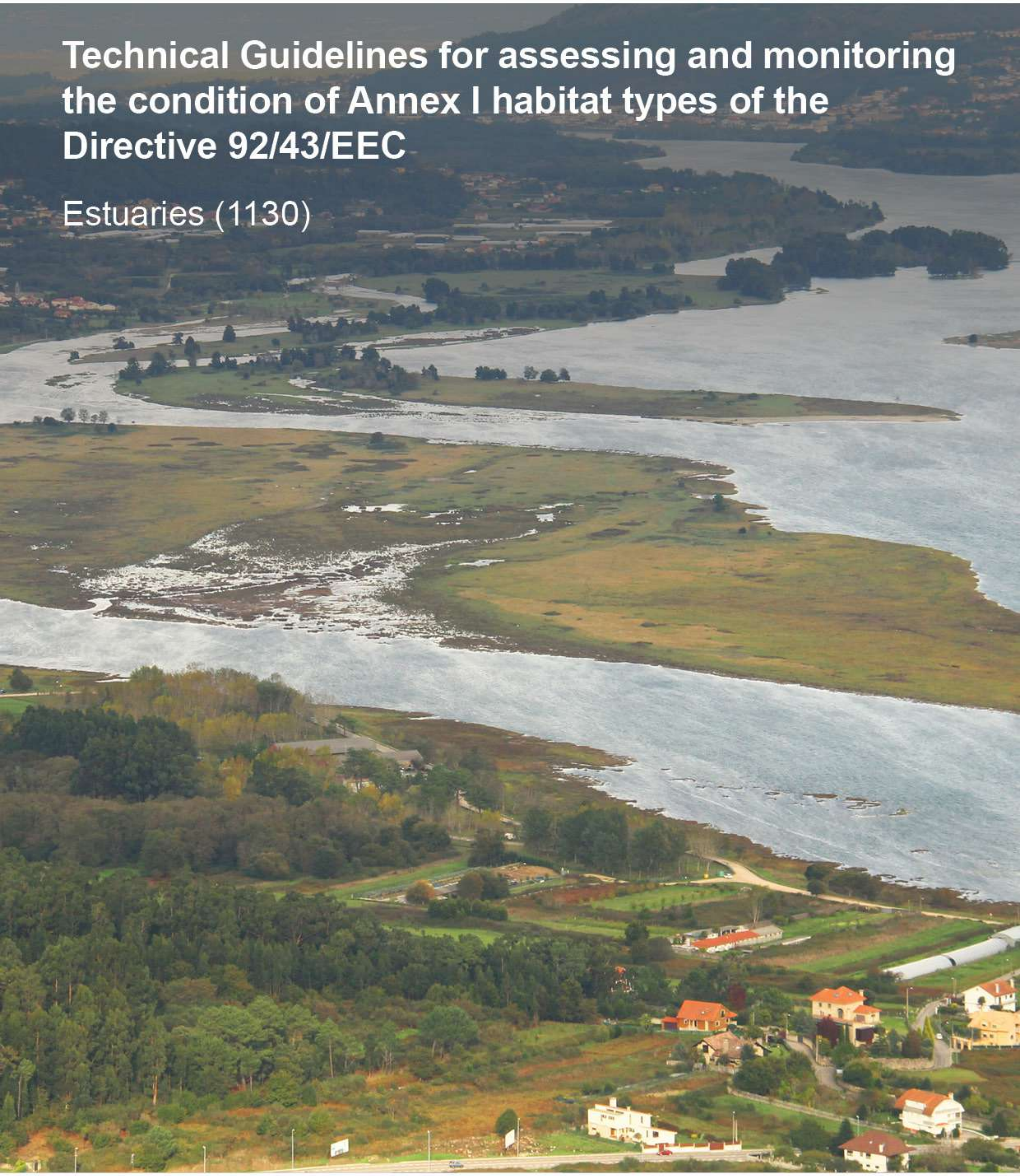
European Commission

Technical Guidelines for assessing and monitoring the condition of Annex I habitat types of the Directive 92/43/EEC

Estuaries (1130)



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Estuaries (1130)

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Contents

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Glossary and definitions

Habitats

Natural habitats: are terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural (Habitats Directive).

Habitat condition: is the quality of a natural or semi natural habitat in terms of its abiotic and biotic characteristics. Condition is assessed with respect to the habitat composition, structure and function. In the framework of conservation status assessment, condition corresponds to the parameter "structure and function". The condition of a habitat asset is interpreted as the ensemble of multiple relevant characteristics, which are measured by sets of variables and indicators that in turn are used to compile the assessments.

Habitat characteristics: are the attributes of the habitat and its major abiotic and biotic components, including structure, processes, and functionality. They can be classified as abiotic (physical, chemical), biotic (compositional structural, functional) and landscape characteristics (based on the Ecosystems Condition Typology defined in the SEEA-EA; United Nations et al., 2021).

Species

Characteristic species: are species that characterise the habitat type, are used to define the habitat, and can include dominant and accompanying species.

Typical species: are species that indicate good condition of the habitat type concerned. Their conservation status is evaluated under the structure and function parameter. Usually, typical species are selected as indicators of good condition and provide complementary information to that provided by other variables that are used to measure compositional, structural and functional characteristics.

Variables

Condition variables: are quantitative metrics describing individual characteristics of a habitat asset. They are related to key characteristics of the habitat that can be measured, must have clear and unambiguous definition, measurement instructions and well-defined measurement units that indicate the quantity or quality they measure. In these guidelines, the following types of condition variables are included:

- **Essential variables:** describe essential characteristics of the habitat that reflect the habitat quality or condition. These variables are selected on the basis of their relevance, validity and reliability and should be assessed in all MSs following equivalent measurement procedures.
- **Recommended variables:** are optional, additional condition variables that may be measured when relevant and possible to gain further insight into the habitat condition, e.g. according to contextual factors; these are complementary to the essential variables, can improve the assessment and help understand or interpret the overall results.
- **Specific variables:** are condition variables that should be measured in some specific habitat types or habitat sub-groups; can thus be considered essential for those habitats, which need to be specified (e.g. salinity for saline grasslands, groundwater level for bog woodlands, etc.).

Descriptive or contextual variables: define environmental characteristics (e.g. climate, topography, lithology) that relate to the ecological requirements of the habitat, are useful to characterise the habitat in a specific location, for defining the relevant thresholds for the condition variables and for interpreting the results of the assessment. These variables, however, are not included in the aggregation of the measured variables to determine the condition of the habitat.

Reference levels and thresholds: are defined for the values of the variables (or ranges) that determine whether the habitat is in good condition or not. They are set considering the distance from the reference condition (good). The value of the reference level is used to re-scale a variable to derive an individual condition indicator.

Condition indicators: are rescaled versions of condition variables. Usually, they are rescaled between a lower level that corresponds to high habitat degradation and an upper level that corresponds to the state of a reference habitat in good condition.

Aggregation: is defined in this document as a rule to integrate and summarise the information obtained from the measured variables at different spatial scales, primarily at the local scale (sampling plot, monitoring station or site).

Abbreviations

EU: European Union

HD: Habitats Directive

IAS: Invasive Alien Species

MS: Member State

EU Member States acronyms:

Austria	(AT)	Estonia	(EE)	Italy	(IT)	Portugal	(PT)
Belgium	(BE)	Finland	(FI)	Latvia	(LV)	Romania	(RO)
Bulgaria	(BG)	France	(FR)	Lithuania	(LT)	Slovakia	(SK)
Croatia	(HR)	Germany	(DE)	Luxembourg	(LU)	Slovenia	(SI)
Cyprus	(CY)	Greece	(EL)	Malta	(MT)	Spain	(ES)
Czechia	(CZ)	Hungary	(HU)	Netherlands	(NL)	Sweden	(SE)
Denmark	(DK)	Ireland	(IE)	Poland	(PL)		

MSFD: Marine Strategy Framework Directive

SEEA EA: System of Environmental Economic Accounting- Ecosystem Accounting

WFD: Water Framework Directive

Executive summary

Estuaries are transitional fluvial-marine systems in which freshwater from the land interacts with saline water from the sea. Estuarine ecosystems include the river channel, to the maximum upstream extent of tidal influence, the adjacent coastal waters, to the maximum extent of freshwater flow, salt marshes and tidal flats that develop along the shoreline, built up from riverine sediments deposited as river flow rate slows at sea level and subject to daily tidal inundation, and associated beaches and dunes.

A general description, including references to the definition in the Habitats Directive Interpretation Manual, EUNIS habitat types (level 4) and Annex I of the Nature Restoration Regulation is provided by way of introduction. As many of the methodologies used to investigate 1130 overlap with those used to investigate habitat types 1110 (shallow sublittoral sandbanks), 1140 (Mudflats and sandflats) and 1160 (large shallow inlets and bays) some of the tables in this report bring together information for these four habitat types (1110, 1130, 1140 & 1160) in the review of the monitoring and assessment requirements as presented in Section 3.

A structured framework for the ecological characterization of habitat 1130 and the selection of appropriate variables for assessing their condition is set out in Section 1. Nineteen **key characteristics and corresponding variables essential for evaluating condition** of the habitat have been identified using the System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA), an international standard for ecosystem accounts adopted by the United Nations Statistical Commission (Section 1.2 and Table 1).

Nineteen Member States have reported habitat 1130 as present in their jurisdictions (BE, BG, DE, DK, EE, ES, FI, FR, GR, HR, IE, IT, LT, NL, PL, PT, RO, SE, SI) and some information has been collected about the location and description of the main characteristics of estuaries by all these Member States. **Specific methodologies** for assessing and monitoring estuaries are available from eleven Member States (BE, BG, DE, ES, FR, IE, IT, LT, NL, PL, RO). Also relevant are reports of estuary surveys and assessments carried out in these and other EU Member States that can or have been used to inform such assessments although not directly stated as a reason for the work.

There is good coverage of **variables** used to describe the ecological characteristics of this habitat type across Member States albeit with differences in the level of detail provided on the approaches taken. Nine of the twelve Member States that provide specific guidance on estuarine habitats have identified the need to monitor variables relating to the chemical characteristics of the habitat with a focus on examining salinity/freshwater influences and water quality. Biotic characteristics are well represented in the monitoring programmes being specifically mentioned by eleven of the twelve Member States that report on estuarine habitats. There is good coverage for monitoring variables of structural state characteristics. Functional state characteristics appear to be the least well covered with primary production specified as a monitoring programme variable in only five Member States, and food web variables recorded by only one Member State (Table 4).

The **reference values and thresholds** applied by Member States to obtain condition indicators for estuaries are variously; very specific, based on trends, use indices, rely on expert judgement or some combination of these.

In most EU Member States, a common rather than habitat specific methodology is used to **aggregate data** on indicators at the local scale to provide a condition assessment at the level of the plot or monitoring locality. Some exceptions are Spain, the Netherlands and Poland

where habitat specific variables are scored and aggregated to give an overall score/assessment at the local level.

There is no single approach to the identification of a number and distribution of **localities, sampling frequencies and methodologies** to carry out the assessment and monitoring of estuaries. Practical consideration, such as accessibility are important as are factors such depth, size, physical variability and diversity of the associated biological communities. Sampling stations may be along transects or distributed across known areas where different biotopes are present. Existing databases are also an important factor to consider when evaluating an estuary.

There is a broadly similar approach to describing and **monitoring** this habitat type across Member States with differences in the detail depending on location, hydrographic conditions and size of the estuaries are being monitored, the accessibility of sampling locations, and whether they are part of long-term studies. The variables monitored cover physical, chemical, composition, structural, functional, and landscape/seascape characteristics.

The final part of document is focused on guidance for harmonising methodologies to ensure consistent data collection and assessment criteria across EU Member States. A proposed list of **essential, recommended and specific condition variables** is presented covering abiotic, biotic, and landscape/seascape characteristics (Table 13). Potential approaches for **making assessments of condition** include comparison to undisturbed areas, hindcasting, modelling and expert judgement. Cross reference is also made to EU reference values in the Water Framework Directive and Marine Strategy Framework Directive that may be relevant.

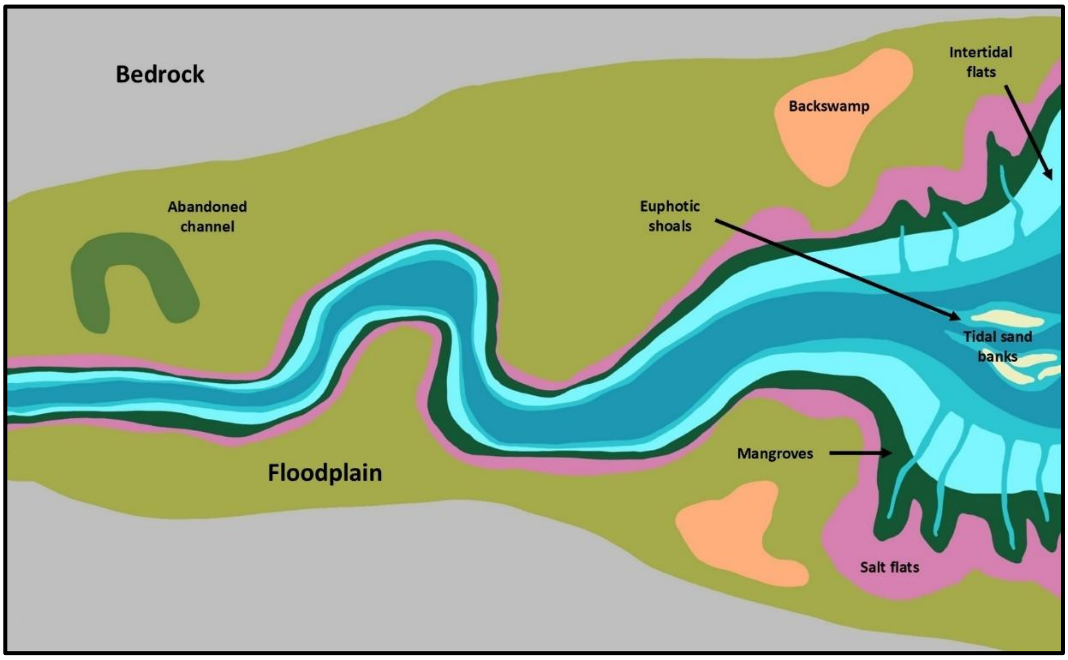
1 Definition and ecological characterisation

1.1 Definition and interpretation of habitats covered

Estuaries are transitional fluvial-marine systems (Nielsen, 2009), in which freshwater from the land interacts with saline water from the sea (Daborn & Redden, 2018). They represent the culmination of an eustatic cycle, whose sedimentary infilling is carried out from river valleys previously excavated, with continental, marine and native sediments (López, 2015). The mixing of continental and marine waters can vary in time and space, displaying strong salinity gradients from land to sea (Ibáñez et al. 2009). The estuaries develop on both rocky and sedimentary coasts and can be found at any coast independently of energy regime and depositional environment (Perillo, 1995).

Estuarine ecosystems include the river channel, to the maximum upstream extent of tidal influence, the adjacent coastal waters, to the maximum extent of freshwater flow, salt marshes and tidal flats that develop along the shoreline, built up from riverine sediments deposited as river flow rate slows at sea level and subject to daily tidal inundation, and associated beaches and dunes. Estuaries are thus complex ecosystems formed by a body of water and a mix of tidal-influenced habitats.

Figure 1. Typical morphology of tide-dominated estuaries



Source: adapted from Scanes, 2017

The diversity of estuaries is due to multiple factors, and consequently it is complex to establish a definition that covers all situations. According to Perillo (1995), an estuary can be defined as *semi-enclosed coastal body of water that extends to the effective limit of tidal influence, within which sea water entering from one or more free connections with the open sea, or any other saline coastal body of water, is significantly diluted with fresh water derived from land drainage, and can sustain euryhaline biological species from either part or the whole of their life cycle* (Figure 1). A typical Atlantic estuary, for example, presents a complex mouth (lower estuary) with a sandy barrier and a dune system. This widens out forming a bay, a sandy or gravelly area with a main channel. Smaller channels and bedforms can appear also in this zone. Tidal flats within the estuary may be colonised by algae and marshes formed by halophytic species. This part is crossed by the main channel which can be split into secondary channels and normally develops sandy and muddy zones on the margins.

Definition of estuary in the Interpretation Manual of EU habitats

Estuaries are listed in the Interpretation Manual under COASTAL AND HALOPHYTIC HABITATS and in the subcategory 'Open Sea and Tidal Areas'. The Interpretation Manual (European Commission, 2013) gives the following definition for estuaries (code 1130):

> Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters. River estuaries are coastal inlets where, unlike 'large shallow inlets and bays' there is generally a substantial freshwater influence. The mixing of freshwater and sea water and the reduced current flows in the shelter of the estuary lead to deposition of fine sediments, often forming extensive intertidal sand and mud flats. Where the tidal currents are faster than flood tides, most sediments deposit to form a delta at the mouth of the estuary.

Baltic river mouths are considered an estuary subtype, with brackish water and no tide, large wetland vegetation (helophytic) and luxurious aquatic vegetation in shallow water areas.

Furthermore, the Interpretation Manual states that *an estuary forms an ecological unit with the surrounding terrestrial coastal habitat types. In terms of nature conservation, these different habitat types should not be separated, and this reality must be taken into account during the selection of sites. That is, the definition of all associated systems should be included when defining an estuarine system.*

Therefore, estuaries are a habitat complex which can include and/or be found in association with mudflats and sandflats not covered by seawater at low tide (1140), *Posidonia* beds (1120) reefs (1170) and shallow sublittoral sandbanks (1110).

There is some overlap in the monitoring and assessment requirements and methodologies for assessment of habitat type 1130 with habitat types 1110 (shallow sandbanks) 1140 (mudflats and sandflats) and 1160 (Large shallow inlets and bays). For example, the need to:

- Map the profile and extent of any intertidal/subtidal areas largely comprised of soft sediments.
- Determine exposure to tides and currents as these can have a major influence on key characteristics of the habitat such its longevity, changing morphology and associated species.
- Undertake sediment and chemical analysis of the soft sediment types.
- Sample infauna and epifauna associated with sandy and muddy sediments, as well as the identification of associated floristic species.

These four habitat types (1110, 1130, 1140 & 1160) are therefore clustered for the purposes of this review of the monitoring and assessment requirements as presented in Section 3.

As stated above, a series of other habitats of Community interest can also be found in the estuarine ecosystem and can be considered as part of the estuary habitat. This is acknowledged in the interpretation of this habitat by several EU Member States (e.g. Belgium-Flanders and Spain); these can include salt marshes (1310, 1320, 1330, 1410, 1420 and 1430), coastal dunes and associated estuarine beaches sometimes presenting 1210, hydrophylous grasslands (6430), rivers with mud banks (3270) and alluvial forests (91E0). Consequently, in some countries, for the assessment of conservation status of the estuary, all the constituent habitats are considered, and the assessment of the different individual habitat patches is carried out using the particular methodology defined for each relevant habitat (Oosterlynck et al., 2020; Aranda et al., 2019).

Furthermore, the water body in the estuary is usually classified as transitional waters under the Water Framework Directive (WFD), i.e. are defined as bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters, but which are substantially influenced by freshwater flows. This means that in many cases the assessment and monitoring of the aquatic component in an estuary uses some of the parameters and methods followed for the assessment of ecological status under the WFD.

According to the 2022 EUNIS marine habitat classification the following EUNIS habitat types (level 3) may be present as components of habitat type 1130: MA12 to MA14, MA22 to MA25, MA32, MA33, MA35, MA42 to MA44, MA52 to MA55, MA62 to MA65, MB12, MB14, MB15, MB22, MB24 to MB25, MB32, MB42, MB43, MB52-55, MB62-65, MC12, MC23, MC64, MC65. Many of these EUNIS level 3 habitats are listed in Group 7 (soft sediments above 1000m) of Annex II of the Nature Restoration Law. Estuaries are also listed in Annex 1; Group 1 -Wetlands of the Nature Restoration Regulation.

An important characteristic is that estuaries are typically made up of a mosaic of marine communities and habitats rather than being uniform. This is illustrated in Annex II of the Nature Restoration Law which lists sub-habitats that may be present particularly within group 7 (soft sediments) using the EUNIS habitat classification as a reference.

Diversity across the regions

Estuaries are present in the following Member States; Belgium (BE), Bulgaria (BG), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Croatia (HR), Ireland (IE), Italy (IT), Lithuania (LT), Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Sweden (SE) and Slovenia (SI).

Estuaries are widespread throughout the **Atlantic** coasts of Europe where the majority are drowned river valleys. In the southern North Sea examples include the Elbe (Hamburg), the Weser (Bremen) and the Scheldt. On the Atlantic, Channel and North Sea coasts there is at ebb tide a significant river flow compared to the ebb current. Some examples of the latter are the Seine and Rance estuaries which discharge into the English Channel, the Gironde and Santander estuaries in the Bay of Biscay, Aveiro, Tejo and Guadiana estuaries on the Atlantic Iberian Margin.

In **Mediterranean** estuaries tidal amplitude is very weak and tidal currents, which generate vertical mixing of the water, are negligible. This favours vertical stratification of salinity with a counter current of saline water beneath the less dense river water (salt wedge estuaries). There are also distinct seasonal differences in salinity. In winter the estuary runoff from winter storms and greater flushing reduces the salinity. In spring, runoff becomes small, and the estuary gradually returns to marine salinities. One consequence is that the benthos of the sublittoral sediments shows rapid transitions from marine to freshwater species[1]. The species present typically have short cycles of development that permit rapid colonization[2]. Some examples of Mediterranean estuaries are the Ebro (Spain) and Po (Italy) deltas.

