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SEEA EEA Revision

Expert Consultation

Working group 1: Spatial units

<u>Background paper 1:</u>
to discussion paper 1.1 on option 3

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Research area #1: Spatial units

Background paper 1: to discussion paper 1.1 on option 3

SEEA-EEA ecosystem typology (Option 3)

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Introduction

This document presents a proposed hierarchical approach to ecosystem classification, aiming at blending a pragmatic, data-driven approach, i.e. the USGS/ESRI "major ecosystem types" and a conceptual, ecosystem functional based approach, i.e. the functional groups of the IUCN red list of Ecosystems. It implements "Option 3" of the SEEA-EEA WG 1 discussion paper "*An ecosystem type classification for SEEA EEA*".

Design notes

- The main aim of this alternative Ecosystem Type classification is to 1) make optimal use of existing frameworks (mainly USGS and IUCN, see below) and 2) align with SEEA-EEA goals and applications (ecosystem asset accounts; assessment of ecosystem services and change monitoring)
    - We build upon the USGS/Esri *Global Ecological Land Units*, and their Marine counterpart to enable efficient, consistent and reliable mapping of ecosystem types.
    - We build upon the IUCN *Red List of Ecosystems* to align (at the functional-group level) with this state-of-the art ecological typology based on ecosystem functioning theory.
    - We deviate from both approaches (in terms of detail compared to USGS, and in terms of hierarchy in terms of IUCN) in order to 1) link both systems explicitly together and 2) introduce new units where appropriate (e.g. in the built-up environments)
- The proposed hierarchy is constructed using numbered sections. The final Ecosystem Types are within these sections, and are introduced by a fleuron (❦) symbol.
    - The ETs are populated by existing (IUCN, WWF, Corinne Land Cover, SEEA-CF) units where possible. Sometimes there is a (complete) overlap between units of different origin. In this case a "**+**" precedes the ET label, suggesting that two or more (existing, named) types could be merged into a single (future) SEEA-EEA ecosystem type.
    - Similarly, a "**+?**" denotes partial overlap, and scope for discussion whether a single (merged) or multiple units are optimal for SEEA-EEA purposes.
    - The ETs listed are not necessary all meant to be included into a final SEEA-EEA type classification. They are just an inventory of available ETs from the

existing classifications used. The goal of this document is to collect and align existing (bottom-up) ET's with each other, and with a top-down approach.
    - A final set of SEEA-EEA Ecosystem Types is to be decided upon later.
- The proposed hierarchy is constructed in such a way that 'easily' observable ecosystem properties take precedence over those which are more difficult to observe. For example, in natural terrestrial ecosystems the first split is on vegetation physiognomy (trees, shrubs, grass, barren), then climate, then soil, then ecosystem processes (competition etc). One example is that e.g. tundra is classified under shrubland ecosystems, not under e.g. polar/alpine ecosystems.
- The changes with respect to the IUCN hierarchy highlight some topics that warrant broader discussion. Example are polar and alpine ecosystems (separate class or not), production forests (forest or plantation?) and rice paddies (wetland or cropland?)

Further notes:

- (Open) discussion topics are identified by a red question mark (?).
- Many descriptions, definitions etc must obviously be expanded, if SEEA decides to continue along the route taken here.
- Note that this classification system essentially is a though experiment, I'm open for any suggestions.

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Macro-scale environments

On the largest level we distinguish between the following macro-scale environments (called environmental domain by USGS and realms by IUCN):

- **Terrestrial**: all land above the mean high (sea) water mark, or unconnected to the marine environment.
- **Freshwater**: all fresh and other non-marine lakes and streams, including estuaries and river mouths.
- **Marine**: all oceans and connected salt sea water areas, excluding riverine and estuarine environments.

Generally speaking, these three macro-scale environments, which all three are (partly) recognized by both USGS and IUCN) are sufficient to be geographically exhaustive. In this case ecosystems situated at the boundary of these environments, e.g. coastal ecosystems, will be assigned to one of the bordering environments. For instance, if the mean highwater mark is used to separate the Terrestrial from the Marine environment, beach ridges will be part of the Terrestrial environment, while the intertidal zone will be part of the Marine environment.

? *Note that the IUCN subterranean realm is excluded here at this moment, because the problems it creates for accounting (extent overlapping with earth surface ecosystems). If SEEA seeks to include subterranean ecosystems into its accounting framework this issue should be solved.*

The alternative option is to distinguish distinct ecotone environments for these transition zones. Starting from the three environments introduced above, three transitions between two environments (Terrestrial–Freshwater, Freshwater–Marine and Terrestrial–Marine), and one transition between all three environments (Terrestrial–Freshwater–Marine) can be thought of. For practical reasons, and ecological similarities, these 4 possible ecotones can be clustered into two major types:

- **Wetlands**, i.e. the Terrestrial–Freshwater ecotone
- **Coastal and Estuarial**, i.e. the Terrestrial–Marine, the Freshwater–Marine and the Terrestrial–Freshwater–Marine ecotones. These include the intertidal zone in between the extreme low and high-water marks, shore areas, salt and brackish wetlands that are geomorphogenetic and ecologic dominantly influenced by marine influences, and estuarial waters.

