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Working group 1: Spatial units

Discussion paper 1.1:
An ecosystem type classification for the SEEA EEA

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Research area #1: Spatial units

Discussion paper 1.1: An ecosystem type classification for the SEEA EEA

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Table of Contents

Executive Summary

The organization of information about spatial areas is at the heart of ecosystem accounting. Current SEEA-EEA ecosystem type classifications have been regarded as inadequate. with respect to (among others) ecological detail and attention to urban and marine environments. As part of the wider SEEA-EEA revision process an improved classification is sought.

This Discussion Paper provides options for the construction of a reference classification of ecosystem types and proposes initial guidance for further disaggregation at a national or regional scale. Accompanying papers provide more background or focus on urban and marine environments.

To provide a clear ecological basis for the SEEA-EEA reference ecosystem type classification, a number of fundamental concepts are reviewed. The concepts described concern ecosystems, their functioning, and their characteristics.

Based on both generic and specific principles, the following six design criteria for the SEEA-EEA ecosystem classification are proposed:

1. The classification typology should represent ecosystems
2. The classification units can be spatially delineated
3. The classification units are geographically and conceptually exhaustive, and comprehensive across all environmental domains
4. The classification types are mutually exclusive, both conceptually and geographically.
5. The classification should be practicable
6. The classification should be linkable to other established classification systems

A number of existing classification systems are evaluated using these criteria. Only two of them, IUCN Red List of Ecosystems (RLE), and the USGS/Esri globally distinct biophysical and biogeographic settings (GDBBS) meet all six criteria.

Based on this review and the design criteria, a number of options are presented as candidates for the SEEA-EEA reference ecosystem type classification:

1. IUCN Red List of Ecosystems
2. USGS/Esri GDBBS
3. A two-tier approach building upon and linking IUCN RLE and USGS/Esri GDBBS
4. Existing habitat classifications (e.g. IUCN, EUNIS)
5. Existing land cover classifications (e.g., FAO; Corine)

Of these, the first three are the recommended options due to their conceptual relevance and depth and their coverage of all relevant environmental domains.

The major strength of the first two options is their strong compliance with the design criteria and their support and maintenance by the authoring organizations. The third option aims at resolving weaknesses of these first options (IUCN RLE focusing on natural systems and lacking a practical mapping method; USGS/Esri GDBBS lacking ecosystem functioning) but is not fully developed and lacks a supporting organization/maintenance process.

The next step in the SEEA-EEA revision process is to seek feedback on the proposed principles and criteria, and on the proposed classification options and their preliminary evaluation. It is envisaged that a process of testing the most appropriate options will be conducted in the second half of 2019 on the basis of this feedback.

The SEEA EEA revision process

The organization of information about spatial areas is at the heart of ecosystem accounting. The focus to date has been the development of an accounting approach that enables relatively broad scale terrestrial ecosystems to be accounted for. The general approach for describing different areas in an accounting context - namely ecosystem accounting areas (EAA), ecosystem assets (EA) and basic spatial units (BSU) - has become relatively well established but there are still important matters requiring resolution.

The key focus in this research area is to establish statistically and accounting relevant classifications for ecosystem types through careful review and application, where possible, of existing classifications of this type. Worldwide, there have been many efforts on mapping land, including land cover, land use etc. For statistical purposes it is necessary to have an agreed set of classes using a common set of principles such that mapping exercises in different countries and locations can work towards a common measurement goal. It has been recognized that for ecosystem accounting, in principle, we need to go beyond land cover and consider a wider range of characteristics in delineating ecosystem assets.

The delineation of ecosystem assets will, ideally, involve the use of a range of ecological and non-ecological criteria, including vegetation type, soil type, hydrology, and land management and use. Distinct focus should also be placed on the description and classification of marine areas given the strong interest in applying ecosystem accounting for these areas. Also, consideration should be given to articulating the connection to atmospheric units in order to complete a spatial delineation of the environment. Furthermore, there is an emerging interest concerning ecosystem accounting for urban areas considering the large proportion of the world population living in cities.

Although these topics have seen significant progress from the initial (interim) land cover classification in the SEEA Central Framework (UN et al, 2014), and subsequently the guidelines provided by The SEEA Experimental Ecosystem Accounting (UN et al, 2014) and the recent SEEA EEA Technical Recommendations (UNSD, 2017), several issues remain unsolved and need to be addressed in the current revision process.

This paper is part of a series of discussion papers on spatial units. For ecosystem accounting purposes, this paper **provides options for the construction of a reference classification of ecosystem types and proposes initial guidance for further disaggregation at a national or regional scale.** This discussion paper is accompanied by two background papers: one providing detail on the review of alternative classifications and the other providing detail on a classification proposed in this paper referred to as "Option 3".

Two other discussion papers are part of this series: a paper that proposes guidance on defining spatial areas to account for ecosystems in urban areas (Discussion paper 1.2) and a paper that proposes an approach to the treatment of the atmosphere and the marine environment in an ecosystem accounting context, particularly with regard to the delineation of spatial units (Discussion paper 1.3).

These discussion papers have been developed by a working group established as part of the SEEA EEA revision process. The working group on spatial units works alongside other working groups across the four research areas (RAs) identified in the SEEA EEA Revision Issues Note: RA1 focuses on spatial units, RA2 on ecosystem condition, RA3 on ecosystem services and RA4 on valuation and accounting.

In terms of **next steps,** we seek a) feedback on the proposed principles and criteria, and b) feedback on the classification options and other materials in the paper. Specific questions have been posed in an accompanying comment form. In addition, there is a need to commence a testing phase involving assessment of the extent to which leading classification options can be mapped in practice and the extent to which the leading options can be linked/concorded/cross-walked to existing national classifications.

1. Introduction

Spatial areas are at the heart of ecosystem accounting. The conceptual model of the SEEA EEA envisages the delineation of areas within a country or a specific region into contiguous, mutually exclusive units, each covered by a specific ecosystem, i.e. dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (CBD, 1992, Article 2, Use of Terms). Each of these units comprises an ecosystem asset, and these form the conceptual base for accounting, in terms of the organization of data on relevant stocks and flows, and the integration of these data within accounts. The stocks are represented by the ecosystem assets, and the flows by the ecosystem services that are supplied by these stocks. Each ecosystem asset is therefore considered to supply a specific basket of ecosystem services. Generally, ecosystem accounts will be compiled and presented according to each ecosystem type (the aggregate area of all ecosystem assets representing each ecosystem type) rather than for individual ecosystem assets. Thus, A classification describing the ecosystem types and a map showing their occurrences in the ecosystem accounting area are essential components of ecosystem accounting as it allows tracking changes in ecosystem assets over time.

