DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS
STATISTICS DIVISION
UNITED NATIONS

System of Environmental-Economic Accounting 2012 - Experimental Ecosystem Accounting Revision

Chapter Draft prepared for Global Consultation

Chapter 3: Spatial units for Ecosystem Accounting

March 2020

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SECTION B: Accounting for Ecosystem Extent and Condition

3 Spatial units for ecosystem accounting

3.1 Introduction

3.1 A key feature of ecosystem accounting is its capacity to integrate spatially referenced data about ecosystems, i.e. data about the location, size and condition of ecosystems within a given area and how these are changing over time. Recording these stocks and changes in stocks in a coherent and mutually exclusive manner supports the derivation of indicators (for example, the rate of change in forest areas relative to the rate of change in agricultural areas).

3.2 For accounting purposes, different ecosystems are reflected as spatial units. The delineation of ecosystems into spatial units requires careful consideration of a range of ecosystem characteristics across the various terrestrial, freshwater and marine ecosystems. The present chapter outlines the approach used in the SEEA to define, classify and delineate spatial units.

3.3 The availability and structure of spatial data used to describe ecosystems and their economic uses and associated beneficiaries is an important driver in the compilation of ecosystem accounts. The spatial and thematic detail of these data, as well as their geospatial comparability and integration into a shared spatial data infrastructure, influences the richness of ecosystem accounts that can be compiled. This issue is discussed further in section 3.4.

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 also 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 ecosystem assets.* ***Ecosystem assets (EA) are contiguous spaces of a specific ecosystem type (ET) characterized by a distinct set of biotic and abiotic components.***

3.6 EAs play a key role in ecosystem accounting. They are the statistical units for ecosystem accounting, i.e. the entities about which information is sought and about which statistics are ultimately compiled. This includes information concerning their extent, condition, the services they provide and their monetary value. In economic statistics terms, EAs are the equivalent of economic units and a complete delineation of all EAs within a country is the ecosystem accounting equivalent of a business register.

3.7 The definition of EAs is a statistical representation of the general definition of ecosystems from the Convention on Biological Diversity.[1] In article 2 ("Use of terms") of the Convention, an ecosystem is defined as *"a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit"*.

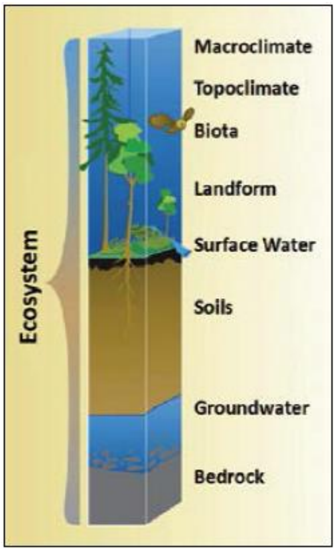
3.8 Ecosystem assets lie within the wider definition of environmental assets established in the SEEA Central Framework. *Environmental assets are the naturally occurring living and non-*

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

living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity (2.17). Thus, as for environmental assets, ecosystem assets are considered assets on the basis of their biophysical existence and hence are not dependent on establishing flows of benefits or ownership as is required for economic assets in the System of National Accounts (SNA). Nonetheless, as discussed in Chapter 11, establishing the economic ownership of ecosystem assets and attributing benefits is required for the integration of ecosystem accounting data with economic accounts.

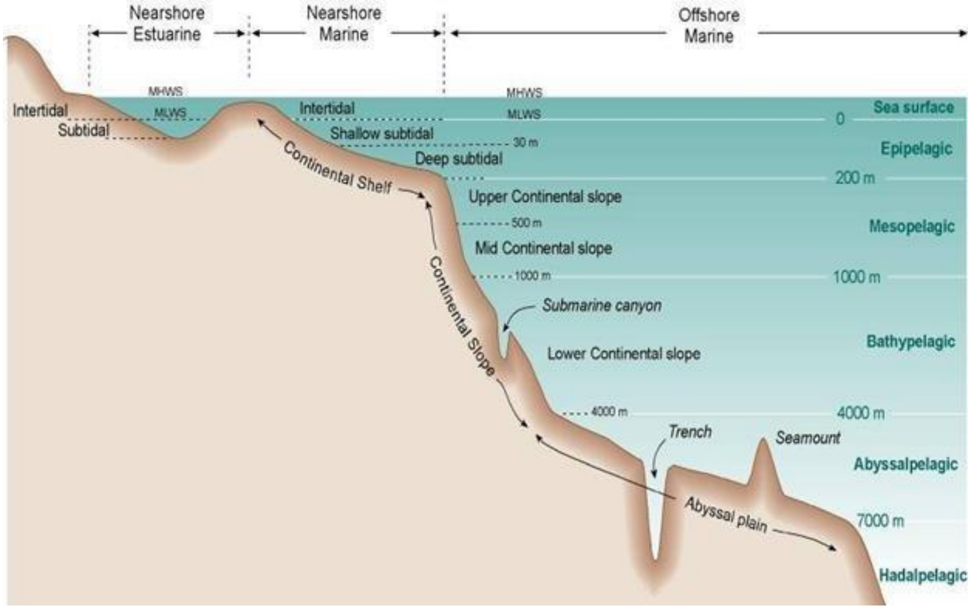
3.9 Conceptually, ecosystem assets are envisaged as three-dimensional spaces (see figures 3.1a and 3.1b). While most ecosystems across the ecological realms – i.e. terrestrial, freshwater and marine ecosystems - are all located close to the Earth's surface, they all have three dimensional characteristics. For example, for terrestrial systems, the biotic components usually extend from the soil life / plant roots below the surface to the vegetation growing above the surface. The abiotic components are those components that directly interact with these living components: the soil, the surface/soil water, and also the air from the atmosphere.

Figure 3.1a: Vertical structure of a terrestrial ecosystem



Source: Bailey (1996).

Figure 3.1b: Vertical structure of marine ecosystems



***<<Note to reviewers:** These two figures are intended to give a general indication of the vertical, 3D structure of ecosystems. Further refinement is intended to align terminology and content in the figures with the text of the chapter.>>*

3.10 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 space. Several important ecological processes are based on the interaction with the atmosphere, including respiration, nitrogen fixation, and those associated with the impact of air pollution on vegetation and fauna such as air filtration.

3.11 The interaction between the land surface and its ecology, and the atmosphere is limited to the atmospheric boundary layer. 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). This forms the natural upper boundary of ecosystem assets. Parts of the atmosphere above this layer are not considered ecosystem assets, but may be considered as a separate environmental asset when relevant for the organization and treatment of certain environmental data, for example, data on air quality.

