0	140
	Wild fish and other natural aquatic biomass provisioning services	Tons			9		9			9		9							0	0	0	9
Regulating and maintenance services																						
Global climate regulation services		Tons CO_2					0	425		425		425							0	0	0	425
Water purification services		Tons N removed				7	7			7		7							0	0	0	7
Cultural services																						
Recreation-related services		Number of visits					0			9 800		0							0	0	0	9 800

Abbreviations: N, nitrogen; m^3, cubic metres.

Note: Resident ecosystem assets are those ecosystem assets that are located within the EAA, while non-resident ecosystem assets are those located outside the EAA.

Table AI.8
Ecosystem services supply and use account in monetary terms – supply table, 2020 (currency units, thousands)

SUPPLY		Agriculture	Forestry	Fisheries	Electricity, gas, steam and air-conditioning supply	**Total Industry**	Government consumption	Household consumption	**Total use by resident economic units**	Exports - final ecosystem services	**Total use by economic units**	Forest	Lake	Cropland	Urban area	Wetland	Seagrass	**Total supply resident ecosystem assets**	Supply from non-resident ecosystem assets - Imports		**TOTAL SUPPLY**
																			Final	Inter-medi-ate	
Selected ecosystem services																					
Provisioning services																					
Biomass provisioning	Crop provisioning													11.25				11.25	0	0	11.25
	Wood provisioning services											8.4						8.4	0	0	8.4
	Wild fish and other natural aquatic biomass provisioning services												1.05				2.1	3.15	0	0	3.15
Regulating and maintenance services																					
Global climate regulation services												3.75			0.125	0.5	6.25	10.625	0	0	10.625
Water purification services																0.7		0.7	0	0	0.7
Cultural services																					
Recreation-related services												7.5	25		12.5		4	49	0	0	49
TOTAL SUPPLY												**19.65**	**26.05**	**11.25**	**12.625**	**1.2**	**12.35**	**83.125**	**0**	**0**	**83.125**

Table AI.9

Ecosystem services supply and use account in monetary terms – use table, 2020 (currency units, thousands)

USE		Agriculture	Forestry	Fisheries	Electricity, gas, steam and air-conditioning supply	**Total industry**	Government consumption	Household consumption	**Total use by resident economic units**	Exports - final ecosystem services	**Total use by economic units**	Forest	Lake	Cropland	Urban area	Wetland	Seagrass	**Total use resident ecosystem assets**	Exports - intermediate services	**Total use by ecosystem assets**	**TOTAL USE**
Selected ecosystem services																					
Provisioning services																					
Biomass provisioning	Crop provisioning	11.25				11.25			11.25		11.25							0	0	0	11.25
	Wood provisioning services		8.4			8.4			8.4		8.4							0	0	0	8.4
	Wild fish and other natural aquatic biomass provisioning services			3.15		3.15			3.15		3.15							0	0	0	3.15
Regulating and maintenance services																					
Global climate regulation services							10.625		10.625		10.625							0	0	0	10.625
Water purification services					0.7	0.7			0.7	0.7	700							0	0	0	0.7
Cultural services																					
Recreation-related services								49	49		49							0	0	0	49
TOTAL SUPPLY		**11.5**	**8.4**	**3.15**	**0.7**	**23.5**	**10.625**	**49**	**83.125**		**83.125**							**0**	**0**	**0**	**83.125**

Commonly, prices for wood, crop and wild fish provisioning services would be derived using directly observed values (e.g. stumpage values for wood, land rental prices) or residual value and resource rent methods. Global climate regulation services are more commonly estimated using data from carbon trading schemes or data on the social cost of carbon (under appropriate assumptions). Water purification services may be estimated using replacement cost techniques and recreation-related services may be estimated using data derived from the application of travel cost methods. These various techniques are described in chapter 9.

Gross ecosystem product (GEP) is equal to the sum of the values of all final ecosystem services less net imports of intermediate services. Since there are no intermediate services in this example, GEP is equal to 83,125 currency units.

The entries for ecosystem services in the physical and monetary ecosystem services flow accounts shown above concern actual ecosystem services flows supplied and used during the accounting period. For the compilation of the monetary ecosystem asset account, it is necessary to estimate expected ecosystem services flows at the opening and closing of the accounting period. At the opening of the accounting period, expected flows are usually estimated based on knowledge available at that point in time concerning past ecosystem services flows, current levels of ecosystem condition and likely future changes in ecosystem condition. At the closing of the accounting period, the actual flows during the accounting period are taken into consideration as well as changes in condition that would affect the capacity to supply services.