The spatial delineation of ecosystems may include a range of ecological and non-ecological characteristics, including vegetation type, soil type, hydrology, climate, land management, land use, and ownership. Approaches to classifying ecosystems vary depending on the particular application for which the classification is being developed, with different emphases on environmental characteristics and ecosystem structure and function. The UN SEEA ecosystem accounting concept requires ecosystem classifications suitable for statistical analysis and accounting. Moreover, to achieve standardization in national reporting and to allow for inter-comparison of results across nations, a set of global, higher order, major ecosystem groupings is necessary. The SEEA Experimental Ecosystem Accounting (2012) and the recent Technical Recommendations (2017) recommended the use of an interim, land-cover classification as a starting point for an ecosystem classification. However, it was recognized that this classification is very coarse, and lacks a clear ecological basis. For ecosystem accounting, in principle, we need to go beyond land cover and consider a wider range of characteristics in delineating ecosystem assets. Furthermore, the initial classes were recognized as emphasizing satellite image derived terrestrial ecosystems, with inadequate or no emphasis on urban, freshwater, marine water, and seabed ecosystems. Therefore, a key revision issue for SEEA EEA is to develop a proposal for a classification that better represents the concept and coverage of ecosystems to be used for ecosystem accounting.

The objective of Discussion Paper 1.1 is twofold:

a) **Provide options for the construction of a reference classification of ecosystem types.** These options should outline a high-level classification scheme providing an appropriate set of classes relevant for internationally comparable ecosystem accounting. In addition, this reference classification should provide a useful starting point for constructing an ecosystem type classification for national / regional accounting.

b) **Provide guidance for further disaggregation for ecosystem accounting at a national or regional scale.** A high-level classification scheme is often not very useful on a national or regional scale. SEEA EEA can provide some general guidelines how to construct ecosystem type classifications and what ecosystem characteristics could be used for this purpose.

In Section 2 we introduce some key ecological concepts and characteristics of ecosystems based on ecological theory. In Section 3 we present six design criteria which should be considered before deciding on a classification scheme for ecosystem types to be used for SEEA ecosystem accounting. In Section 4 we present the review of some existing relevant and potentially useful classifications. Additional detail of the review is provided in an accompanying background document. In Section 5, we propose five options for a high-level international classification scheme based on the design criteria discussed in the previous section. Additional detail on a newly proposed classification, referred to as Option 3, is provided in an accompanying background document. Finally, in Section 6 we describe some general guidelines that can be used for the construction an ecosystem type classification for compiling SEEA EEA accounts on a national/ regional level. Discussion on issues concerning spatial units in the context of urban areas, the atmosphere and marine environments are presented in discussion papers 1.2 and 1.3.

2. Ecological theory

In this section we introduce some key ecological concepts and characteristics of ecosystems relevant for constructing an ecosystem type reference classification.

2.1 Some key ecological concepts

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

2.1.1 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 (2019, in prep.), 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. 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.

2.1.2 Habitat and biotope

The concept of *habitat* is closely related, but not identical to ecosystems. In literature, many slightly different definitions can be found. In the European Nature Information System (EUNIS) a 'habitat' is defined as "*a place where plants or animals normally live, characterized primarily by its physical features (topography, plant or animal physiognomy, soil characteristics, climate, water quality etc.) and secondarily by the species of plants and animals that live there*". 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 related concept of *biotope* refers to a specific habitat: "areas with particular environmental conditions that are sufficiently uniform to support a characteristic assemblage of organisms". A biotype is thus comparable to an SEEA-EEA ecosystem asset (but referring to habitats, instead of ecosystem type)

2.1.3 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, 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 it is convenient to recognize. They broadly correspond with climatic regions, although other environmental controls are sometimes important. They are the equivalent to the concept of major plant formations in plant ecology, but are defined in terms of all living organisms and of their interaction with the environment (and not only with the dominant vegetation type).

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.

2.1.4 Ecoregions

An ecoregion is a "*large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions*" (WWF). Although ecoregions are sometimes considered macroscale ecosystems, ecoregions are in fact large areas containing many ecosystems, which may or may not have a strong functional relationship with one another. Ecoregions are complexes of ecosystems.

Ecoregions can be 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). In this respect, ecoregions are to biomes what biotopes are to habitats and ecosystem assets to ecosystem type.

2.1.5 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.

2.2 Key characteristics of ecosystems

Across the three main environmental domains (terrestrial, freshwater, and marine), ecosystems are similarly understood as occupying space and comprising an abiotic complex, a biotic complex, and interactions between the two. This section describes the key characteristics of terrestrial, freshwater and marine ecosystems. These characteristics are linked to ecosystem structure and functioning and will play a large role in ecosystem classification.

2.2.1 Terrestrial ecosystems

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

- **Climate**, pragmatically defined as the statistics of weather, is an important characteristic of many ecosystems, because of its strong links to resources (water, energy) and constraints (, droughts, etc.). 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 and soil** controls vegetation primarily through a number of resource 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.
- **Time** has an impact on ecosystems, which naturally progress from pioneer stage to a climax vegetation, provided stable environmental conditions pertain.
- **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.
- **Human impact** on ecosystems can be either direct (e.g. land cover change, movement of biota) or indirect (e.g. resource use, climate change). See also Section 2.2.4.

2.2.2 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 components 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** (Straight; meandering; wandering; braided; anastomosing)
  - **Bedform** (Planar; ripples; pool-riffle; bars)
- **Hydrology** (ephemeral; intermittent; perennial; interrupted)
- **Chemistry** (e.g. Na/Ca vs total salt)

  The biotic component includes

- fish; macroinvertebrates; vegetation

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

Abiotic features 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.

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 characteristics 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)

2.2.3 Marine ecosystems

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

- **Horizontal zonation**: e.g. intratidal 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 components are:

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

2.2.4 Anthropogenic characteristics

In addition to ecological characteristics, the following land related characteristics may be considered in the design of an ecosystem type classification.

Land cover versus land use

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. The area of coastal waters is excluded. (SEEA CF 5.257).

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, protected areas, as they are under the active management of institutional units of a country for the purpose to conserve biodiversity and other environmental values, excluding economic or human activity from that area (SEEA CF 5.246).

Land cover and land use, in combination, may be sufficient as proxies to define some ecosystem types, especially highly managed types such as production forest, most agricultural areas and the built-up environment. For natural and semi-natural ecosystems land use and land cover are insufficient, mainly because they cannot sufficiently represent ecosystem functioning in the absence of additional descriptors (see also the discussion on design criterion #1 (Section 3.1).

Land ownership and management

Ownership of land is a key characteristic that provides a direct link between ecosystems and the system of natural accounts. Economic assets, including land, can be assigned and classified to institutional units (i.e. corporations, nonprofit 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 (i.e. beyond the EEZ).

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 highly managed (build up areas, cropland) to not managed (e.g. polar regions, oceans). Land management can have positive or negative effects on the terrestrial ecosystems. Of particular interest is the protection status of land and water areas / ecosystems. These may vary between ‘unprotected’ to varied degrees of protection. The degree of land management / protection status is related to land use, but not the same.