In the **Baltic** examples of estuaries include areas around river mouths in Denmark (e.g. Gudenåen-Randers Fjord, Horsens Fjord, Vejle Fjord, Kolding Fjord), Sweden (e.g. Bräkneån, Hagbyån, Virån, Loftaån), Germany (eg.Trave estuary, Warnow estuary, Peene mouth area),

[1] Factsheet of Red list habitat type A5.32: https://eunis.eea.europa.eu/habitats/8454
[2] Factsheet of Red list habitat type A2.31: https://eunis.eea.europa.eu/habitats/8359

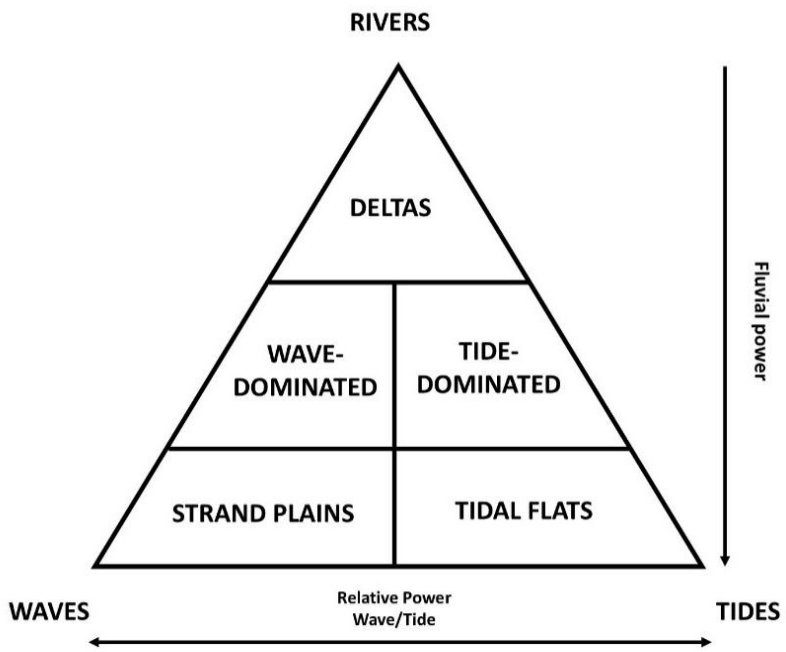
and Finland (e.g. Porvoonjoki river mouth area, Kymijoki river mouth area). Along the Polish Baltic coast rivers are mostly regulated, with reinforced banks and/or they are located within port waters (Świna, Dziwna, Rega, Parsęta, Wieprza, Słupia, Łeba, Wisła Śmiała and Przekop, Elbląg). Relatively natural conditions in the mouth have been preserved in Piaśnica, Reda, and Wisła Królewiecka. Coastal vegetation occurs in a few estuaries, e.g. in Reda or Nogat (Barańska et al., 2021).

There are few estuaries in the **Black Sea.** The ancient Danube estuary (partially in Romania) is at present filled up with sediments forming the Delta with runoff regulated by dams. Hence, the estuarine waters (the fresh and saltwater mixing zone) with their characteristic processes and biocenoses are moved to an area starting inside the mouths of the Danube and reaching into the Black Sea to depths of 20m or further depending on freshwater outflows (Zaharia et al., 2013). The water level of the rivers has a great impact, therefore the conditions in the estuaries can vary from freshwater (in spring high-water periods) to slightly saline where the water is mixed. In the summer when the water level is low there can be stable stratification (Biserkov et al., 2015). In Bulgaria, small areas with estuarine characteristics occur around the discharge regions of the rivers such as the Kamchia, Ropotamo and Veleka. Some are separated from the sea by sandbars and may only have occasional incursions of saline waters such as the Butamiata and Vaya river mouths whereas others such as the mouth of the Hadjiiska have small zones of incursion.

Estuary classification

Estuarine environments may be classified in several ways, according to their origin and resulting morphology (see Box 1, Figures 2 and 3), the balance between precipitation and evaporation, the tidal range, and the degree to which salt water and freshwater are mixed (see Box 2). All these classifications reflect the interaction between geological history, geographic location, and sea-level variations (Daborn & Redden, 2018).

Figure 2. Simplified classification of coastal environments associated with estuaries



Source: adapted from Dalrymple et al. 1992

Box 1. Types of estuaries based on their form

(based on Valle-Levinson, 2010 and Fitzgerald et al., 2015)

Bar-built estuaries were formed from indentations along the coast that transitioned into partially enclosed environments due to littoral drift, which led to the development of a sand bar or spit separating the coastal area from the open ocean. The Algarve in Portugal is an example of a European bar-built estuary.

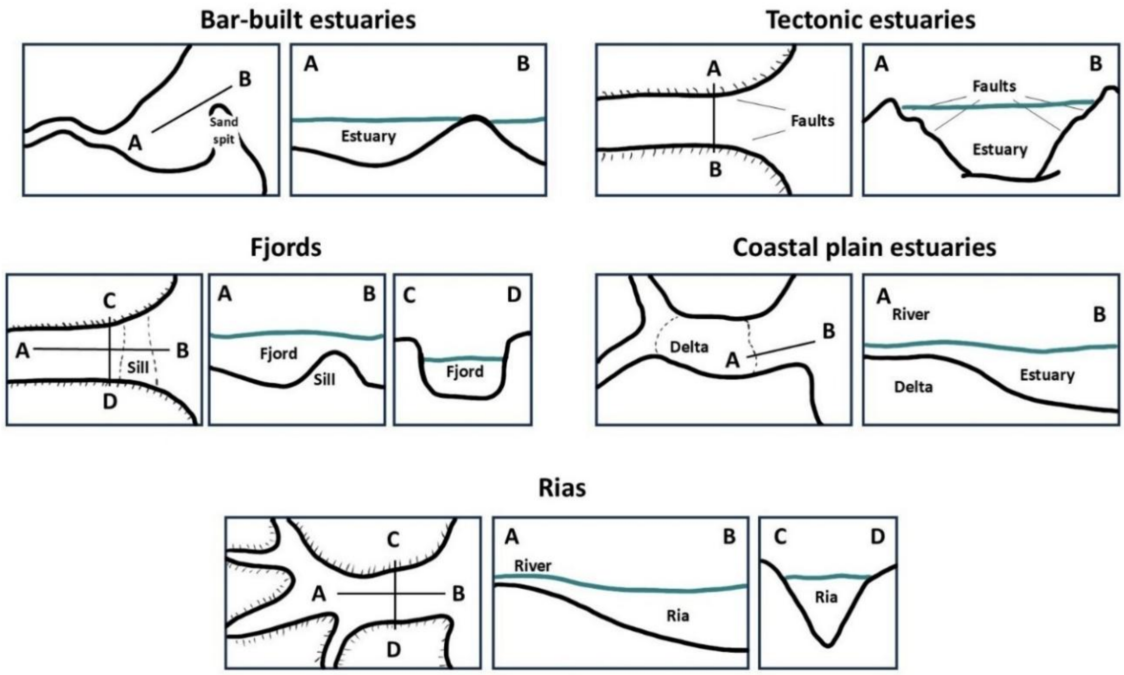
Tectonic estuaries originated from seismic activity such as earthquakes or fractures in the Earth's crust, resulting in the creation of faults in coastal regions. These faults caused portions of the crust to subside, forming a depression or basin. As the ocean subsequently inundated this basin, an estuary was formed. This is the process that originated some Rias in Spain.

Fjords are typically found in regions of high latitudes where glacial activity is prominent. They are distinguished by their long, deep channels and a sill at their entrance. This sill is often connected to the moraine, which could be from either a presently active glacier or one that has become extinct.

Coastal plain estuaries emerged due to the Pleistocene era's sea level rise, approximately 15,000 years ago. Initially formed by rivers, these estuaries gradually took shape over millennia as rising sea levels inundated the land. They retain a resemblance to modern-day rivers but are significantly broader. Typically spanning several kilometres in width and with depths around 10 meters, they exhibit considerable width-to-depth aspect ratios. Coastal plain estuaries in Europe can include the Thames and Gironde.

Ria estuaries occur at the mouths of river valleys that have been drowned by rising sea level. An example in Europe is Bantry Bay in Ireland.

Figure 3. Geomorphic classification of estuary types



Source: adapted from Fitzgerald et al., 2015

Box 2. Types of estuaries based on the extent of vertical stratification

Estuaries can be classified based on the extent of vertical stratification, ranging from highly stratified systems to well-mixed ones with minimal or no vertical salinity differences (Figure 4).

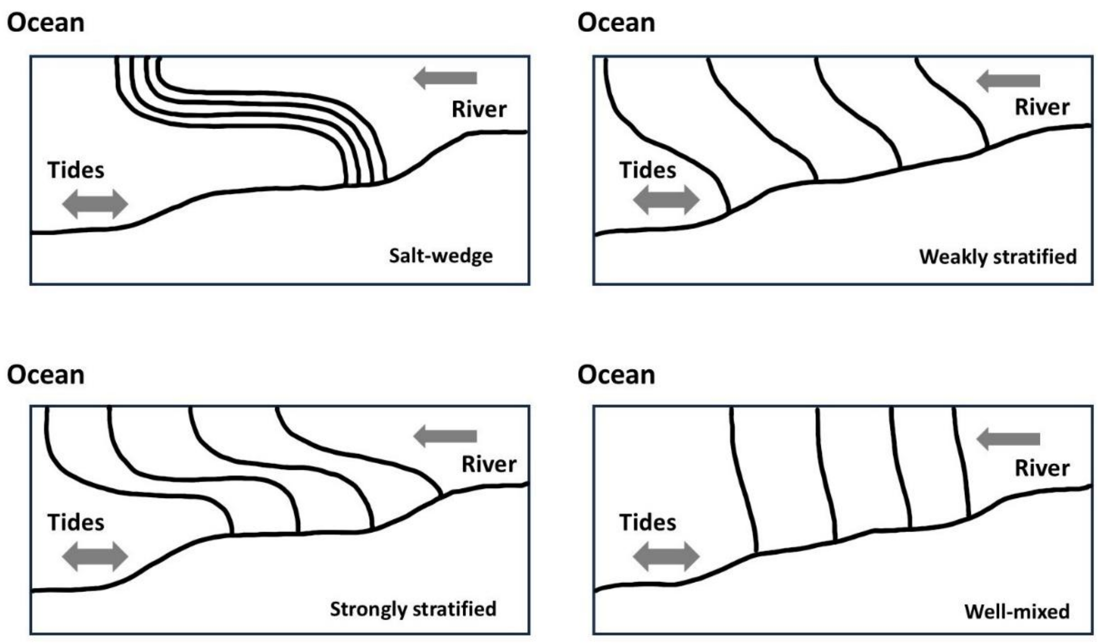
The level of stratification is shaped by factors such as coastal topography, channel structure, freshwater influx, tidal range near the estuary's mouth, and the characteristics of tidal wave propagation. The mixing induced by tidal forces depends on the tidal prism, which is the volume of seawater entering the estuary during each tidal cycle.

Salt-wedge estuaries, like the Ebro estuary (Spain), are formed by the combination of large river discharge and weak tidal influence (Valle-Levinson, 2010). These systems are strongly stratified during flood tides, when the ocean water intrudes in a wedge shape.

Strongly stratified estuaries are characterized by moderate to significant river discharge and relatively mild to moderate tidal influence. This type of estuary shares similarities in stratification with salt wedge estuaries; however, the strong vertical layering persists consistently throughout the tidal cycle, resembling the stratification observed in fjords and other deep estuaries, typically exceeding depths of 20 meters (Valle-Levinson, 2010).

In **well-mixed estuaries**, tidal mixing exerts sufficient force to counteract vertical stratification. As a result, these estuaries exhibit increased complexity, where flow patterns and exchange are primarily influenced by horizontal and transverse salinity gradients due to the absence of significant vertical stratification (Fitzgerald et al., 2015).

Figure 4. Estuary classification according to salinity profiles (Adapted from Fitzgerald et al., 2015 and Valle-Levinson, 2010).



Source: adapted from Fitzgerald et al., 2015

1.2 Environmental and ecological characterization and selection of variables to measure habitat condition

The main characteristics which determine the structure and function of estuaries are:

- Topography/physical characteristics
- Hydrology- tidal range/currents/wave action/mixing
- Salinity/stratification
- Turbidity/sedimentation
- Oxygen levels
- Nutrient levels
- Primary production
- Infauna and epifaunal assemblages
- Associated fish, seabirds and marine mammals
- Vegetation zones – Macrophytes/Macroalgae/eelgrass

They can be classified into abiotic, biotic and landscape characteristics as described below.

1.2.1 Abiotic characteristics

Abiotic characteristics describe both the physical and chemical state of the habitat. Numerous parameters are measured in estuaries to give an overview of these characteristics and there is considerable overlap with the variables measured for reporting and monitoring under the WFD. In the Northern Adriatic for example (Vilibić et al., 2019) the following list (Box 3) includes all the parameters that are measured, although not all with the same frequency and not all covering the whole area.

Box 3. Physical and chemical parameters measured in the Northern Adriatic under the Water Framework Directive

Physical parameters (atmosphere and sea): air humidity, air temperature, air pressure, wind direction, wind speed, wind gust, precipitation rate; pressure, current speed, current direction, wave height, wave period, wave direction, water temperature, water salinity, water transparency, conductivity, fluorescence, turbidity, CDOM.

Chemical parameters: dissolved oxygen, pH, dissolved organic carbon, coloured dissolved organic carbon, inorganic carbon, dissolved macronutrient concentration ($N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$, $P\text{-}PO_4^{3-}$, $Si\text{-}SiO_4^{4-}$).

Tidal range, together with topographical characteristics and depth have a significant influence on the form and extent of estuaries as well as on the development and stability some of the features within them such as beaches, channels and tidal pools (e.g. Lefebvre et al., 2021). The associated biota will also be affected by the degree and length of time of submergence/emergence as determined by the tidal regime. The variable **salinity** together with varying periods of **tidal inundation and exposure, sediment mobility, and strength of tidal streams** all have a significant influence on the epifauna and infauna of estuaries (e.g. Barnes, 1974). Some freshwater organisms may live in low salinity zones and some marine species can tolerate substantially reduced salinity and it is these euryhaline marine organisms that dominate the estuarine species assemblage, since there are relatively few species restricted only to such brackish waters. In most estuaries salinity changes are accompanied by changes in the suspended sediment (turbidity) and temperature. Current speed, wave action and substrate type may also change radically. The extent of stratification in an estuary is also an important parameter. The distribution of some species is likely to be affected by all these factors as can physical characteristics such as the form, and position of channels and intertidal banks.

As a result of the combined factors of tidal oscillations and riverine input, estuaries tend to retain **organic matter**. Consequently, estuaries tend to have high overall productivity and are rich in nutrients. In most cases the main source of nutrients entering an estuary are from freshwater inputs (rivers), direct discharges (e.g. sewage treatment works) and coastal water exchange. Other potential nutrient sources may include groundwater seepage, and atmospheric deposition.

Nutrient status is a key factor in estuaries because it drives primary production both in the water column and in the benthos. This, in turn, manifests itself in the production of organic carbon that deposits in estuarine sediments in combination with other anthropogenic sources of carbon input. However, the expression of this primary production is dependent on limiting factors such as the residence time of the water, the turbidity of the estuary and levels of nutrients such as nitrogen, phosphorus and silica. Changes in the nutrient status of a system may involve biological change even if the system does not become eutrophic.

Turbidity levels are usually much higher in estuaries than those in adjacent coastal waters thus reducing water clarity. The main source of turbidity is likely to derive from re-suspended sediments, because of the strong dynamics of the estuaries, and fluvial loads although plankton blooms may be a contributory factor in spring and autumn. Most estuarine communities are used to turbid conditions and increases from man-induced sources are likely to be tolerated. However, increases in turbidity levels brought about by activities such as dredging and disposal may, under certain conditions, have adverse effects on filter-feeding organisms, clogging feeding or respiratory structures. Increases in turbidity may also reduce light penetration through the water. This may reduce the growth rate of organisms that are dependent on sunlight for photosynthesis.

1.2.2 Biotic characteristics

Estuaries are typically highly productive environments although poor in the numbers of species compared to fully marine or freshwater systems. Phytoplankton and macroalgae are the main **primary producers** which together with inputs of organic matter (which enters estuarine systems from surrounding habitats such as saltmarshes as well as from upstream sources) influence the trophic status. High productivity areas are classed as eutrophic. The **fauna** comprises species that are permanently resident (mainly invertebrates) and those (mainly vertebrate) species such as fish and birds entering estuaries at high or low tide principally to feed.

The distribution and community structure of macrobenthic communities is affected by salinity, depth, current and sediment characteristics which can result in distinct gradients in diversity, abundance and biomass along and across estuaries (e.g. Ysebaert et al., 2003; Sousa et al., 2006).

Biogenic structures, such as shellfish bed and worm reefs may be present in some estuaries developing in both intertidal and subtidal areas. They consolidate the substrate, for example by trapping sediment, and providing some protection from the erosion, as well as adding to the diversity of the estuarine flora and fauna. Mussel beds, for example, are important in sediment dynamics of coastal systems, as a food source for birds, and as habitat for a large number of species including serving as essential fish habitats[3]. Honeycomb worm reefs (*Sabellaria alveolata*) create spatial and trophic niches for colonisation by other species as well as hosting different associated fauna at different stages of reef development (Schlund et al., 2016; Dubois et al., 2002).

Estuaries are particularly susceptible to the introduction of non-native, **opportunistic/invasive species** as they are frequently centres for activities that are significant vectors for introduction such as shipping and aquaculture/mariculture. In some situations, they can significantly alter diversity, community structure and ecosystem process as illustrated by Pacific oyster (*Crassostrea gigas*) where a hard concretion of live and dead oysters can develop, displacing native species and habitats (Herbert et al., 2016).

Seagrass beds influence the local hydrodynamics in estuaries by damping the effects of waves and currents, stabilising the substrate and supporting accretion of sediment. They provide shelter or substratum for a wide range of species, as well as being important nursery areas for some fish species. *Zostera* is also a major source of food for wildlfowl (OSPAR, 2009). **Macroalgae** in estuaries may be free-floating or attached to the substrate. They are also a source of food, provide shelter and a nursery habitat for some species, remove nutrients like phosphorus and nitrogen from the water, and release oxygen into the water as a by-product of photosynthesis. Changes in extent and condition of seagrass and macroalgae can not only changes these characteristics of estuaries but also result in changes and/or loss of the associated species.

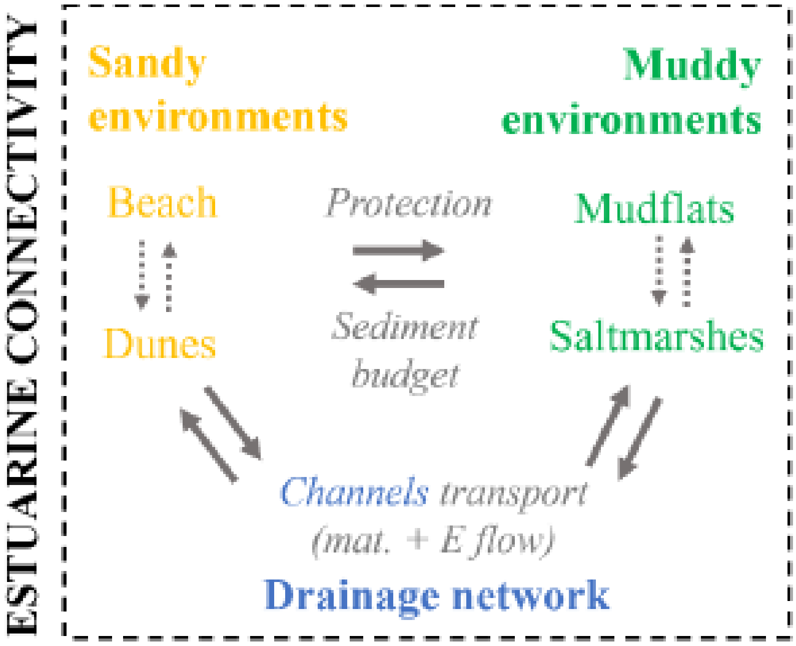
Fish, seabirds and marine mammals. Estuaries act as resting, breeding and feeding areas for migratory seabirds as well as non-migratory birds. Fish, particularly demersal fish are a key factor in energy transfer from the benthic system to the water column, and a potential transmitter of contaminants to higher trophic levels (Wolowicz et al., 2007).

1.2.3 Landscape/seascape characteristics

Landscape scale characteristics of the **connectivity and/or fragmentation** of estuarine habitats affect many aspects of the physical, chemical and biologically functioning of estuaries. It allows for flows of energy, nutrients and species and is relevant in responses to disturbance and habitat change (e.g. Bernhardt & Leslie, 2013; Davis et al., 2024). These can, for example result in changes in the physical form of estuary channels, (perhaps as a result of dredging or placement of barriers), alterations in the drainage from the surrounding land affecting water quality and disrupting the ability of species to migrate along estuaries or feed on intertidal areas and surrounding marshes. Understanding the processes connecting the estuarine system is important to enhance current schemes in ecosystem connectivity (Figure 5), and for the long-term functioning of the ecosystem (Bouma et al., 2016) and, therefore, its management.

[3] OSPAR Status Assessment 2023 – Intertidal Mytilus edulis beds on mixed and sandy sediments: https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/mytilus-edulis-beds/ [accessed 05/02/2025}

Figure 5. Processes connecting the estuarine main subsystems



Source: Aranda, 2021

Examples of variables used to measure these characteristics when reporting on the condition of habitat type 1130 are given in Table 1. The classification of the ecological characteristic and associated variables follows the UN-SEEA ecosystem condition typology (ECT), which has six classes: abiotic physical, abiotic chemical, biotic compositional, biotic structural, biotic functional and landscape/seascape characteristics (United Nations et al*.,* 2021).