Table AI.10
Net present value (NPV) calculations for forest, 2020

		Opening value (1 January 2020)	Closing value (31 December 2020)
Expected physical flows	Wood provisioning (m^3)	150	120
	Global climate regulation (tons CO_2)	160	125
	Recreation-related (number of visits)	1 600	1 450
		Currency units	
Expected prices	Wood provisioning	60	65
	Global climate regulation	25	26
	Recreation-related	5	5
Expected exchange values	Wood provisioning	9 000	7 800
	Global climate regulation	4 000	3 250
	Recreation-related	8 000	7 250
	Total	**21 000**	**18 300**
NPV	Wood provisioning	387 885	336 167
	Global climate regulation	172 393	140 070
	Recreation-related	344 787	312 463
	Total	**905 065**	**788 700**
Change in NPV			**-116 366**

Assuming changes in condition are relatively gradual and other potential drivers (such as changes in population) are steady, measures of expected flows would not change significantly over an accounting period and may be quite closely aligned with the actual ecosystem services flows during the accounting period.

For *SEEALand*, the expected physical flows and expected prices at the opening and closing of the accounting period are shown in the complementary spreadsheet. In summary, there are a range of small differences between the expected flows at the opening of the accounting period and the actual flows recorded during the period. At the closing of the accounting period, the expected flows are lower for wood provisioning, global climate regulation and recreation-related services for forests, reflecting the ecosystem conversion that took place. An increase in crop provisioning services is also expected. A small decline in global climate regulation services from wetland, reflecting its decline in condition, is expected, as is a small rise in ecosystem services from lake, reflecting its improvement in condition. Recreation-related services for urban area are expected to increase owing to larger populations but decrease for seagrass due to decline in condition.

With respect to prices, they are expected to remain the same for crop provisioning, water purification and recreation-related services and to increase for wood and wild fish provisioning, driven by both increased demand and increased regulation of the sustainability of those industries. It is also expected that the price of global climate regulation services will increase, reflecting increases in the marginal damages incurred through carbon release.

Monetary ecosystem asset account

Estimates of opening and closing asset values are estimated for each ecosystem type covering all relevant ecosystem services. As explained at various points throughout SEEA EA, the monetary values recorded in the monetary ecosystem asset account cannot be interpreted as reflecting a complete or universal measure of the value of nature, since they exclude a range of values, such as intrinsic values, that may be ascribed to ecosystems but may not be quantified in monetary terms.

In deriving the estimate of NPV, the following assumptions are made:

- An asset life of 100 years
- A constant flow of ecosystem services and constant price of ecosystem services over asset life (as noted above, some changes in expected physical flows and prices have been incorporated reflecting a change in expectations between the opening and closing of the accounting period, as a result in part of ecosystem conversions)
- No further ecosystem conversions to the closing extent on 31 December 2020
- Discount rate of 2 per cent in real terms for all ecosystem services
- Income earned at the end of the accounting period

The detailed calculations for each ecosystem type in terms of future ecosystem flows and prices and resultant NPV are shown in the “NPV by ET” sheet of the spreadsheet. Table AI.10 directly below displays the structure of information used to compile NPV for forest.

The entries in the monetary ecosystem asset account (table AI.11) are derived following the principles described in chapter 10 and the steps described in appendix A10.1 for the decomposition of the change in asset values. The following key observations can be drawn from the monetary ecosystem asset account regarding *SEEALand*:

- The asset value of lake is the highest among the six ecosystem types
- Ecosystem degradation has been recorded for forest, wetland and seagrass, reflecting their decline in condition and the associated decline in expected ecosystem services flows
- Ecosystem conversion from forest to cropland has a net negative effect on asset values
- Revaluations reflecting changes in expected prices for ecosystem services can be seen to affect all ecosystem types (except cropland, where prices for the only ecosystem service, that is, crop provisioning, did not change)

Table AI.11
Monetary ecosystem asset account, 2020 (currency units)