Of particular interest will be the management of semi-natural areas. Especially in the developed world, with a long history of anthropogenic land use change, many high-valued ecosystems which are now labeled ‘nature’ are the by-product of earlier land use. Examples from Europe include temperate heath land (resulting from clearcutting the natural forests and subsequent grazing) and drift sand areas (resulting from overgrazing). Some areas of these ecosystems are clearly out of equilibrium and can only maintained in their current state with a proper management regime.

3. Design criteria

There are a number of criteria which should be contemplated before deciding on a classification scheme for ecosystem types to be used for a) national level ecosystem accounting, and b) ecosystem accounting on a global level which permit comparisons of aggregated accounting results between countries. While the ecosystem classes needed may vary for the national or global level, the criteria for evaluating their utility for accounting are the same. It is assumed that any candidate ecosystem classification is robust and scientifically credible, has a hierarchal structure and should be able to track changes over time, so these important characteristics will be assumed and not set out herein as criteria.

An ecosystem type classification that is to be used for SEEA ecosystem accounting must meet six design criteria:

3.1 Based on ecological principles

Criterion 1: The classification typology should represent ecosystems

This criterion examines the conceptual foundations of the classification. It examines whether or not the ecosystem typology under consideration indeed represent ecosystem assets. Because the intent of the SEEA ecosystem accounting is to develop a set of area-based statistical accounts (e.g. ecosystem extent, ecosystem condition, ecosystem services values, etc.) associated with ecosystems, it stands to reason that the units under consideration should indeed represent ecosystems.

The variable that is classified – "ecosystem type" – is the set of properties of an ecosystem within a geographic unit. These properties will be grounded in theory, which includes "a range of ecological and non-ecological criteria, including vegetation type, soil type, hydrology, and land management and use." (SEEA EEA TR, 1.65). Ecosystems are universally understood as assemblages of biological communities interacting with each other and with their physical environment. As such, to be considered a classification of ecosystems, the units should include a consideration of both organisms and their environmental setting. A flat plain is not an ecosystem, it is a landform. An area of unconsolidated sediments is not an ecosystem, it is a lithological setting. A region of subtropical climate is not an ecosystem, it is a climate setting. An area dominated by shrubs is not an ecosystem, it is a vegetation type. However, a subtropical shrubland on a flat plain over unconsolidated sediments clearly fits the narrative of an ecosystem because 1) the environment is described, and 2) the organisms that are found there in response to the environmental potential are described. It is fundamental that to be considered an ecosystem, the abiotic environment and the biological assemblages it supports are identified.

In addition to characterizing ecosystems by their physical environment and associated biological assemblages, they can also be distinguished on the basis of numerous other ecological properties and processes, including trophic levels and interactions, predation and competition dynamics, hierarchical ecological organization, productivity and biomass properties, cycling of nutrients, energy, and materials, etc. Some of these characteristics could be used in the classification and spatial delineation of ecosystems. There are also other more theoretical and abstract ecosystem properties relating to the self-organizing, emergent, directional, oscillatory and self-renewing nature of ecosystems, which, while interesting, are likely not useful properties for classifying or mapping ecosystems.

A gradient exists from pristine nature areas to strongly anthropogenically modified ecosystems. While the former are mainly governed by natural ecological processes, the latter will primarily be defined by land cover and land use, with ecological processes following. Examples include production forests; croplands and meadows, and built-up environments. From this it follows that there is a role for land cover and land use classifications in ecosystem classification (see also the discussion on land use and cover in Section 2.2).

3.2 Mappable

Criterion 2: The classification units can be spatially delineated

Ecosystem accounting is an area-based approach, and requires the use of spatially explicit ecosystem units. It is absolutely essential that ecosystem units be mapped, and that quantitative, GIS-based assessments of ecosystem extent, condition, and economic and non-economic value can be conducted. Conceptual ecosystem classifications are often merely a set of criteria for describing what might occur at any point on the landscape or in the seascape. However, the landscape or seascape itself has not been mapped, as conceptual classifications are often not map-based classifications. For SEEA ecosystem accounting purposes, a mapped classification is essential, wherein the ecosystem entities are mapped as geographic occurrences and these occurrences are attributed with geometric (e.g. area), ecological, and other (e.g. economic value) properties.

Many conceptual classifications are in essence a list and description of ecosystems known or thought to exist on the landscape or in the seascape. They are a priori in nature, that is the number and kinds of ecosystems comprising the classification are known prior to mapping the classes out. If a conceptual classification is to be used for ecosystem accounting, a map will have to be developed showing the spatial occurrences of the ecosystem type. In contrast, map-based classifications are a posteriori in nature, that is the number and types of ecosystems emerge from the spatial modeling and mapping process itself. Map-based classifications are very suitable for ecosystem accounting because they incorporate feature attribute tables where every occurrence of an ecosystem type is a record in a database. Conceptual classifications, once mapped, are also suitable for the spatial analytical requirements of ecosystem accounting.

3.3 Collective exhaustive

Criterion 3: The classification units are geographically and conceptually exhaustive, and comprehensive across all environmental domains

The ‘exhaustive’ criterion is understood as both spatially and conceptually comprehensive. The broad ecosystem types should completely “occupy” (tesselate) the ecosystem accounting area, without missing any environmental domains or obvious ecosystem categories. The classification system should be comprehensive across the three primary environmental domains. All nations will have terrestrial and freshwater ecosystems that should be accounted for in the UN SEEA accounting exercises. Those nations with a coastline will need to account for coastal and marine ecosystems that fall within their national jurisdictions as well.

Note that there is a potential conflict between this criterion and the first criterion that units “should represent ecosystems”. For example, a given spatial area might be parking lot, but this will usually not be seen as an ecosystem. Therefore, to conform to both criteria all artificial land covers, including built-up areas, are associated with ecosystem types as well.

3.4 Mutual exclusive

Criterion 4: The classification types are mutually exclusive, both conceptually and geographically.

Because SEEA ecosystem accounting is area-based, the ecosystem units must not overlap, either conceptually or geographically. Any area on the land or the seafloor, or any horizontal depth layer in the ocean, can be occupied by one and only one ecosystem type. As long as the units are mutually exclusive, there can be no “double-counting” from the same area. While this seems straightforward, in practice it can be difficult to classify a land area into just one type when contemplating all the environmental domains. For example a depression on the landscape might be regularly inundated and occupied by a dense hydrophyllic vegetation. A terrestrial ecologist might classify the ecosystem as a forest based on the vegetation physiognomy, but a freshwater ecologist might classify the same area as a woody wetland. However, for ecosystem accounting purposes, only one ecosystem type can be assigned to any location.