3.12 Likewise, the subsoil that is directly involved with ecosystem processes is considered part of the ecosystem asset. This holds for both terrestrial (soil), freshwater and marine ecosystems (sediments). These ecosystem processes include water flows between soil layers and aquifers, bioturbation, carbon cycling, the cycling of nutrients, other diagenetic processes etc. How far the ecosystem extends downwards is very much dependent on the nature of the soil/ sediment and bedrock. Unconfined aquifers containing groundwater that are directly influenced by the (surrounding) ecosystem by water infiltration or possible contamination, are considered part of that ecosystem asset. Abiotic resources located in the deeper substrate within the lithosphere, like natural gas, oil and coal, that are in no direct interaction the surrounding ecosystems, are not considered components of ecosystem assets, but are included in the broader definition of environmental assets.

3.13 Although ecosystem assets are conceptually three-dimensional, they have a two-dimensional footprint. This footprint is defined by the intersection of the 3D bounding envelope of the ecosystem asset with earth's surface. The sides of this envelope are assumed to be vertical, such that the resulting footprints of adjacent ecosystem assets do not overlap. In practice therefore, for accounting purposes, the EAs are represented in two dimensions by their area.

3.2.2 Ecosystem accounting areas

3.14 The second type of spatial unit for ecosystem accounts are ecosystem accounting areas. The ***ecosystem accounting area (EAA) is the geographical area for which an ecosystem account is compiled.*** The EAA therefore determines which EAs are included in an ecosystem account.

3.15 Common forms of EAA are:

i. National jurisdictions / groups of countries (e.g. countries of the European Union);

ii. Subnational administrative areas (e.g. state, province);

iii. Environmentally defined areas within a country (e.g. water catchments, ecoregions);

iv. Other areas of policy or analytical interest such as protected areas or areas owned by specific industries or sectors, e.g., government-owned land.

3.16 Generally, the measurement objective of the SEEA is to provide information about the changes in ecosystem-related stocks and flows in relatively large and diverse areas covering different ETs. Conceptually, it is possible to compile ecosystem accounts for an individual EA, such as a single forest, wetland or agricultural area but this is not the focus of the SEEA. Usually, EAA will reflect 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 ET (e.g., for all natural grasslands in a country). Within one country different EAA may be delineated for different purposes and hence EAA may overlap, i.e. each EAA would contain common EAs. However, the accounts for each EAA will be discrete and no double-counting is implied. Nonetheless, aggregation of EAA should only occur where the boundaries are not overlapping.

3.17 Within each EAA, multiple EAs will be grouped into different ETs, e.g., forests, wetlands and agricultural land. The resulting accounting structures will generally be such that measures of ecosystem extent, ecosystem condition and ecosystem services will present information for aggregations of EAs, i.e. by ETs. For example, for a given subnational administrative area, an ecosystem extent account would show the changing total area of each ET (e.g., forest, wetland or agricultural land) but not the changing area of each individual EA. The same underlying data may be mapped to show the configuration and distribution of individual EAs within an EAA. Approaches to accounting for ecosystem extent are discussed in Chapter 4.

3.18 Consistent with the scope in the SEEA Central Framework, the scope of national jurisdictions for ecosystem accounting should extend to include all relevant ecological realms, i.e. terrestrial, freshwater and marine ecosystems, out to the boundary of the Exclusive Economic Zone (EEZ).In practice, the initial scope may be limited, for example to cover terrestrial and freshwater ecosystems; but it is important to aim to extend the coverage to incorporate all ecosystems under national jurisdiction.

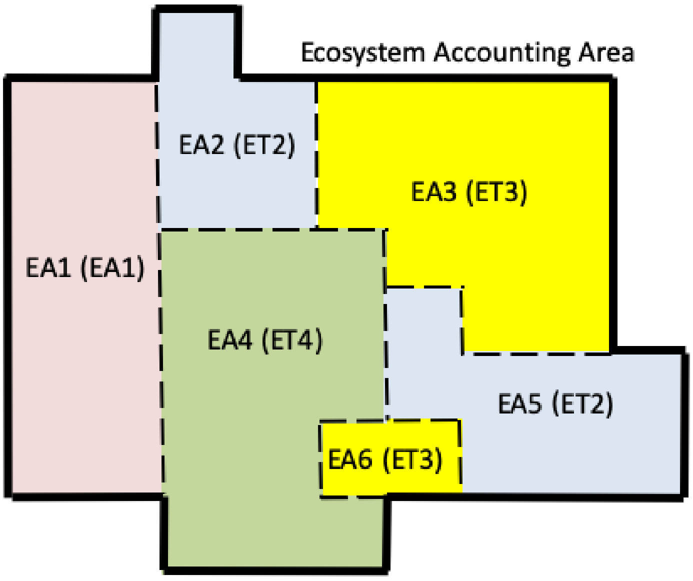
3.2.3 Linking EA and EAA

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

3.20 Commonly, accounts for a single EAA (for example, a country) are presented in tabular form by grouping together multiple EA of the same ET. Similarly, maps of an EAA would show the size and configuration of different EA by ET. Figure 3.2 shows the relationship between EAA, EA and ET.

3.21 The relationships between the spatial units can also be presented in tabular form where, at a given point in time, the sum of the areas of different ET will be equal to the total EAA. This is shown in Table 3.1. Table 3.1 provides the basic entry point to accounting for ecosystem extent which is discussed in Chapter 4.

Figure 3.2: Relationships between spatial units in ecosystem accounting



Note: Ecosystem assets (EA) represent individual, contiguous ecosystems.

Table 3.1: Tabular presentation of spatial units

Spatial unit	**Size***
Ecosystem type #1 (EA1)	12
Ecosystem type #2 (EA2 & EA5)	13
Ecosystem type #3 (EA3 & EA6)	15
Ecosystem type #4 (EA4)	14
Ecosystem Accounting Area (EAA)	**54**

**:* Any measurement unit for area may be used, including for example hectares and square kilometres

3.3 Delineating and classifying ecosystem assets

3.3.1 General principles

3.22 In concept, an EA is differentiated from neighbouring EAs by the extent to which the relationships between biotic and abiotic components within the EA are stronger than the relationships with components outside of the EA. The differences in relationships will be reflected in differences in function, structure and composition. Hence, EAs should be delineated based on various ecological characteristics such as vegetation structure and type, species composition, ecological processes, climate, hydrology, soil characteristics, topography and depth. Annex 3.1 provides a summary of relevant ecological concepts.