	Forest	Lake	Crop-land	Urban area	Wet-land	Sea-grass	TOTAL
Opening value	905 065	1 078 321	484 856	522 568	51 718	529 679	3 572 207
Ecosystem enhancement	0	15 300	0	0	0	0	15 300
Ecosystem degradation	-108 111	0	0	0	-1 099	-163 946	-273 156
Ecosystem conversions							
Additions	0	0	16 944	0	0	0	16 944
Reductions	-43 435	0	0	0	0	0	-43 435
Other changes in volume of ecosystem assets							
Catastrophic losses							
Upward reappraisals	0	0	47 704	43 098	0	0	90 802
Downward reappraisals	0	0	0	0	0	0	0
Revaluations	35 180	47 624	0	215	840	160 929	244 789
Net change in value	-116 366	62 924	64 648	43 314	-259	-3 017	51 244
Closing value	**788 700**	**1 141 244**	**549 504**	**565 881**	**51 459**	**526 662**	**3 623 451**

Annex II
Research and development agenda

SEEA EA provides a consistent accounting framework for delineating and measuring ecosystems. Data compiled using SEEA EA are invaluable inputs for the evaluation of policy and analysis of environmental and economic issues. As environmental and economic contexts change, as understanding of the links between the environment and the economy develops and as policy and analytical requirements evolve, SEEA EA must be reviewed to ensure its ongoing relevance.

In addition, as implementation of SEEA EA is carried out increasingly across the world, the range of experience gained will offer new insights into the measurement of ecosystem assets and services that should be considered in the conceptualization of environmental and economic accounts.

As the accounting basis for SEEA EA is the System of National Accounts (SNA), developments in accounting within the context of that international standard will also need to be considered. The research agenda for the SNA is presented in annex 4 of the 2008 SNA (United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank, 2009) and a new programme of work is under consideration. Of particular relevance in this regard is the expanding range of new economic instruments that are being created and implemented as part of policies for managing the environment. The research agendas of SEEA EA, the SEEA Central Framework and the SNA need to reflect these developments.

The process for reviewing and updating SEEA EA will follow standard processes that have developed for the review of international standards. Thus, there will be consideration within the United Nations statistical system of (a) the relative importance of updating the standard to ensure its ongoing relevance; (b) the consequences of making any changes and the potential impact on implementation; and (c) the extent to which research into an area of proposed change has been completed. The process for selecting topics for investigation and determining the appropriate changes to SEEA EA will entail widespread consultation and will involve both compilers and users of ecosystem accounts.

Since SEEA EA is an integrated accounting system with links among different accounts, changes in individual areas in response to specific concerns is likely to have broader ramifications. As SEEA EA has strong links as well to other emerging areas of statistics beyond accounting, such as geospatial statistics, updating the standard must be completed in a coordinated and integrated fashion.

Described below are the major topics identified during the revision of SEEA EEA as being the ones that would benefit from further consideration within the international statistical community. These topics concern both conceptual issues and issues related to methods and implementation. They are categorized broadly and will need to be detailed and refined through further discussion before the commencement of research work. Additional topics may be proposed in due course.

Topics concerning conceptual issues

Description and measurement of ecosystem capacity

Classification of ecosystem services

Treatment of the atmosphere

Connections to complementary valuations of ecosystem services and ecosystem assets

Ongoing alignment with the SNA

Topics concerning methods and implementation

Further adapting measurement techniques to support implementation

Data standards and availability

Applications and indicators

Research and development in some of these areas might be usefully combined with work on the research agenda of the SEEA Central Framework. Specifically, research work on accounting for soil resources, valuation of water resources and development of land-cover and land-use classifications could be considered jointly.

A regular review of the research and development agenda, including for setting work priorities, will be undertaken by the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA). An important facet of advancing this work will be the coordination of research and testing, including a recognition of the differences between countries in terms of resources, data and the complexity of their environmental, social and economic contexts.

Advancement of the research and development agenda will be undertaken under the auspices of the Committee of Experts but it is expected that it will involve substantive collaboration with experts and stakeholders extending well beyond the statistical community, in keeping with the spirit of development of SEEA EA itself. It is also expected that beyond work within the national and international public sectors, there will be active participation by the academic community and organizations focused on environment and sustainability. Further, collaboration in the context of advances under way in accounting for natural capital in the corporate sector should be pursued.