Table 1. Ecological characterisation and selection of condition variables

Ecological characteristics	Types	Description	Examples of associated variables
Abiotic characteristics	**Physical state characteristics**	Degree of submergence / depth, tidal regime, currents.	Depth in relation to chart datum Tidal range, current speed
		Topography / physical characteristics / form / extent	Physical dimensions, tidal prism/cross-sectional area relationship, extent, longitude and latitudinal gradients, form and features e.g. sandbanks, islands
		Turbidity	Suspended particles
		Sediment composition / distribution / dynamics	Sediment particle size distribution, proportion of different grain sizes in samples. Deposition/erosion rates and locations
		Hydrodynamics - Exposure to current, wave action, scour & surge	Current speed, direction, height, seasonal extremes
	Chemical state characteristics	Salinity/freshwater influence/stratification	Salinity
		Water quality	Various parameters including nitrates & phosphates
		Sediment quality - hazardous substances, organic carbon	Redox potential in bottom sediment, % dry matter
		Oxygen levels	Oxygen concentration/dissolved oxygen
Biotic characteristics	**Compositional state characteristics**	Invertebrates - Epifaunal & infaunal assemblages,	Number of biocenosis, presence & abundance of species (SACFO scale), diversity index, biomass
		Biogenic structures, presence and condition	Type, extent, volume/biomass
		Vertebrates -Associated fish, seabirds & marine mammal	Abundance, distribution, population structure
		Opportunistic/invasive species	Presence, distribution and abundance/biomass
	Structural state characteristics	Abundance and condition of characteristic species	Percentage cover, biomass, Synthetic indicators (M-AMBI, BENTIX etc)
		Macrophytes / macroalgae / eelgrass, presence and condition	Spatial extent, taxonomic composition, % cover, depth (m) limit of angiosperms
	Functional state characteristics	Primary production	Phytoplankton blooms (frequency/longevity Macroalgae/angiosperm (growth rates, dry weight/m2)
		Food webs	Number of species/functional groups and qualitative links Average energy transfer between trophic levels (%) Stable isotopes (13C, 5N,34S) Stomach content analysis
Landscape / Seascape characteristics		Connectivity / Fragmentation	Presence of anthropogenic structures and their % cover
Other		Disturbance	Length of modified banks

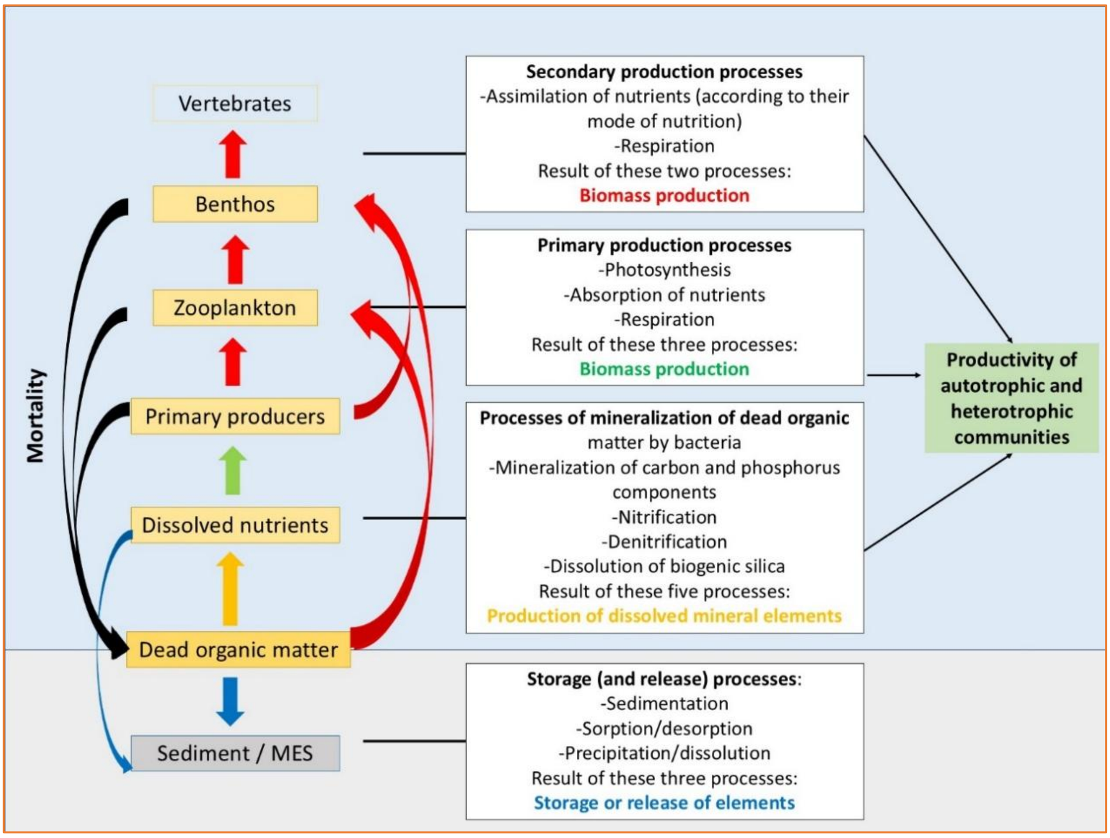
1.2.4 Ecological processes that are relevant regarding proper functioning

Estuaries are dynamic habitat complexes, with their formation, stability and degradation strongly influenced by coastal processes such as erosion and deposition, tidal flows, and fresh-water inputs. Exposure to wave action, tidal scour and currents will help to shape them whilst human interventions such as the construction of barriers, land claim, and coastal protection works modify their physiographic features. Such interventions also have implications for associated wildlife such as migrating fish that need access to areas upstream, and birds that feed on exposed mudflats or roost on surrounding wetland areas.

Inflow, circulation and mixing of water is of major importance in determining the condition of any estuarine habitat because it affects salinity, nutrient levels, chemical characteristics, turbidity and oxygenation. Some of these changes will be part of the evolution of undisturbed estuarine environments such as sedimentation in areas of low flow. In other cases, the changes can be the consequence of human activities such as phosphate and nitrate run-off from surrounding land or the discharge or resuspension of pollutants such as heavy metals both within an estuary as well as further upstream.

Organic matter from the adjacent land or upstream areas circulates in estuaries and biogeochemical processes involving the production and mineralisation of organic matter in the water column as well as in the sediments affect nutrient flows and biological production. An illustration of the various processes involved is given in Figure 6 (Capderrey, 2019).

Figure 6. Main ecological functions and underlying biogeochemical processes in estuaries (adapted and translated from Capderrey, 2019)



Source: adapted and translated from Capderrey, 2019

1.3 Selection of typical species for condition assessment

Typical species of the habitat are used to assess whether a habitat is at Favourable Conservation Status. The assessment of typical species is included as **part of the assessment of the structure and function** parameter, although a **full assessment** of the conservation status **of each typical species is not required**.

According to the guidelines for reporting under Article 17 (European Commission, 2023), the selection of 'typical species' should include species which are good indicators of favourable habitat quality. They should include species sensitive to changes in the condition of the habitat ('early warning indicator species'). Moreover, assuming that the habitat's structure and function are already being monitored, it is important that they provide any useful additional information.

Given the ecological and geographical variability of Annex I habitat types, different species can be selected as typical species for a habitat type in different marine regions. Indeed, even within one Member State **different typical species may be present in different parts of the range of the habitat type or in different subtypes**. On the other hand, many species may be typical for several habitats and not dependent on a single Annex I habitat type (European Commission, 2023).

Variations in physiochemical parameters within the estuarine environment, such as salinity, hydrodynamics and turbidity, cause natural physiological and physical stresses on the organisms that live there. The number of species capable of adapting to these rigorous conditions tends to be limited. Consequently, estuaries typically have low biological diversity but significant abundance and biomass (Elliott & Mc Clusky, 2002). The infauna and epifauna on the sediments vary according to the type of sediment, salinity, geographical location and strength of tidal streams. Estuaries can be nursery areas as well as acting as migration corridors for fish, and the high productivity an important source of food particularly for waders and wildfowl.

The parts of estuaries furthest away from the open sea are usually characterised by soft sediments and the salinity is more strongly influenced by riverine freshwater input. Here the sediment-living animal communities are typically dominated by oligochaete worms, with few other invertebrates. Where rock occurs, there may be community's characteristic of brackish flowing water, consisting of green unicellular algae, sparse fucoid seaweeds, and species of barnacle and hydroid. The silt content of the sediment decreases towards the mouth of the estuary, and the water gradually becomes more saline. Here the animal communities of the sediments are dominated by species such as ragworms, bivalves and sandhopper-like crustaceans. In the outer estuary, closer to the open sea, the substrate is often composed of fine sandy sediment, and supports more marine communities of bivalves, polychaete worms and amphipod crustaceans. Where rock occurs, a range of species more characteristic of the open coast is found. The sheltered areas of estuaries often support saltmarsh, whilst nearer the estuary mouth this may be replaced by beach-dune systems (JNCC, 2004).

The species used to monitor the condition of this habitat type differ depending on particular characteristics of each estuary. Table 2 indicates frequently present groups from which species for monitoring are selected, and the types of changes in quality they could be used indicate.

Table 2. Selecting typical species for monitoring habitat 1130 (estuaries)

Species group	Ecological notes	Sensitive to changes in quality
Angiosperms	Fringing saltmarsh and seagrass may be present. Stabilise sediment, affect productivity, act as shelter/nursery areas/food source. They help to stabilize the sediment as well as capturing carbon in the root systems, particularly in the case of long-established beds. Seagrass beds act as nursery areas for some species of fish and invertebrates.	Physical disturbance, for example associated with anchoring and demersal fishing gears can uproot seagrasses and fragment beds, while nutrient levels can enhance growth but not if this results in the smothering of the plants by encouraging the growth of epiphytes. Increases in turbidity can have a negative effect on seagrass growth and condition by reducing photosynthesis.
Charophytes	Charophytes may be present as a marginal species in this habitat in slow moving brackish or fresh water where they can form extensive meadows. They have an important ecological role, trapping sediment, accumulating nitrogen, and providing food and shelter for other species (Schubert et al., 2024).	Charophytes can be used as indicators of turbidity, low nutrient changes in sedge communities can reflect disturbances. The decline of sensitive species and the proliferation of tolerant ones can indicate habitat degradation.
Molluscs	Both infauna and epifauna. Benthic macrofauna have a pivotal role in the mixing, ventilation, oxygenation and irrigation of sediments (bioturbation). This improves nutrients cycling, substrate permeability, redistribution of food resources, buffering against nutrient enrichment and benthic-pelagic coupling (Di Camillo et al., 2023).	Physical disturbance and changes in nutrient/organic matter levels can be indicated by monitoring species from this group. Molluscs have been used as biotic tools for ecological status assessment in the context of WFD status classification (Leshno et al., 2016; Nerlović et al., 2011), as ecological indicators (La Valle et al., 2011) and bioindicators of environmental contamination (Coelho et al., 2014; Velez et al., 2016). For example, the bivalve *Corbula gibba* has been proposed as a proxy of eutrophication with distribution influenced by *Chl a* concentration (Moraitis et al*.,* 2018).
Polychaetes	Infauna. Cycle nutrients, affect productivity, affect sediment structure/productivity. Reef building species (*S.spinosa*) may be present as well as infauna with species preferences depending on grain size, organic matter, oxygen levels (Vanosmael et al.1982).	Physical disturbance and changes in nutrient/organic matter levels can be indicated by monitoring species from this group.
Crustaceans	Infauna and epifauna. Cycle nutrients, affect productivity, affect sediment structure.	Water quality, productivity.
Echinoderms	Both infaunal and epifauna species of echinoderms are present in this habitat. They include bioturbators and bioirrigators such as the sea potato *Echinocardium cordatum* which rework organic matter into the sediment. Besides the general permeability of sediments, the constant movement of these large-bodied infaunal burrowers can have profound influence on sediment-bound biochemical processes, benthic nutrient fluxes and, thus, on local benthic and pelagic primary production (Huettel et al., 2014; Lohrer et al., 2004; Wrede et al. 2017). These are essential ecosystem functions (Beerman et al*.,* 2023).	Physical disturbance and changes in nutrient/organic matter levels can be indicated by monitoring species from this group.

Species group	Ecological notes	Sensitive to changes in quality
Fish	Both resident and migratory fish are present in estuaries which they use as nursery areas, as well as for feeding, rest/refuge, reproduction and transit.	Productivity, water quality, migration barriers. Indicators of change include variation in the abundance of the population of one or more species. This can be measured as a decrease or increase in the number of individuals, their biomass, their average size and age, as well as an expansion or contraction of their distribution range over time.
Seals	Forage in estuaries and use drying areas as haul out sites and pupping sites.	Productivity, human disturbance.
Birds	Resident and migratory waders, wildfowl feed and roost on estuarine habitats. Some seabirds feed in estuarine waters.	Productivity, human disturbance.

2 Analysis of existing methodologies for the assessment and monitoring of habitat condition

Some information has been collected about the location and description of the main characteristics of estuaries by all the Member States that have reported habitat 1130 as present within their jurisdiction[4]. Specific methodologies for assessing and monitoring estuaries are also available from twelve Member States (BE, BG, DE, ES, FR, HR, IE, IT, LT, NL, PL, RO). There are also reports of estuary surveys and assessments carried out in these and other EU Member States that are relevant, and that can or have been used to inform such assessments although not directly stated as a reason for the work (e.g. surveys carried out in Belgium, Denmark, Spain and Portugal) (e.g. Conley et al., 2000; Chowdhury et al., 2023; Nascimento et al., 2021). All these methodologies have been considered in the following review albeit distinguishing between what is being done by Member States for reporting on habitat condition under Article 17 and what has been done as part of other initiatives.

2.1 Variables used, metrics and measurement methods, existing data sources

A summary of the ecological characteristics and main variables typically used to measure habitat condition of estuaries is presented in Table 1 (Section 1). Examples of the characteristics and variables used by Member States to report on estuaries condition, as part of the assessment of their conservation status are presented in Table 3 and a summary analysis is given in Table 4. Table 4 shows that whilst the monitoring and assessment programmes set out by Member States cover abiotic, biotic, landscape and other characteristics there are differences in emphasis.

Eleven of the twelve Member States that report on estuarine habitats have identified the need to monitor variables relating to the **physical characteristics** of the habitat. Of these 'topography/physical characteristic' and 'turbidity' are the most frequently covered, but there are differences in emphasis and in the detail provided. For example, five Member States mention monitoring sediment composition/distribution/dynamics. This is specifically listed by Romania which states that "particle size distribution" is an attribute that can define the favourable condition of estuaries (Zaharia, 2013). A more general statement is given by Belgium which identifies one of the elements of favourable condition as being when "in each zone of the estuarine gradient, the variation in salinity and erosion – sedimentation is within the limits of natural variation" (Oosterlynck, 2020). Another consideration is that whilst some Member States might not specifically mention a variable in their published methodologies it may nevertheless be covered. An example is the tidal regime of an estuary which is only specified by six Member States but is highly likely to be noted in all cases.

Nine of the twelve Member States that report on estuarine habitats have identified the need to monitor variables relating to the **chemical characteristics** of the habitat with a focus on examining salinity/freshwater influences and water quality. In the latter case there is cross referencing to monitoring requirements under the WFD but some variation in the detail of specified attributes to be measured. Poland (Bajkiewicz-Grabowska et al., 2022), for example lists O_2, N (total and inorganic) P and Cl whilst Spain (La Mesa et al., 2019) refers to sampling of surface water and sediments for analysis of nutrients and pollutants. Salinity is not specified by

[4] as evidenced by the submitted Standard Data Forms for designated sites where 1130 is a feature and Art.17 reporting for this habitat

all Member States however as with all the other characteristic, it may be distinguished elsewhere in the assessment protocols. France, for example, does not specify salinity measurements however a multimetric indicator is used to assess faunistic composition which takes into account the salinity gradient present in most estuaries (Le Floch, 2015).

Biotic characteristics are well represented in the monitoring programmes being specifically mentioned by eleven of the twelve Member States that report on estuarine habitats. The most frequently cited are ‘epifaunal and infaunal assemblages’, and ‘abundance and condition of characteristic species. Assessing ‘biogenic structures’ is specifically cited by the Netherlands (shellfish banks and tubeworm banks) (van Beek et al., 2021), it is likely that this may be considered by other Member States in their more general reporting of the abundance and condition of species.

There is good coverage for monitoring variables of structural state characteristics. Of the two functional state variables identified for this habitat (primary production and food webs) there is no indication of monitoring food webs. Five Member State specifically refer to monitoring primary production.

Connectivity/fragmentation as a **landscape/seascape** characteristic that needs to be assessed is specifically mentioned by seven Member States while six Member States assess disturbance albeit in different forms. This may for example be the length of modified banks or the effects of human activity such as sand extraction. Disturbance has been included in the category **other**.

Table 3. Examples of variables used by Member States to assess condition of habitat 1130 (estuaries)

Description	Examples of variables used by Member States	Notes
1. Abiotic characteristics		
1.1 Physical state characteristics		
Degree of submergence / depth, tidal regime	DE- Hydrology etc. NL – Presence and variation in tidal currents PL – Flow cross section of channel	Whilst not necessarily highlighted in all assessment methodologies, these characteristics are usually included in the descriptions of Natura 2000 sites where habitat 1130 is present (e.g. in the SDFs).
Topography / physical structure	BE - Longitudinal and lateral gradients FR - Morphological change IT – Morphobathymetry NL- Presence of multi-channel systems	The gross morphology of habitat 1130 provides an overview of the feature and can also give some insight into formation, stability, and dynamics. These characteristics are usually included in the initial descriptions of the protected habitats as well as providing context for what might constitute "natural change" in the future even if they are not specifically mentioned in the methodologies.
Turbidity	BG - Water transparency, Secchi disk depth ES - Degree of light penetration, Secchi disk depth IT - Water clarity LT - Water clarity PL - Transparency, Secchi disk depth	Measurements of this variable are not specifically mentioned in all the methodologies examined but may be included as part of water quality sampling.
Sediment composition, distribution and dynamics	IE - Proportion of grain size classes RO - Particle size distribution BE –Natural sedimentation-erosion processes sustainably maintained. DE – Relationship between erosion and sedimentation	Estuarine habitats are typically dominated by soft sediments however the distribution of these sediments is rarely static. This can not only lead to changes in the gross morphology of the estuary but also has a major influence on the associated infauna and epifauna as well as on the distribution and accessibility of feeding and roosting sites for waders and wildfowl.
Hydrodynamics - Exposure to current, wave action, scour and surge	BE (Flanders)- Balance between basin storage and hydrodynamics IT - Coastline morphobathymetry from satellite images or high-resolution photographs	Whilst not necessarily highlighted in all assessment methodologies, these characteristics are usually included in the descriptions of Natura 2000 sites where habitat 1130 is present, at least in general terms.

Description	Examples of variables used by Member States	Notes
1.2 Chemical state characteristics		
Salinity / freshwater influence / stratification	ES - Salinity and conductivity IT - Determination of salinity and salt wedge % PL - Chlorides	Measurements of this variable are not specifically mentioned in all the methodologies examined but as it is a key characteristic of estuaries it would be included in any water quality sampling
Water quality	IT - Water quality sampling analysis of nutrients and pollution PL - Total nitrogen, inorganic nitrogen, phosphate, phosphorus, total phosphorus	There is frequent mention of water quality sampling for assessments of this habitat type. Much of the published guidance is general in nature although specific variables are mentioned in some cases.
Sediment quality	DE – Hazardous substance as indicated by OSPAR	There is frequent mention of sampling hazardous substances for assessments of this habitat type. Much of the published guidance is general in nature but specific parameters are mentioned in some cases.
Oxygen levels	ES - Dissolved oxygen measure at depth and on the surface in the upper, middle and lower part of the estuary with a minimum monthly frequency PL – Dissolved oxygen	
2. Biotic characteristics		
2.1 Compositional state characteristics		
Invertebrates - Epifaunal & infaunal assemblages, abundance and diversity of characteristic species	ES - Shannon-Wiever diversity index, AMBI index which groups benthic macroinvertebrates into 5 ecological groups based on tolerance or sensitivity to pollution. IE – Number of marine community types RO - Number and abundance of species	These characteristics are reported in all the Member States where this habitat is present, but the methodologies examined reveal some variation in the level of detail. In some cases, there is reference to compiling species lists, for example and in others to recording biocenosis or keystone communities.
Biogenic structures, presence and condition	IE - Area of keystone communities RO - Proportions and presence of main biocenoses	These characteristics are not necessarily mentioned specifically in assessment methodologies but are likely to be covered during surveys to record species and biocenoses present.
Vertebrates - Associated fish, birds, marine mammals	ES - (Basque Country) - Trophic composition of fish (% omnivores/ piscivores) IT – Presence of habitat typical birds	These characteristics are not necessarily mentioned specifically in assessment methodologies but are likely to be covered during surveys to record species present given the importance of many estuaries for migratory fish, waders & wildfowl.
Opportunistic/ invasive species	LT - List of problematic species and estimated cover (%) along transect FR -Maximum area effectively colonised by green algae as a function of area potentially colonizable. IE – Indexes to detect negative species RO - Average concentration of phytoplankton during summer	

Description	Examples of variables used by Member States	Notes
2.2 Structural state characteristics		
Abundance and condition of characteristic species	HR – Abundance and coverage of species (Braun Blanquet) IE – Changes in area (%) occupied by keystone communities LT - Estimated cover (%) of species along transect FR - Density of diadromous, benthic and resident fish	These characteristics are reported in all of the Member States where this habitat is present, but the methodologies examined reveal some variation in the variables measured. Abundance measures (e.g. % cover or biomass) are most common, but there are also condition measures (e.g. patchiness).
Macrophytes/Macroalgae/eelgrass presence and condition	ES (Cantabria) - Richness, coverage and invasive species compared to use an Estuarine Vegetation Index FR - *Zostera noltii* density (no/m^2), average leaf length & width, leaf & rhizome biomass. Angiosperm Quality Index. NL - Presence of seagrass and/or *Ruppia* fields	Several Member States make specific mention of monitoring variables for this characteristic and provide detailed methodologies. It may also be picked up under reporting of the 'abundance and condition of characteristic species' (see above)
2.3 Functional state characteristics		
Primary production	BG - Phytoplankton blooms ES (Cantabria) - Concentration of chlorophyll *a* & presence of phytoplankton species toxic to the environment. FR – Biomass and abundance of phytoplankton RO – Extent	
Food webs	FR –Distribution of trophic groups	
3. Landscape/seascape characteristics		
Connectivity/ fragmentation	BG - % of area fragmented FR – Degree of habitat fragmentation NL- Migratory fish routes not affected	
4. Other		
Disturbance	DE – Disturbances from different activities PL - % of total length of modified banks to the total length of river banks within the habitat; elements of technical development	