3.23 In delineating EAs for the purpose of ecosystem accounting, the following principles should apply.

i. *The EAs should represent ecosystems.* The spatial units should align with the definition of ecosystems following the CBD in which there is consideration of both organisms, their environmental setting and ecosystem processes. It is accepted that the delineations cannot be perfect representations of the complex ecological reality.

ii. *The EAs should be capable of being mapped.* Ecosystem accounting is commonly implemented using a spatially-based approach, in which case it is necessary that EAs can be mapped and identified in a specific location.

iii. *The EAs should be geographically and conceptually exhaustive, and comprehensive across ecological realms.* The 'exhaustive' criterion is understood as reflecting comprehensiveness, both spatially and conceptually. The set of EAs should allow for an EAA to be fully tessellated, i.e. filled, covering the three major ecological realms – terrestrial, freshwater and marine.

iv. *The EAs should be mutually exclusive, both conceptually and geographically.* Thus, EAs should not overlap, either conceptually or geographically, and any area on the land or the seafloor, or any horizontal depth layer in the ocean, should be occupied by one and only one ecosystem type. As long as the EAs are mutually exclusive, there can be no "double-counting" of the same space.

3.24 The occurrence and extent of EAs delineated using these principles can change over time. Indeed, the expectation is that over time, through the use of the same principles and classifications, different EA boundaries would be delineated to reflect the changing sizes and configuration of spatial units (e.g. due to deforestation). Recording these changes is the focus of accounting for ecosystem extent discussed in Chapter 4.

3.25 Where the boundary of an EAA, e.g. a country's national border, passes through a delineated EA, only the area of the EA inside the EAA boundary should be included in the account. While this effectively partitions the EA, it ensures that the area of all EAs is equal to the total EAA area.

3.26 An EAA will contain a range of ET. In broad terms, a gradient exists from pristine natural areas to intensively managed ecosystems, including production plantation forests; croplands and meadows, and built environments. While natural and semi-natural areas are mainly governed by natural ecological processes, the intensively managed areas will primarily be defined by land use maintained by human activity. However, since all of these types of areas may be within an EAA, all of these ET should be accounted for.

3.3.2 Treatment of specific ecosystems and features

3.27 **Linear features:** Conceptually, most ETs have a two-dimensional (2D) footprint geometry, allowing their extent to be measured by their area. However, for some ET this approach is less appropriate because their length far exceeds their width, such that their footprint geometry is effectively one-dimensional (1D). Typical examples are streams and smaller rivers, hedgerows and road verges. These are collectively referred to as linear features.

3.28 An extent account for linear features can be compiled by recording the length of each individual linear feature (each being an EA). Each linear feature can also be assigned an ET allowing aggregation by type of linear feature. This follows the same logic as for a 2D extent account but uses length units instead of area units. The resulting 1D extent account can complement a 2D extent account, but total 1D length cannot be aggregated with total 2D area due to the different dimensionality.

3.29 A distinction should be made between 'narrow' linear features, whose width is small enough to be neglected without affecting total area of an EAA (which must be equal to the sum of areas of individual EAs), and 'wide' linear features, whose width is large enough such that the associated area should be recognized. Thus, for some linear features it will be necessary to estimate an area that can be incorporated with the areas of other ETs. An example of a presentation showing this distinction is presented in Table 3.2 where (larger) rivers are shown having both area and length while (smaller) streams are recorded as having only length. The fact that narrow linear features have an assumed area of zero, does not disqualify them from being EAs with an associated condition or the potential to supply ecosystem services.

Table 3.2: Extent account presentation including both 1D and 2D ecosystem types

Ecosystem Type		**Extent**	
		Area (km2)	**Length (km)**
2D	Forest	345	
	Lakes	50	
1D	Rivers	5	50
	Streams		200
	Total	400	250

3.30 The following treatments are adopted in the SEEA using the distinction between narrow and wide linear features and considering rivers and streams separately from other linear features.

- For rivers and streams, width will change downstream along a river system, such that there will be a transition from 'narrow' upstream headwater reaches, to 'wide' downstream trunk rivers. The treatment of this transition in the accounts will depend on the nature of the source data involved.
    - *Raster data, e.g. from classified remote sensing imagery* — entire pixels will be classified as either stream/river, or as another ET. Extent is computed by multiplying the pixel count with the pixel area. There is no explicit distinction between narrow and wide streams.
    - *Vector data from e.g. digital stream network maps* — The systematic downstream increase in river width can often be approximated by the relationship between river width and Strahler stream order. On the global scale, reaches having a stream order of 5 or more, should be interpreted as 'wide' streams with area > 0, while those river reaches with a stream order of 1-4 should be considered 'narrow' with area set to zero[2]. If data are available, local width – stream order relationships may be used.

[2] This distinction is based on a review by Downing et al (2012) Global abundance and size distribution of streams and rivers, Inland waters, 2:4, 229-236. https://www.tandfonline.com/doi/pdf/10.5268/IW-2.4.502 The Strahler stream order is used as a proxy for stream size based on a hierarchy of tributaries. Headwaters have a stream order of 1 by definition, and order increases when two streams of the same order merge. Stream orders at the mouths of major rivers range from mostly around 9 to a maximum of 12 for the Amazon. While streams of order 1–4 constitute the bulk (95%) of the length of rivers and streams, the majority (75%) of the area of rivers and streams in located in those of stream order 5 or more.

- *Vector data from e.g. large-scale topographic maps or GIS layers* — On these maps, smaller streams are often represented as polyline features, while larger streams are represented as polygon features. In this case, the polyline streams should be interpreted as narrow streams without area, while the polygon streams should be interpreted as wide streams with area[3].

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

- For any linear features that are not ecologically linked to the surrounding landscape, such as forest access roads, the choice is to treat them like streams and rivers (i.e. a separate ET potentially having an associated area), or to include them with the surrounding ETs. This choice should be guided by the added value that a separate ET would have for the account or its applications.

3.31 It is noted that where a linear feature is attributed to a 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, e.g. increases in the 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.

3.32 **Complex mosaics**: Some ecosystems are characterised by a complex mix of different features, including linear features. Examples include urban areas and agricultural areas with small farm holdings. Where ecosystem accounting is undertaken for relatively large regions, it is recommended that the complex mix be seen as reflecting characteristics within a broader ecosystem type where changes in the characteristics (e.g. changes in the share of urban green spaces) may be accounted for as a change in the condition of the ecosystem asset.

3.33 Where it is considered important to account specifically for complex mosaics, including urban areas, it will likely be appropriate to apply complementary classifications of ecosystem types (e.g. to identify urban parks) and then apply the general principles for the delineation of EAs within those mosaics. A discussion on the broader issues of accounting for alternative themes, such as accounting for urban areas, is presented in Chapter 12 on thematic accounting.