The outputs of work on the topics discussed below may emerge in a number of forms including published research papers, technical guidance and notes and training materials. Ultimately, a revision of SEEA EA would be considered at an appropriate time in the same way that all statistical standards are considered for updating in order to reflect current best practice.

Topics on conceptual issues

Description and measurement of ecosystem capacity

SEEA EA provides a definition of ecosystem capacity in terms of the ability of ecosystem assets to supply individual ecosystem services without reducing ecosystem condition. This is a meaningful and implementable definition. Nonetheless, the discussion of ecosystem capacity highlights a general conceptual preference for a more systemic approach that takes into consideration relationships among ecosystem services and among ecosystem assets.

Further research on this topic is appropriate, building on the initial discussion of a systemic approach to the definition and measurement of ecosystem capacity. That research should in particular consider the links between the concept of ecosystem capacity and that of ecosystem condition; examine the implications of a systemic definition of ecosystem capacity for the definition and measurement of ecosystem degradation, ecosystem enhancement and other changes in the value of ecosystem assets; and assess the potential of a systemic definition of ecosystem capacity to better articulate the ways in which ecosystem accounting can support discussion of ecosystem resilience, maintenance of ecosystem function and measurement of ecological thresholds and limits.

Classification of ecosystem services

SEEA EA provides a reference list of ecosystem services including 33 main ecosystem services and agreed labels and descriptions. This reference list supports development of methods, sharing of knowledge and experience and comparison of estimates of ecosystem services. It was developed in collaboration with experts who have been leaders in the development of a range of ecosystem service classifications and typologies including the Common International Classification of Ecosystem Services (CICES), the National Ecosystem Services Classification System (NESCS Plus), The Economics of Ecosystems and Biodiversity (TEEB) approach and the "nature's contribution to people" approach under the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). It was not possible, however, during the revision process to establish an agreed classification of ecosystem services for ecosystem accounting purposes that satisfied general principles for a statistical classification.

Correspondences between the reference list and the existing range of classifications and typologies have been developed and are available in the form of an online annex to SEEA EA. They can serve as the basis for advancement of work towards an internationally agreed classification of ecosystem services for statistical purposes.

Treatment of the atmosphere

Both SEEA EA and the SEEA Central Framework exclude measurement of the atmosphere from the scope of environmental assets. In the case of SEEA EA, this reflects a focus on the biosphere; in the case of the Central Framework, this has reflected a lack of potential for quantifying the atmosphere in a meaningful way for accounting purposes. At the same time, both documents recognize the significance of the atmosphere as part of the environment, for example, in terms of the importance of air quality and the atmosphere's role as a sink for GHG emissions.

Further work is needed to articulate how the atmosphere and its functions may be appropriately characterized in accounting terms. This work should consider how the atmosphere might be partitioned into relevant spatial units; how the condition of the atmosphere might be assessed; whether there are ecosystem services provided by the atmosphere; and how transactions related to the atmosphere, for example, transactions associated with reducing GHG emissions, are most appropriately recorded. Research on this topic must be linked to related work within the context of the SEEA Central Framework and the SNA.

Connections to complementary valuations of ecosystem services and ecosystem assets

SEEA EA provides a clear valuation concept (i.e. exchange values) and a clear measurement boundary related to ecosystem services, which support a consistent approach to the monetary valuation of ecosystem services and ecosystem assets for accounting purposes. While the concept of exchange values is well established in national accounting, it has been less commonly applied in environmental valuation, where alternative economic valuation concepts are applied.

Further discussion is appropriate, based on the concepts described in SEEA EA and the complementary valuation measures described in chapter 12, with regard to further refining and communicating the connections between exchange value-based estimates from the ecosystem accounts and other approaches to valuation of the environment. A particular focus should be on ensuring appropriate application and interpretation of different valuation concepts in different decision-making contexts. This work may entail consideration of complementary valuations such as measurement of consumer surplus and changes in welfare; assessment of ecosystem disservices and negative externalities; treatment of non-use values; wealth accounting based on shadow prices; and restoration cost-based approaches to the measurement of ecosystem degradation. Work on this topic should be undertaken in consultation with SNA experts.