3.5 Practical

Criterion 5: The classification should be practicable

Any ecosystem classification to be used a) for national ecosystem accounting or b) as a set of higher order ecosystem groupings which can be used for intercomparison of accounting results from different countries, should **satisfy** the four criteria above. For the higher order classes that would permit standardized reporting of national results and intercomparison between countries, practicality is another criterion. While hundreds of ecosystem types are expected to be accounted for in national assessments, a smaller number of the higher order groupings would be more manageable for reporting and comparisons between countries. Moreover, the higher order groups should have simplified, universally understandable names to facilitate use of the ecosystem classes by the broadest possible audiences.

3.6 Linkable

Criterion 6: The classification should be linkable to other established classification systems

Whatever classification is ultimately chosen, it should preferably be linkable to other existing ecosystem classification schemes, and – partially – to habitat or land cover classifications. In particular, a classification and map adopted for local or national use should be linkable to one of the higher-order set of ecosystem complexes recommended below to permit intercomparison between different countries. Crosswalking of one classification scheme to another is simplified when there are generally one-to-one relationships between classes, but crosswalking can be a complex undertaking when there are a number of many-to-one or one-to-many relationships.

4. Review of existing classification schemes

This section examines existing relevant and potentially useful classifications. A background paper provides more in-depth information on the review of existing classification schemes described below.

4.1 Selection of relevant classification schemes

A set of ecosystem and land cover classifications was selected for review which were considered comprehensive in geographic and conceptual scope and potentially fit for purposes of ecosystem accounting. The set of reviewed classification types is a subset of the many international ecosystem, habitat, vegetation, and land cover classifications in existence. The classifications selected for review are listed and contrasted in Table 1. **We note that this list is not comprehensive (there are many more relevant international and national classification schemes around), but represents a meaningful selection for our review purposes.**

4.2 Results of the review

The classifications are contrasted with respect to their satisfaction of the design criteria in Table 1. The summary results of the review and comparison of classifications are presented in Annex 1. Below we highlight the main outcomes.

Table 1. Summary of design criteria satisfaction for reviewed classifications[1]

	IUCN ET	USGS/Esri	MAES / Eosystems types for Europe	IUCN habitat	EUNIS habitat	WWF Biomes	FAO LCCS	Corine (CLC) level 2	GLC2000
1) Ecological base	ecosystems	Biophysical Settings	ecosystems	habitat	habitat	Biomes	Land cover	Land cover	Land cover
2) Spatial delineation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3) Domain comprehensive and exhaustive	Yes	Yes	Yes?[1]	Yes	Yes?[1]	No	Focus on land	No detail for marine	Focus on land
4) Mutally exclusive classes	Yes	Yes	Yes	Yes	Yes	?	Yes	Yes	Yes
5) Practical	Yes	Yes	Yes	?	Yes	?	Yes	Yes	?
6) Linkable to other classifciations	Yes	Yes	Yes	Yes	Yes	Yes	?	Yes	Yes
Number of levels in hierarchy	6	variable	2 or 3	2	3	2	variable	3	2

1 As these are European classification schemes, it is not clear whether they are comprehensive and exhaustive on a global scale

Design criteria

[1] See the accompanying background paper for more information on, and references for, the various classifications

Which classifications best match with the six design criteria? This means that units: must represent ecosystems (derived from and characterized by ecological properties); be spatially delineable; be comprehensive across environmental domains (terrestrial, freshwater, and marine); be mutually exclusive; and be exhaustive.

- Only IUCN RLE (Red List of Ecosystems) Global Ecosystem Typology and USGS/Esri Globally Distinct Biophysical and Biogeographic Settings (GDBBS) meet all criteria. The IUCN RLE classification, described below, is hereafter referred to as IUCN ET, and the USGS/Esri GDBBS is hereafter referred to as USGS/Esri. The IUCN ET is an a priori classification, developed from conceptual foundations as a list and description of the ecosystems of the planet. The USGS/Esri GDBBS is an *a posteriori*, map-based classification of ecologically meaningful, environmentally distinct areas. The IUCN ET develops the classification from conceptual foundations, whereas the USGS/ESRI classification emerges from the combination of multiple layers of observations of ecological properties.
- for the other classifications: IUCN Habitats and EUNIS focus on habitats, not ecosystems; FAO classifications focus on land use and crops; CLC and Italy are biased towards terrestrial and freshwater; StatCan ELC classifies ecoregions rather than ecosystems. The MAES / ecosystem types for Europe classification also scores well on all design criteria, however it is not clear if this classification can be applied on a global scale.

Scope (coverage of specific variants)

- Most classifications do not distinguish? transitional types or ecotones. IUCN ET does to some extent.
- IUCN ET, IUCN Habitats, EUNIS, CLC, USGS/ESRI make a distinction between artificial or managed versus natural or unmanaged ecosystem types.
- IUCN ET, IUCN Habitats, USGS/ESRI, and CLC distinguish between urban versus rural areas (mostly at level 2).
- Oceanic layers and the seabed are included in IUCN ET, IUCN Habitats, EUNIS, and USGS/ESRI. IUCN ET and IUCN Habitats are the only classification that include caves. The atmosphere is not covered in any classification.

Hierarchy and rank order of properties

- All classifications have a hierarchical structure.
- Only IUCN ET and StatCan ELC have a clear rank order of properties. USGS/ESRI allows users to determine their own rank order if desired, or supplies a rank-ordered hierarchy sequentially by temperature, moisture, and landform type (for terrestrial ecosystems).

Conceptual basis

- StatCan ELC, Italy, IUCN ET, and USGS/ESRI have a clear conceptual basis as well as supporting documentation that explains the conceptual basis.
- IUCN Habitats, MAES, and CLC do not have a clear conceptual basis and/or supporting documentation. IUCN Habitats is an amalgam of existing systems including Holdridge's biophysical system and RAMSAR wetland classification. MAES classifies ecosystems but its conceptual foundations are unclear as are those of CLC.
- Most classifications incorporate information on land use, land cover, geo-ecology. Some (StatCan ELC, Italy, IUCN ET) also cover climate, and biotic and abiotic processes. Land management and ownership are generally excluded or only included implicitly.

Definitions and similarity criteria

- IUCN ET, EUNIS, FAO, CLC, and USGS/ESRI have detailed documentation on the delineation of types and classes, have defined types and classes in terms of observable data, have classes that are unambiguous, discrete, and easy to interpret, and explain definitions as well as similarity criteria.
- Where definitions and similarity criteria are concerned IUCN Habitats and MAES are the least useful classifications.

4.3 Comparison of the highest-level classes

A useful point of comparison for the reviewed classifications is the number and types of highest order ecosystem complexes which are one level down in the hierarchy from the three primary ecological domains (terrestrial, freshwater, and marine). For both the IUCN and the USGS/Esri classifications, these highest order complexes, fully listed in Annexes 2 and 3, and described in Sections 5.1 and 5.2, illustrate that even though these classifications have a different conceptual base and/or serve different user needs, they do show a high degree of correspondence (Table 2):

Table 2. Preliminary links between high-level ecosystem units following IUCN and USGS/Esri classifications.