3.34 **Marine ecosystems**: An important difference between terrestrial and marine ecosystems is that marine ecosystems are not concentrated near one surface (i.e. the air-land/water interface). Rather they extend through the water column and the underlying sediment.

3.35 In concept, ecosystem assets for marine ecosystems could be delineated based on both area and depth, i.e. taking account of ecological differences within the water column. The conceptual approach in the SEEA EEA is:

- For marine ecosystems within the continental shelf, delineate EAs based on the areas of different ecosystem types associated with the sea bed – e.g. seagrass meadows, subtidal sandy bottoms and coral reefs.

[3] Note that even if the source data on stream polylines include a width measure (either as absolute number, or as an interval class) as an attribute, this data should not be used to compute an equivalent area for use in area based accounts, because that will result in double counting due to the implicit overlap with the adjacent polygons for other EA (e.g. representing pastures bordering a stream).

- For marine ecosystems beyond the continental shelf[4], adopt vertically stratified spatial units, i.e. the ecosystem assets are delineated with respect to both location and depth within the water column. Here the sea floor is distinguished from the overlying water column.

3.36 From the two-dimensional perspective of an EAA, the area of all marine ecosystems beyond the continental shelf cannot easily be incorporated. Therefore, for the purposes of accounting for ecosystem extent and aligning the area of the EAA and EAs, only the area of ocean beyond the continental shelf should be included in the extent account. However, complementary accounts for marine ecosystems beyond the continental shelf that encompass the full range of relevant ecosystem assets, including those associated with pelagic ocean waters and deep sea floors can be compiled. These accounts will be able to adopt all of the core ecosystem accounting principles, such as concerning measurement of condition and ecosystem services, but variation is required concerning accounting for ecosystem extent given the three-dimensional nature of the ecosystem structure. These accounts are described in Chapter 12 on thematic accounting.

3.37 **Subterranean ecosystems:** There are a variety of subterranean ecosystems including caves and underground streams. These ecosystems satisfy the general conceptual definition of ecosystem assets. However, from the two-dimensional perspective of an EAA, these ecosystems will represent a layer underneath other ecosystems, primarily terrestrial. Therefore, for the purposes of accounting for ecosystem extent and aligning the area of the EAA and EAs, subterranean ecosystems should be excluded from scope. As for marine ecosystems, complementary accounts for subterranean ecosystems can be compiled.

3.3.3 Classifying ecosystem assets

3.38 Ecosystem assets are classified into ecosystem types (ET). Given the variety of ecosystem types and contexts around the world, there are many examples of ecosystem related classifications. For SEEA purposes, any ecosystem classification to be used for national ecosystem accounting or as a set of higher order ecosystem types for the comparison of results among different countries, should satisfy the principles for delineating EAs listed in section 3.3.1.

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

3.40 It is recommended that the classification of EAs used for ecosystem accounting be based on an existing national ecosystem classification scheme that satisfies the principles outlined above. Where a national classification of EAs is not available, the SEEA Ecosystem type reference classification, based on the IUCN Global Ecosystem Typology (described in section 3.3.4) can be used with a focus on those ETs of most relevance in the local context. If considered necessary, a new classification may be established satisfying the principles outlined above.

[4] The continental shelf is that part of the continental margin which is 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.

3.41 For the purposes of international reporting and comparison, the SEEA Ecosystem type reference classification should be applied.

3.3.4 SEEA Ecosystem type reference classification

3.42 The SEEA Ecosystem type reference classification is the International Union for the Conservation of Nature (IUCN) Global Ecosystem Typology (GET) developed to support the Red List of Ecosystems. It represents 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 (described in Annex 3.1) is used to identify key properties that distinguish functionally related ecosystems, and to synthesize traditionally disparate classification approaches across terrestrial, freshwater and marine realms. A full description of the IUCN GET and its approach to classification is provided in Keith et al, 2020.[5]

3.43 The IUCN GET has a hierarchical structure consisting of six levels. The three upper levels (levels 1-3) differentiate the functional properties of ecosystems and are the focus for the SEEA Ecosystem type reference classification. Levels 4-6 correspond to finer levels of detail that will be relevant in specific situations and in making correspondences among ecosystem and related classification systems.

3.44 The top level defines four realms: marine (M); freshwaters and saline wetlands (F); terrestrial (T); and subterranean (S). A realm is a major component of the biosphere that differs fundamentally in ecosystem organization and function. Consistent with the accounting scope described in section 3.3.2, the subterranean realm is excluded from the SEEA ET reference classification. The top level also provides for the classification of atmospheric units to the atmospheric realm at a future date to complete coverage of the entire biosphere. As noted in section 3.2.1, that part of the atmosphere above the boundary layer is not included in the scope of ecosystem assets.

3.45 The second level of the classification broadly follows the modern functional biome concept in 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, 2018). The IUCN GET recognizes 25 biomes: four exclusively in the marine realm; three exclusively in the freshwater realm; seven exclusively in the terrestrial realm; two exclusively in the subterranean realm; and nine that are located in transitional areas between different realms. These transitional areas represent interfaces between various combinations of the marine, freshwater, terrestrial and subterranean realms.

3.46 Levels 1 and 2 of the SEEA ET reference classification are shown in Table 3.3. Many of the ET described at Level 2 are familiar as naturally occurring biomes, including tropical forests, deserts, freshwater lakes and others. In addition, four biomes are defined by anthropogenic processes[6], where human activity is pivotal to ecosystem assembly and maintenance of ecosystem components and processes.

3.47 The third level of the classification describes ecosystem functional groups (EFG) which are functionally distinctive groups of ecosystems within a biome. Ecosystem types within the same EFG share common ecological drivers which promote convergence of the biotic traits that characterize the group. There are 103 different EFGs in the IUCN GET but it would be

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[5] Keith et al (2020) https://iucnrle.org/static/media/uploads/references/research-development/keith_etal_iucnglobalecosystemtypology_v1.01.pdf

[6] Also referred to as "anthromes" - see Ellis et al (2010); Ellis (2011)

highly unlikely for a country to have EAs representative of all EFG. More commonly, less than 40 EFG would be present in a single EAA. A full listing of EFG classes is provided in Annex 3.2.

3.48 For the compilation of ecosystem accounts at national or sub-national level it is expected that the delineation of EA at EFG level, or the equivalent level within a national classification, will be appropriate for the compilation of accounts. It is expected that for the purposes of international comparison, the reporting of data at biome level (level 2) through the aggregation of EFG level data, would be appropriate.