Ongoing alignment with the SNA

One motivation in the conceptual design of SEEA EA has been to utilize the potential to compare and align estimates from the ecosystem accounts with measures of income and wealth from the SNA. As economic and environmental contexts change, all statistical standards are subject to reconsideration. In this regard, a number of emerging asset boundary issues deserve ongoing and joint consideration by relevant experts to ensure the ongoing alignment between SEEA EA and the SNA. In a number of cases, those issues are emerging because of ongoing changes in institutional arrangements and markets structures in response to the effects of climate change and other environmental challenges. The issues include treatment of stranded assets such as fossil fuel reserves; valuation of water resources; valuation of renewable resources; treatment of payments for ecosystem services and transactions in environmental markets; and recognition of liabilities in the context of environmental damage.

In addition, further engagement with national accounts experts would be beneficial in the area of treatment of public goods and recording of relevant transactions, for example, concerning collective consumption and social transfers in kind. These topics are of relevance in the context of allocation of the use of some ecosystem services and design of the sequence of institutional sector accounts. The update of the 2008 SNA provides an excellent opportunity to address some of the above-mentioned issues.

Topics on methods and implementation

Further adapting measurement techniques to support implementation

There are many components to be measured across the conceptual framework of the ecosystem accounts. There are also well-established measurement approaches for those components covering the delineation of ecosystem types, the measurement of ecosystem condition and the measurement of ecosystem services flows. At the same time, adapting these approaches to the requirements of ecosystem accounting is relatively recent, and it is expected that there will be further testing and development of measurement techniques in all areas of ecosystem accounting as part of the wider implementation process.

Work in this area should build on technical guidance on ecosystem accounting.[d] Specific areas of focus in the testing and developments of methods for accounting in physical terms concern:

- Delineation of ecosystem assets, especially in relation to measurement of change over time and identification of ecosystem conversions

[d] In particular the *Guidelines on Biophysical Modelling for Ecosystem Accounting* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022a) and the *Monetary Valuation of Ecosystem Services and Assets for Ecosystem Accounting. Interim report* (United Nations, Department of Economic and Social Affairs, Statistics Division, 2022b).

- Selection of a minimum set of ecosystem condition variables and determination of reference levels and conditions for different ecosystem types along a gradient from natural to anthropogenic
- Articulation of relationships between ecosystem condition variables, ecosystem characteristics and processes and ecosystem services
- Spatial modelling of ecosystem services, especially with respect to use of ecosystem services and relative to ecosystem capacity
- Methods to account for specific ecosystem types, for example, oceans, urban areas and wetlands

Areas of focus in the testing and development of methods for accounting in monetary terms concern:

- Collection of data on ecosystem services by ecosystem type and taking into account the location of users and variations in institutional arrangements
- Application of value transfer techniques for accounting purposes, in particular in the context of alignment with exchange value concepts, consistency with data collected in physical terms on extent, condition and services flows and advancement of the potential of value generalization techniques
- Approach to the measurement of future flows and prices of ecosystem services as input to the calculation of NPVs for ecosystem assets
- Interpretation of data from ecosystem accounts in monetary terms

Data standards and availability

The compilation of ecosystem accounts involves the collation and integration of a wide variety of types of data, many of which may be unfamiliar to statistical offices. Establishing a platform for the development of shared data tools, frameworks for assessing data quality and expectations on quality would be a significant part of the implementation process. Areas of focus in the context of this work include:

- Principles and practices for the development of infrastructure for spatial data to support ecosystem accounting
- Determination of a minimum set (tier 1) of account-ready data
- Principles and practices for accessing and sharing data, including tools to support the interoperability of data and systems
- Bridge tables and crosswalks from SEEA EA reference classifications and lists for ecosystem types and ecosystem services to other, related classifications, lists and typologies
- Development of spatial sampling methods and strategies
- Articulation of data quality assessment frameworks, tools and processes, especially concerning spatial data

Applications and indicators

Section E of SEEA EA provides an introduction to a range of complementary presentations, thematic accounts and indicators that demonstrate the potential for using ecosystem accounts data to support decision-making. Advancement of applications and indicators building on ecosystem accounting can be continued as part of a wider implementation programme. Specific areas of focus include:

- Development of guidance for SEEA-based thematic accounts for biodiversity, climate change, oceans and urban areas