Realm(s)	IUCN RLE	USGS/Esri
Terrestrial	T1 Tropical–sub-tropical forests	1 Forestlands
	T2 Temperate–boreal forests & woodlands	
	T3 Shrublands & shrub-dominated woodlands	2 Shrublands
	T4 Savannas and grasslands	3 Grasslands
		4 Woodlands and Savannas
	T5 Deserts and semi-deserts	5 Barren Lands
	T6 Polar/alpine	
	T7 Intensive anthropogenic terrestrial systems	6 Croplands
		20 Built Environment
Freshwater	F1 Rivers and streams	7 Rivers and Streams
	F2 Lakes	8 Lakes and Ponds
	F3 Artificial Wetlands	*— not specified —*
Marine	M1 Subtidal shelfs and shelf-breaks	15 Sunlit Shelf
		16 Twilight Shelf
		17 Continental Slope
	M2 Pelagic ocean waters	11 Sunlit Ocean Waters
		12 Twilight Ocean Waters
		13 Deep Ocean Waters
	M3 Deep sea floors	18 Deep Ocean Floor
		19 Trench Floor
	M4 Artificial marine systems	*— not specified —*
Transitional	FT1 Palustrine wetlands	9 Freshwater Wetlands
	FM1 Transitional waters	10 Estuaries
	MT1 Shoreline systems	*— not specified —*
	MT2 Coastal vegetation	*— not specified —*
	MT3 Artificial shorelines	*— not specified —*
	MFT1 Brackish tidal systems	14 Intertidal Seabed

Note: IUCN Subterranean (S) biomes are excluded since they are all absent from the USGS/Esri classification

5. Options for a (high level) reference classification scheme

Based on the design criteria and the review of existing classifications described in the previous sections, we propose five options for a high-level international reference classification for ecosystem types. **The starting point for choosing these options is that we want to propose an existing international classification that complies with all (or most) of the design criteria that we have defined.** For each option we explain why we have chosen this as an option, provide a short description of the classification and identify the main strengths and weaknesses. At this stage of the discussion we will not draw any conclusions what would be the preferred option. However, at the end of this section we will draw an interim conclusion by expressing initial preferences with regard to the five options.

5.1 Option 1: The IUCN RLE classification

Why choose this as an option?

- *Complies to all design criteria*
- *This classification takes ecosystems as its conceptual base*
- *Includes approach for further disaggregation*

Short description

The Red List of Ecosystems (RLE) classification (IUCN ET classification) as has been developed by IUCN (Keith et al. 2019 in prep.) represents a global typological framework that applies process-based approach to ecosystem classification across the whole planet. The primary aim of this framework is to develop a scalable framework that support generalizations about groups of functionally similar ecosystems and recognizes different expressions within these groups defined by contrasting biotic composition. Ecological assembly theory is used to identify key properties that distinguish functionally related ecosystems, and synthesize traditionally disparate classification approaches across terrestrial, freshwater and marine environments. This classification is based on similar design criteria as defined in Section 3.

The hierarchical structure consists of six levels (see Annex 2): three upper levels differentiate functional properties. The top level of classification defines four realms of the biosphere: marine (M); freshwaters and saline wetlands (F); terrestrial (T); and subterranean (S). The second level of classification broadly follows the 'modern biome concept' (Mucina 2018). The ecosystem typology recognizes 25 biomes: four marine; three freshwater; seven terrestrial; four subterranean; and seven in transitional realms. Many of the units recognized at Level 2 by their distinctive ecological traits are familiar as 'traditional' biomes, including rainforests, deserts, reefs, freshwater lakes and others. In addition, four biomes are 'anthromes' defined by anthropogenic processes, where human activity is pivotal to ecosystem assembly and maintenance of ecosystem components and processes. Level 3 of the classification describes functionally distinctive groups of ecosystems within a biome. Ecosystem types within the same Functional group are united by a distinctive set of traits that result from unique combinations of assembly filters that come to the fore in particular environments.

Strengths

- The IUCN ET classification complies with all design criteria as described in Section 3 (see also Section 4).
- Of key Importance is that this classification is one of the few that has an explicit theoretical foundation and takes ecosystem as its conceptual base. The conceptual model underlying the classification is based on ecological processes that help frame ecosystem assets (stocks) and the services they provide (flows), as required in UN SEEA-EEA.
- Other key qualities of the typology including representation of biota, scalability, comprehensiveness and parsimony (Table 1) are intimately linked to its structure, and are supported by a clearly defined terminology and explicit descriptions of units to aid ecosystem identification.

- Clear hierarchal structure.
- Includes an approach to further disaggregation on national / regional level.
- Linked to other policy-relevant tools such as IUCN Red List of Ecosystems, with substantial existing buy-in at national and international levels.
- Developed by a large global network of terrestrial, freshwater and marine ecosystem specialists.
- Support infrastructure for users provided by IUCN.

Weaknesses

- For use in ecosystem accounting, the classification would have to be mapped out across the ecosystem accounting area. A map of the global distribution of the spatial occurrences of the ecosystem classes is not currently available.
- The classification has not yet been officially published, this will probably occur in May / June 2019.
- The classification focusses on natural ecosystems and less so on agriculture / urban areas
- Number of classes (at level 3) may be too high (100)?

5.2 Option 2: USGS/Esri GDDBS

Why choose this as an option?

- *Complies to all design criteria*
- *Manageable set of units*
- *Includes practical approach for further disaggregation*

Short description

This classification provides a high-level set of global ecosystem reporting categories representing globally distinct biophysical and biogeographic settings (GDBBS) that can be used as ecosystem proxies for SEEA ecosystem reporting. It is based on several USGS/Esri/GEO Global Ecosystems Mapping Products (Sayre et al, 2014; 2016; 2017; 2018). The categories were developed using strict criteria that ecosystems spatial units be geographically mutually exclusive (non-overlapping), and conceptually and geographically exhaustive. The new units are biome-level ecosystem groupings, and the new classification represents a map-based partitioning which first assigns all geographic space into an environmental domain, and then further partitions those domains into mutually exclusive and exhaustive biomes as high order ecosystem groups. A number of recognized global ecosystems and global land cover classifications and maps were reviewed and contributed to the development of the revised units. The new set of classes is distinguished from previous classifications in that it is comprehensive across all environmental domains, mutually exclusive, spatially and conceptually exhaustive, and readily understood by the broadest possible user groups.