Table 4. Main ecological characteristics and associated variables monitored in the assessment of structure and function of habitat 1130 (estuaries) by EU Member States

Ecological characteristics	Variables	Metrics	BE	BG	DE	ES	FR	HR	IE	IT	LT	NL	PL	RO
1. Abiotic characteristics														
1.1 Physical state characteristics														
Degree of submergence / depth / tidal regime	Depth in relation to chart datum; exposure to current wave action, scour and surge	Metres (m), maximum & minimum with seasonal patterns, current speed (Knots) direction, height and extremes												
Topography/physical characteristics	Physical dimensions; extent; longitude and latitudinal gradients; elevation, form and features (e.g. sandbanks, islands)	Area (km^2), degrees of slope (°), tidal prism/cross-sectional area relationship physical features from a reference list												
Hydrodynamics - Exposure to current, wave action, scour & surge	Current speed; direction; height; seasonal extremes	Current speed (Knots) direction, height and extremes (m)												
Turbidity	Suspended particles; light transmission through water samples; Secchi disk depth	Nephelometric turbidity units (NTU), formazin turbidity units (FTU), Secchi disc depth (m)												
Sediment composition / distribution / dynamics	Sediment particle size; thickness of oxidised layer (for silt); deposition/erosion rates and location	% of three classes of particle size (mm), oxidised layer (mm)% change, sediment size distribution. and rates of change (mm/year, -g/m^2)												

Ecological characteristics	Variables	Metrics	BE	BG	DE	ES	FR	HR	IE	IT	LT	NL	PL	RO
1.2 Chemical state characteristics														
Salinity/ freshwater influence/ stratification	Salinity; conductivity	Parts per thousand Sodium and Chloride ($^{0}/_{00}$), depth/ boundaries (m) of different water bodies												
Water quality	Various substances (including chemicals listed in the WFD and EQSD, nitrates & phosphates, oxygen, chlorophyll, dissolved solids)	Temperature (^{0}C), pH, Chromophoric dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM), total dissolved solids (TDS), dissolved oxygen (mg/l), oxygen saturation (%)												
Sediment quality	Inorganic and organic chemical contaminants; organic carbon	Redox potential in bottom sediment, traces of hydrocarbons, hydrogen sulphide concentration in the sediment (µM), organic carbon % dry matter, g_{MO}(MS)/ m^2/day												
Oxygen levels	Oxygen levels (measured at surface and depth)	Concentration/dissolved oxygen (% saturation), extent of area with spatial and temporal hypoxia.												
2. Biotic characteristics														
2.1 Compositional state characteristics														
Invertebrates - Epifaunal & infaunal assemblages	Abundance and diversity of characteristic species from standardised lists	Number of biocenosis/taxa, presence & abundance of species (SACFOR scale), diversity index, (Shannon-Wiener diversity index, AMBI index) biomass, estimated % cover												
Biogenic structures	Type; extent; condition	Biomass, estimated % cover, condition												
Vertebrates - Associated fish, birds & marine mammals	Abundance and diversity of characteristic species from standardised lists.	Number, population structure, trophic composition (e.g. % omnivores/piscivores), distribution				fish	fish			birds		fish		fish
Opportunistic/ invasive species	Presence, distribution and abundance	Number, biomass, % cover, population structure												

Ecological characteristics	Variables	Metrics	BE	BG	DE	ES	FR	HR	IE	IT	LT	NL	PL	RO
2.2 Structural state characteristics														
Characteristic species	Abundance & condition; volume; biomass; fragmentation	Percentage cover, biomass, density. Synthetic indicators (M-AMBI, BENTIX etc)												
Macrophytes, macroalgae, eelgrass	Abundance; extent; condition	Spatial extent (area and depth), taxonomic composition, % cover of substrate, density (no/m^2), biomass (dry weight/m^2) eelgrass average leaf length & width, leaf & rhizome biomass												
2.3 Functional state characteristics														
Primary production	Frequency / longevity / strength of plankton blooms; angiosperms / macroalgae	Concentration of chlorophyll *a* (µg/ l), phytoplankton species. Plant/macroalgae growth rates, dry weight/m^2.												
Food webs	Species / functional groups; stomach contents; energy transfer between trophic levels; stable isotopes	Number of species/functional groups and qualitative links, % wet weight of prey/species number/frequency of occurrence, Stable isotopes (^{13}C, ^{15}N,^{34}S)												
3. Landscape/Seascape characteristics														
Connectivity / Fragmentation	Continuous / fragmented; presence of anthropogenic structures and their % cover; affected / modified length of linear habitats	Area (ha) % area directly affected by human activity												
4. Other														
Disturbance	Footprint of activity; number and intensity of negative pressures	Presence/absence, Length of modified banks (m), % area directly affected by human activity (e.g. by demersal fisheries or sand extraction, anthropogenic structures)												

Methodologies used for assessment and monitoring of habitat condition and existing data sources

Accessibility/location, size, depth, and hydrographic conditions have a major influence on data gathering, including the level of detail in which the variables are recorded. Table 5 lists some of the typical methodologies used to gather information on the key characteristics of this habitat type.

Table 5. Example of survey methods used to investigate some of the key characteristics of habitat 1130 (estuaries)

Abbreviations: ACDP - Acoustic Doppler Current Profiler, AGDS – Acoustic Ground Discrimination Systems, DDV – Drop-drown video, DGPS-RTK - Differential Global Positioning System Real-Time Kinematic, LIDAR – Laser Induced Detection and Ranging, MBES – Multibeam Echo Sounders, ROV – Remotely Operated Vehicle, SSS - Side Scan Sonar

Key characteristics	Methodologies
Topography	Aerial survey (Satellite/Drone imagery/LIDAR), Acoustic surveys (SSS, AGDS, MBES), geological maps, DGPS-RTK
Hydrology - Tidal range/currents/wave action	Hydrographic charts, modelling, Aerial survey (Satellite/Drone imagery), Current meters (ADCP)
Salinity/stratification	Water chemistry data loggers
Turbidity/Sedimentation	Secchi disc, water chemistry data loggers, satellite data, sediment sampling, sediment traps
Oxygen levels	Water chemistry data loggers
Primary production	Chlorophyll A concentrations, sediment organic carbon concentrations, abundance/biomass data, satellite data
Food webs	Stable isotopes (^{13}C, ^{15}N, ^{34}S), stomach content analysis
Sediment composition/distribution	Sediment sampling/profiling (core, grab), particle size analysis, DDV. Multicorer/boxcorer for biological components and organic matter composition
Vertebrates - Associated fish, seabirds, marine mammals	Visual census, aerial and boat-based surveys
Macrophytes, macroalgae, eelgrass	Photographic quadrats, video transects, visual census, direct sampling
Invertebrates - Epifaunal & infaunal assemblages	Photographic quadrats, video transects, visual census, direct sampling (grab, core) ROV or DDV. Multicorer or boxcorer (depending on water depth) to collect sediment samples for quantitative biological and trophic analyses.

2.2 Definition of ranges and thresholds to obtain condition indicators

The reference values and thresholds applied by Member States to determine the condition of estuaries (i.e. structure and function) are variously; very specific, based on trends, use indices, rely on expert judgement or any combination of these. Table 6 gives some examples of these different approaches.

Table 6. Examples of reference values and approaches used for estuaries

Example of variable used	Method / metric and reference values	Country: Reference
Quantitative		
Transparency	Condition FV if value >1m or to the bottom of the water level if this is less than 1m; U1 if value in the range of <1.0 - 0.5m>, U2 if value <0.5m.	Poland: Bajkiewicz-Grabowska et al., 2022
Structure determining species	Presence of seagrass and/or *Ruppia* fields, shellfish concentrations, littoral sandbanks and species that ensure mixing of the sediment allocated one point for each (must apply to at least 75% of the surface area). Overall scores for conservation status A (Excellent structure) =8-6 pts, B (Well preserved structure) =5-3 pts, C (passable or affected structure) =2-0 pts	Netherlands: Jansen et al., 2014.
Qualitative		
Landscape form	All typical estuarine habitats (from deep over shallow water to mud flats to high salt marshes, …) are present along the full salinity gradient (from saline to fresh, from tidal to non-tidal)	Belgium: Oosterlynck et al., 2020
Vegetation structure	Completeness of vegetation complex	Germany: Krause et al., 2008
Indices / Additional		
Estuarine & Lagoon fish index	Multimetric indicator taking into account salinity gradient in estuaries. Densities of diadromous, benthic, resident fish etc.	France: Delpech et al., 2010
Biotic index	Distributes Biotic Coefficient (AMBI) values for soft bottom invertebrate species into 5 ecological groups. This is then converted to a Biotic Coefficient corresponding to 8 contamination levels e.g. A level of 1.2-3.3 is considered slightly contaminated and a level between 5.5 -6.0 as extremely polluted	Spain: Ibanez et al., 2009
Benthic opportunistic Annelida index	Ratio between opportunistic polychaete species as well as the genus Clitellata and sensitive amphipod species which respond very quickly to contamination of the environment.	France: Le Floch, 2015
Relative importance of threats graded; H, M, L.	For example, area of mining of sand & gravel: affects habitat area H;>=1%. M; affects 0.1 -1% of habitat area, L: affects habitat area <-0.1%	Bulgaria[5]
Scoring		
Estuarine Fish Assessment Index	Integrates seven metrics; species richness, % marine migrants, number of species and abundance of estuarine resident species, number of species and abundance of piscivorous species, status of diadromous species, status of introduced species and status of disturbance sensitive species. Scoring system is applied based on expert knowledge. Used for reporting under WFD	Portugal: Cabral et al., 2012

[5] Information system for protected areas from the ecological network Natura 2000 – Bulgaria: https://natura2000.egov.bg/EsriBg.Natura.Public.Web.App/Home/Reports?reportType=Habitats

Example of variable used	Method / metric and reference values	Country: Reference
Linked to other programmes – e.g. WFD, MSFD, OBV		
Scheldt monitor	Yearly reports on available scientific data for the Scheldt estuary, MONEOS reports (monitoring activities), six yearly evaluation reports (T-reports), development of 18 indicators for Long Term Vision Objectives. The latter include indicators that are directly relevant to monitoring and assessment for the Habitats Directive e.g. threats to biodiversity and the status of species and habitats	Belgium/Netherlands: Ouberkerk et al., 2022
Long term Ecological Research Programme	To better understanding, analysing, and monitoring changes in ecosystem patterns and processes over extended time periods. LTER-Italy is made up of 25 research sites. Includes the Po Delta. Records various abiotic, biotic variables e.g. phytoplankton abundance, blooms, composition; nitrates, salinity. Used primarily for MSFD reporting but relevant to HD	Italy: Vilibic et al., 2019
Trend		
E.g. completeness of the typical habitat structure. Criteria include those relating to hydrology, structures of the sublittoral and eulittoral and bank structures.	In the case of bank structures; complete expression of natural or near-natural bank structures, high-diversity near-natural bank structures; low diversity near-natural bank structures.	Germany: Krause et al., 2008
Under development		
Guidance	Guidance is given on factors of structure & function which should be considered during the assessment for each habitat group and when selecting typical species but not for coastal and halophytic habitats as this covers a wide variety of habitat types	Belgium (Flanders): Oosterlynck et al., 2020

In additional to the general approaches some Member States have methodologies specific to estuaries. In France, a number of indices have been reviewed. In the case of faunal composition for example, they include an Estuarine and Lagoon fish Index, Benthic Opportunistic Annelida Index, Macrobenthic Index for sheltered systems – transitional waters, Benthic Opportunist Polychaete amphipods index, and a Marine Biotic Index (Le Floch, 2015). Floristic composition indicators include an Angiosperm quality index which brings together three indices; the diversity of habitats, the loss of surface area of habitats compared to optimal coverage and the proportion of the natural habitat compared to the total surface area of the estuary (Le Floch, 2015; Garcia et al., 2009). A resource use indicator assigns intensity of disturbance to a list of activities that can take place within the estuary. These are then brought together to give an overall quality status on the use of resources in the estuary (Aubry & Elliott, 2006). Table 7 shows a summary table of the indicators used in the context of estuaries (Le Floch, 2015).

Table 7. Summary table of indicators used in the context of estuaries in France

Criteria	Indicator
Surface covered	
Evolution of the coastline surface	Morphological change of the coastline
Structure and functioning	
Floristic composition	**Phytoplankton** [WFD] Biomass and abundance of phytoplankton
	ABER [WFD] Presence of specific algae on hard and loose substrate
	TW-OGA [WFD] Presence of opportunistic macroalgae
	Angiosperms [WFD] Composition, extension and development of herbaria
	JNCC indicator Presence of characteristics species
	AQI Habitat diversity and coverage
Faunal composition	**ELFI** [WFD] Diversity of fish community
	BOPA [WFD] Presence of opportunistic polychaetes
	MISS-TW [WFD] Abundance and diversity of benthic communities
	BO2A [WFD] Presence and opportunistic polychaetes and the genus *Clitellata*
	AMBI [WFD] Distribution of benthic communities
	M-AMBI [WFD] Distribution of benthic communities
	ITI Distribution of benthic trophic groups
	I-IBI Abundance and diversity of benthic communities
	BIEC Abundance and diversity of Spionidae and tubeworms
	BQI Abundance of tolerant species
	Foreshore Presence of specific taxa
	Environmental quality and its perception
Alterations	
Affected by anthropogenic activities	**Environmental quality and its perception**
	Resource use

2.3 Aggregation methods at the local scale

In most EU Member States, a generic rather than habitat specific methodology is used to aggregate data on indicators at the local scale to provide a condition assessment at the level of the plot or monitoring locality. The approach taken in France is illustrated in Box 4.

Box 4. Aggregation of indicators at a local scale - France

In France, for evaluation at the scale of Natura 2000 sites three parameters (surface, structure and functions and alterations) are assessed against several criteria, themselves represented by one or more indicators filled in or calculated from metrics collected in the field. In this "Patri-Nat" method, each indicator assessed is compared with a threshold value.

Then each indicator is given a score (negative or zero) which is subtracted from the starting score of 100. A good indicator score will result in few points being subtracted, and a bad indicator score will result in more points being subtracted. Final scores indicate the overall status along a gradient (Table 8 & Figure 7 below).

Table 8. Example of scoring for three indicators A, B, C presenting different response modalities (extracted from Delavenne & de Bettignies, 2023 and Lepareur et al., 2018).

PARAMETERS	CRITERIA	INDICATORS	MODALITIES (threshold values)	GRADE
Parameter 1	Criterion X	A	0-3	0
			3-6	-5
			6-9	-10
Parameter 2	Criterion Y	B	80%-100%	0
			20%-80%	-10
			0%-20%	-15
		C	>1	0
			<0	-20
			Final score (example)	100-0-15-20 = **65**

Figure 7. Determination of conservation status based on its overall score

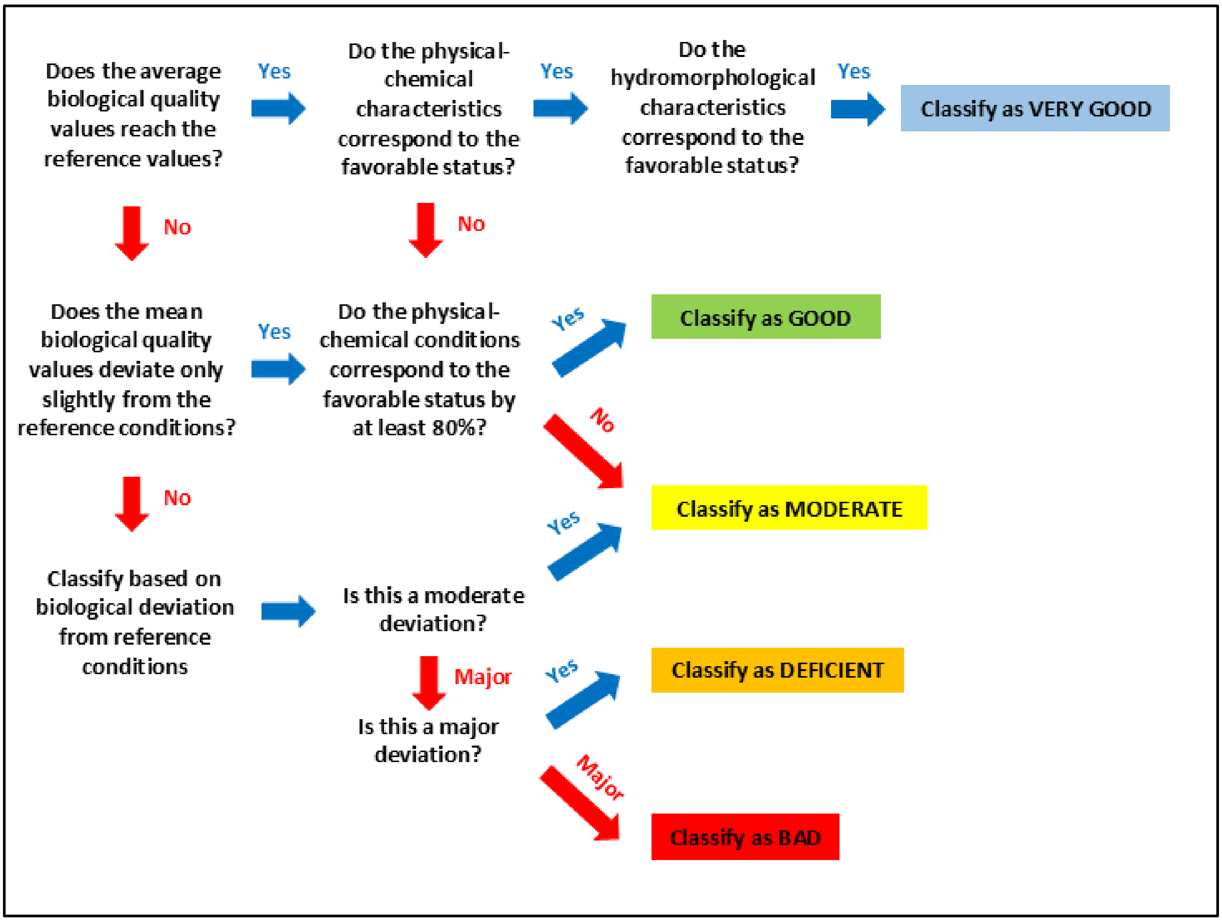
Source: Delavenne & de Bettignies (2023) and Lepareur et al. (2018)

There are also some methodologies specific to estuaries. In **the Netherlands**, for example, the conservation status of a particular Natura 2000 site designated for estuaries is determined by aggregating scores for Structure (structure-determining species, internal structure & scenic setting); Function (water, processes, connectivity); and Area to give an overall score (Janssen et al., 2014).

In **Poland** individual variables specific to habitat type are rated (FV, U1, U2) with the lowest grading determining the aggregated result for 'structure & function'. An overall assessment for the site is the lowest grading given by aggregating results for the assessment of 'structure & function' with those for 'area' and 'future prospects' (see Bajkiewicz-Grabowska et al., 2022 for major details).

The approach in **Spain** is to determine the ecological state based on biological, physical-chemical and hydromorphological factors at each sampling point following the scheme shown in Figure 8. The results are then extrapolated for the entire body of water or type of habitat of community interest or hydrographic district.

Figure 8. Procedure for determining ecological status used in Spain



Source: adapted and translated from Ibañez et al (2009), extracted from Spanish Royal Decree Law 817/2015

2.4 Aggregation at biogeographical scale

To assess the conservation status at a biogeographical scale, the area, quality and trends in the habitat need to be assessed. There is a lack of information on how Member States have undertaken aggregation at the biogeographical scale specifically for this habitat type, but it is expected that the relevant guidance is followed. The most recent recommendation (for the reporting period 2019-2024) is that if 90% of habitat area is considered as in 'good' condition', then the status of 'structure and functions' parameter is 'favourable'. If more than 25% of the habitat area is reported as 'unfavourable, then the 'structure and functions' parameter is 'unfavourable-bad' (European Commission, 2023).

2.5 Selection of localities

There is no single approach across the Member States regarding the number and distribution of localities to carry out the assessment and monitoring of this habitat, however there is much commonality in approach.

The first stage of monitoring and assessment of estuaries is defining the limits of the habitat. The seaward boundary can be particularly complex to define. This can be at the furthest extent of morphological features, a line connecting headlands, salinity boundaries or some combination of all of these. In **Poland**, some examples of the limits of estuaries defined as Natura 2000 habitats are boundaries between the sea and land intersecting the current (Piaśnica), a line between breakwaters extending into the sea (Dziwna, Rega) and furthest extent of the delta (Reda) (Bajkiewicz-Grabowska et al., 2022). Each estuary has a designated station where measurements and water quality tests are carried out. Specific transects as monitoring locations are also identified in Lithuania with guidance on the optimal time for this work (Nature Research Centre, 2014).

In **Spain**, in order to select localities for monitoring of coastal habitats, eleven criteria were developed and apply to each biogeographical region (Gracia et al., 2019), in order of priority:

- Representativeness within the Natura 2000 Network and the Protected Area Networks.
- Statistical significance. A minimum number of monitoring locations is necessary in the region so that the assessment can be extrapolated from local to regional level.
- Number of types of habitats of community interest present in the location, taking into account the subsystems composing estuaries, i.e. beaches, dunes and saltmarshes, mainly.
- Range/Occupied surface area.
- Representative presence within the coastal province.
- Threat status (danger of disappearance) and conservation status. Includes habitat types with a certain degree of degradation or threat, which have a current tendency to decrease or have had a historical tendency in this sense.
- Reference ecosystems.
- Ecological significance and national/community uniqueness.
- Environmental-ecological diversity.
- Distance to other monitoring points.
- Representativeness within the autonomous communities.