Table 3.3: SEEA Ecosystem Type Reference Classification based on the IUCN Global Ecosystem Typology*

Realms (and transitional areas)	Biomes
Terrestrial	T1 Tropical–sub-tropical forests
	T2 Temperate–boreal forests & woodlands
	T3 Shrublands & shrubby woodlands
	T4 Savannas and grasslands
	T5 Deserts and semi-deserts
	T6 Polar-alpine (cryogenic)
	T7 Intensive land-use systems
Freshwater	F1 Rivers and streams
	F2 Lakes
	F3 Artificial wetlands
Marine	M1 Marine shelf
	M2 Pelagic ocean waters
	M3 Deep sea floors
	M4 Anthropogenic marine
Transitional areas	TF1 Palustrine wetlands
	FM1 Transitional waters
	MT1 Shorelines
	MT2 Supralittoral coastal
	MT3 Anthropogenic shorelines
	MFT1 Brackish tidal

*: Following the treatment of subterranean ecosystems described in 3.37, subterranean biomes and transitional areas involving subterranean biomes have been excluded from the reference list. These biomes and transitional areas and the associated EFG are included in the list in Annex 3.2.

3.4 Considerations in the delineation of spatial units

3.4.1 Delineation of ecosystem assets in practice

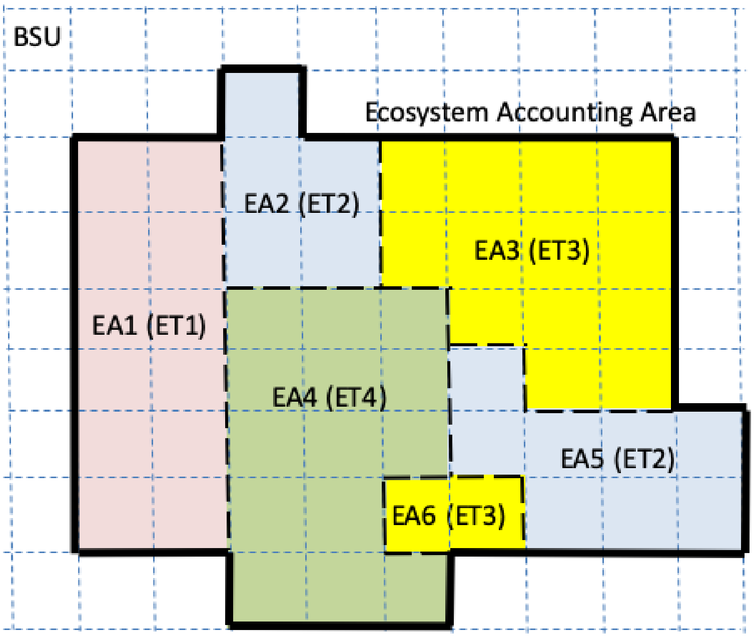
3.49 The distinction between EAs of different types is an ecological one reflecting an understanding of the composition of different biotic and abiotic components and characteristics. In principle then, delineating the boundaries between ecosystem assets might be undertaken through assessments by ecologists on the ground, including delineation of changes over time.

3.50 In practice, the high resource costs involved in ground assessments mean that the delineation of EAs will involve the mapping of ecosystem assets within an EAA using geographic information systems (GIS) platforms and techniques. This field of work is highly specialised but there is extensive practical and theoretical understanding of the use of GIS to support ecosystem accounting. An introduction to the key aspects is provided in Annex 3.3 and technical guidance is being developed. The use of GIS platforms and techniques will be relevant in many areas of ecosystem accounting.

3.51 While the use of GIS is standard, it will be necessary to involve ecological expertise to assure that the boundaries drawn between EAs are appropriate in ecological terms with regard to the ET 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.

3.52 To operationalise the delineation of EA within GIS systems, it can be appropriate to use a basic spatial unit (BSU) which is a a geometrical construct representing a small spatial area. The purpose of BSUs is to provide a fine-level framework within which a range of different pieces of information can be incorporated. An example of a BSU is a grid cell, but other BSU shapes, in particular reflecting polygons, may be used. Figure 3.3 shows how a grid based BSU can be applied to assist in delineating the EA within the earlier example (shown in Figure 3.2).

Figure 3.3: Applying a grid based BSU to delineate EA



3.53 To apply a BSU technique, each BSU is attributed with data on relevant characteristics that are relevant in distinguishing between EAs of different types. One way of considering this is that over the entire EAA each characteristic is mapped at the BSU level to establish a data layer for that characteristic.

3.54 As noted, different ET will 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 additional attributes may be considered, for example concerning water, carbon, nutrients, etc. Each ET will reflect a particular combination of characteristics and hence by mapping the combinations individual EAs will be delineated.

3.55 This approach has been applied in a number of contexts. An example is the map of terrestrial World Ecological Settings (WES) (Sayre et al 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.

3.56 The extent to which it is possible to combine multiple data sets to delineate EAs will depend on data availability. Where available, existing maps that delineate EAs may be used. As a second option, EA maps may be generated using national level information on land cover, climate, landforms and other characteristics as relevant following the descriptions above and in Annex 3.1. Where national level data on basic characteristics are not available, global datasets may be used. As a final option, it may be necessary to use data on the single characteristic of land cover to provide an initial delineation of EAs.

3.57 Since EAs are, by definition, ecologically defined, they are delineated on the basis of ecological characteristics. However, for those biomes that are subject to direct human management (e.g. Biome T7: Intensive land-use systems) it will be appropriate to incorporate data on land/ecosystem use in addition to land cover in the delineation of EAs as an indicator of differing ecological characteristics and functioning. While measurement of ecosystem use, including ecosystem services is of course, highly relevant for ecosystem accounting, this data should not influence the delineation of EAs except to distinguish where they can be used to highlight differences in ecological functioning.

3.4.2 Relationship with data on land

3.58 The role of land cover and land use data in the delineation of EAs was noted in the previous section. In short, land cover data should be combined with data about other ecological characteristics to delineate EAs and land use data may be relevant in delineating EAs in biomes which are intensively managed. Thus, while land cover and land use data are not sufficient to delineate EAs, they provide much relevant information.

3.59 Both land cover and land use data should be organised 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, it 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.

3.60 There are several international land cover classifications that may be used, providing well documented and tested metadata. The standard classification of land cover in the SEEA Central Framework is based on the FAO Land Cover Classification System (LCCS).[7]

3.61 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, for example,

[7] FAO Land Cover Classification System (LCCS) http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036361/

protected areas, as they are under the active management of institutional units of a country for the primary purpose of conserving biodiversity and other environmental values (SEEA CF 5.246).