? *However, even when these ecotones are used; classification issued remain, e.g. to which distance onshore are ecosystems considered to be Coastal? For example, 'coastal dunes' may reach a width of >5 km. Here, it is suggested that these ecosystems should be classified as Terrestrial.*

1 Terrestrial ecosystems

The Terrestrial realm is defined as all land above the mean high (sea) water mark, or unconnected to the marine environment (i.e. land below sea level). It includes all ecosystems on a mineral or organic substrate that is either impermeable or aerated during most of the growing season of vegetation, if any. (i.e., not classifying as a wetland).

The terrestrial realm is where most human activities occur. Monitoring of the change from a natural environment to cultural land use such as agricultural or build-up is often a main goal of ecosystem accounting. Therefore, we propose the main subclasses to reflect this:

- **Natural** and semi-natural ecosystems.
- **Agricultural** areas
- **Built-up** and other **artificial surfaces**

Note that semi-natural ecosystems are classified along with natural ecosystems because often the difference is gradual or subtle (i.e. secondary forests; heathland).

? *These three subclasses are strongly linked to accounting issues related to landscape mosaics, such as developed in the Discussion Paper on Urban ecosystems. We can think of the terrestrial environment as tessellated by three types of mosaics: 'natural', 'rural/agricultural' and 'urban', each dominated by (but not exclusively composed of) ecosystems from the corresponding subclass. We may thus a obtain a scalable mapping structure.*

1.1 Natural and semi-natural

In the terrestrial domain, natural ecosystems are controlled by resource availability (mainly water, energy, nutrients), disturbance regime (fire) and ambient environment (temperature, salinity) [Keith et al, 2019]. Note that climate as such is not listed here explicitly, but directly controls water availability (a resource) and temperature (ambient environment).

Given ample supplies of water, energy and nutrients, the climax vegetation under all but the most hostile local conditions will be forest, with non-forest ecosystems being found where it is too dry, too cold, too wet or too nutrient-poor to sustain trees as the dominant life form.

For each resource spatial gradients exists where forest is one end of the scale and desert is on the other end, with various types of grass, shrubs or tree-grass mixture ecosystems in between.

Given that the life-forms involved are relatively easy to map out, e.g. on the global scale using remote sensing, while the underlying limiting factors are not or less easy, it makes sense to use a life-form / land-cover based typology to define the subclasses in the terrestrial realm.

Here, we use (a selection of) the USGS/Esri 20 major ecosystems:

- Forest ecosystems (Forestlands)
- Shrublands
- Grasslands
- Woodlands and Savannas
- Barren Lands

1.1.1 Forest ecosystems

Forest ecosystems are found where resources are abundant, disturbances are limited and ambient environmental conditions are favourable.

On the global scale, forest ecosystem types are broadly defined by the various types of constraints posed by climate or resources. Of these, climate will be dominant factor on the global scales, and thus gives rise to several *zonal* forest biomes. Within each climatic zone local conditions, related to either local climate, soil, nutrients or other limiting factors, will result in various types of *azonal* forest biomes.

- USGS 1: Forestlands

1.1.1.1 Tropical and subtropical forest ecosystems

These are the forests in tropical and subtropical climates, i.e. without significant frost, and with abundant moisture availability. The main subdivision is for rainfall seasonality.

1.1.1.1.1 Moist (sub)tropical forest ecosystems

Rainfall is abundant throughout the year (with peaks when the intertropical convergence zone (ITC) passes over.

- IUCN: **T1.1 Tropical/Subtropical humid lowland forests**. Closed, multilayered evergreen canopy; high nutrient turnover rate; high functional and taxonomic diversity. Strong light competition (autolimitation) favouring e.g. lianas and epiphytes.
- +? WWF: **Tropical and subtropical moist broadleaf forests.**
- +? WWF: **Tropical and subtropical coniferous forests.**

1.1.1.1.2 Seasonal dry (sub)tropical forest ecosystems

Rainfall is more seasonal, causing a relatively dry season, favouring deciduous vegetation.

- IUCN: **T1.2 Tropical/Subtropical dry forests**
- \+ WWF: **Tropical and subtropical dry broadleaf forests**.

1.1.1.1.3 Tropical azonal forest ecosystems

Various tropical forested ecosystems characterized by local climatic or non-climatoc conditions and/or ecosystem functioning.

- IUCN: **T1.3 Tropical/Subtropical moist montane forests.** This is an azonal *orobiome*: an ecosystem characterized by the microclimate of tropical mountain slopes. A characteristic trait is the extraction of moisture by vegetation from clouds, hence the name ‘cloud forests’ often used.
- IUCN: **T1.4 Tropical heath forests**. This is an azonal *peinobiome*, characterized by nutrient deficits due to mostly sandy soils with little or no lithogenic buffer capacity.
- Other tropical forest ecosystems n.e.m.

1.1.1.2 Mediterranean forests

Climate characterized by warm and dry summers, and cool wet winters. Soils are generally nutrient-poor. Vegetation adapted to both nutrient deficiencies and seasonal droughts (e.g. sclerophyllous leaves)

- IUCN: **T2.6 Temperate pyric sclerophyll forests and woodlands**
- \+ WWF: **Mediterranean Forests, woodlands and scrubs**

1.1.1.3 Temperate forests

Cold to cool winters and cool to warm summers; humid climate; mostly deciduous forests.