The units of the first two tiers in a hierarchical classification represent all ecosystems on the planet (see Table 3). Subsequent levels in the classification are determined by the primary, secondary, and successive key drivers that influence biotic distributions within each major ecosystem type. These types are both domain comprehensive and geographically exhaustive in x (longitude), y (latitude), and z (elevation/depth) spatial dimensions, such that any location on Earth will fall into one and only one major ecosystem type and its parent domain. It thus provides a flexible approach for further disaggregation on a national / regional level.

Strengths

- This classification complies to all design criteria as described in Section 3 (see also Section 4).
- Very comprehensive in environmental descriptions and factors (e.g. for terrestrial: climate, landform, substrate chemistry – the three main drivers for vegetation distributions).
- Includes an approach to further disaggregation on national / regional level.
- Geodata (at 250m resolution) for the terrestrial domain is available on ArcGIS Online.

Weaknesses

- Not explicitly based on biotic factors
- Number of units for terrestrial environment quite small (7, including the built environment)
- The derivation of the finest level units is well described in multiple publications (Sayre et al., 2014, 2017, 2018). The logic for and method of aggregation of these building block units into the higher order classes is not yet published (manuscript in preparation – Sayre et al., 2019).
- This option does not have an established process by which it would be maintained.

5.3 Option 3: Bridging IUCN ET and USGS/Esri

Why choose this as an option?

- *Fully hierarchic approach, allowing for mapping on multiple scales*
- *Explicit links with USGS/ESRI major ecosystems (option 2 units) on the coarse levels of the hierarchy to warrant mappability, especially for areas lacking in ecological ground-truth data.*
- *Maximal use of IUCN RLE units (option 1) to populate the fine levels to maximize ecological meaningfulness.*

Short description

Both the IUCN ET classification and the USGS/Esri mapping system have many strengths, but there are some issues making each of these less usable for SEEA EEA accounting purposes in their original form. Below we describe some points where gaps can be filled and synergy can be maximized. The starting point here is the set of IUCN "functional groups" (level 3).

1) Enhance mappability by explicit linking the IUCN classes to e.g. the USGS/ESRI global ecological land units (i.e., Option 2).

2) Provide more detail for agricultural and urban/built-up areas. The focus of the IUCN ET is on natural ecosystems, although semi natural ecosystems and non-natural ecosystems are recognized as ecosystem types (e.g. T7 Intensive anthropogenic terrestrial systems and analogues in freshwater and marine realms). A few additional types and urban and rural mosaics are introduced.

3) Marine units are strictly two-dimensional, i.e. integrating pelagic and benthic zones, and focusing on photic zone characteristics.

4) Restructure hierarchy to implement the above points, based on a pragmatic approach starting with realms and major ecotones, then move on to land cover (which probably can be mapped without detailed ecological data) and finally arrive at the IUCN classes for the quasi-natural ecosystem types.

Strengths

- It is still mainly based on the IUCN ET classification for the definition of ecosystem types, which complies to all design criteria.
- Maximizes use of information available through the USGS/Esri mapping system.
- It incorporates in the classification some key issues making it more relevant for SEEA EEA accounting.
- Naturally allows for a tiered approach: USGS/Esri land cover (tier 1); IUCN functional groups (tier 2); 3D oceanic units or other refinements (tier 3).

Weaknesses

- It deviates from existing, published, classification schemes.
- Discussion is needed to reach consensus on the modifications.

- If not carefully crafted, potentially weakens the operational links between the SEEA-EEA, USGS/Esri and IUCN ET and their respective applications.
- This option does not have an established process by which it would be maintained.

5.4 Option 4: Existing habitat classifications (e.g. IUCN or EUNIS)

Why choose this as an option?

- *Habitat is often used as a proxy for ecosystems*
- *Habitat classifications are well developed and widely used*

Short description

As discussion in Section 2.1.2, a habitat is "*the living place of an organism or a community characterized by its physical and biotic components*". Habitats are not the same as ecosystems (see Section 2.1.2), but may serve as a good proxy for them. Options of existing international classification schemes that are internationally used are the IUCN and EUNIS habitat classification systems.

Strengths

- Habitat is a widely used concept and habitat classifications are used for several policy areas.
- Well described international classification systems are available.

Weaknesses

- Species' habitat classifications were not designed explicitly to represent ecological processes.
- The available habitat classifications do not have a clear conceptual basis.
- IUCN habitat classification: Limited descriptive information makes classes difficult for different users to interpret them consistently, even though many of the classes will be familiar to many users.
- EUNIS habitat classification: This is a classification developed for only Europe, it is not comprehensive conceptually or spatially at the global level.

5.5 Option 5: Existing land cover classification (e.g. FAO or Corine)

Why choose this as an option?

- *Land cover classifications are highly developed, well documented and widely used.*
- *Land cover can, with caution, be used as a proxy for ecosystems.*

Short description

Land cover is often used as a proxy for ecosystem type. There are several international land cover classifications that may be used, providing well documented and tested metadata. This option basically falls back to the original proposal in SEEA EEA and SEEA EEA TR to use the (interim) SEEA land cover classification as a starting point for an ecosystem classification. A land use classification may be used to further disaggregate certain land cover classes.

Strengths

- Land cover classifications like LCCS from FAO and the European Corine classification are highly developed, well documented and widely used.
- When ecological and land use characteristics are not available, a land cover based classification may be used as a starting point. Land cover data is widely available.
- Land cover classes are usually easy to interpret.

Weaknesses

- Land cover classifications are more directly concerned with the physical aspects of ground cover mainly for land use planning and management than with biodiversity or community aspects of vegetation aspects. It is therefore a poor proxy of ecosystems making it less suitable for ecosystem accounting.
- The focus of land cover classifications is on the terrestrial and freshwater realms, often they do not include the marine realm.

5.6 Interim conclusion

There are several good options for a reference classification scheme for SEEA EEA that meet the design criteria we have defined. Of the five options we have selected, **we express a preference for options 1, 2 or 3,** as these options have an explicit theoretical foundation and take ecosystem as their conceptual base. Habitat and land cover classifications were not designed specifically to represent ecological processes and are thus less suitable as a reference classification for ecosystem accounting.

6. Guidance for further disaggregation on national / regional level

Here we provide some guidelines that can be used for the construction an ecosystem type classification for compiling SEEA EEA accounts on a national/ regional level. As yet, this is not a comprehensive set of guidelines, we recognize that this is just a starting point for further work.