The guidance states that survey sites for habitat 1130 must be selected, on the basis of existing cartographic data, on a regional scale so as to be representative of different environmental conditions and impacts of different intensities, taking into account the monitoring activities already implemented in implementation of the Water Framework Directive and the Habitats Directive, and in the Marine Protected Areas, provided they have not already been investigated, with particular regard to the Natura 2000 network areas. However, there are often systems that meet these characteristics and could represent the reality of the region, but for which there is no historical database to quantify the state of conservation. For instance, in the absence of gauging stations or measurements of water quality or biodiversity. In such cases, it should be assessed whether it is a system of regional relevance or whether it is better to opt for those for which more exhaustive monitoring can be carried out. In Romania and Spain, it is noted that if other Annex I habitat types are present (e.g. sandbanks, reefs, coastal lagoons, dunes), they must have their own dedicated monitoring programme. The estuarine monitoring programme may therefore be an aggregation of both sampling programmes for a range of habitat types and a dedicated sampling programme for additional estuarine habitat types in its entirety (Zaharia, 2013).

2.6 General monitoring and sampling methods

A six yearly cycle of reporting, as specified under Article 17, is required under the Habitats Directive. This includes reporting on the conservation status of habitats listed in Annex 1 of the Directive. It applies throughout the territory of the Member State concerned, not only where the habitat occurs within Natura 2000 sites. To inform this reporting, six-yearly monitoring of the relevant habitats would be the minimum required.

Sampling of key characteristics such as salinity, nutrient levels, sediment type and epifauna typically takes place along the length and width of the estuary with reference to tidal and meteorological conditions. Individual parameters such as temperature and salinity may be used as indicators, but data may also be combined. An example of the latter is the Benthic Quality Index (Rosenberg et al., 2004). Sampling frequency may also be determined by the condition of the body of water. This is the case in Spain (Table 9) (Ibañez et al., 2009).

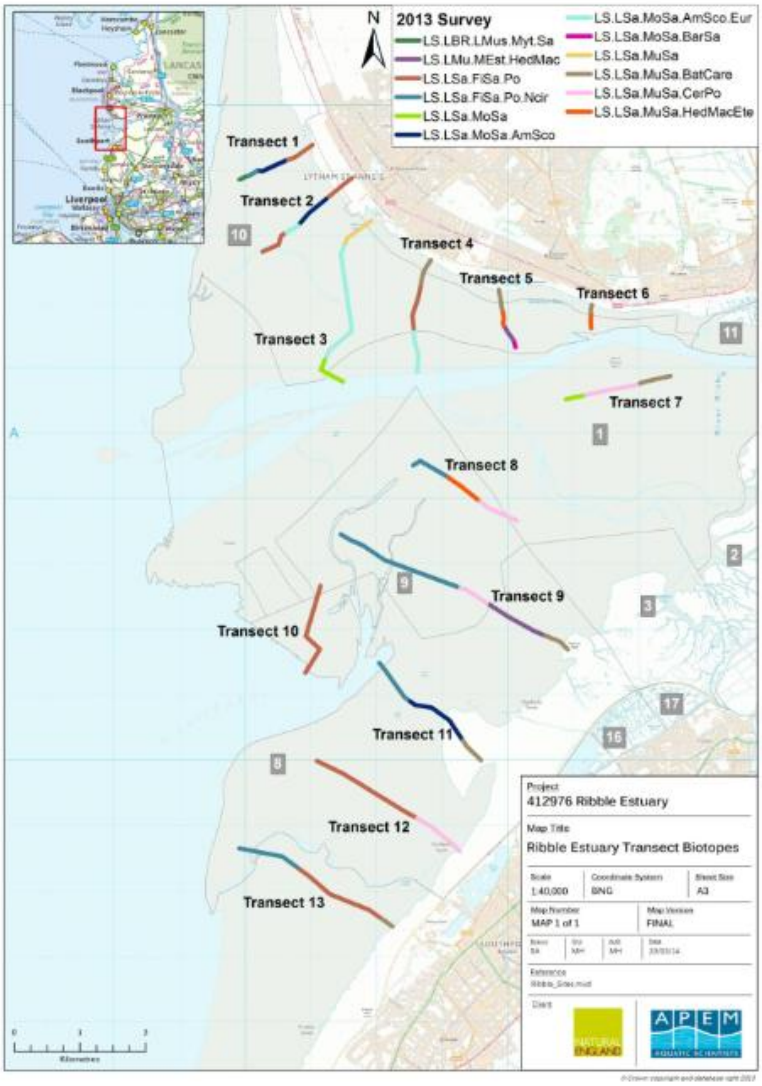
Table 9. Sampling frequency of the different factors in estuaries depending on the particularities of the water body in which habitat 1130 is located in Spain

*Note that the authors understand that the risk of the habitat type will be determined based on the risk that the water bodies where it is located do not reach good ecological status, which is equivalent to saying that it could be in an unfavourable state of conservation. The risk analysis must be carried out based on a pressure analysis and an impact analysis, determined according to Ibáñez et al. (2009)

	Biological			Physical-chemical	Hydromorphological
	Macro-invertebrates	Phytoplankton-macrophytes	Fishes		
No risk*	2 years	2 years	6 years	6 months	3 years
At risk*	1 year	1 year	3 years	1 month	2 years

As many estuaries are large, sampling protocols may be needed within each site to assess the condition of the whole feature. A stratified approach may be adopted for extensive sites where the available resources only permit a few locations to be investigated in detail and the results must be extrapolated to the whole site. This should include a series of ‘spot checks’ throughout the site to ensure that any extrapolated results are representative of the condition of the entire site (Davies et al., 2001). Sampling/recording along transects also helps to build a picture of the extent, distribution, and other characteristics of the biotopes and sediment characteristics of an estuary (Figure 9) (APEM, 2015), although accessibility and sensitivity to intrusion in these types of systems is not easy and field surveys should be designed carefully.

Figure 9. Example of surveying along transects on the Ribble estuary (United Kingdom)



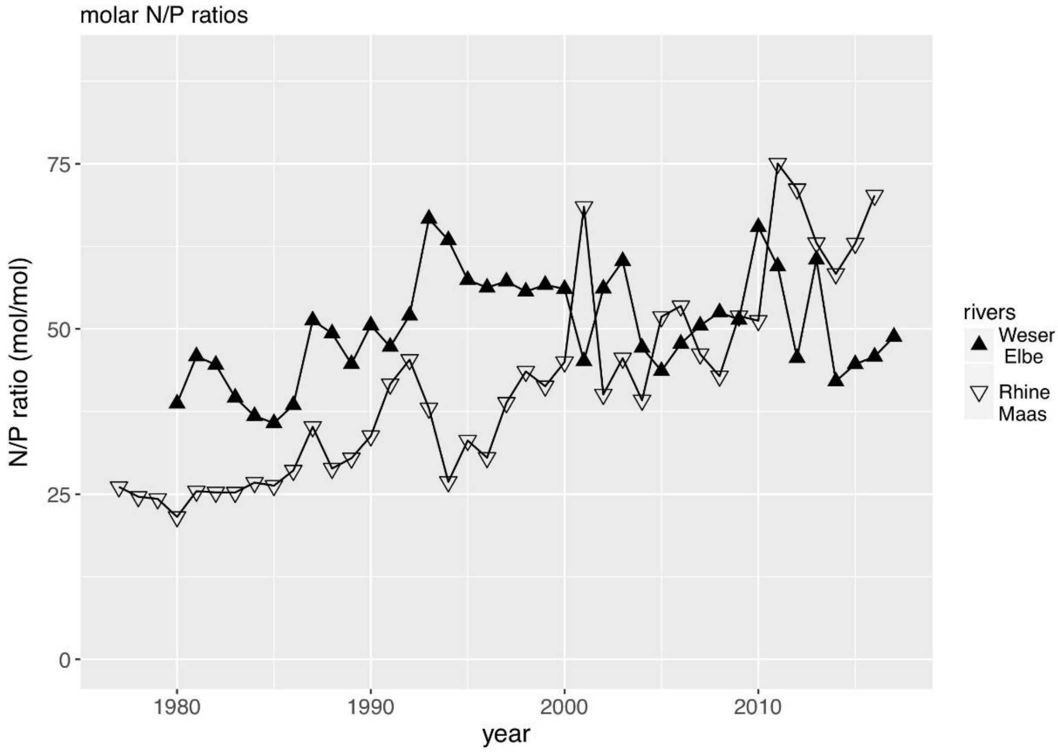
Map of linear extent of habitat types along transects based on a combination of Phase 1 and quantitative coring survey across the Ribble Estuary Site of Special Scientific Interest Units 1, 8, 9 & 10,

Source: APEM (2015)

In Italy 3-yearly surveys are recommended to record the extent of the habitat, variations and possible colonization by plant species. The survey period should be from the beginning of May to the end of October and surveys carried out during exceptionally low tides. The survey frequency should be annual, varying the position of the survey areas from year to year, returning to the same area once every 3 years (La Mesa, 2019).

Long-term monitoring stations have been established in some estuaries. This is the case in the Wadden Sea where there are time series data recording eutrophication levels from before 1990 in the five estuaries in the Wadden Sea region (Figure 10) (van Beusekom et al., 2019). Floating modules which operate continuously over a short term are also used and their potential for long-term monitoring in coastal waters has been investigated during a 2-year study at the lower Guadiana estuary (Portugal) (Garel & Ferriera, 2011).

Figure 10. Molar N/P Ratio of the major rivers impacting the southern Wadden Sea (Rhine, Maas) and the northern Wadden Sea (Weser, Elbe)



Source: van Beusekom et al. (2019)

There are many estuary monitoring schemes within EU Member states both individually and jointly where estuaries cross national borders. Whilst not necessarily specifically aimed at reporting and assessment for the Habitats Directive they can provide valuable, relevant information. One example is the Scheldt monitor programme (Anon, 2010). This provides annual reports on available scientific data for the Scheldt estuary, MONEOS reports (monitoring activities), six yearly evaluation reports (T-reports), and 18 indicators for Long Term Vision Objectives[6]. The latter include indicators that are directly relevant to monitoring and assessment for the Natura 2000 habitats in the Scheldt estuary e.g. threats to biodiversity and the status of species and habitats, and is used to assess the conservation of status of the estuary.

Co-ordination also takes place with other monitoring scheme both to inform HD reporting and to support other reporting schemes. This is especially relevant in the case of estuaries which overlap with monitoring requirements under the Water Framework Directive (WFD) as they occur in 'transitional waters'. Under WFD this requires monitoring of phytoplankton, macrophytes, benthic invertebrates, and ichthyofauna. Monitoring for the Habitats Directive may therefore be additional. This is the case in Denmark, for example, which has a "supplementary control monitoring programme" for seas and fjords (Hansen & Høgslund, 2024). The reverse also applies with monitoring data collected for the Habitats Directive used to inform other initiatives, one example being in the Wadden Sea Quality Status Reports (Schuchardt & Scholle, 2017).

[6] https://www.scheldemonitor.org/en/indicatoren.php

2.7 Other relevant methodologies

A variety of methodologies and projects provide valuable information on assessing the structure and function of estuaries even though they may not be specifically aimed at Article 17 reporting.

They include:

- Work carried out under Regional Seas Programmes such as the Quality Status Reports prepared by OSPAR (e.g. Eutrophication Thematic Assessment,) and HELCOM.
- Reporting under other EU Directives, in particular the Water Framework Directive and the Marine Strategy Framework Directive.
- Scientific research/databases e.g. The Belgium Fish Information System. A database on fish in Flanders including fish stocks and fish indices.
- Surveys/monitoring of offshore developments/human activities/EIAs.

Examples of data collected through projects include the following.

In Portugal the Estuarine Fish Assessment Index integrates seven metrics and scores them to assess ecological quality (see Table 10) (Cabral et al., 2012).

Table 10. Scores from each metric of the Estuarine Fish Assessment Index

Metrics	Scores		
	1	3	5
Species richness (SR)	≤10	11–20	>20
Percentage of marine migrants (%MM)	≤10%	10–50%	>50%
Estuarine resident species (ES) **-Percentage of individuals** **-Number of species**	≤10% or >90% ≤2	10–30% or 70–90% 3-5	30–70% >5
Piscivorous species (P) **-Percentage of individuals** **-Number of species**	≤10% or >90% ≤5	10–30% or 70–90% 6-12	30–70% >12
Diadromous species (D)	Absent or few species present/ Inability to complete life cycle	Several species present but rare	Several species present and common
Introduced species (I)	Present and abundant	Present but rare	Absent
Disturbance sensitive species (S)	Absent or few species present in low abundance	Several species present but rare	Several species present and common

Italy has a Long term Ecological Research programme (LTER-Italy), established in the 1980s to improve understanding, analysing, and monitoring changes in ecosystem patterns and processes over extended time periods, typically decades. The marine component of LTER-Italy is made up of 25 research sites, organized in eight parent sites, mainly representing transitional and coastal ecosystems. Among them, the LTER parent site Northern Adriatic Sea (NAS) includes four research sites (Gulf of Trieste, Gulf of Venice, Po Delta and Romagna Coast, Senigallia-Susak Transect), where meteo-oceanographic and biological data, mainly on plankton, are gathered through both oceanographic cruises and fixed-point observatories. Data from the Po Delta for example on chemical and biological characteristics is relevant to monitoring and assessment of the estuarine features of this Natura 2000 site.

Indicators and thresholds being developed under the auspices of other programmes can also inform the process for the Habitats Directive. One example is a **United Kingdom** project which developed an approach to determining how far an estuary is from favourable condition with regard to its morphology and the amount of intertidal habitat. The methodology has been used to predict the equilibrium planform (the outline of the estuary as seen from above) which can then be compared to the observed plan form (Table 11) (JNCC, 2004).

Table 11. Description of the tidal prism/cross sectional area morphological equilibrium attribute

Attribute	Measure	Target	Comment	Method
Morphological Equilibrium	Tidal prism/ cross-sectional area (TP/CS) relationship	No significant deviation from the intra-and inter- estuarine TP/CS relationship.	The relationship between TP and CS provides a measure of the equilibrium of an estuary which is fundamental to the way it adjusts to tidal energy and is reflected in rates of deposition and erosion. Substantial changes in this relationship may indicate that human-induced factors are taking effect and this would trigger more detailed evaluation of potential problems.	Bathymetric survey every 12 years, or sooner if saltmarsh boundary measurements indicate a deviation away from standard limits of natural variation.

The potential for information derived from Environmental DNA (eDNA) to become an additional monitoring tool in estuaries is a developing field. This can be used to detect single or a small number of species, or on whole communities of species. A trial, using the San Francisco Estuary (California, USA) as an example was conducted to see if it could assist modernising the monitoring of this estuary which is subject to multiple monitoring programmes collected by several agencies (Nagarajan et al*.*, 2022). A number of potential management questions that could benefit from eDNA based sampling were identified (Table 12), although it was also recognised that there were limitations in using this technique at present. For example, eDNA assays are not available for all of the species of most concern, identified by the various agencies.

Table 12. Potential management questions that could benefit from eDNA-based sampling

Potential management questions that could benefit from eDNA-based sampling	
Management questions	**How eDNA sampling can help**
1. Where is this endangered species occurring? Where is this hard-to-find species of interest occurring? Does site use change seasonally?	Sampling for eDNA offers increased sensitivity for rare and protected species that may be present in low numbers or are even just hard to detect with traditional survey methods. Environmental DNA sampling can be used in conjunction with other survey methods (seines, trawls, electrofishing, rotary screw traps, fyke traps) and can be carried out at sites where traditional surveys are difficult to use. Sampling plans can vary over space and time to help better understand when and where a species is found.

Potential management questions that could benefit from eDNA-based sampling	
Management questions	**How eDNA sampling can help**
2. How has community composition changed after this habitat has been restored? Has this habitat restoration been effective to support species of interest?	Environmental DNA samples can be analysed using metabarcoding to look at community composition before and after a restoration, providing a community wide snapshot of presence. This can be carried out in conjunction with other community survey methods (seines, trawls, electrofishing, rotary screw traps, fyke traps).
3. Is this invasive species present in the watershed? Could a harmful algal bloom (HAB) occur?	Due to its sensitivity and ability to detect species at low concentrations, eDNA sampling can be used for early warning monitoring for new invasive species and nuisance species.
4. Do I need to carry out monitoring at this site?	Environmental DNA sampling can be used as an initial step to determine if monitoring or further analysis that is more time intensive is necessary. This preliminary sampling can increase efficiency and save time and resources.
5. Could the species of interest be infected? Where is this pathogen occurring?	Environmental DNA sampling can be used for pathogen screening, which could affect management actions. In addition to catching and inspecting a species, eDNA sampling could inform whether a pathogen is currently in the system.

Under development and potentially relevant is the Global Estuaries Monitoring Programme which is establishing a network to monitor environmental contaminants in major urban estuaries worldwide. One of the aims is to develop standard sampling and analysis methods.

2.8 Conclusions

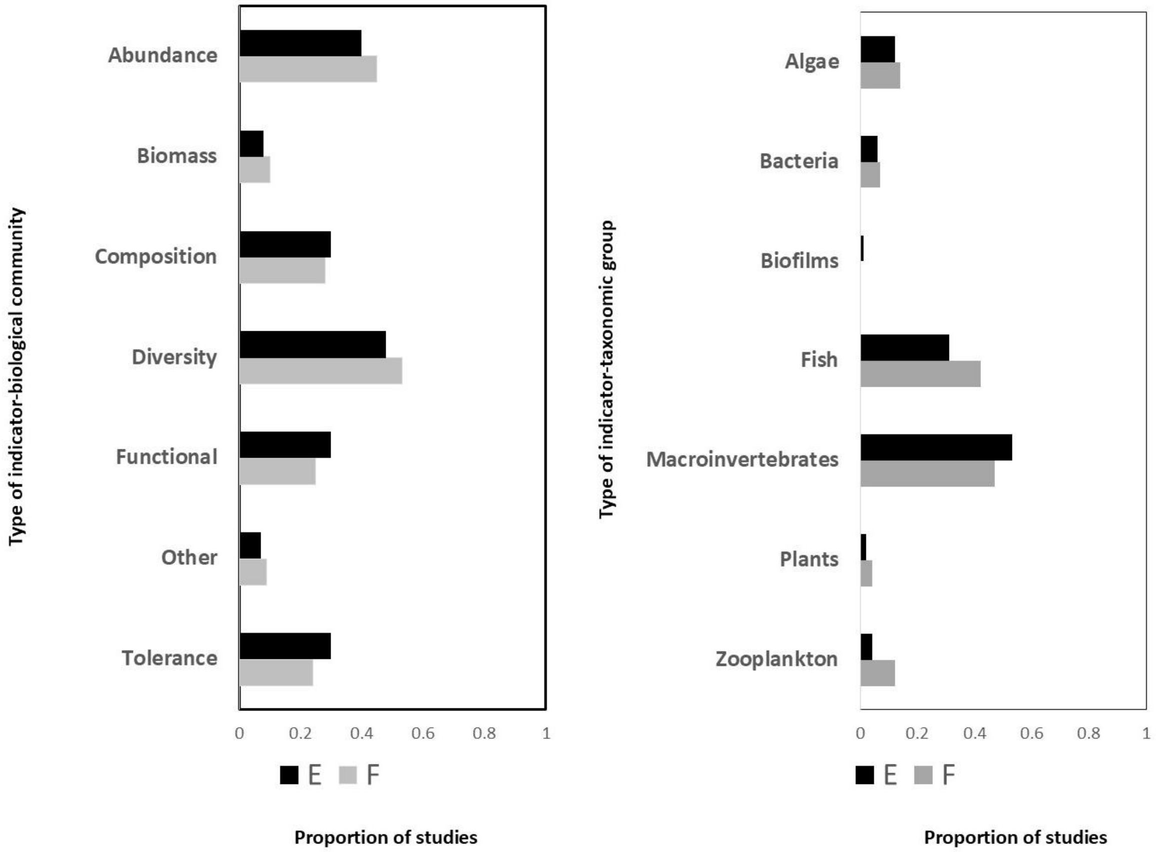
Some information has been collected about the location and description of the main characteristics of estuaries by all the Member States that have reported habitat 1130 as present within their jurisdiction[7]. Specific methodologies for assessing and monitoring estuaries are also available from eleven Member States (BE, BG, DE, ES, FR, IE, IT, LT, NL, PL, RO). Also relevant are reports of estuary surveys and assessments carried out in these and other EU Member States that can or have been used to inform such assessments although not directly stated as a reason for the work.

There is a broadly similar approach to describing and monitoring this habitat type across Member States with differences in the detail depending on location, hydrographic conditions and size of the estuaries are being monitored, the accessibility of sampling locations, and whether they are part of long-term studies. The variables monitored cover physical, chemical, composition, structural, functional, and landscape/seascape characteristics.

A review of studies from around the world that assess the ecosystem health of estuarine and freshwater environments collected information on the types of biological, physical and chemical indicators used in assessments (O'Brien et al., 2016). Thirty-three of these studies were of estuaries. Typically, a combination of indicators was used with a strong bias towards fish and macroinvertebrate community metrics (e.g. diversity, abundance and composition). Only two of the studies considered both freshwater and estuarine sections of the ecosystem (Figure 11).