- IUCN: **T2.2 Deciduous cool temperate forests and shrublands**
- \+ WWF: **Temperate broadleaf and mixed forests**

- IUCN: **T2.3 Cool temperate evergreen forests and woodlands**
- + WWF: **Temperate Coniferous Forest**
- IUCN: **T2.4 Warm temperate rainforests**.
- IUCN: **T2.5 Temperate pyric humid forests**

1.1.1.4 Boreal forests

Long cold winters alternated with short warm summers (GDD>xxx). Vegetation mostly characterized by evergreen or deciduous (*Larix*) coniferous trees, depending of winter extrema.

- IUCN: **T2.1 Boreal forest and woodland** – Taiga.
- + WWF: **Boreal forests / Taiga**

? *Explicitly distinguish between evergreen and deciduous? Might be usefull for tracking changes due to global warming*

1.1.2 Savannas and other woodlands

These are the ecosystems where trees may still be a significant or dominant component of vegetation structure, but canopies are not closed and a second dominant life form is present, either as shrubs or as grass. Typically these ecosystems are found in water-limited ecosystems in between the forest biomes (where moisture is ample), and the desert biomes (where water is too limited to sustain tree growth). Savannas are defined as 'any system with a continuous layer of C4 grasses, regardless of whether trees are present'[1]. If trees are present, they compete with the grass for water and/or nutrients. Climate is not a conclusive control on the distribution of savanna ecosystems. Especially under more favourable conditions, where both water and nutrients may be sufficient to sustain a closed forest canopy, herbivory and/or fires result in forest and savanna as alternative stable states.

- USGS 4 Woodlands and Savannas

1.1.2.1 Tropical and subtropical savannas

- IUCN: **T4.1 Trophic savannas** – high fertility; low rainfall; strong herbivory
- IUCN: **T4.2 Pyric tussock savannas** – lower fertility; higher, but strongly seasonal, rainfall; episodic fires.
- IUCN: **T4.3 Hummock savannas**
- +? WWF: **Tropical and subtropical grasslands, savannas and shrublands**

1.1.2.2 Temperate savannas

- IUCN: **T4.4 Temperate wooded savannas**
- +? WWF: **Temperate grasslands, savannas and shrublands**

1.1.3 Shrubland

Occurs under adverse (cold, dry, and/or nutrient deficient) conditions where overall resilient shrubs outcompete trees.

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[1] Lehmann, C. E., Archibald, S. A., Hoffmann, W. A., & Bond, W. J. (2011). Deciphering the distribution of the savanna biome. *New Phytologist*, 191(1), 197–209.

- USGS **2 Shrublands**

1.1.3.1 Tropical and subtropical shrublands

- IUCN: **T3.1 Seasonally dry tropical shrublands** – Heathlands in tropical but seasonally dry climates on nutrient-poor acid substrates
- \+ WWF: **Tropical and subtropical grasslands, savannas and shrublands**

1.1.3.2 Mediterranean shrublands

- IUCN: **T3.2 Seasonally dry temperate heaths and shrublands** – Heathlands in Mediterranean climates on nutrient-poor substrates

1.1.3.3 Temperate shrublands

- IUCN: **T3.3 Cool temperate heathlands** – Heathlands in wet, cool-temperate climates on nutrient-poor substrates.
- \+ WWF: **Temperate grasslands, savannas and shrublands** – Zonal

1.1.3.4 Boreal shrublands

- IUCN: **T6.3 Polar tundra** – Shrublands in boreal climates (energy and nutrient limited)
- \+ WWF: **Tundra**

? *Note that 'tundra' is listed here under shrubland, while in the IUCN RLE system tundra is listed under 'polar/alpine'. The reasoning here is that the ecological expression of a limiting factor (i.e. shrubland) is taking precedence over the cause (i.e. the cold temperatures)*

1.1.3.5 Azonal (montane) shrublands

- IUCN: **T6.5 Tropical alpine meadows and shrublands**
- \+ WWF: **Montane grasslands and shrublands**

1.1.4 Grassland

Extensive grasslands occur where water availability is too little to sustain shrubs or trees in. significant densities. Note that tropical/subtropical C4 grasslands are classified as 'Savanna' (see there)

- USGS **3 Grasslands**

1.1.4.1 Tropical and subtropical grasslands

? *Here we need more guidance whether tropical C4 grasslands (i.e., without trees) actually exists as a stable biome. There is some empirical[2] and theoretical[3] evidence that it does. For the time being, they are merged with savannas.*

Note that the absence of this ET poses potential issues for mapping and/or linking IUCN with USGS.

[2] Hirota, M., Holmgren, M., Van Nes, E. H., & Scheffer, M. (2011). Global resilience of tropical forest and savanna to critical transitions. *Science*, 334(6053), 232–235.

[3] Staal, A., Dekker, S. C., Hirota, M., & van Nes, E. H. (2015). Synergistic effects of drought and deforestation on the resilience of the south-eastern Amazon rainforest. *Ecological Complexity*, 22, 65–75.