- Design of global accounts that incorporate data within and beyond national jurisdictions, for example, concerning oceans and the atmosphere
- Description of aggregates and indicators based on SEEA EA and related data to support environmental monitoring and reporting. This includes the development of aggregate indices of ecosystem condition; indicators linking ecosystem accounting data to data on economic production, employment and restoration expenditure; and indicators designed to support global environmental conventions including the Convention on Biological Diversity; the United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa; and the United Nations Framework Convention on Climate Change

Glossary

A

Abiotic flows: contributions to benefits from the environment that are not underpinned by, or reliant on, ecological characteristics and processes. (para. 6.35)

Anthropogenic ecosystems: ecosystems that is influenced predominantly by human activities and for which a stable natural ecological state is unattainable and future socioeconomic interventions are required to maintain a new stable state. (table A5.2.1)

B

Balance sheet: a statement drawn up in respect of a particular point in time, of the values of assets owned and of the liabilities owed by an institutional unit or group of units. (2008 SNA, para. 13.2)

Basic spatial unit (BSU): a geometrical construct representing a small spatial area. (para. 3.72)

Benefits: goods and services that are ultimately used and enjoyed by people and society. (para. 2.15)

Biodiversity: the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. (Convention on Biological Diversity, art. 2, entitled "Use of terms")

Biome: "a biotic community finding its expression at large geographic scales, shaped by climatic factors and characterized by physiognomy and functional aspects, rather than by species or life-form composition" (Mucina, 2019). (para. 3.62)

C

Catastrophic losses: reductions in assets due to catastrophic and exceptional events. (SEEA Central Framework, para. 5.49)

Cultural services:[*] experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contribute to a range of cultural benefits. (para. 6.51)

[*] The label "cultural services" is a pragmatic choice and reflects its long-standing use in the ecosystem services measurement community. It is not meant to imply that culture itself is a service; rather it is a summary label and as such is intended to capture the variety of ways in which people connect to, and identify with, nature and the variety of motivations for those connections.

D

Depletion: in physical terms, the decrease in the quantity of the stock of a natural resource over an accounting period that is due to the extraction of the natural resource by economic units occurring at a level greater than that of regeneration. (SEEA Central Framework, para. 5.76)

Discount rate: rate of interest used to adjust the value of a stream of future flows of revenue, costs or income to account for time preferences and attitudes to risk. (SEEA Central Framework, para. 5.145)

E

Economic owner: the institutional unit entitled to claim the benefits associated with the use of an asset in the course of an economic activity by virtue of accepting the associated risks. (2008 SNA, para. 10.5)

Ecosystem: "a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit" (Convention on Biological Diversity, art. 2, entitled "Use of terms").

Ecosystem accounting area (EAA): the geographical territory for which an ecosystem account is compiled. (para. 2.12)

Ecosystem asset life: the period over which an ecosystem asset is expected to generate ecosystem services. (para. 10.72)

Ecosystem assets: contiguous spaces covered by a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions. (para. 2.11)

Ecosystem capability: concerns an ecosystem's ability to generate an ecosystem service under current conditions and type of use, irrespective of the potential impacts of increasing the supply of that service on the supply of other ecosystem services. (para. 6.150)

Ecosystem capacity: ability of an ecosystem to generate an ecosystem service under current ecosystem condition, management and uses, at the highest yield or use level that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem. (para. 6.141)

Ecosystem characteristics: system properties of an ecosystem and its major abiotic and biotic components (water, soil, topography, vegetation, biomass, habitat and species). Examples of such characteristics include vegetation type, water quality and soil type. (para. 5.28)

Ecosystem condition: quality of an ecosystem measured in terms of its abiotic and biotic characteristics. (para. 2.13)

Ecosystem condition indicators: rescaled versions of ecosystem condition variables. (para. 5.60)

Ecosystem condition indices (and subindices): composite indicators that are aggregated from the combination of individual ecosystem condition indicators recorded in the ecosystem condition indicator account. (para. 5.81)

Ecosystem condition typology (ECT): a hierarchical typology for organizing data on ecosystem condition characteristics. (para. 5.30)

Ecosystem condition variables (ECV): quantitative metrics describing individual characteristics of an ecosystem asset. (para. 5.41)

Ecosystem conversions: situations in which, for a given location, there is a change in ecosystem type involving a distinct and persistent change in ecological structure, composition and function, which, in turn, is reflected in the supply of a different set of ecosystem services. (para. 4.23)