3.62 Land management is the process of managing the use and development of land resources. The degree that areas of land and water are managed by humans may differ from intensively managed (build up areas, cropland) to not managed (e.g. polar regions, oceans). The degree of land management can have positive or negative effects on ecosystems and monitoring changes in the degree of management may be of interest in monitoring the links between changes in EA, their condition and land management policies and decisions.

3.63 Land ownership, encompassing ownership across all ecological realms, is a key characteristic that provides 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, non-profit organizations, government, households) based on ownership. Within the SNA, a distinction is made between legal ownership and economic ownership. Not all land/ water/ecosystems are owned, namely some remote natural areas or the oceans (e.g. the high seas beyond the EEZ) and hence various accounting conventions are established. Relevant conventions are discussed in Chapter 11 in the context of integrating ecosystem accounts with the SNA sequence of accounts.

3.64 Data on land ownership for terrestrial ecosystems is available in many countries in the form of cadastres. Cadastres are registers of areas defined administratively and delineated on the basis of land ownership. Data from cadastres, for example on the sector of ownership or the nature of the land tenure can be attributed to EAs, and hence provide a basis for monitoring the effects of land management policies within a given region, e.g. a water catchment.

3.4.3 Organising data about socio-economic and other characteristics

3.65 As discussed above, the delineation of EAs will require the use of various data concerning ecological characteristics. The organisation of these data to undertake delineation creates the opportunity to establish a richer data base of spatial information, i.e. beyond the data on characteristics required for the delineation of EAs. This would include data on land management and ownership described above but also data on, for example, the flows of water through the landscape, measures of soil and water quality, production of agricultural outputs, recreational activities, cultural sites, pollution and other residual flows and species diversity.

3.66 A strong motivation for organising these additional data emerges from ecosystem accounting since while data on only certain characteristics are required for the delineation of EAs, there are many other characteristics that will be relevant for accounting for ecosystem condition and estimating flows of ecosystem services. Further, analysis of data on ecosystem extent, condition and services may be enriched by integration of spatially detailed socio-economic data, for example population data.

3.67 Particular note is made concerning measurement of ecosystem services where both the supply and the use of ecosystem services must be recorded. In some cases, e.g. biomass provisioning services, the location of the supply and the use of the services is the same and occurs in a single EA. In other cases, e.g. air filtration services, the supply of the service may take place in a different EA from the use; and in other cases, e.g. flood mitigation services, the supply of the service emerges from a combination of EAs. Spatial attribution of the supply and use of ecosystem services is therefore an important task to ensure appropriate recognition of the role of different ecosystems and the mix of different users. These issues are discussed further in Chapters 6 and 7.

3.68 Spatial data concerning additional characteristics would be attributed to EAs 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 which will most commonly be available with varying coverage, scales and projections. Since the extent and configuration of EAs will change over time, the nature of the attribution of data to EAs will also change and hence use of an agreed BSU structure will likely provide considerable computational advantages.

3.69 Key aspects of operationalising spatial data for ecosystem accounting are described in Annex 3.3. The annex also notes that, ideally, a country would establish a National Spatial Data Infrastructure (NSDI) that would underpin the collation and organisation of spatial data, which in turn could provide a coherent "one-map" for a country across many characteristics. Countries are therefore encouraged to use the implementation of ecosystem accounting as an opportunity to integrate spatial data and techniques.

Annex 3.1: Ecological concepts underpinning spatial units for ecosystem accounting

Key ecological concepts

In ecology, a range of related but different characteristics of areas are used, each reflecting different ecological concepts. This section summarizes the key concepts of relevance in the context of ecosystem accounting.

Ecosystems

The central concept of interest for ecosystem accounting and classification is that of the ecosystem itself: a "*dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*" (Definition from CBD).

The most important element of this definition is the final clause "*interacting as a functional unit*", which means that the abiotic environment (climate, lithology, hydrology, etc.) is not relevant on its own, but in relation to biota (if only in a one-directional way), from an ecosystem functioning point of view. Ecosystem function refers to the processes related to the fluxes of resources like energy and water, photosynthesis and decomposition, that make up the interactions between the ecosystem components (Ågren and Andersson, 2012).

Keith et al (2020), building upon assembly theory (i.e. the selection of ecological communities through environmental filtering of available trait/species pool; Keddy, 1992), distinguish five groups of processes that govern ecosystem functioning.

- **Resources** (Energy, nutrients, water, carbon, oxygen etc.). One of more of these 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.). These are largely endogenous processes that shape ecosystem structure and function, but they include organisms that act as mobile links connecting different ecosystems and regulating transfers of matter and energy between them.
- **Human activity** Anthropogenic processes are a special kind of biotic interaction that influence structure and function of ecosystems either directly (e.g. land cover change, movement of biota) or indirectly (e.g. the harvest of biomass and other forms of resource use, climate change)

Together, these processes and conditions give rise to a variety of ecosystem traits, such as productivity, diversity, trophic structure, physiognomy, life forms and phenology. The assembly processes and ecosystem traits both influence stocks of assets and flows of services by shaping ecosystem structure and function.

Habitat and biotope

The concept of *habitat* is closely related, but not identical to ecosystems. It 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). It thus is organism-specific, focuses on both biotic and abiotic factors, and has a geographical component. Thus, habitats are provided *by* ecosystems *for* individual species. For example, a closed cover of *Larix* trees may define a taiga forest ecosystem which provides a habitat for woodpeckers.

The term biotope is often used interchangeably with habitat, but 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 geographic region, share a biotope (Dimitrakopoulos and Troumbis, 2019). A biotope is a topographic unit, and can be considered to be equivalent with Ecosystem Asset.

Biome

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, 2018). Biomes are the largest geographical biotic communities that are convenient to recognize. Most of them broadly correspond with climatic regions (zonobiomes), although other environmental controls are sometimes important, e.g. soils (pedobiomes) or topography (orobiomes).

There is no single authoritative list of biomes. While some biomes are recognized by all authors (e.g. tropical rainforest, taiga) many different biomes are proposed for less well-defined ecosystems, especially those on ecotones, such as savannas and woodland. For SEEA purposes, the IUCN GET list of biomes is used as a reference.

Ecoregions

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. where 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 as soil, climate and topography. Ecoregions are often used within a mapping context, and are described with a hierarchical structure. Terrestrial ecoregions are often grouped into higher order biogeographic regions, where the different biogeographic regions (e.g. Nearctic for North America, Indomalaya for India and SE Asia, etc.) reflect global differences in species distributions due to geographic 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 et al., 2001).