1.1.4.2 Temperate grasslands

- IUCN: **T4.5 Temperate grasslands**
- + WWF: **Temperate grasslands, savannas and shrublands**

1.1.4.3 Azonal (montane) grasslands

- IUCN: **T6.5 Tropical alpine meadows and shrublands**
- IUCN: **T6.4 Temperate alpine meadows and shrublands**.
- + WWF: **Montane grasslands and shrublands**

1.1.5 Deserts, and other scarcely vegetated

Deserts and semi-deserts are the ecosystems found in climates that are too dry to sustain a closed vegetation cover of any kind. Plant life is by definition adapted to the dry conditions (e.g. xerophytes; sclerophyllous leaves) and/or herbivory (thorns etc.)

- USGS **5 Barren Lands**
- WWF: **Deserts and xeric shrublands**

1.1.5.1 Subtropical (semi-)desert

- IUCN: **T5.1 Semi-desert steppes** – Low vegetation cover (10–30%); mixed grass/shrubs
- IUCN: **T5.2 Thorny deserts and semi-deserts** – Low vegetation cover (10–30%); Spinescent and succulent vegetation
- IUCN: **T5.3 Sclerophyll deserts and semi-deserts** – Low vegetation cover; mostly sclerophyll shrubs
- IUCN: **T5.5 Hyper-arid deserts** – Extremely low vegetation cover (<1%)

1.1.5.2 Temperate (semi-)desert

- IUCN: **T5.4 Cool temperate deserts**

1.1.5.3 Boreal (semi-desert)

? *No IUCN unit for polar deserts? Or are these included in T6.3 Polar Tundra?*

1.1.5.4 Other scarcely vegetated ecosystems

These are the ecosystems that are characterized by a low vegetation cover for reasons other than a dry climate.

- IUCN: **T3.4 Rocky pavements, screes and lava flows** – Lichens and dwarf-shrubs on extreme shallow (or no) soils, with limited water retention capacity and chemical weathering products.
- IUCN: **T6.1 Ice sheets, glaciers and perennial snowfields** –
- IUCN: **T6.2 Polar/alpine rocky outcrops** –

? *Not sure what the difference between IUCN T6.2 and T3.4 is. Also not sure if polar (non-alpine) outcrops exist; There will be a lot of physical weathering converting any semi-horizontal outcrop into a rocky pavement.*

1.2 Agricultural

These are mainly those land use types that are very clearly agricultural in nature: croplands, rice paddies etc., but not production forests, mainly because they often perform the dual role of timber production and natural habitat, and the associated issue whether 'production' forest can and should be distinguished from 'natural' forest. Orchards, proper plantations etc are in most cases sufficiently distinct from natural ecosystems to be classified as 'agricultural'.

The subclasses proposed here mirror the overall structure of (semi-)natural ecosystems, i.e. ordered by overall physiognomy, starting with trees and other permanent woody vegetation, and ending with grassland.

For now, we include units proposed by SEEA-CF, IUCN, EU-CLC (Corine Land Cover) and FAO.

For high-level mapping (as explained in the introduction to Section 1) several high-level units may be developed. Existing examples include:

- CLC: **242 Complex cultivation patterns**
- CLC: **243 Land principally occupied by agriculture, with significant areas of natural vegetation**
- CLC: **244 Agro-forestry areas**

1.2.1 Plantations, orchards, etc.

These are permanent tree- and shrub-type of crops. Examples will be oil palm, olives, coffee, berries etc. Permanency of the crops might warrant

- IUCN: **T7.3 Plantations**
- +? CLC: **223 Olive groves**
- +? CLC: **221 Vineyards**
- +? CLC: **222 Fruit trees and berry plantations**

? *Permanency of these woody crops might warrant dedicated ecosystem types per crop type; alternatively crop type could be a condition account attribute (see Croplands, below)*

1.2.2 Croplands

Because the actual crops being grown varies considerable both between regions and possibly years, we propose that specific crop type is to be part of the Condition Account rather than an Ecosystem Type. For national scale mapping, it might be desirable to define crop-specific ETs, though.

- USGS **6 Croplands**
- IUCN: **T7.1 Croplands**
- + CLC: **211 Non-irrigated arable land** – Irrigation status in condition account
- + CLC: **212 Permanently irrigated land**– Irrigation status in condition account
- + CLC: **241 Annual crops associated with permanent crops**
- + SEEA-CF LU: **1.1.1 Land under temporary crops** – permanency status in condition account

- + SEEA-CF LU: **1.1.4 Land under permanent crops** – permanency status in condition account

1.2.3 Rice fields (paddies)

These are classified at a high level as agriculture, rather than wetlands (as IUCN does), 1) because of the primarily agricultural nature, 2) to facilitate monitoring LU conversion from natural ecosystems to agriculture, and 3) because terraced rice paddies are found on locations where natural wetlands would be impossible.

- IUCN: **F4.2 Rice paddies**
- + CLC: **213 Rice fields**

1.2.4 Pastures, meadows

- IUCN: **T7.2 Sown pastures and old fields**
- + CLC: **231 Pastures, meadows and other permanent grasslands under agricultural use**
- + SEEA-CF LU: **1.1.2 Land under temporary meadows and pastures**
- + SEEA-CF LU: **1.1.5 Land under permanent meadows and pastures**

1.2.5 Aquaculture

- SEEA-CF LU: **1.3.1 Land used for hatcheries**
- + SEEA-CF LU: **1.3.2 Managed grow-out sites on land**

1.2.6 Other

- SEEA-CF LU: **1.1.3 Land with temporary fallow**
- SEEA-CF LU: **1.1.6 Agricultural land under protective cover** – Greenhouses etc.