Ecosystem degradation: the decrease in the value of an ecosystem asset over an accounting period that is associated with a decline in the condition of the ecosystem asset during that accounting period. (para. 10.21)

Ecosystem disservices: arise in contexts in which the outcomes of interactions between economic units and ecosystem assets are negative from the perspective of the economic units. (para. 6.75)

Ecosystem enhancement: the increase in the value of an ecosystem asset over an accounting period that is associated with an improvement in the condition of the asset during that accounting period. (para. 10.15)

Ecosystem extent: size of an ecosystem asset. (para. 2.13)

Ecosystem functional groups (EFGs): functionally distinctive groups of ecosystems within a biome that are defined in a manner consistent with the definition of ecosystems under the Convention on Biological Diversity and that make up the third level of the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET) classification. (para. 3.64)

Ecosystem integrity: an ecosystem's capacity to maintain its characteristic composition, structure, functioning and self-organization over time within a natural range of variability (Pimentel and Edwards, 2000). (para. 5.10)

Ecosystem service measurement baseline: the level of service supply with which a regulating or maintenance service provided by an ecosystem is compared in order to quantify the service. (para. 7.71)

Ecosystem services: the contributions of ecosystems to the benefits that are used in economic and other human activity. (para. 2.14)

Ecosystem services mapping: the process of allocating the supply and use of ecosystem services to locations. (para. 7.66)

Ecosystem type (ET): reflects a distinct set of abiotic and biotic components and their interactions. (para. 2.11)

Environmental assets: the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity. (SEEA Central Framework, para. 2.17)

Environmental pressure: a human-induced process that alters the condition of ecosystems. (Maes and others, 2018). (para. 5.105)

Exchange values: the values at which goods, services, labour or assets are in fact exchanged or else could be exchanged for cash. (2008 SNA, para. 3.118)

Exclusive economic zone (EEZ): (of a country): the area extending up to 200 nautical miles from a country's normal baselines as defined in the United Nations Convention on the Law of the Sea. (SEEA Central Framework, para. 5.248 and related footnote)

Externalities: impacts that "arise when the actions of an individual, firm or community affect the welfare of other individuals, firms or communities [and the] agent responsible for the action does not take full account of the effect" (Markandya and others, 2001). (para. 12.14)

F

Final ecosystem services: those ecosystem services in which the user of the service is an economic unit (e.g. business, government or household). (para. 6.24)

G

Gross ecosystem product (GEP): is equal to the sum of all final ecosystem services at their exchange value supplied by all ecosystem types located within an ecosystem accounting area over an accounting period less the net imports of intermediate services. (para. 9.18)

I

Intermediate services: those ecosystem services in which the user of the ecosystem services is an ecosystem asset and where there is a connection to the supply of final ecosystem services. (para. 6.26)

International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET): a global typological framework that applies an ecosystem process-based approach to ecosystem classification for all ecosystems around the world. The SEEA ecosystem type reference classification reflects IUCN GET. (para. 3.58)

L

Land cover: the observed physical and biological cover of the Earth's surface and includes natural vegetation and abiotic (non-living) surfaces. (SEEA Central Framework, para. 5.257)

Land management: the process of managing the use and development of land resources. There may be differences in the degree to which areas of land or water are managed by humans, ranging from more intensively (in the case, for example, of built-up areas and cropland) to less intensively (in the case, for example, of polar regions and oceans). (para. 3.83)

Landownership: a key characteristic that constitutes a direct link between ecosystems, their management and economic statistics. (para. 3.84)

Landscapes (including those involving freshwater): (as defined for accounting purposes) groups of contiguous, interconnected ecosystem assets representing a range of different ecosystem types. (para. 2.20 with footnote)

Land use: reflects both (a) the activities undertaken and (b) the institutional arrangements put in place for a given area for the purposes of economic production, or the maintenance and restoration of environmental functions. (SEEA Central Framework, para. 5.246)

Legal owner: the institutional unit entitled in law and sustainable under the law to claim the benefits associated with the entities. (2008 SNA, para. 10.5)

M

Managed expansions: represent an increase in the area of an ecosystem type due to direct human activity in the ecosystem, including the unplanned effects of such activity. (para. 4.15)