[7] as evidenced by the submitted Standard Data Forms for designated sites where 1130 is a feature and Art.17 reporting for this habitat

Figure 11. Proportion of freshwater and estuarine studies that used (a) the different community metric and (b) taxonomic groups used in the ecosystem health assessments



Source: adapted from O-Brien et al. (2016)

Given estuaries and freshwater systems are intrinsically linked through transfers of water, nutrients, contaminants and biota, the review called for more studies that consider both the freshwater and estuarine components simultaneously to allow environmental managers to better implement whole riverine ecosystem management strategies. This type of integration can be seen in Belgium (Flanders) (Oosterlynck et al., 2020) where the assessment matrix for estuaries includes assessments of habitats that may occur within it such as saltmarshes (e.g. habitat types 1310, 1320, 1330, 3270, 6430.), or in Spain that not only includes saltmarshes habitat but also dune and beaches habitats linked to estuarine systems.

The reference values and thresholds applied by Member States to obtain condition indicators for estuaries are variously; very specific, based on trends, use indices, rely on expert judgement or any combination of these. There is consistent and good coverable of variables used to describe the ecological characteristics of this habitat type across Member States although the level of detail may vary depending on practical considerations and capacity. Some reference values are qualitative with expert judgement being used to determine whether they are being exceeded.

In most EU Member States, a common rather than habitat specific methodology is used to aggregate data on indicators at the local scale to provide a condition assessment at the level of the plot or monitoring locality. Some exceptions are Spain, the Netherlands and Poland.

There is no single approach to the identification of a number and distribution of localities to carry out the assessment and monitoring of estuaries. Practical consideration, such as accessibility are important as are factors such depth, size, physical variability and diversity of the associated biological communities. Sampling stations may be along transects or distributed across known areas where different biotopes are present. Existing databases are also an important factor to consider when evaluating an estuary.

A six yearly cycle of reporting, as specified under Article 17, is required under the Habitats Directive. This includes reporting on the conservation status of habitats listed in Annex 1 of the Directive. It applies throughout the territory of the Member State concerned, not only where the habitat occurs within Natura 2000 sites. To inform this reporting, six-yearly monitoring of the relevant habitats would be the minimum required. In practice, some monitoring of estuaries specifically for Habitats Directive reporting is more frequent (e.g. 3 yearly or even annually). Relevant data collected under other programme (e.g. WFD, MSFD and any regional/national schemes) are also used as and when they become available. This is especially relevant in the case of estuaries which overlap with monitoring requirements under the Water Framework Directive as they occur in ‘transitional waters’.

3 Guidance for the harmonisation of methodologies for assessment and monitoring of habitat condition

3.1 Selection of condition variables, metrics and measurement methods

Variables identified for monitoring programmes need to be robustly associated to the key characteristics and processes (functions) that determine habitat condition and must be sensitive to natural threats or human pressures that decrease favourable condition (Maes et al., 2023). A set of variables associated with all types of characteristics (abiotic physical and chemical, biotic compositional, structural and functional, landscape variables) should be measured.

The description of the condition variables, metrics and measurement methods need to be informed and clear so that they can be applicable in all Member States.

The ecological characteristics, methodologies, variables and metrics used to investigate and assess the condition of habitat types 1110 (sublittoral sandbanks), 1130 (estuaries), 1140 (mudflats & sandflats) and 1160 (inlets and bays) are rather similar. This section therefore presents joint proposals for a minimum common set of variables, recommended metrics, and measurement procedures for all four of these habitat types (1110, 1130, 1140 & 1160). A proposed list of essential, recommended and specific condition variables is presented in Table 13. 'Essential' variables describe the common essentials of the habitat, 'recommended' variables are relevant but can be neglected in some contexts, while 'specific' variables are those which should be measures in some circumstances.

- **Essential** condition variables describe essential characteristics of the habitat, reflecting its conservation quality. They are selected on the basis of intrinsic and instrumental relevance, validity, reliability, availability, simplicity and compatibility, and should be assessed in each MS, following equivalent procedures.
- In addition, a set of **Recommended** condition variables are proposed as optional, additional or complementary variables that may need to be applied in some cases, according to contextual factors operating on habitats in the different MSs.
- There are also **Specific** condition variables which are more suitable to be measured on some habitat subtypes or which may be particularly relevant in some Member States.

Some **descriptive or contextual variables** are included in this section. These variables define environmental characteristics (e.g. climate, topography, lithology) that can influence the habitat condition, are useful to define thresholds for the condition variables and interpret the results of the assessment but are not used in the aggregation of variables to determine the condition of the habitat.

There are contextual factors operating in the different Member States, which may determine the values of the variables characterizing the habitat condition as favourable, particularly biogeographical as good condition of the same habitat may vary across biogeographical regions. Salinity is a good example of this given the different salinity profiles of the different Regional Seas.

Table 13 uses the main characteristics of the four different habitats (described in section 1.2.1 of each habitat report), together with the information provided by Member States about the assessment the condition of these habitats and habitat specific literature. The proposed metrics are intended to be easily but reliably obtained.

The main **abiotic characteristics** are physical (describing the form, influencing factors such as tidal range, exposure to currents, temperature, turbidity and sediment composition /distribution) and chemical (related to water and sediment quality). Only one of the physical characteristics (exposure to current, wave action, scour & surge) does not appear to be routinely monitored for condition assessment across all four habitats. The exception is estuaries, potentially because of prevailing sheltered conditions. However, it should be noted that this variable can have a significant influence on condition around the mouths of estuaries and within exposed channels therefore it is proposed as essential.

In the case of chemical characteristics, salinity/freshwater influence/stratification will have a significant influence on the condition of habitats 1130 & 1140, less so for 1160, and potentially not an issue for examples of 1110 which lie offshore. For this reason, monitoring has been proposed as recommended (although essential in the Black Sea after justification by some Member States). Water quality needs to be monitored across all habitat types, however there will be differences in the variables that are measured. In estuaries with industrial facilities along the shoreline for example, monitoring of heavy metals would be highly relevant but not in the case of offshore sandbanks, hence the recommendation that monitoring is essential but with recommended elements.

The main **biotic characteristics** are compositional (associated species), structural (presence and condition of species) and functional (influencing factors such as sedimentation and phytoplankton blooms). All of these are already subject to monitoring by Member States however monitoring biogenic structures has been listed in Table 13 as recommended as such structures are not always present. The same applies to macroalgae/eelgrass presence and condition. Monitoring the presence of opportunistic/invasive species is also recommended as the risk may be higher in some locations/habitats, and it may be considered precautionary measure so that any potential effects on habitat condition can be picked up at an early stage.

The main **landscape/seascape characteristics** are connectivity, form and extent, and a single variable, ‘disturbance’, has been proposed for monitoring in the category ‘**other’**. Extent and disturbance would be the minimum required to get an overview of the condition of the site at both large and small scales, and they are therefore proposed for essential monitoring. Connectivity and form provide more detail and are therefore recommended monitoring variables.

Table 13. Proposals for essential, recommended and specific condition variables for habitats 1110, 1130, 1140, and 1160

The variables are included in the types recognized in the SEEA EA methodology (United Nations et al., 2021). Metrics may show several options. including current monitoring for each habitat type across Member States (*), metrics and measurement procedures. Abbreviations: ACDP - Acoustic Doppler Current Profiler, AGDS – Acoustic Ground Discrimination Systems, CTD - Conductivity, temperature and depth, DDV – Drop-drown video, LiDAR – Laser Induced Detection and Ranging, MBES – Multibeam Echo Sounders, ROV – Remotely Operated Vehicle, SBES – Single Beam Echo Sounders, SSS - Side Scan Sonar

Characteristics	Variables	Metrics	1110	1130	1140	1160	Application	Standardised measurement procedures	Considerations relating to Methodologies
1. Abiotic characteristics									
1.1 Physical characteristics									
Degree of submergence/ depth	**- Depth in relation to chart datum**	- Metres (m)	*	*	*	*	Essential if not positionally stable	SBES, MBES, AGDS, LiDAR, Hydrographic charts, modelling, Aerial survey (Satellite/Drone imagery), Tide gauges	Depth, together with topographical characteristics and tidal regime have a significant influence on the form and extent of these habitat types as well as on the development and stability some of the features within them such as beaches, channels and tidal pools. The associated biota will also be affected by the degree and length of time of submergence/ emergence as determined by the tidal regime.
Tidal regime	**- Tidal range**	- Maximum & minimum (m) with seasonal patterns	*	*	*	*	Essential in tidal areas for 1130, 1140 and 1160. Recommended for 1110.	Tide gauges, modelling, Aerial survey (Satellite/Drone imagery).	Depth, together with topographical characteristics and tidal regime have a significant influence on the form and extent of these habitat types as well as on the development and stability some of the features within them such as beaches, channels and tidal pools. The associated biota will also be affected by the degree and length of time of submergence/ emergence as determined by the tidal regime

Characteristics	Variables	Metrics	1110	1130	1140	1160	Application	Standardised measurement procedures	Considerations relating to Methodologies
Topography	**- Physical dimensions - Extent - Longitude and latitudinal gradients - Elevation, - Form and features (eg. banks, islands, troughs)**	- Area of features (km^2) - Tidal prism/cross-sectional area relationship - Degrees of slope (°) - Physical features	*	*	*	*	Essential if not positionally stable for 1110, 1130 and 1140. Recommended for 1160.	SSS, MBES, SBES, AGDS, LiDAR Aerial survey (Satellite/Drone imagery) Geological maps	Most appropriate methodology will depend on issues such as the size of the area to be mapped, resolution required, object detectability, and the depth range over the survey area. For baseline broad scale mapping where relatively large geological features such as sand waves or reefs are present, MBES may be more cost effective. For the identification of small habitat features, a combination of MBES and SSS can give both quantitative bathymetric data (1m resolution) and qualitative, high-resolution habitat relief data but is costly. For small scale habitat mapping, high resolution SSS, underwater photography, ROVs, and grab sampling data can be combined for habitat mapping. Satellite imagery, LIDAR is particularly useful in shallow waters although affected by turbidity of the water.
Hydrodynamics - Exposure to current, wave action, scour & surge	**-Current speed -Direction -Height -Extremes**	- m/s - Metres (m)	*	*	*	*	Essential	Hydrographic charts Modelling Aerial survey (Satellite/Drone imagery) Current meters (ADCP).	Seasonal changes and storm events will be apparent when recording these variables. Species composition is an indirect indicator of these variables.
Temperature	**- Water temperature**	-Temperature (ºC)	*	*	*	*	Essential	CTD	Temperature is usually recorded as part of water quality sampling programmes.
Turbidity	**-Suspended particles -Light transmission through water samples -Secchi disk depth**	- Nephelometric turbidity units (NTU) - Formazin turbidity units (FTU) - Secchi disc depth (m)	*	*	*	*	Essential	Turbidity sensor, Secchi disc, water chemistry data loggers, satellite data, sediment sampling, sediment traps	Different turbidity unit depending on tools used, therefore the same instrument should be used for comparability of data. Turbidity caused by resuspension of sediments results in associated effects of increased oxygen demand, release of nutrients and potentially toxic substances.
Sediment composition/ distribution	**- Sediment particle size and distribution - Thickness of oxidised layer (for silt) - Deposition/ erosion locations**	- % of three classes of particle size (mm; Folk diagram) - Oxidised layer (mm) - Rates of change (mm/year, -g/m^2)	*	*	*	*	Essential	Benthic grab/core sampling, suction sampling, sediment profile camera Video/photographic transects MBES Aerial imagery Modelling	Variation in sediment composition can occur over both small and large distances. A systematic and consistent approach to sampling will therefore be required to give sufficient overview of this characteristic across the habitat as well as identifying boundary areas and any locations with particularly different/distinctive sediment compositions characteristics.

Characteristics	Variables	Metrics	1110	1130	1140	1160	Application	Standardised measurement procedures	Considerations relating to Methodologies
1.2 Chemical characteristics									
Salinity/ freshwater influence/ stratification	**- Salinity** **- Conductivity**	- Parts per thousand Sodium and Chloride (0/00) - Depth/ boundaries (m) of different water bodies	*	*	*	*	Essential in the Baltic Sea, Specific in all other Seas	CTD, Water chemistry data loggers	Changes in salinity within and across the habitat are a major natural characteristic of estuaries as well as across mudflats/sandflats and islets and bays due to tidal movements and freshwater run-off. The resulting variation may be apparent diurnally, seasonally or as pulses in response to events such as storms and flooding. Salinity gradients can also lead to stratification of the water column which has chemical, physical and biological implications for the associated biota.
Water quality	- Various substances (including chemicals listed in the WFD and EQSD, nitrates & phosphates, oxygen, chlorophyll, dissolved solids)	- pH - Chromophoric dissolved organic matter (CDOM) - Fluorescent dissolved organic matter (FDOM) - Total dissolved solids (TDS) - Dissolved oxygen (mg/l) - Oxygen saturation (%)	*	*	*	*	Essential but with specific elements as variables will depend on depending on habitat type, pressures and threats.	CTD with sensors to measure oxygen (saturated in % and dissolved in mg/l), pH, nitrate, chlorophyll, turbidity currents	Numerous parameters may be recorded under the variable "water quality". The standards set under the WFD for transitional waters are particularly relevant and are already being used as reference values/thresholds for a number of parameters. These include general parameters such as oxygenation, nutrients, nitrogen, phosphorus, as well as chemical and physio-chemical quality elements.
Sediment quality	- Inorganic and organic chemical contaminants - Organic carbon	- Redox potential in bottom sediment - Traces of hydrocarbons - Hydrogen sulphide concentration in the sediment (µM) - Organic carbon (% dry matter)	*	*	*	*	Essential	Sediment sampling/profiling (core, grab), particle size analysis, DDV, photographic record of samples	Variation in sediment quality can occur over both small and large distances. A systematic and consistent approach to sampling will therefore be required to give sufficient overview of this characteristic across the habitat as well as identifying boundary areas and any locations with particularly different/distinctive sediment qualities.
Oxygen levels	**- Oxygen levels measured at surface and depth.**	- Concentration/ dissolved oxygen (% saturation)		*			Specific	Dissolved oxygen meters, optical sensors	

Characteristics	Variables	Metrics	1110	1130	1140	1160	Application	Standardised measurement procedures	Considerations relating to Methodologies
2. Biotic characteristics									
2.1 Compositional state characteristics									
Invertebrates - Epifaunal & infaunal assemblages	**- Abundance of characteristic species from standardised lists.** **- Diversity of characteristic species from standardised lists.**	- Number of taxa - Presence & abundance of species (SACFOR scale) - Diversity index, (Shannon-Wiener index, AMBI index) - Biomass, - Estimated % cover - Density (ind./10 cm^2) and Shannon-Wiener for meiofauna	*	*	*	*	Essential, although recommended for meiofauna	Macrofauna: Photographic quadrats, video transects, visual census, direct sampling (grab, core, dredge, suction), ROV or DDV. Meiofauna: Diver-operated corer (3 replicates in floor sediment)	Allows quantitative data on macro and meiofauna. Allows identification of mega epibenthos. Non-destructive methods are likely to be favoured and the methodology will depend on the species as well as factors such as the extent, location, and any seasonality.
Vertebrates - Associated fish, birds & marine mammals	**- Abundance and diversity of characteristic species from standardised lists.**	- Number - Population structure - Trophic composition (e.g. % omnivores/ piscivores) - Distribution	*	*	*	*	Essential for some groups, specific for some others	Aerial/boat-based surveys photographic/satellite imagery, in situ observations, eDNA Fish: nets & traps	Methodology will depend on the species.
Biogenic structures	**- Type** **- Extent**	- Biomass - Estimated % cover - Condition	*	*	*	*	Specific but essential if present	Photographic quadrats, video transects, visual census, direct sampling (grab, core), ROV or DDV, aerial photography for intertidal areas.	Methodology will depend on the species. Non-destructive methods are likely to be favoured.
Opportunistic/ invasive species	**- Presence** **- Distribution** **- Abundance**	- Number - Biomass - % cover - Population structure.	*	*	*	*	Recommended	Benthic/pelagic sampling methods as well aerial imagery if intertidal.	Methodology will depend on the species and whether it is present intertidally or subtidally. Opportunistic/invasive species can cause very significant changes in the biotic composition of any of the habitats in this cluster as well as some potential impacts on their physical structure. Examples include Pacific Oyster *Crassostrea gigas*, forming reefs on intertidal flats, dense meadows of the alga *Caulerpa cylindracea* smothering areas of rock, sand, mud and seagrass beds within inlets and bays, and Chinese Mitten Crab *Eriocheir sinensis* undermining soft sediment banks in estuaries.

Characteristics	Variables	Metrics	1110	1130	1140	1160	Application	Standardised measurement procedures	Considerations relating to Methodologies
2.2 Structural state characteristics									
Characteristic species	**- Condition**	- Percentage cover - Biomass - Density - Synthetic indicators (M-AMBI, BENTIX etc)	*	*	*	*	Essential	Birds, marine mammals, fish: Visual census, aerial and boat-based surveys. Epifaunal and infaunal assemblages: Photographic quadrats, video transects, visual census, direct sampling (grab, core, trawl) ROV or drop-down video data	Methodology will depend on the species. For example, some may be visually dominant and therefore can be surveyed by visual means whereas more cryptic species or infauna may require direct sampling. The monitoring schedule will need to take account of any seasonal changes.
Biogenic structures	**- Abundance - Extent - Condition**	- Volume/ biomass - Fragmentation - Ecological volume	*	*	*	*	Specific	Photographic quadrats, video transects, visual census, direct sampling (grab, core) ROV or DDV, AGDS, SSS, aerial/satellite imagery. For ecological volume: Photogrammetry 3D; integration of SSS and MBES; quadrants and transects; ROVs.	Non-destructive methods are likely to be favoured and the methodology will depend on the reef forming species as well as factors such as the extent and location.
Vegetation zones	**- Abundance - Extent - Condition**	- Area (ha) - Depth (m) limit of angiosperms - Biomass (dry weight/m^2) - Ecological volume	*	*	*	*	Specific	Visual and acoustic surveys (e.g. covering presence, density, extent) photographic quadrats, video transects, visual census, direct sampling. For ecological volume: Photogrammetry 3D; integration of SSS and MBES; quadrants and transects; ROVs.	Comparisons of recording data will reveal temporal changes in the presence and/or condition of macroalgae/eelgrass. Any such changes may be part of a natural cycle e.g. seasonal changes in macroalgal cover. Alternatively, they may be an indicator of anthropogenic impacts directly (e.g. removal) or indirectly (e.g. increasing turbidity of the water column).
Macrophytes, macroalgae, eelgrass	**- Abundance - Extent - Condition**	- Spatial extent (area and depth) - Taxonomic composition - % cover of substrate - Density (no/m^2) - Average leaf length & width - Leaf & rhizome biomass. - Ecological volume	*	*	*	*	Specific	Visual and acoustic surveys (e.g. covering presence, density, extent), photographic quadrats, video transects, visual census, direct sampling. For ecological volume: Photogrammetry 3D; integration of SSS and MBES; quadrants and transects; ROVs.	Comparisons of recording data will reveal temporal changes in the presence and/or condition of macroalgae/eelgrass. Any such changes may be part of a natural cycle e.g. seasonal changes in macroalgal cover. Alternatively, they may be an indicator of anthropogenic impacts directly (e.g. removal) or indirectly (e.g. increasing turbidity of the water column).

Characteristics	Variables	Metrics	1110	1130	1140	1160	Application	Standardised measurement procedures	Considerations relating to Methodologies
2.3 Functional state characteristics									
Primary production	**- Frequency of plankton blooms - Longevity of plankton blooms - Strength of plankton blooms - Angiosperms/ macroalgae**	- Concentration of chlorophyll a (µg/ l) - Phytoplankton species - Growth rates - Dry weight/m^2	*	*	*	*	Specific	Plankton sampling, spectrophotometry, flurometry, high performance liquid chromatography.	This variable is an indicator of factors such as nutrient load, seasonality, and water temperature and it can also be one of a number of significant markers of changes associated with climate change. Research undertaken for this project suggests that it is not typically recorded for all the habitats in this cluster however this may be misleading as it may be included in water quality and macroalgae/eelgrass sampling.
Food webs	**- Energy transfer between tropic levels**	- Number of species/functional groups and qualitative links - Average energy transfer between trophic levels (%) - Stable isotopes (^{13}C, ^{15}N, ^{34}S) -Stomach content analysis	*	*	*	*	Specific	Combined trophic analyse (both stomach analysis, stable isotope analysis and DNA analysis as barcoding/metabarcoding)	Use standardized methods to collect samples of benthic organisms, plankton, and fish across multiple fixed stations and depth zones. This ensures representative data on all food web components. Measure environmental parameters (sediment type, water quality) and implement quality control procedures (replicates, reference standards) to ensure data reliability and comparability between sites.
3. Landscape/seascape characteristics									
Connectivity/ Fragmentation	**- Continuous/ fragmented - Presence of anthropogenic structures and their % cover - Affected/ modified length of linear habitats**	- % cover, patch size		*	*	*	Recommended	Visual survey and mapping, aerial/satellite imagery.	Ecological impact assessment can be used to assess species richness and composition in fragmented versus continuous patches, or changes in hydrology due to fragmentation. Patch size and the scale at which the assessment is carried out are important considerations Trend analysis comparing current fragmentation levels with historical data can identify trends over time but will need comparable data.
4. Other									
Disturbance	**- Footprint of activity**	- Presence/ absence -Modified banks length(m) -% area directly affected by human activity (e.g. by demersal fisheries or sand extraction, anthropogenic structures)	*	*	*	*	Essential	Visual survey and mapping, aerial/satellite imagery. SSS and MBES for physical disturbance on sublittoral areas from activities such as trawling and dredging.	Many different "types" of disturbance may be reported, and they can be categorised in a variety of ways e.g. physical/chemical/biological; presence/absence. The significance of any disturbance on the structure and function of the habitat may be related to aspects such as frequency, permanence, level and type of impact.

3.2 Guidelines for the establishment of reference and threshold values, and obtaining condition indicators for the variables measured

The observed measurements of the condition variables need to be compared to reference values and critical thresholds, in order to assess the condition for each variable. A reference level is the value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable. The difference between the value of a variable and its reference level represents the distance to the reference condition.