1.3 Urban, built-up and infrastructure

This category is characterized by an overall lack of vegetated or otherwise natural land cover. Vegetation may be present, but in the form of parks, zoos etc, and as e.g. a tree canopy layer overlying infrastructure. Here, we build upon existing (SEEA-CF land use and EU-CLC classifications, clustering units where this seems appropriate, i.e. similar physical appearance but variable economic use).

? *Note that these units are probably not satisfactory for SEEA-EEA purposes. Final classes should be based on structural differences (between classes) in ecosystem services provided by the corresponding assets, and/or useful to track LU change (from natural to intensively managed).*

To do: include results of the “Urban” discussion paper.

As with agriculture, high level units may be distinguished for certain mapping scales, e.g.

- USGS **20 Built Environment**
- IUCN: **T7.4 Urban and infrastructure lands**

1.3.1 Mining and quarrying

- SEEA-CF LU: **1.4.1 Mining and quarrying**
- \+ CLC: **131 Mineral extraction sites**

1.3.2 Manufacturing, Commercial, financial and public services

- SEE-CF LU: **1.4.3 Manufacturing**
- +? SEEA-CF LU: **1.4.6 Commercial, financial and public services**
- \+ CLC: **121 Industrial or commercial units and public facilities**

? *Economic sector can be stored as attribute in either ecosystem asset and/or condition account.*

1.3.3 Infrastructure

- SEEA-CF LU: **1.4.4 Technical infrastructure**
- \+ SEE-CF LU: **1.4.5 Transport and storage**
- \+ CLC: **122 Road and rail networks and associated land**
- \+ CLC: **123 Port areas**
- \+ CLC: **124 Airports**

? *All infrastructure to be merged into a single class; infrastructural type can be stored as attribute in either ecosystem asset and/or condition account.*

? *Infrastructure* within *an urban region should probably be part of an urban mosaic unit.*

1.3.4 Residential

- SEEA-CF LU: **1.4.8 Residential**
- \+ CLC: **111 Continuous urban fabric**
- \+ CLC: **112 Discontinuous urban fabric**

? *Relative cover of residential vs green to be stored as asset attribute and/or condition variable.*

1.3.5 Recreational facilities

- CLC: **141 Green urban areas** – Public parks etc.
- CLC: **142 Sport and leisure facilities**
- \+ SEEA-CF LU: **1.4.7 Recreational facilities**

? *Distinguish between ‘natural’ (grass) sport fields and those with artificial surfaces (astroturf)?*

1.3.6 Other

- SEEA-CF LU: **1.4.2 Construction** – Useful to track LU change?
- \+ CLC: **133 Construction sites**
- +? CLC: **132 Dump sites**

? *More?*

2 Freshwater ecosystems

The freshwater macroscale environment is characterized by open water, i.e. a water column above the soil surface during a significant amount of time, especially during the growing season. A major distinction is between *flowing* water bodies, such as rivers and streams, and *non-flowing* water bodies, such as lakes and ponds. Many lakes are both upstream and downstream connected to streams (inlets and outlets), but still the residence time of water in such a lake is large compared to that of a stream.

? *Can a formal criterion (i.e. a single threshold value for velocity and/or residence time) be devised to distinguish lakes from streams?*

2.1 Rivers and streams

These are ecosystems characterized by flowing water (i.e. a low volume/flux ratio). There are many stream classification systems, based on abiotic and biotic attributes.

Abiotic attributes 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** attributes include

- Vegetation
- Macrofauna (fish; macroinvertebrates)
- Microbiota

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

Because streams are by definition hydro-geomorphological features with a clear longitudinal gradient, and because both sediment transport and ecological functioning follow form here, it seems appropriate to classify streams on a hydro-geomorphological base, despite the understanding that rivers are part of a continuum.

It is further proposed that additional key characteristics of streams (i.e. those which are relevant from an ecological functioning point of view, e.g. planform, sediment size, hydrologic regime) are either recorded as an auxiliary attribute associated with the individual asset, or as a condition indicator. If required for specific applications or national fine-grained classifications, they can be made part of appropriate sub-classes.

On the upstream end, streams are spatially connected to the wetland realm, either in the form of marshy source areas, or as stream-lining riparian wetlands. A pragmatic criterion to define the boundary of the two realms is by vegetation: submerged or floating macrophytes occur in the freshwater realm, but not in the wetland realm.

On the downstream end, streams can either directly flow into the marine realm, or indirectly, through an estuary or similar freshwater-marine ecotone (section 0).

- USGS **7 Rivers and Streams**
- CLC: **511 Water courses**

2.1.1 Bed rock streams

Typically, low-order streams that are supply-limited from a sediment point of view. Bed consisting of either bedrock or large cobbles.

- New: **Bed-rock streams**

2.1.2 Gravel-bed alluvial rivers

Intermediate-order streams of upland areas with gradients and stream power sufficient to sustain transport of gravel. Channel form often braided or straight to sinuous, with alternating bars.