Managed reductions: represent a decrease in the area of an ecosystem type due to direct human activity in the ecosystem, including the unplanned effects of such activity, or to cases where the activity may be illegal. (para. 4.15)

Market prices: amounts of money that willing buyers pay to acquire something from willing sellers. (2008 SNA, para. 3.119)

N

Natural ecosystems: ecosystems that influenced predominantly by natural ecological processes and characterized by a stable ecological state maintaining ecosystem integrity; ecosystem condition ranges within its natural variability. (table A5.2.1)

Natural inputs: all physical inputs that are moved from their location in the environment as part of economic production processes or are directly used in production. (SEEA Central Framework, para. 3.45)

Natural resource residuals: natural resource inputs that do not subsequently become incorporated into production processes and, instead, immediately return to the environment. (SEEA Central Framework, para. 3.98)

Natural resources: include all natural biological resources (including timber and aquatic resources), mineral and energy resources, soil resources and water resources. (SEEA Central Framework, paras. 2.101 and 5.18)

Net present value (NPV): the value of an asset determined by estimating the stream of income expected to be earned in the future and then discounting the future income back to the present accounting period. (SEEA Central Framework, para. 5.110)

Non-SNA benefits: goods and services that are not included in the production boundary of the System of National Accounts (SNA). (para. 6.18)

Non-use values: values that people assign to ecosystems irrespective of whether they use or intend to use those ecosystems. (para. 6.70)

O

Other changes in the volume of ecosystem assets: changes in the value of an ecosystem asset, other than (a) those due to ecosystem enhancement, ecosystem degradation or ecosystem conversion and (b) those that are the result solely of changes in unit prices of ecosystem services. (para. 10.36)

P

Potential supply: concerns the ecosystem's ability to generate an ecosystem service, without the constraint of considering current patterns of use but while still requiring that the condition of the ecosystem be unaffected. (para. 6.150)

Provisioning services: those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems. (para. 6.51)

R

Realm: a major component of the biosphere that differs fundamentally in ecosystem organization and function. (para. 3.61)

Reference condition: the condition against which past, present and future ecosystem condition is compared in order to measure relative change over time. (para. 5.69)

Reference level: the value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable. (para. 5.65)

Regulating and maintenance services: those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles and thereby maintain environmental conditions beneficial to individuals and society. (para. 6.51)

Residuals: flows of solid, liquid and gaseous materials, and energy that are discarded, discharged or emitted by establishments and households through processes of production, consumption or accumulation. (SEEA Central Framework, para. 3.73)

Resource rent: the economic rent that accrues in relation to environmental assets, including natural resources. (SEEA Central Framework, para. 5.114)

Revaluations: changes in the value of ecosystem assets over an accounting period that are due solely to movements in the unit prices of ecosystem services that underpin the derivation of the net present value of those assets. (para. 10.41)

S

Seascapes (including those involving freshwater): (as defined for accounting purposes) groups of contiguous, interconnected ecosystem assets representing a range of different ecosystem types. (para. 2.20 with footnote)

SNA benefits: goods and services that are included in the production boundary of the SNA. (para. 6.17)

Spatial functions: (a) flows related to the use of the environment as a location for transportation and movement, and for buildings and structures; and (b) flows related to the use of the environment as a sink for pollutants and waste. (table 6.1 and para. 6.36)

Supply and use tables (SUTs): accounting tables structured to record flows of final ecosystem services between economic units and ecosystems and flows of intermediate services among ecosystems. Entries can be made in physical and monetary terms. (para. 7.5)

U

Unmanaged expansions: represent an increase in area of an ecosystem type resulting from natural processes, including seeding, sprouting, suckering or layering. (para. 4.15)

Unmanaged reductions: represent a decrease in area of an ecosystem type associated with natural processes. (para. 4.15)

Use values: values arising when the benefit to people is revealed through their direct, personal interaction with the environment or through indirect use. (para. 6.69)

V

Value transfers: comprise a set of techniques that can be applied to enable utilization of data from specific locations in the estimation of monetary values in other locations (also known as benefit transfers). (para. 9.80)

W

Welfare values: those monetary values reflecting the total benefit accruing to consumers and suppliers in the exchange of goods and services. It is commonly measured as the sum of consumer and producer surplus. (para. A12.8)

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