- A classification for ecosystem types on a national / regional level should also comply to the six design criteria defined in Section 3, i.e. units must represent ecosystems (derived from and characterized by ecological properties); be spatially delineable; be comprehensive across environmental domains (terrestrial, freshwater, and marine); be mutually exclusive; be exhaustive and manageable. Furthermore, the classification should have a clear hierarchal structure.
- The ecosystem typology should be manageable (also one of the design criteria). This means that classification scheme in principle should not have so many classes that it requires too much time and effort for it to be feasible. It should be recognized that the greater the number of ecological and anthropogenic characteristics used for delineation, the greater the number of ecosystem types that will be identified. A balance must be found between the number of different ETs that are identified and the availability of information, noting that the use of a limited number of types will also limit the sophistication of the questions that can be answered using the accounting information. Ideally, any ecosystem type providing a distinct bundle of ecosystem services (types of services, amount) should be included within the classification.
- It is recommended that the initial focus for ET classification should be on ecological principles since EAs are considered the units that function to supply ecosystem services. However, it is also recommended to consider additionally to use anthropogenic factors, such as (artificial) land cover, or land use for (some) ecosystem types, for example agricultural lands. Possible ecological and anthropogenic characteristics that can be used for disaggregation are described in Section 2.2. See also the discussion on design criterion #1 in Section 3.1.
- A key consideration for building a national classification are the (national) user needs. The detail required for policy and analysis may determine the number of levels in the hierarchy and the number of classes.
- Next to user needs, data availability also plays a key role. The choice of characteristics that can be used to build the classification scheme may be limited by data availability, including the scale of the available data.

Basically, there are three approaches that can be followed for the construction of a national / regional ET classification

1. Use as a starting point the reference classification that will (ultimately) be recommended in SEEA EA (see Section 5) (top down approach). As a first step identify which classes from the reference classification are relevant for the national/ regional level. Next, based on user needs and data availability, disaggregate these classes using some key ecological and anthropogenic characteristics (see Section 2.2).
2. Use as a starting point an existing national classification scheme. Preferably, use a classification that represents ecosystems or habitats, and that can be bridged to the reference ET classification. This allows efficient use of available data, facilitates the integration of datasets and avoids producing partially overlapping datasets.
3. Build the classification 'from scratch' (bottom up approach). Based on user needs and data availability choose the key ecological and anthropogenic characteristics on which you want to base the classification (see Section 2.2). Countries will generally have land cover maps that can be used as a basis for preparing an ecosystem extent account inclusive of a mutually exclusive and exhaustive definition and delineation of EAs. By adding for example layers for vegetation and/or land use additional detail can be added to make it more an 'ecosystem classification'. As a last step, this classification has to be bridged to the reference ET classification. Consideration of species composition is especially key for building a detailed ecosystem classification.

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Annex 1: Summary results of the comparison of classifications

Table 3. Summary results of the comparison of classifications

Classification type	Look for a match with fundamental design criteria: units must represent ecosystems (derived from and characterized by ecological properties); spatially delineable; comprehensive across environmental domains (terrestrial, freshwater, and marine); units are mutually exclusive; units are exhaustive
Is it a national or an international classification?	2 national; 8 international/global
Has the classification been produced for a specific (national, regional, global) purpose? Is there a bias towards a specific environment or specific properties?	IUCN Habitats and EUNIS focus on habitats; FAO focus on crops; focus on terrestrial and freshwater (SEEA land cover, CLC land use; Italy; StatCan ELC ecoregions not ET; two classifications appear to meet all criteria: IUCN ET and USGS/ESRI; difference is that IUCN ET develops classification from conceptual foundations up, whereas USGS/ESRI classification emerges from combination of multiple layers of observations of properties
Scope (comprehensiveness)	
What is the degree of variety at the most detailed level of the classification?	
How does the classification deal with transitional types or ecotones?	Mostly not IUCN ET does to some extent
Does the classification distinguish between artificial or managed versus natural or unmanaged ecosystem types? If so, at what level?	Some do: IUCN ET, IUCN Habitats, EUNIS, CLC, USGS/ESRI
How does the classification deal with urban versus rural areas?	Not all classifications deal with urban areas. Mostly at level 2. IUCN ET, IUCN Habitats, USGS/ESRI, CLC
Does the classification include oceanic layers and the seabed, the (sub)soil, and the atmosphere?	Some do: IUCN ET, IUCN Habitats, EUNIS, USGS/ESRI
Hierarchy	
Does the classification have a hierarchical structure?	All classifications have a hierarchical structure.
What is the number of levels in the hierarchy?	Mostly 2, 3 or 4 IUCN ET has 6
What is the rank order of properties in the hierarchy?	Only IUCN ET and StatCan ELC have a clear rank order of properties. USGS/ESRI allows users to determine rank order.
Which properties that might represent a layer in a hierarchy are implicit?	Most classifications explicitly capture all relevant properties (exception is IUCN Habitats where climate and hydrology are implicit); as IUCN ET states: "Properties that explicitly define lower-level units may sometimes be implicit in higher-level units even though they are not used to define the latter."
Conceptual basis	
Does the classification have a clear conceptual basis? If so, what is that basis?	7 yes; 3 no or unclear (IUCN Habitats; MAES; CLC)
Does the classification incorporate information on geo-ecology, land cover, land use, bio-ecology, land ownership, land management, etcetera?	most classifications incorporate information on land use, land cover, geo-ecology; some (StatCan ELC, Italy, IUCN ET) also climate and biotic and abiotic processes; land

	management and ownership are generally excluded or included implicitly
Is there supporting documentation that explains the conceptual basis?	4 yes (StatCan ELC; Italy; IUCN ET; USGS/ESRI); 6 no or summary
Definitions and similarity criteria	
Is there detailed documentation on the delineation of types and classes?	8 yes; 2 no (IUCN Habitats; MAES)
Are types and classes defined in terms of observable data (e.g. how to recognise a deciduous forest in a satellite photograph)?	6 yes (IUCN ET, EUNIS, FAO, SEEA, CLC, USGS/ESRI)
Are classes unambiguous, discrete, and easy to interpret?	Mostly yes; no or limited IUCN Habitats and MAES
Is there supporting documentation that explains definitions and similarity criteria?	8 yes; 2 no (Italy; IUCN Habitats)

Annex 2: IUCN Red List of Ecosystems

Table 4. Upper three levels of the IUCN Red IUCN Red List of Ecosystems (RLE), as described in Section 5.1 and Keith et al. (2019). Realms listed are Terrestrial (T), Freshwater and saline wetlands(F), Marine (M), Subterranean (S), and transitions between these.