Hydrological regime can be either included in the classification, recorded elsewhere, as proposed above (section 2.1).

- IUCN: **F 1.1 Permanent upland streams**
- IUCN: **F 1.4 Monsoonal upland stream**

? *Not sure here if the 'monsoonal' aspect is sufficient to distinguish these from other upland streams, which also might experience strong seasonal discharge variability, for reasons other than monsoons, like e.g. snow melt or seasonal evapotranspiration.*

2.1.3 Sand-or-finer bed rivers

High-order lowland streams with lower gradients with sand or clay as the dominant sediment in transport. Channel form often meandering or anastomising.

- IUCN: **F 1.2 Permanent lowland rivers**
- IUCN: **F 1.5 Monsoonal lowland rivers**

? *idem.*

2.1.4 Other

- IUCN: **F1.3 Freeze-thaw rivers and streams**
- IUCN: **F 1.6 Arid episodic lowland rivers**
- New: **Seasonal intermittent streams**
- New: **Artifical streams and canals**

2.2 Lakes and ponds

These are ecosystems characterized by a relatively high volume/flux ratio. Often a distinction is made between proper lakes (large) and ponds (small), the threshold used varies considerably and size by itself does not appear to be highly relevant from an ecological functioning point of view, except that it is often correlated with lake depth, which does have an ecological relevance.

Lakes are almost by definition the result of a positive water balance: the inflow of water (from streams, precipitation or groundwater) into a topographic depression is larger than the outflow (as streams, evaporation or groundwater). Given the potentially strong fluctuations in streamflow, precipitation and potential evaporation this balance may be negative as well, causing dynamics in lake volume, and, in the extreme case, the seasonally disappearance of the lake. Given the strong effect of lake disappearance of lake biota, permanency of lakes is a first order ecological property.

Additional high-order lake features often used in lake typologies are related to stratification and mixing, trophic levels and salinity (discussed below for the permanent lakes.

By origin

Lakes can also be classified by origin (O'Sullivand and Reynolds, 2005, and references therein):

- Tectonic basins and lakes
- Volcanic lakes
- Lakes formed by landslides
- Lakes formed by glacial, nival activities and by permafrost
- Lake basins formed by karstic events and solution processes
- Fluvial lakes, lakes in flood-plains and deltaic areas
- Coastal lakes
- Lakes formed by deflation
- Lakes formed by plant accumulation and by animals
- Artificial lakes and reservoirs
- Meteoric impacts

Given the fact that lake origin is often only indirectly linked to the lake ecosystems, it is proposed that this classification is not primarily used for ecosystem classification. It does, however contribute relevant additional information about individual lakes that is worth recording in either asset attributes or the condition account.

By stratification type

An additional ecological relevant physical property of permanent lakes is the mixing behavior. Because water has its highest density at 4 ˚C, under specific conditions lakes tend to be stratified, with a warm surface layer on top of a denser cold bottom layer, with very little mixing of the two layers, decreasing oxygen supply to the bottom layer, which may lead to ecologically unfavourable anaerobic conditions. If during some time of the year due to the temperature regime mixing does occur, this effect is limited, while in absence of mixing the anaerobic conditions may be permanent, which has a strong effect on the trophic balance of the lake.

- **Amictic lakes** are not stratified. They are only found below ice, and have a thermal gradient from 0 ˚C (just below the ice) to 4 ˚C (near the bottom). Mostly found in Arctic, Antarctic and Alpine environments.

- **Meromictic lakes** never completely mix, either because it is too deep compared to the surface area, or because of a higher density of bottom water due to solutes.
- **Monomictic lakes** mix complete onece a year.
    - **Cold-type monomictic** lakes are frozen and stratified in winter, and mix during the summer season.
    - **Warm-type monomictic** lakes are stratified in summer, and mix during the winter.
- **Dimictic lakes** mix twice a year, during spring and fall. These is the most common lake type at temperate latitudes (Lampert and Sommer, 2007)

Polymictic lakes mix often, or are mixed continuously. These are often shallow lakes.

By trophic level

A trophic classification of lakes that is widely used is based on a study commissioned by the OECD (Vollenweider and Kerekes, 1982). Nothing that phosphor concentration often is a limiting factor, the following classes have been proposed:

- **ultraoligotrophic:** P_{tot} <5 µg/l
- **oligotrophic:** P_{tot} 5–10 µg/l
- **mesotrophic:** P_{tot} 10–30 µg/l
- **eutrophic:** P_{tot} 30–100 µg/l
- **hypereutrophic:** P_{tot} >100 µg/l.

Combinations

Although one option is to treat above lake typologies as either auxillary asset attributes, or as part of the condition account, they can also be used in combination to define lake ecosystem types, e.g. "*mesostrophic dimictic freshwater lake of glacial origin*".

Existing classifications

Existing lake typologies as used within global or continental-scale ecosystem typologies (i.e. IUCN, CLC, FAO, WWF) are only partially aligned, if at all, with above classifications.

- USGS **8 Lakes and Ponds**
- CLC: **512 Water bodies** – no further subdivision.

2.2.1 Episodic and seasonal lakes

These are lakes that exist either seasonal (e.g. each wet season) or episodic (only after intense and/or prolonged rainfall). Fish will be mostly absent.