Ecotones

Ecotones are places where ecosystems grade into each other along a gradient in one or more resources or environmental controls. A typical example is the transition from forest to grassland on a gradient of moisture availability. The precise location of ecosystem types, and hence the ecotones between them is ultimately subjective. Where these gradients are very gentle, ecotones can occupy quite extensive areas. The translation of gradients and ecotones on ecosystem classification will depend on the nature and 'sharpness' of the transition, and the scale of application.

Key drivers and characteristics of ecosystems

In each of the three primary environmental realms - terrestrial, freshwater, and marine - ecosystems are commonly understood as occupying space and comprising an abiotic complex, a biotic complex, and interactions between the two. This section describes the key drivers of characteristics of terrestrial, freshwater and marine ecosystems. These characteristics are linked to ecosystem structure and functioning and play a key role in classifying ecosystems within each realm, as well as in measuring their condition.

Terrestrial ecosystems

For terrestrial ecosystems, key drivers are climate, topography and lithology. Key elements of the abiotic complex are soil and moisture regime. Key elements of the biotic complex include vegetation, animals and often human activity:

Drivers:

- **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:
    - **Temperature**: mean annual temperature; seasonality; temperature of the coldest month; accumulated growing degree-days.
    - **Precipitation**: total annual precipitation; seasonality
    - **Potential evapotranspiration**: annual total; seasonality.
- **Topography and geomorphology**, affects climate (on the global or local scale) and moisture conditions (on the regional and local scale), and nutrient redistribution Examples include:
    - **Hillslopes vs plains**: hillslopes have improved drainage condition compared to plains.
    - **Gentle vs steep slopes**: Steeper slopes will have shallow soils, faster drainage and possible more disturbance due to mass movements.
    - **Low vs high topography**: Adiabatic expansion of rising air causes cooler and wetter (micro) climate on high plains and mountains.
    - **Profile and planform convexity**: topographic controls on hillslope hydrology promote relative dry conditions on convex divergent hillslopes, and relatively wet conditions on concave hollows and the convergent channel network.
- **Lithology** determines the parent material for soil formation, and as such controls vegetation primarily through a number of resource processes, especially nutrient availability, through mineral composition and weathering products.
- **Time** drives the succession of ecosystems, which naturally progress from pioneer stage to a climax vegetation, provided that stable environmental conditions pertain.
- **Human impact** on ecosystems can be either direct (e.g. land cover change, movement of biota) or indirect (e.g. resource use, climate change).

Elements:

- **Soil**, controls vegetation primarily through a number of resource processes, and is formed partially by the local current and past ecosystem processes:
    - **Lithology** affects nutrient availability, through mineral composition and weathering products.
    - **Soil chemical properties** such as Cation Exchange Capacity (CEC) determine the capacity of the soil to retain nutrients
    - **Soil physical properties**, such as its water retention characteristics, control moisture availability during dry spells.

- **Soil Organic Matter**, is an important biota-controlled soil characteristics that contributes to these chemical and physical properties

- **Vegetation**, as a proxy for all biota. The terms vegetation and ecosystems are often used interchangeably (e.g., Tropical Rainforest), but vegetation is rather a biotic element of an ecosystem, and exists in a physical environment context which 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 which 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 (e.g. Pérez-Harguindeguy et al, 2013).
  - **Growth form**, e.g. trees, shrubs, grass etc. and the corresponding **canopy architecture**.
  - **Raunkiær life-form**, e.g. Phanerophytes (woody, buds >25 cm above the ground), geophytes (buds in dry ground), hydrophytes (buds below water) etc. and **Life history**, e.g. annuals vs perennials.
  - **Leaf type and phenology**, e.g. broadleaved, needle-leaved, deciduous, evergreen.
  - **Adaptations** to oxygen stress (phreatophytes), moisture stress (xerophytes) or salt stress (halophytes)
- **Animals** play a vital role in ecosystem function as detritivores, herbivores and predators. They may be sometimes difficult to detect due to their behavior and mobility.

Freshwater ecosystems and wetlands

Fresh water ecosystems are characterized by the presence of permanent or ephemeral surface waters whose surface extents vary spatially over time, and whose vegetation consists of largely aquatic species. The main distinction is between flowing water systems (rivers and streams) on one side of the spectrum and low- or non-flowing systems (lakes, ponds, and wetlands) on the other side.

Abiotic drivers of **Rivers and streams** include

- **Geomorphology**. By definition, rivers and streams are geomorphological features.
  - **Stream order**, i.e. the position from source (lowest order) to outlet (highest order), as a proxy for and classification of, drainage area.
  - **Fluvial zone** (erosional; transfer; depositional)
  - **Sediment size** (bedrock; boulders; gravel; sand; clay) and mobility (bedload, suspended).
  - **Channel pattern**[8] (Straight; meandering; wandering; braided; anastomosing)
  - **Bedform** (Planar; ripples; pool-riffle; bars)
- **Hydrology** (ephemeral; intermittent; perennial; interrupted)
- **Chemistry** (e.g. Na/Ca vs total salt)

[8] Note that channel pattern is strongly controlled by bank strength, which itself is partly controlled by vegetation. On longer time scales channel pattern can thus be regarded as an ecosystem element, rather than a driver

The biotic elements includes

- fish; macroinvertebrates; vegetation

Note that many of these attributes are correlated with each other, and vary reasonably predictive along a downstream gradient.

Abiotic drivers of **Lakes and pools** include:

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

While biotic elements are generally similar as for rivers and streams

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).

Some key abiotic drivers are:

- **Morphology**: terrain-conforming vs self-emergent
- **Hydrological system**: minerotrophic (groundwater, surface) vs ombrotrophic (precipitation)
- **Trophic status**: oligotrophic (nutrient-poor) vs eutrophic (nutrient-rich).
- **Landscape position**: along streams(riverine), lakes (lacustrine), estuarine or disconnected/upstream (palustrine)

Their key biotic feature is:

- **Dominant vegetation type**: Bryophytes and graminoids (bog and fen or peatland), graminoids, shrubs, forbs or emergent plants (marsh) or trees, shrubs and forbs (swamp), submerged of floating aquatic plants (shallow water)

Marine ecosystems

Marine ecosystems consist of all salt-water ecosystems that are directly connected to the world's oceans. The key abiotic drivers of marine ecosystems are:

- **Horizontal zonation**: e.g. intertidal zone, continental shelf, continental margin, abyssal plain.
- **Vertical layering**: water column (pelagic zone) vs sea bottom (benthic zone); photic zone.
- **Climate**: tropical, temperate, polar waters.
- **Water quality:** e.g. nutrients and transparency
- **Currents:** esp. upwelling zones.
- **Bottom characteristics**: e.g. rocky, sand, mud, biogenic.