Realm(s)				Biome	Functional group (ecotype)
T	F	M	S		
▯				T1 Tropical-subtropical forests	T1.1Tropical/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 montane needle-leaved forest and woodland
▯					T2.2 Temperate deciduous forests and shrublands
▯					T2.3 Cool temperate rainforests
▯					T2.4 Warm temperate rainforests
▯					T2.5 Temperate pyric humid forests
▯					T2.6 Temperate pyric sclerophyll forests and woodands
▯				T3 Shrublands & shrub-dominated woodlands	T3.1 Seasonally dry tropical shrublands
▯					T3.2 Seasonally dry temperate heaths and shrublands
▯					T3.3 Cool temperate heathlands
▯					T3.4 Rocky pavements, screes and lava flows
▯				T4 Savannas and grasslands	T4.1 Trophic savannas
▯					T4.2 Pyric tussock savannas
▯					T4.3 Hummock savannas
▯					T4.4 Temperate wooded savannas
▯					T4.5 Temperate grasslands
▯				T5 Deserts and semi-deserts	T5.1 Semi-desert steppes
▯					T5.2 Thorny deserts and semi-deserts
▯					T5.3 Sclerophyll deserts and semi-deserts
▯					T5.4 Cool temperate deserts
▯					T5.5 Hyper-arid deserts
▯				T6 Polar/alpine	T6.1 Ice sheets, glaciers and perennial snowfields
▯					T6.2 Polar/alpine rocky outcrops
▯					T6.3 Polar tundra
▯					T6.4 Temperate alpine meadows and shrublands
▯					T6.5 Tropical alpine meadows and shrublands
▯				T7 Intensive anthropogenic terrestrial systems	T7.1 Croplands
▯					T7.2 Sown pastures and old fields
▯					T7.3 Plantations
▯					T7.4 Urban and infrastructure lands

Table 4 (continued)

Realm(s) T	F	M	S	Biome	Functional group (ecotype)
	▯			F1 Rivers and streams	F1.1 Permanent upland streams
	▯				F1.2 Permanent lowland rivers
	▯				F1.3 Freeze-thaw rivers and streams
	▯				F1.4 Monsoonal upland stream
	▯				F1.5 Monsoonal lowland rivers
	▯				F1.6 Arid episodic lowland rivers
	▯			F2 Lakes	F2.1 Freeze-thaw freshwater lakes
	▯				F2.2 Large permanent freshwater lakes
	▯				F2.3 Small permanent freshwater lakes
	▯				F2.4 Ephemeral freshwater lakes
	▯				F2.5 Permanent inland salt lakes
	▯				F2.6 Ephemeral salt lakes
	▯			F3 Artificial wetlands	F4.1 Large reservoirs
	▯				F4.2 Rice paddies
	▯				F4.3 Constructed lacustrine wetlands
	▯				F4.4 Canals and storm water drains
		▯		M1 Subtidal shelves and shelf breaks	M1.1 Seagrass meadows
		▯			M1.2 Kelp forests
		▯			M1.3 Photic coral reefs
		▯			M1.4 Shellfish beds and reefs
		▯			M1.5 Marine animal forests
		▯			M1.6 Rocky reefs
		▯			M1.7 Subtidal sandy bottoms
		▯			M1.8 Subtidal muddy bottoms
		▯			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
		▯		M3 Deep sea floors	M3.1 Continental slope and island slopes - soft substrate
		▯			M3.2 Continental slope and island slopes - hard substrate
		▯			M3.3 Marine canyons
		▯			M3.4 Abyssal plains - soft substrate
		▯			M3.5 Hadal zones
		▯			M3.6 Seamounts, plateaus, hills, knolls
		▯			M3.7 Deepwater biogenic systems
		▯			M3.8 Chemosynthetically-based ecosystems
		▯		M4 Artificial marine systems	M4.1 Artificial reefs

Table 4 (continued)

Realm(s)				Biome	Functional group (ecotype)
T	F	M	S		
□	□			FT 1 Palustrine wetlands	FT1.1 Tropical flooded forests and peat forests
□	□				FT1.2 Seasonal floodplain marshes
□	□				FT1.3 Subtropical/temperate forested wetlands
□	□				FT1.4 Episodic arid floodplains
□	□				FT1.5 Boreal, temperate and montane peat bogs
□	□				FT1.6 Boreal and temperate fens
□	□				FT1.7 Artesian springs and oases
□	□				FT1.8 Geothermal wetlands
	□	□		FM1 Transitional waters	FM1.1 Deepwater coastal inlets
	□	□			FM1.2 Permanently open riverine estuaries and bays
	□	□			FM1.3 Intermittently closed coastal lagoons
□		□		MT1 Shoreline systems	TM1.1 Rocky Shores
□		□			TM1.2 Muddy Shores
□		□			TM1.3 Sandy Shores
□		□			TM1.4 Boulder/cobble shores
□		□		MT2 Coastal vegetation	TM2.1 Coastal shrublands and grasslands
□		□		MT3 Artificial shorelines	TM3.1 Artificial shores
□	□	□		MFT1 Brackish tidal systems	MFT1.1 Coastal river deltas
□	□	□			MFT1.2 Intertidal forests and shrublands
□	□	□			MFT1.3 Intertidal marshes
			□	S1 Lithic subterranean systems	S1.1 Aerobic caves
			□		S1.2 Endolithic systems
			□	S2 Subterranean freshwaters	S2.1 Underground streams and pools
			□		S2.2 Groundwater aquifers
			□	S3 Tidal subterranean systems	S3.1 Anchialine caves
			□	S4 Anthropogenic subterr. systems	S4.1 Subterranean excavations
			□	S4 Anthropogenic subterr. systems	S4.2 Water pipes and subterranean canals

Annex 3: USGS/Esri GDDBS classifications

Ecosystem reporting categories for the UN SEEA ecosystem accounting based on the USGS/ESRI map products (Sayre et al, 2014; 2016; 2017; 2018). These maps follow a stratification approach using layers for e.g. land cover, climate and topography, resulting in many (>>100) combinations. On the largest levels there are 4 environmental domains and 20 major ecosystem types.

Table 5. Major ecosystem types within the USGS/Esri GDDBS

Environmental domain	USGS/ESRI Major Ecosystem Type
Terrestrial	1 Forestlands
	2 Shrublands
	3 Grasslands
	4 Woodlands and Savannas
	5 Barren Lands
	6 Croplands
Freshwater	7 Rivers and Streams
	8 Lakes and Ponds
	9 Freshwater Wetlands
Marine waters	10 Estuaries
	11 Sunlit Ocean Waters
	12 Twilight Ocean Waters
	13 Deep Ocean Waters
Marine seabed	14 Intertidal Seabed
	15 Sunlit Shelf
	16 Twilight Shelf
	17 Continental Slope
	18 Deep Ocean Floor
	19 Trench Floor
Any	20 Built Environment

For the terrestrial domain, lower level ecosystem types can be defined by combining these major types with classifications of climate (18 classes) and landforms (4 classes):

Table 6. Climatic and Landform classifications for refinement of the USGS/Esri GDDBS (terrestrial domain only)

9 Major ecosystem types		18 World Climate regions				4 Global landforms
1 Forestlands		Polar		Moist		Tablelands
2 Shrublands		Boreal		Dry		Mountains
3 Grasslands	×	Cool Temperate	×	Desert	×	Hills
4 Woodlands and Savannas		Warm Temperate				Plains
5 Barren Lands		Subtropical				
6 Croplands		Tropical				
7 Rivers and Streams						
8 Lakes and Ponds						
9 Freshwater Wetlands						