Reference levels should be defined in a consistent manner across different variables within an ecosystem type, and for the same variable across different ecosystem types. This ensures that the derived indicators are compatible and comparable, and that their aggregation is ecologically meaningful (United Nations, 2021).

Reference levels are usually set with high and low levels reflecting the limits or endpoints of the range of a condition variable that can be used in re-scaling. For example, the high level may refer to a natural state and the low level may refer to a degraded state where ecosystem processes are below a threshold for maintaining function (Keith et al., 2013, in United Nations, 2021).

Establishing reference values and thresholds is therefore essential to determine whether habitats are in good condition or have become degraded. Reference values represent the desired state of an ecosystem, often reflecting intact or minimally disturbed conditions. These values serve as benchmarks for assessing habitat condition.

These guidelines do not intend to provide specific rules or values for these thresholds, but to define the main criteria and guide on the establishment of reference values that would help determining good or not good condition, considering the ecological variability of the habitats across their range.

In a review of approaches for setting reference conditions for assessing marine ecosystem quality, Borja et al. (2012) recommend that they should be defined/described with reference to:

(1) Multiple sites with similar physical characteristics within an ecoregion or habitat type.
(2) Ideally represent minimally impaired or undisturbed conditions (i.e. absence or minimal human pressure).
(3) Provide an estimate of the variability in biological communities and habitat quality due to natural physical and climatic factors.

They identified four main approaches: crossing referencing pristine areas, hindcasting, modelling and best professional judgement.

Pristine areas: Reference values set against “pristine” areas could be developed with knowledge of either undisturbed habitats or habitats that are considered to be in good condition. However, for this to be credible, it would require comprehensive knowledge of the pressures and impacts on the different habitats, and the implications for their condition. Finding such locations is also likely to be problematic, especially as many examples of the habitats which are being assessed are adjacent to the coast or within territorial waters and therefore likely to have been subject to many pressures/impacts sometimes over significant periods of time.

Hindcasting: Using hindcasting to set reference levels requires cross reference to some historical reference condition. This may be a condition which is considered unimpacted (see above) or a set date (as with the Habitats Directive where 1994 is used as a baseline). Issues will arise around deciding when to set any baseline, the reliability and availability of historic data, and how to account for any natural oscillations in condition. For example, a habitat may not be in favourable condition in the selected baseline year, there may be a lack of sufficient data to inform decisions on the most appropriate baseline year, and global changes in recent decades could alter the former reference conditions making any comparisons with datasets from 50, or 100 years ago impossible.

Modelling: Modelling by extrapolating biological attributes can be used to summarise/simplify, visualize and explain actual or predicted situations e.g. the Driver-Pressure-State-Impact-Response (DPSIR) framework (OECD, 1993). There are, however, many considerations with developing and applying such models (Patricio et al., 2016). They include data availability, the level of confidence in the outcomes, how to scale up interpretations, for example from a site to a region, and how to assess cumulative impacts. There is an additional consideration that modelling approaches can be complex with less transparency and comprehensibility for stakeholders and policymakers.

Expert judgement: This is widely used when there is limited data but should ideally be underpinned by some clearly stated criteria and it has less transparency and comprehensibility for stakeholders.

The analysis carried out by Borja et al. (2012) (summarized in Table 14) considered that whilst using pristine or minimally impacted conditions was the best single method, others were also adequate when combined with expert judgement. Setting targets was seen as an alternative approach where none of the traditional reference conditions approaches were applicable, which implicitly indicates conditions where the indicator in question is not adversely affected or only slightly affected. Their conclusions, looking specifically at assessing benthic ecological status, were that a combination of methods in setting reference conditions is more adequate in obtaining final quality assessments related to the pressures on a habitat than one method alone.

Also relevant is the consideration that, regardless of the approach, there may be existing relevant thresholds and reference values set within legal obligations. For marine habitats this is the case at a European level, under the Marine Strategy Framework Directive and the Water Framework Directive.

Finally, the lack of experts in certain habitats can pose an additional difficulty for the correct use of this approach. The analysis carried out by Borja et al. (2012) (Table 14) was that whilst using pristine or minimally impacted conditions was the best single method, others were also adequate when combined with expert judgement.

Table 14. Evaluation of target and reference condition setting methods, regarding different issues

Methods / issues	Reference conditions			Expert judgement	Targets		
Main issues	**Pristine areas**	**Historical data**	**Modelling**	**Best profesional judgement**	**Baseline set in the past**	**Current baseline**	**Directional/ trends target**
Legislation using/ proposing it	WFD, CWA	WFD, CWA, OSPAR	WFD, CWA	WFD, CWA	OSPAR	HD	OSPAR
Data needs	Moderate (2)	High (1)	High (1)	Low (3)	Moderate (2)	Moderate (2)	Moderate (2)
Scientific robust-ness	High (3)	Moderate (2)	Moderate/ high (2.5)	High (3)	High (3)	High (3)	High (3)
Confidence of the method	High (3)	Moderate (2)	Moderate/ high (2.5)	High (3)	Moderate (2)	High (3)	Moderate (2)
Applicability	High (3)	Low (1)	High (3)	High (3)	Moderate (2)	Moderate (2)	Moderate (2)
Practicality of the method within available time scales	High (3)	Moderate (2)	High (3)	High (3)	Moderate (2)	Moderate (2)	Moderate (2)
Transparency and comprehen-sibility	High (3)	High (3)	Low (1)	Low (1)	High (3)	High (3)	High (3)
Total scores	17	11	13	16	14	15	14

Note that scores are high: 3, moderate: 2, and low: 1, except in the case of data needs, which are opposite (the lowest data need the highest score). WFD: Water Framework Directive; HD: Habitats Directive; CWA: Clean Water Act; OSPAR: Oslo-Paris Convention.

Source: Borja et al. (2012)

General guidance on setting environmental thresholds is included in The Marine Strategy Framework Directive which requires that Good Environmental Status (GES) should be achieved in EU marine waters as described by eleven environmental Descriptors. At the core of the GES assessment lies the need for threshold values which enable a quantitative assessment of environmental status for the indicators and elements used for each GES Criterion.

Principles and guidelines on how these thresholds should be set are specified in Article 4(1) of Commission Decision (EU) 2017/848 (EU, 2017) (Box 5)[8].

[8] Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU) Article 13.

Box 5. Article 4 of Commission Decision (EU) 2017/848 (EU, 2017)

Article 4 - Setting of threshold values through Union, regional or subregional cooperation

1. Where Member States are required under this Decision to establish threshold values through Union, regional or subregional cooperation, those values shall:

(a) be part of the set of characteristics used by Member States in their determination of good environmental status;

(b) be consistent with Union legislation;

(c) where appropriate, distinguish the quality level that reflects the significance of an adverse effect for a criterion and be set in relation to a reference condition;

(d) be set at appropriate geographic scales of assessment to reflect the different biotic and abiotic characteristics of the regions, subregions and subdivisions;

(e) be set on the basis of the precautionary principle, reflecting the potential risks to the marine environment;

(f) be consistent across different criteria when they relate to the same ecosystem element;

(g) make use of best available science;

(h) be based on long time-series data, where available, to help determine the most appropriate value;

(i) reflect natural ecosystem dynamics, including predator-prey relationships and hydrological and climatic variation, also acknowledging that the ecosystem or parts thereof may recover, if deteriorated, to a state that reflects prevailing physiographic, geographic, climatic and biological conditions, rather than return to a specific state of the past;

(j) be consistent, where practical and appropriate, with relevant values set under regional institutional cooperation structures, including those agreed in the Regional Sea Conventions.

A review of the state of play with thresholds for MSFD criteria used by Member States, published in 2022, shows the progress made (e.g. Table 15 for Descriptor 5, Eutrophication) but it also indicates there is still some way to go before this is achieved for all eleven descriptors (Vasilakopoulos et al*.,* 2022). No thresholds have been agreed as yet for D6 (sea floor pressures and impacts), for example.

Table 15. Agreed thresholds setting methods and values for Descriptor 5 (Eutrophication) criteria

D5 Criterion	Compartment	Agreed threshold methods	Threshold Values available	Comments	Related regulations
D5C1	Coastal waters	Nutrient concentration in surface water or in the water column	From 10 to 13 MSs reported TVs for the nutrient categories	Strong input of WFD in coastal waters, some MSs TVs still missing, especially in the open sea.	WFD
	Open sea		From 7 to 14 MSs reported TVs for the different nutrient categories		
D5C2	Coastal waters	Chlorophyll-a in the water column	15 MSs reported TVs	Strong input of WFD in coastal waters.	WFD
	Open sea		17 MSs reported TVs		
D5C3	Coastal waters	Harmful algal blooms in the water column	Only Baltic MSs reporting a cyanobacteria bloom index	No index (e.g. red tides) in other marine regions	
	Open sea				
D5C4	Coastal waters	Photic limit (transparency) of the water column	11 MSs reported TVs		WFD
	Open sea		11 MSs reported TVs		
D5C5	Coastal waters	Dissolved oxygen at the bottom of the water column	12 MSs reported TVs	For some regions, TVs from project results and WFD are combined with expert evaluation. D5C5 may be substituted by D5C8.	WFD
	Open sea		14 MSs reported TVs		
D5C6	Coastal waters	Opportunistic macroalgae of benthic habitats	3 MSs reported TVs		WFD
	Open sea		None		
D5C7	Coastal waters	Macrophyte communities of benthic habitats	5 MSs reported TVs	Availability of TVs across regions is challenging	WFD
	Open sea		None		
D5C8	Coastal waters	Macrofaunal communities of benthic habitats	9 MSs reported TVs A	Availability of TVs across regions is challenging	WFD
	Open sea		None		

The colour in fourth column indicates the degree of achievement in setting threshold; green: high, yellow: moderate, red: low.
Source: Vasilakopoulos et al., 2022.

The Water Framework Directive (WFD) requires Member States to protect and where necessary restore water bodies in order to reach good status (chemical and ecological) and to prevent deterioration. Standards for priority substances and certain other pollutants are set out in the Environmental Quality Standards Directive (2008/105/EC)[9].

All the variables identified for assessing the structure and function of habitats 1110, 1130, 1140 and 1160 are covered in some way by the MSFD GES descriptors. Some WFD Environmental Quality Standards are also directly applicable. A consistent approach, cross-referencing agreed thresholds for MSFD descriptors and WFD thresholds, with those that are also relevant to assessing the condition of the structure and function of marine and coastal habitats covered by the Habitats Directive is clearly desirable.

The harmonization of reference values and thresholds regarding the variables used for the assessment of habitat condition should consider the following **common requirements**:

- Thresholds need to consider the natural variability of the habitats across their range, and different threshold or reference values for the same habitat in different Member States or regions within a MS can be appropriated.
- Thresholds, limits and reference values need to be tested with sufficient data sets, which include full range of habitat conditions – from degraded habitats to best quality ones.
- The reference values should fulfil the criteria of validity (connection to relevant ecological integrity), robustness (reliability), transparency, and applicability (Czúcz et al., 2021; Jakobsson et al., 2020).
- A description of the methodology for establishing the threshold and reference values applied by each MS for each variable must be provided, justified and perfectly understandable.
- The methodologies should be suitable to be regularly evaluated and improved according to the best available scientific knowledge and any modifications made, and the impact these may have on previous monitoring work, must be communicated.
- Common training or guidance on setting threshold and reference values should be programmed for experts from the different MSs in order to achieve full harmonisation.

Table 16 makes some initial recommendations for setting reference/threshold values for the proposed variables for assessing and monitoring the condition of habitats 1110, 1130, 1140 and 1160.

[9] Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council.

Table 16. Considerations for setting reference/threshold values for habitats 1110, 1130, 1140 and 1160

Characteristics	Variables	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/Thresholds	Relevant MSFD Descriptors
1. Abiotic characteristics					
1.1 Physical state characteristics					
Degree of submergence / depth	**-Depth in relation to chart datum**	Quantitative, Trend	Depth is not static but subject to both diurnal and seasonal variation, as well as across the habitat being monitored. The existing status is therefore in equilibrium with the prevailing conditions. If this were to be disrupted to a significant degree, there can be major changes in both the physical and biological characteristics of the habitats.	QE2 (QE2-1, QE2-3)	D7
Tidal regime	**-Tidal range**	Quantitative, Trend	Tidal range is not static but subject to both diurnal and seasonal variation, the existing status is therefore in equilibrium with the prevailing conditions. If this were to be disrupted to a significant degree, there can be major changes in both the physical and biological characteristics of the habitats. One example would be potential increases or decreases in the extent of marginal vegetation such as saltmarsh. Issues are likely to arise if the changes are either sudden and/or permanent for example due to the creation of barriers/dams which hold back water permanently inundating areas previously subject to tidal fluctuations or, at the other extreme, land claim/infilling. Also relevant are the parameters/ status/ environmental quality standards recorded under WFD which include morphological conditions, as well as hydrological or tidal regime.	QE2 (QE2-1, QE2-3)	D7

EQS: Environmental Quality Sandards. WFD Quality Elements: QE1 – Biological Quality Elements, QE1-1 – Phytoplankton, QE1-2-1 - Macroalgae, QE1-2-2 - Angiosperms, QE1-2-3 – Macrophytes, QE1-2-4 – Phytobenthos, QE1-3 - Benthic invertebrates, QE1-4 - Fish, QE2 – Hydromorphological quality elements, QE2-1 – Hydrological or Tidal regime – QE2-3 – Morphological conditions, QE3 - Chemical and physico-chemical quality elements, QE3-1 – General parameters (Transparency, thermal, oxygenation, salinity, acidification, nutrient, Nitrogen, Phosphorus conditions), QE3-1-1 – Transparency, QE 3-1-3 – Oxygenation conditions, QE3-1-4 - Salinity conditions.

MSFD Descriptors: D1 – Marine biodiversity, D2 – Non-indigenous species, D3 – Commercial fish and shellfish, D4 – Food webs, D5 – Human-induced eutrophication, D6 – Seabed integrity, D7 – Hydrographical conditions, D8 – Contaminants, D10 – Marine litter, D11 – Energy, including underwater noise.

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/Thresholds	Relevant MSFD Descriptors
Topography	**- Physical dimensions** **- Extent** **- Longitude and latitudinal gradients** **- Elevation, form and features (eg. sandbanks, islands)**	Quantitative, Qualitative, Expert judgement	Comparisons of imagery data over time can reveal gross changes in topography of the habitat however, for the purposes of setting thresholds and reference values, any changes will need to be viewed in the context of "natural" changes as these habitats are naturally subject to erosion and deposition as well as patterns of erosion and deposition which are the consequence of human activity. Threshold values will need to be set in the context of and with regard to knowledge of such changes where the habitat is in a state of dynamic equilibrium. Where historical data are available these could be used to set a reference value relative to a specific point in time. Also relevant are the parameters/ status/ environmental quality standards recorded under WFD which include morphological conditions, as well as hydrological or tidal regime.	QE2 (QE2-1, QE2-3)	D7
Hydrodynamics - Exposure to current, wave action, scour & surge	**- Current speed** **- Direction** **- Height** **- Extremes**	Quantitative, Trend	Seasonal changes (eg. in freshwater run off, onshore winds from winter storms, tidal currents/range) are part of the natural variation. If this were to be disrupted to a significant degree, there can be major changes in both the physical and biological characteristics of the habitats.	QE2 (QE2-1)	D7
Temperature	- **Water temperature**	Quantitative	Reference values for temperature might be carefully defined for each habitat subtype and according to depth and annual cycle, since thermal stress varies within species, assemblages and other physical (e.g. depth, surge) or geographical parameters (e.g. latitude/longitude, currents).	QE3 (QE3-1-2)	D1, D5, D7
Turbidity	**- Suspended particles** **-Light transmission through water samples** **-Secchi disk depth**	Quantitative, Trend, Indices	Estuaries have zones of high turbidity known as turbidity maxima, often located in the zones of low salinity. The size of the turbidity maximum could be a useful focus for monitoring purposes. Increases in turbidity levels by activities such as dredging, and disposal may have an adverse effect on filter feeds and may also reduce the growth rate of organisms dependent on sunlight for photosynthesis	QE3 (QE-3-1, QE3-1-1)	D5

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/Thresholds	Relevant MSFD Descriptors
Sediment composition / distribution / dynamics	**-Sediment particle size** **-Thickness of oxidised layer (for silt)**	Quantitative, Trend, Indices	Sediment deposition is controlled by the type, direction and speed of the currents and size of the particles. The patterns of sediment movement in and around the habitats in this cluster not only have a major influence on their form and the associated biota but also characterise the natural cycles which either sustain, erode or extend sedimentary features within the habitat. Any reference values or thresholds therefore need to be based on an understanding of what constitutes "natural change" and over what time periods. Whilst this may be possible in some locations that have been studied for decades it is difficult to set a single figure/level across the board either for all Member States or across a biogeographical region.	QE2 (QE2-1, QE2-3)	D7
1.2 Chemical state characteristics					
Salinity / freshwater influence / stratification	**- Salinity** **- Conductivity**	Quantitative, Trend	Changes in salinity attributed to human activity are the most relevant when setting thresholds and reference levels. This may be the result of ongoing activities and/or one-off events e.g. industrial discharge. Targets could be selected to represent the limits of the range of the characteristic species/biotope in key locations.	QE3 (QE3-1-4)	D7
Water quality	**- Various substances (including chemicals listed in the WFD and EQSD, nitrates & phosphates, oxygen, chlorophyll, dissolved solids)**	Quantitative, Trend, Indices, linked to WFD	The parameters and Environmental Quality Standards that apply under the WFD for transitional waters (e.g. in relation to chemical and physico-chemical quality elements) are particularly relevant to determining water quality for this cluster of habitats and are already being used as reference values/thresholds by Member States.	QE3 (QE3-1)	D5, D8
Sediment quality	**- Inorganic and organic chemical contaminants** **- Organic carbon**	Quantitative, Trend, Indices, Scoring			D8
Oxygen levels	**- Oxygen levels measured at surface and depth.**	Quantitative, Trend, linked to WFD	The parameters and Environmental Quality Standards that apply under the WFD for transitional waters (eg. in relation to chemical and physico-chemical quality elements) are particularly relevant to determining water quality for this cluster of habitats and are already being used as reference values/thresholds by Member States.	QE3 (QE3-1-3)	D5

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/Thresholds	Relevant MSFD Descriptors
2. Biotic characteristics					
2.1 Compositional state characteristics					
Invertebrates - Epifaunal & Infaunal assemblages	**- Abundance of characteristic species from standardised lists. - Diversity of characteristic species from standardised lists.**	Quantitative, Indices/ additional, Scoring		QE1 (QE1-2-4, QE1-3)	D1, D4, D6
Vertebrates – Associated fish, birds & marine mammals	**- Abundance of characteristic species from standardised lists. - Diversity of characteristic species from standardised lists.**	Quantitative, Indices/ additional, Scoring.		QE1 (QE1-4)	D1, D3, D11
Biogenic structures	**- Type - Extent**	Quantitative, Indices/ additional, Scoring.	Reference values will need to take into account natural cycles of change, and to distinguish these from changes which are the result of human activity. For example, physical damage of some types of biogenic structures (e.g. *Sabellaria* worm reefs) may be the result of storm events or demersal trawling.		D1, D6
Opportunistic / invasive species	**- Presence - Distribution - Abundance**	Quantitative, Indices			D1, D2
2.2 Structural state characteristics					
Characteristic species	**- Condition**	Quantitative, Indices/ additional, Scoring, linked to WFD		QE1 (QE1-2-4, QE1-3)	D1, D4, D6

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/Thresholds	Relevant MSFD Descriptors
Biogenic structures condition	**-Condition**	Quantitative, Indices/ additional, Scoring, linked to WFD	Reference values and thresholds need to take account of changes that may be due to natural variation (e.g. burial by sediment, responses to cyclical changes in predator/prey levels) including specific natural events such as damage caused by storms or flooding.	QE1 (QE1-3)	D1, D6
Vegetation zones	**-Abundance** **-Extent** **-Condition**	Quantitative, Indices, linked to WFD		QE1 (QE1-2-2)	D1, D5, D6
Macrophyte, macroalgae, eelgrass	**-Abundance** **-Extent** **-Condition**	Quantitative, Indices/ additional, Scoring, linked to WFD	Reference values and thresholds for good condition will not only vary according to biogeographical region but also from location to location because of the factors such as depth, location, species etc. (see variables). Two types of thresholds should be considered. A threshold relating to extent, and a threshold relating to condition. Extent - change in distribution AND in the density/diversity of the relevant species. Condition - change in key features (e.g. length, biomass) and other evidence of declining condition such increasing prevalence of disease.	QE1 (QE1-2-1, QE1-2-3, QE1-2-4)	D1, D5, D6
2.3 Functional state characteristics					
Primary production	**-Frequency of plankton blooms** **-Longevity of plankton blooms** **-Strength of plankton blooms** **-Angiosperms/ macroalgae**	Quantitative, Indices/ additional, Scoring, linked to WFD	An understanding of primary production (phytoplankton and macrophytes) and/ and/or species composition within the habitat and how it affects the structure and function is needed to set any targets and reference levels. In some cases, there may be long term data sets. WFD has a classification of status including nutrient status, hydromorphological parameters and phytoplankton.	QE1; (QE1-1)	D1, D5
Food webs	**-Energy transfer between tropic levels**	Quantitative, Indices	An understanding of food webs within the habitat and how it affects the structure and function is needed to set any targets and reference levels. In some cases, there may be long term data sets. WFD has a classification of status including nutrient status, hydromorphological parameters and phytoplankton.	QE1	D1

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/Thresholds	Relevant MSFD Descriptors
3. Landscape/Seascape characteristics					
Connectivity/ Fragmentation	**-Continuous/ fragmented -Presence of anthropogenic structures and their % cover -Affected/ modified length of linear habitats**	Qualitative, Expert judgement	Comparisons of imagery data over time can reveal any habitat fragmentation. However, for the purposes of setting thresholds and reference values, any such changes will need to be viewed in the context of "natural" variation as these habitats are naturally subject to erosion and deposition (seasonally as well as associated with spring neap tide cycles and storm events). These need to be distinguished from patterns of erosion and deposition which are the consequence of human activity. Threshold values will need to be set in the context of and with regard to knowledge of such changes. Where historical data are available these could be used to set a reference value relative to a specific point in time.		D6
4. Other					
Disturbance	**-Footprint of activity**	Quantitative, Qualitative, Expert judgement	For sites which are considered to be in favourable condition, the current state could be used as the reference value. Threshold values could be declines in condition or declines/changes which have an impact on the structure and function. Each location should characterise the major types of disturbance first and then for each of these consider what is considered significant.		D6, D8, D10

Table 17 indicates possible approaches for establishing thresholds and reference values applicable to the proposed variables, based on the procedures followed by Member States and the existing literature. A combination of approaches is suggested to better inform the setting of reference levels or thresholds, given the degree of uncertainty when setting reference levels. The different approaches described are not exclusive, they are often combined. For example, expert judgement is necessary when establishing reference cases for good condition or for certain decisions on modelling the relationship between variables and condition. Modelling-based approaches complement those based on good condition or undisturbed cases and can also be combined with statistical approaches.