The key biotic elements are:

- **Pelagic biota**: e.g. algae; invertebrates; fish; mammals.
- **Benthic biota**: e.g. plants; invertebrates; coral.

Annex 3.2: IUCN Global Ecosystem Typology

Upper three levels of the IUCN Global Ecosystem Typology - Keith et al. (2020). Realms listed are Terrestrial (T), Freshwater and saline wetlands (F), Marine (M), Subterranean (S), and transitions between these.

Realm T	Realm F	Realm M	Realm S	Biome	Ecosystem Functional Group
•				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 & woodlands	T2.1 Boreal and temperate montane forests and woodlands
•					T2.2 Deciduous temperate forests
•					T2.3 Oceanic temperate rainforests
•					T2.4 Warm temperate rainforests
•					T2.5 Temperate pyric humid forests
•					T2.6 Temperate pyric sclerophyll forests and woodlands
•				T3 Shrublands & 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 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 meadows and shrublands
•					T6.5 Tropical alpine grasslands and herbfields
•				T7 Intensive land-use systems	T7.1 Annual croplands
•					T7.2 Sown pastures and fields
•					T7.3 Plantations
•					T7.4 Urban ecosystems

Realm T	F	M	S	Biome	Ecosystem Functional Group
	•			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 stream
	•				F1.5 Seasonal lowland rivers
	•				F1.6 Arid episodic arid 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 lakes
	•				F2.7 Ephemeral salt lakes
	•				F2.8 Artesian springs and oases
	•				F2.9 Geothermal pools and wetlands
	•				F2.10 Subglacial lakes
	•			F3 Artificial fresh waters	F3.1 Large reservoirs
	•				F3.2 Constructed lacustrine wetlands
	•				F3.3 Rice paddies
	•				F3.4 Freshwater aquafarms
	•				F3.5 Canals and storm water drains
•	•			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
	•	•		FM1 Transitional waters	FM1.1 Deepwater coastal inlets
	•	•			FM1.2 Permanently open riverine estuaries and bays
	•	•			FM1.3 Intermittently closed and open lakes and lagoons

Realm T	Realm F	Realm M	Realm S	Biome	Ecosystem Functional Group
		•		M1 Marine shelf	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
		•			M1.7 Subtidal sandy bottoms
		•			M1.8 Subtidal mud plains
		•			M1.9 Upwelling zones
		•		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 Chemosynthetically-based ecosystems
		•		M4 Anthropogenic marine systems	M4.1 Submerged artificial structures
		•			M4.2 Marine aquafarms
•		•		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 systems	MT 2.1 Coastal shrublands and grasslands
•		•		MT3 Anthropogenic shorelines	MT 3.1 Artificial shorelines
•	•	•		MFT1 Brackish tidal	MFT1.1 Coastal river deltas
•	•	•			MFT1.2 Intertidal forests and shrublands
•	•	•			MFT1.3 Coastal saltmarshes
			•	S1 Subterranean lithic	S1.1 Aerobic caves
			•		S1.2 Endolithic systems
			•	S2 Anthropogenic subterranean voids	S2.1 Anthropogenic subterranean voids
	•		•	SF1 Subterranean freshwaters	SF1.1 Underground streams and pools
	•		•		SF1.2 Groundwater ecosystems
	•		•	SF2 Anthropogenic subterranean freshwaters	SF2.1 Water pipes and subterranean canals
		•	•	SM1 Subterranean tidal	SM1.1 Anchialine caves

Annex 3.3: Geospatial data for ecosystem accounting

Basic spatial units (BSUs)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Developing a national spatial data infrastructure

Within the context of the framework described in this chapter, including the points emerging from the discussion, countries can focus on a number of steps in testing and experimentation in ecosystem accounting. A common principle running through these recommendations is that work whose goal is to establish the spatial areas required for ecosystem accounting is best undertaken within the broader context of work, whether already completed or planned, to establish a national spatial data infrastructure (NSDI) which would support integration of environmental and socioeconomic data. It should be recognized that an NSDI is not essential to the commencement of work on the compilation of ecosystem accounts

The first step towards utilization of an NSDI for ecosystem accounting is to take an inventory of the spatial data infrastructure that already exists within a country, in particular within government entities such as spatial planning and environmental agencies. This assessment should include documenting the most commonly used GIS software packages and the available data sets. Wherever feasible, the development of a spatial data infrastructure for accounting should build upon existing infrastructure.

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

Data layers and delineation

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

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

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

With these data sources and tools in place, there are a range of choices available for delineating the spatial units needed for ecosystem accounting. Choices will depend on scale (i.e., the level of spatial detail) and thematic detail (the number of classes in the classification).

The integration of information across different spatial scales

A primary objective of ecosystem accounting is the organization of information sets for the analysis of ecosystems at a level suitable for the development, monitoring and evaluation of public and private policy. Consequently, consideration must be given to collecting and collating information pertaining to many ecosystems across a region or country.

Spatial techniques that facilitate this integration of information include:

- Downscaling: the attribution of information from a larger area to a smaller area included within it. For example, a few 10ºC bands with similar temperatures may represent average temperature for a country. A BSU existing within a given band would be attributed with the temperature range of that band. Downscaling can be further refined by using additional criteria. For example, BSUs in higher elevations may be assigned a lower average temperature.
- Overlaying: network features such as roads and rivers can be attributed to BSUs by overlaying maps of these features and recording the length of road or river that passes through the BSU, which can then be recorded in the “register”.
- Aggregating: smaller features can be counted or their area added to determine the number or area within the BSU. For example, the number of people residing in a BSU can be counted if census statistics are sufficiently detailed. The total areas of residences and farms can be added up to generate a total for a BSU.

The scaling of data

Often, a large amount of information on ecosystems comes from focused evaluations at individual sites. Therefore, in order for information to be developed for other sites or over larger areas (without conducting additional studies), it is necessary to consider how the available information may be best used.

Different approaches are available for transferring information across sites or to a broader land area: (a) *value transfer* which involves using information from a specific study site and developing estimates for a target or policy site; (b) *scaling up,* which involves using information from a study site and developing information for a larger area that has similar characteristics; and (c) *meta-analysis*, which is a technique for assessing a large volume of information on various study sites and integrating that information so as to produce factors that can be used to develop estimates for target areas, taking into account various ecosystem characteristics.

SEEA Experimental Ecosystem Accounting recommends that a rigorous description of statistical units following standard statistical practice be undertaken together with the application of rigorous geospatial methods before an aggregation of information to national or regional levels occurs. Using such a description of units, the application of the advancing techniques centring around benefit transfer may be undertaken with greater robustness and in a manner more in line with the standard approaches in official statistics (such as sampling, weighting, editing and imputation).

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