- IUCN: **F2.4 Ephemeral freshwater lakes**
- IUCN: **F2.6 Ephemeral salt lakes**

2.2.2 Permanent lakes

Lakes that exist throughout a series of years.

- IUCN: **F2.1 Freeze-thaw freshwater lakes** – cold monomictic?
- IUCN: **F2.2 Large permanent freshwater lakes**
- IUCN: **F2.3 Small permanent freshwater lakes**
- IUCN: **F2.5 Permanent inland salt lakes**

- New: **Artifical lakes**

? *What types of artificial lakes to distinguish? Fishing ponds? Reservoirs?*

3 Marine ecosystems

Marine ecosystems are defined as saline aquatic ecosystems physically connected to the world's oceans.

? *Note that this definition excludes the Caspian Sea. This issue is politically relevant, because the countries bordering the Caspian Sea do not agree of it is a lake (to be divided up equally by bordering countries) or a sea (governed by the UN Law of the Sea)*

In contrast to what is used elsewhere (UK?), it is proposed that the marine realm is bounded by the mean *low water* mark and excludes emergent non-aquatic vegetation such as salt marshes and mangroves. This choice enables inclusion of the intra-tidal area in a separate Coastal category (Section 5.1).

? *Clearly, this is a discussion point.*

Because marine ecosystems depend strongly on the supply of sunlight and nutrients, the ecological zonation reflects the underlying geophysical zonation.

From a horizontal point of view the marine realm is traditionally subdivided between shallow *continental shelf* seas (on continental crust), the *abyssal plain* (on oceanic crust), and the *continental slope* in between. The related ecological zones are the *neritic* zone on the shelf and the *oceanic* zone for deeper waters.

From a vertical point of view, the first distinction is between the *pelagic* zone (water column) and the *benthic* zone (at or near the sea bottom). Within the pelagic zone, the most relevant subdivision is between the *photic* zone near the water surface, where sunlight penetrates, and the deep waters below it. The lower boundary of the photic zone is given by the *compensation point*, i.e. the depth at which oxygen production by photosynthetic process is equal to oxygen consumption by the primary producers involved. The depth of the compensation point varies with water transparency (i.e. because of suspended sediment). For the North Sea it is about 35m, while for the open ocean it can be 150m (Speight and Henderson, 2010)

? *See the separate discussion paper on a discussion of whether marine ecosystem units should be 2D or 3D, and layering should or should not be included.*

3.1 Continental shelf / neritic zone.

Attached to the continents (lying on continental crust); water depth usually up 150m. The photic zone may or may not penetrate to the bottom.

? *Are there significant non-photic-benthic areas on continental shelfs?*

? *Shouldn't some climatic zonation (based on currents and water temperature) not appropriate here?*

- USGS **15 Sunlit Shelf**
- +USGS **16 Twilight Shelf**
- IUCN: **M1.1 Seagrass meadows**
- IUCN: **M1.2 Kelp forests**
- IUCN: **M1.3 Photic coral reefs**
- IUCN: **M1.4 Shellfish beds and reefs**

- IUCN: **M1.5 Marine animal forests**
- IUCN: **M1.6 Rocky reefs**
- IUCN: **M1.7 Subtidal sandy bottoms**
- IUCN: **M1.8 Subtidal muddy bottoms**
- IUCN: **M1.9 Upwelling zones**

3.2 Continental slope

Continental slopes form the transition (‘margin’) from the continental shelf to the deep ocean’s abyssal plain. A geophysical distinction is between gentle-sloping *passive margins*, where continents and ocean are on the same tectonic plate and do not move with respect to each other (e.g. along the Atlantic Ocean), and steeper *active margins*, where an oceanic plate subducts below a continental plate (e.g. along the Pacific ‘ring of fire’). Although the type of margin will impact distribution, extent and characteristics of the associated ecosystem types, the direct ecological relevance is less clear.

- USGS **17 Continental Slope**
- IUCN: **M3.1 Continental slope and island slopes - soft substrate**
- IUCN: **M3.2 Continental slope and island slopes - hard substrate**

? *Are these for both active and passive margins? Or restricted to passive margins?*

- IUCN: **M3.3 Marine canyons**

3.3 Deep ocean

These are the benthic ecosystems on the abyssal plain (and other deep ocean floor types), and the pelagic waters above them.

? *How to deal with the ocean waters layering needs to be decided upon (see earlier remarks). Here we simply list the existing ET’s and distinguish between Pelagic (water column) and Benthic ecosystems.*

3.3.1 Pelagic ecosystems

- USGS **11 Sunlit Ocean Waters**
- +USGS **12 Twilight Ocean Waters**
- +USGS **13 Deep Ocean Waters**
- IUCN: **M2.1 Epipelagic ocean waters** — 0–200m
- +IUCN: **M2.2 Mesopelagic ocean** waters — 200–1000m
- +IUCN: **M2.3 Bathypelagic ocean waters** — 1000–4000m
- +IUCN: **M2.4 Abyssopelagic ocean waters** — >4000m

3.3.2 Benthic ecosystems

- USGS **18 Deep Ocean Floor**
- USGS **19 Trench Floor**

- IUCN: **M3.4 Abyssal plains - soft substrate**
- IUCN: **M3.5 Hadal zones**
- IUCN: **M3.6 Seamounts, plateaus, hills, knolls**
- IUCN: **M3.7 Deepwater biogenic systems**
- IUCN: **M3.8 Chemosynthetically-based ecosystems**

3.4 Other

- IUCN: **M4.1 Artificial reefs**

4 Wetland ecosystems.

Wetlands are ecosystems on the interface of terrestrial and freshwater realms. The defining feature of wetlands is the presence of water-logged conditions during the growing season and the presence of *hydrophytes*.

A major distinction is between *terrain-conforming* and *self-emergent* wetlands. Most wetlands originate at terrain conforming wetlands, as the result of water stagnation or seepage in topographic lows. Water supply is often dominated by nutrient-rich groundwater (*minerotrophic*), favouring *eutrophic* wetland ecosystems. When the prevailing water-logged conditions lead to anaerobic soil conditions and hence decreased decomposition of organic matter peat formation is favoured. Because peat has a high water holding capacity, a positive feedback may result in self-emergent (raised) wetlands. Water supply is now no longer dominated by ground- or surface water but by nutrient-poor precipitation (*ombrotrophic*), favouring *Oligothrophic* wetland ecosystems.

A second distinction is due to location in the landscape relative to the freshwater realm. *Lacustrine* and *riverine* wetland border lakes and streams, respectively, while *palustrine* wetlands are decoupled or upstream from the freshwater ecosystems.

- USGS **9 Freshwater wetlands**

4.1 Palustrine wetlands

Palustrine wetlands are either upstream of the stream network, or decoupled from it. They thus receive water and nutrients only from precipitation (ombrotrophic) or groundwater (minerotrophic).

4.1.1 Mires

Mires are peat-dominated wetlands. They develop from the co-evolution between vegetation, SOM decomposition (or the absence of it), and hydrology.

? *There are many more types of mires than the ones mentioned here (string bogs; blanket bogs; palsa mires; aapa mires; prairie potholes). What level of detail is appropriate for SEEA-EEA ET classification purposes?*

4.1.1.1 Bogs

Peat bogs are ombrotrophic (rainfall fed) mires.

- IUCN: **FT1.5 Boreal, temperate and montane peat bogs**

4.1.1.2 Fens

Fens are minerotrophic (groundwater fed) mires.

- IUCN: **FT1.6 Boreal and temperate fens**

4.1.2 Other

- IUCN: **FT 1.7 Artesian springs and oases**

4.2 Riverine and lacustrine wetlands

Wetlands along rivers consist mainly of floodplains and other wet riparian areas. Water is supplied mostly by the streams, but also as groundwater from the side slopes. The major distinction is between *marshes* (grass and herb dominated) and *swamps* (shrub and tree dominated).

Lacustrine wetlands are bordering lakes. Water supply is either by groundwater seepage, or by episodic or seasonal flooding due to rising lake water levels. As with riverine wetlands, the major distinction is based on vegetation type.

Because of the great similarities between lacustrine and riverine wetlands, e.g. in ecosystem functioning, there are merged into a single categorie.

4.2.1 Riverine and lacustrine marshes

Floodplains etc. dominated by grasses and/or herbaceous vegetation

- IUCN: **FT 1.2 Seasonal floodplain marshes**
- +? WWF: **Flooded grasslands and savannas**
- IUCN: **FT 1.4 Episodic arid floodplains**

4.2.2 Riverine swamps

Floodplains etc. dominated by woody vegetation

- IUCN: **FT 1.1 Tropical flooded forests and peat forests**
- IUCN: **FT 1.3 Subtropical/temperate forested wetlands**

4.3 Other

- IUCN: **FT 1.8 Geothermal wetlands**

5 Coastal and estuarine ecosystems

Coastal ecosystems are found near the interface of the Terrestrial and the Marine realms, and at the interface of the Freshwater and Marine realms. These will be first subclasses.

5.1 Coastal Ecosystems

5.1.1 Supratidal ecosystems

- IUCN: **TM 2.1 Coastal shrublands and grasslands**
- ? *Includes Machair?*

5.1.2 Shores and other intertidal ecosystems

- USGS **14 Intertidal Seabed**
- IUCN: **TM 1.1 Rocky Shores**
- IUCN: **TM 1.2 Muddy Shores**
- ? *Includes Intertidal mudflats (which are definitively *not* shores)?*
- IUCN: **TM 1.3 Sandy Shores**
- IUCN: **TM 1.4 Boulder/cobble shores**
- IUCN: **TM 3.1 Artificial shores**

5.1.3 Coastal wetlands

- IUCN: **FM 1.3 Intermittently closed coastal lagoons**
- ? *Includes back-barrier marshes?*
- WWF: **Mangroves**
- New: **Salt marshes**

5.2 Estuarine and other river mouth ecosystems

- USGS **10 Estuaries**
- IUCN: **FM 1.1 Deepwater coastal inlets** – fjords etc.
- IUCN: **FM 1.2 Permanently open riverine estuaries and bays**
- New: **Tidal freshwater wetlands** – see e.g. Barendregt and Swarth (2013)
- ? *Or should these classify under Riverine Marshes?*

6 References

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