The evaluation of the condition of the habitats is based on determining whether the variables used in the assessment indicate 'good' or 'not good' condition. Different criteria are applied to attribute these condition categories according to the characteristics of each variable, for example, whether they are definitive (e.g. no alien species allowed), or quantitative variables which may obey linear or non-linear relationships with the condition (Jakobsson et al., 2020). Some can be directly standardized to apply aggregation procedures.

Owing to the different metrics, measurement units and magnitudes applied to the variables that characterise the habitats, the values obtained from their measurement require some form of standardisation, e.g. by re-scaling, to build indicators combining different variables. The values obtained from the measurement of the variables can be scaled according to their reference levels, thus normalised to a common scale and direction of change, and can then be combined to form a composite index or to obtain an overall result of the assessment using appropriate aggregation approaches (see further details below in Section 3.3 on Aggregation).

Table 17. Some initial recommendations for setting thresholds for the proposed variables

Description	Application	Comparison to undisturbed areas	Comparison to good condition areas	Hind-casting	Modelling	Expert judgement	EU Relevant existing reference values
1. Abiotic characteristics							
1.1 Physical state characteristics							
Degree of submergence / depth	Essential*						WFD, MSFD
Tidal regime	Essential*						WFD, MSFD
Topography	Essential*						WFD, MSFD
Hydrodynamics - Exposure to current, wave action, scour & surge,	Essential						WFD, MSFD
Temperature	Essential						WFD, MSFD
Turbidity	Essential						WFD, MSFD
Sediment composition / distribution	Essential						MSFD

Description	Application	Comparison to undisturbed areas	Comparison to good condition areas	Hindcasting	Modelling	Expert judgement	EU Relevant existing reference values
1.2 Chemical state characteristics							
Salinity / freshwater influence / stratification	Essential*						
Water quality	Essential*						WFD, MSFD
Sediment quality	Essential						MSFD
Oxygen levels	Specific						
2. Biotic characteristics							
2.1 Compositional state characteristics							
Invertebrates – Epifaunal & infaunal assemblages	Essential*						WFD, MSFD
Biogenic structures	Specific*						MSFD
Vertebrates - Associated fish, birds & marine mammals	Essential*						WFD, MSFD
Opportunistic/ invasive species	Recommended						MSFD
2.2 Structural state characteristics							
Characteristic species	Essential						WFD, MSFD
Biogenic structures	Specific						WFD, MSFD
Vegetation zones	Specific						WFD, MSFD
Macrophytes, macroalgae, eelgrass	Specific						WFD, MSFD
2.3 Functional state characteristics							
Primary production	Specific						WFD, MSFD
Food webs	Specific						WFD, MSFD
3. Landscape/Seascape characteristics							
Connectivity / Fragmentation	Recommended						MSFD
4. Other							
Disturbance	Essential						MSFD

Dark grey: Preferred approaches; Light grey: additional approaches

*: Check Table 13 for further information

3.3 Guidelines for the aggregation of variables at the local level

Ecological assessments require the integration of physical, chemical, and biological quality parameters. The choice of the aggregation method of such partial assessments into an overall assessment has been widely discussed within the scientific community, since the methodology can have a considerable influence on the outcome of the assessment. Different approaches can be used to integrate the values of the measured variables to give an overall value that indicates the overall condition of habitat types at the local scale, i.e. the monitoring plot, station or site.

An appropriate aggregation method is crucial to categorising local-scale condition into good/not good. This is because the proportion of the habitat type in **good/not good condition** is the main information required for assessment of the structure and function of the habitat type at the biogeographical level.

3.3.1 Overview of aggregation methods

In a review of methods for aggregating and integrating information when assessing the status of marine ecosystems under the MSFD, focusing mostly on the descriptors related to biodiversity, Borja et al. (2014) discussed the advantages and disadvantages of several different approaches used to combine a number of variables into an overall assessment. A review and discussion of advantages and disadvantages of several different aggregation methods for marine biodiversity status assessments has also been carried out by Barnard & Strong (2014).

The main approaches are summarised below.

One-out, all out (OAOO)

The OOAO rule has been recommended for assessment of Ecological Status under the Water Framework Directive (CIS, 2003). The logic behind this is that a water body could not achieve good ecological status if any of the quality elements measured fail. This means that an OOAO approach using the “worst case” scenario for its assessment. This can be viewed as a rigorous precautionary approach. One criticism, however, is that it could lead to an underestimation of the true overall status.

A precautionary one-out, all-out approach is also used in the aggregation of the parameters used in the assessment of conservation status under the Habitats Directives and the IUCN Red List of Species and the IUCN Red List of Ecosystems.

The OOAO rule is a rigorous and conservative approach which follows the precautionary principle, and works well where all the necessary information is available. In the marine environment, where there may be significant data gaps it is important to clarify the extent to which such an approach may be “preliminary”, “partial” or “incomplete” due to lack of data.

Averaging approach

The averaging approach is the most commonly used method to aggregate indicators (Shin et al., 2012) and consists of simple calculations, using methods such as arithmetic average, hierarchical average, weighted average, median, sum, product or combinations of those rules, to come up with an overall assessment. Differential weighting applied to the various indicators can be used when calculating means or medians. An adequate basis for assigning weights is not always available and assigning weights often involves expert judgment: However, expert opinions applied in such a way can show important differences.

This approach needs a normalisation of the obtained data to be used.

Conditional rules

Conditional rules are an approach where indicators can be combined in different ways to generate an overall assessment, depending on specified criteria. For instance, it can be formulated in a way that requires that specific proportion of the variables to achieve good status or if a certain number of variables do not meet the threshold, the overall status fails.

Scoring or rating

In this method different scores are assigned to a particular status for a number of different elements, e.g. ranging from 1 to 5 for poor to good). The scores may then be summed to derive a total score which is then rated according to the number of elements taken into account. Different weights can be assigned to the various elements.

Multimetric indices to combine indicators

Within the WFD there are many examples of multimetric indices developed for different biological elements. Within the MSFD, the use of multimetric indices or multivariate techniques for integrating indicators of seafloor integrity have been recommended (Rice et al., 2010). Multimetric methods that are used to combine multiple parameters in one assessment may result in robust indicators, but ideally the various parameters should not be inter-correlated.

Multidimensional approaches

Multivariate methods, such as Discriminant Analysis or Factor Analysis combine parameters in a multi-dimensional space. Multivariate methods have the advantage of being more robust and less sensitive to correlation between indicators. However, interpretation is less intuitive than other methods, as information on individual indicators in each ecosystem is lost and links to management options are less obvious.

Decision tree

Decision trees provide the opportunity to apply different, specific, rules to combine individual assessments into an overall assessment. A decision tree allows implementing individual rules at each of its nodes and thus incorporates decisions at each step within the decision tree. The decision rules can be quantitative or qualitative as well as based on expert judgment. This gives room for a high degree of flexibility in reaching the final assessment.

Probabilistic approach

In some cases the results for each indicator may be uncertain due to several factors e.g., natural variation in the sampling sites, random variation in the samples, insufficient scientific understanding about what should be the reference value for good status, etc. If these uncertainties can be approximated, this gives rise to the possibility of taking this information into account when integrating the indicators. The more uncertain indicators will get less weight in the integrated assessment, while the more certain ones will be more reliable and hence get more weight.

High level integration

This approach, which includes the selection of an agreed reduced set of indicators and agreed weighting rules, could be considered a pragmatic compromise, reducing the risks associated with OOAO while still giving an overall assessment. An example of a high-level integration, where assessments for several ecosystem components are merged into a final assessment, is the HELCOM-HOLAS project (HELCOM, 2010).

As seen in Section 2.3, across EU Member States, the aggregation at local-scale assessments relies on integrating information from multiple variables, though specific approaches varying by country and habitat. Several MSs however apply a conditional rule, whereby a number of relevant variables measured must reach or pass the defined thresholds for good condition, or even the one-out, all-out rule, which requires that all the variables reach the threshold, for the overall habitat condition at the local scale to be considered good.

3.3.2 Recommendations for the aggregation of the measured variables to determine the habitat type condition at the local scale

A common aggregation method to integrate all essential and specific variables measured to assess the habitat should be applied consistently across the habitat range in the EU in order to obtain comparable results. Considering the various approaches described above and with the aim of harmonising the assessment of marine habitat types at the local scale, we suggest a two-step approach, in which a first aggregation is carried out separately for each group of variables associated to abiotic, biotic and landscape characteristics, and then, the results of such partial assessments are then integrated into the overall local assessment of the habitat condition following a one-out , all-out rule, as described below but being clear about where data is limited or insufficient to make such an assessment (Figure 12).

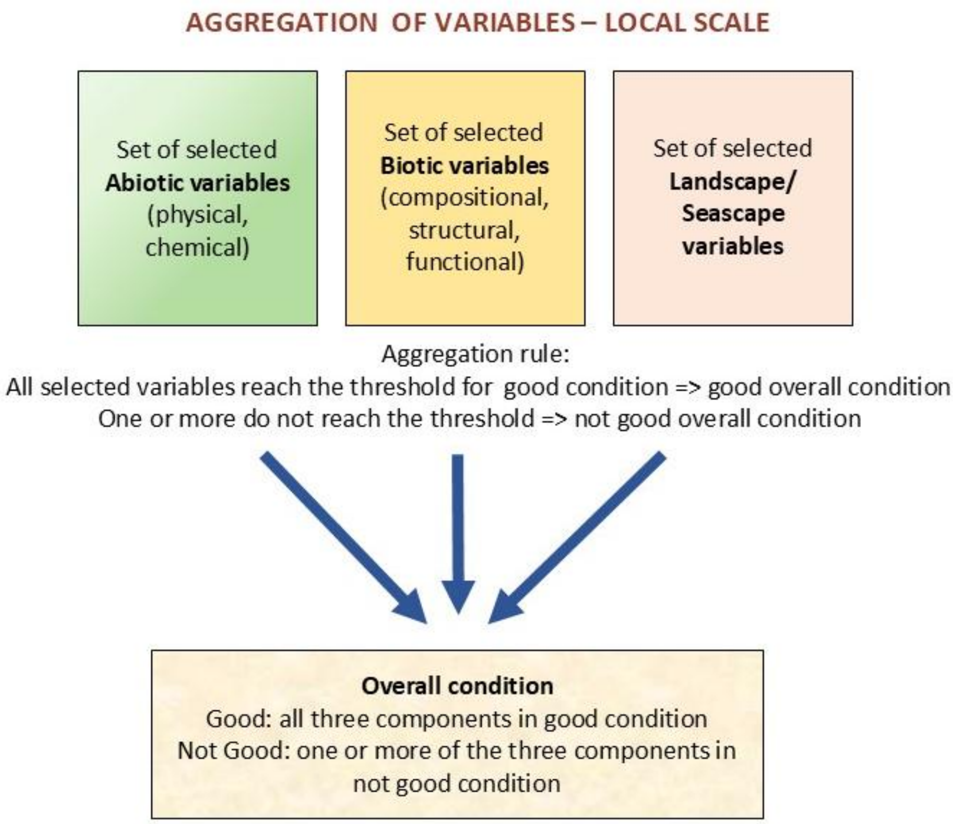
Step 1 – Aggregation of the variables measured in each group of characteristics

A first step would involve using a conditional rule. This would aggregate the variables for each group of characteristics whilst noting that a minimum set of essential variables in each group must reach/exceed the defined threshold for good condition. This would be done for each habitat component (abiotic, biotic, landscape). The selection of the set of variables that must reach the threshold is made considering their indicator value, i.e. their relative importance or relevance to determine whether the habitat is in good condition or not. These should be variables for which a clear threshold can be defined to distinguish good and not good condition. If any of those selected variables do not reach/exceed the minimum thresholds, the condition cannot be considered good for the corresponding component of the habitat (abiotic, biotic, landscape). If there are insufficient data on any particular variables to make such an assessment this should be noted.

Step 2 – Aggregation of the three groups of variables or habitat components

In a second step, the results achieved in each the three components or groups of characteristics (abiotic, biotic, landscape) would be aggregated following the “one-out, all-out” rule, which requires that all the three components have been assessed in good status for the overall condition of the habitat at the local scale to be considered good. If any of these components do not reach an overall good status, the condition of the habitat at the local scale cannot be considered good. Where there are data gaps on any of the habitat components (biotic, abiotic or landscape), a clarification should be provided to show that the assessment is incomplete or preliminary.

Figure 12. Scheme of the proposed aggregation of variables at the local level



3.4 Guidelines for aggregation at the biogeographical region scale

As a minimum requirement Member States must follow the recommendations from the Art. 17 reporting guidelines for the period 2013-2018, which states that "if 90% of habitat area is considered as in 'good' condition, then the status of 'structure and functions' parameter is 'favourable'. If more than 25% of the habitat area is reported as 'not in good condition', then the 'structure and functions' parameter is 'unfavourable-bad'".

This rule highlights the importance of a sampling design that ensures sufficient representativeness of the total habitat area and diversity (see section 3.6 below).

3.5 Guidelines on general sampling methods and protocols

Harmonised monitoring protocols are crucial for assessing habitat conditions across Europe. These protocols should offer standardised methods for data collection, analysis, and interpretation to ensure consistency and comparability over time and across regions. This section includes recommendations on sampling designs and monitoring protocols.

Large-scale survey techniques (e.g. charts, remote sensing) can be used to provide data for the whole feature across its range and assist with developing a stratified sampling programme to select a few locations to be investigated in detail. If so, the ability to relocate these sampling stations is essential (JNCC, 2004).

As the features across this habitat will not be uniform, for example, in varying stages of development or activity, a single sample for a physical-chemical characterisation is unlikely to provide a reliable description of the habitat as a whole. Multiple sampling and analysis may therefore be required, for example along transects and using quadrats to adequately record such heterogeneity.

Article 17 of the Habitat Directive requests a maximum period of 6 years to coincide with reporting. However, this period can be completed through different approaches depending on the resources of Member States. For example, not all plots and not all variables need to be measured each 6 years. Regarding plots, Member States may establish a large number of monitoring sites, selecting a small number of them to be surveyed every season in order to gather a suitable number of plots with a complete monitoring at least every six years.

Within the six-year period, seasonality needs to be considered to avoid comparison of different time frameworks as the biotic and any associated macroalgae can change with seasons. Regarding variables, most variables are recommended to be seasonally surveyed (or at least annually), except tidal ranges with respect to LAT, that can be surveyed every 6 years. Adaptive monitoring is always recommended, allowing flexibility in frequency based on initial findings.

3.6 Selecting monitoring localities and sampling design

The identification and selection of localities for the assessment and monitoring of this habitat requires a systematic approach to ensure that the selected sites provide comprehensive and representative data. The selection of localities for sampling along with the sample size (number of plots) and power (statistical significance) are crucial to ensure the representativity of the results obtained in the assessment and monitoring of each habitat at the biogeographical scale.

Different approaches are recommended:

- **Geospatial Analysis**: remote sensing techniques (e.g. Acoustic surveys - side scan sonar, AGDS, MBES) as well as geographic information systems are essential tools to identify, analyse and integrate spatial data (e.g. extent, topography, and changes over time) and to identify areas of interest based on various criteria such as biodiversity, threats, and ecosystem services.
- **Field Surveys**: initial visits to potential sites are advisory to gather on-the-ground information about zonation patterns, accessibility, and logistics.
- **Review of existing data/knowledge**: reviews can help prioritise areas based on scientific knowledge.

Selecting a minimum number of localities for monitoring involves balancing several criteria to ensure comprehensive and effective coverage:

1. **Biogeographical or marine heterogeneity**: this habitat is present in all marine biogeographic regions but with different characteristics especially because of differences in tidal range and salinity profiles. Monitoring sites should be distributed across the entire area to represent the full range of ecological diversity and capture regional variations as well as habitat heterogeneity.
2. **Spatial Distribution**: monitoring sites must be distributed across the full geographical range of the habitat (subject to accessibility constraints) to avoid geographical bias and

to capture regional variations and ensuring they represent a significant proportion of the habitat's area.

3. **Statistical Criterion**: It would be advisable to ensure that the number of sites is statistically sufficient to detect changes and trends with desired confidence levels (e.g., 95%). Multiple sites within similar ecological contexts should be included for data reliability and robustness.

4. **Existing data and monitoring sites**: Due to potential limitations in surface area and/or budget, previous research can help determine a more realistic number of monitoring locations. Making use of existing monitoring sites with historical data can also strengthen the understanding of long-term trends and changes in habitat condition. Such sites provide valuable baselines for comparison and support robust trend analyses over time.

5. **Degree of conservation and exposure to threat levels**: Monitoring locations should include both protected and high-risk areas experiencing significant threats. The selection should include areas that show different degrees of conservation or degradation to capture the existing variation in the habitat condition across its range. This requires including localities representing well-conserved habitat areas, with minimal human impact, as well as areas subjected to degradation and different pressures and threats. To capture the range of pressures affecting the habitat, localities should be selected across a spectrum of threat levels, from low to high and considering different sources of threats, such as water quality, disturbance/accessibility and resource extraction.

6. **Presence inside and outside Natura 2000 sites**: The assessment and monitoring of habitats conservation status must be done both inside and outside Natura 2000 sites, which requires selecting localities – and an appropriate number of sampling stations/transects – that reflect the proportion to the habitat’s distribution within and outside the Natura 2000 network.

7. **Accessibility and practicality**: Monitoring localities should be accessible for regular visits, taking into account logistical factors and ease of access. Practical considerations also include the safety of field personnel and the feasibility of transporting equipment to and from the site.

Once the sampling localities have been identified for each habitat type, the minimum number of sampling stations in each locality and across the biogeographical region must be calculated in order to balance the sampling effort with representative data.

The **size of the sample** influences two statistical properties: 1) the precision of estimates and 2) the power of the assessment to draw conclusions. The number of sampling stations must be **statistically sufficient** to be able to detect changes and trends with desired confidence levels. Appropriate statistical methods should be used for determining an adequate sample size.

Considering the heterogeneity of habitat types, it is highly recommended to consult with a sampling statistician regarding the sample size, i.e. the minimum number of sampling stations/transects etc. required to ensure representativity and statistical significance.

Some key elements to ensure a proper representation of the habitat condition in the sample are summarised below.

Key elements for statistical representation

Sample size and distribution:

- The number of localities/transects etc. should be sufficient to provide a statistically robust sample size. This ensures that the data collected can be generalized to the entire habitat type within the region.
- Statistical methods such as stratified random sampling are often used to ensure that all habitat subtypes and environmental gradients are adequately represented.

Sampling design:

- Within each sampling area or locality, multiple plots are established to collect detailed data on benthos, infauna, mobile species and other ecological indicators. The distribution and number of sampling stations depend on the variability and size of the habitat patch. Sampling areas (plots, transects) are laid out considering the existing main ecological gradients, e.g., exposure to waves/currents/tides, depth, sediment characteristics.

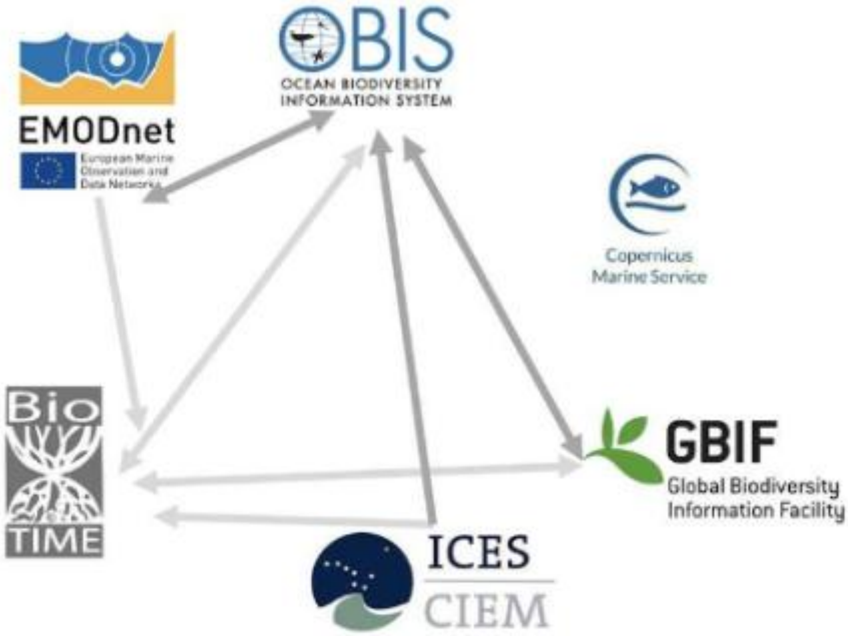
Replication and randomization:

- Replication of sampling units within each locality and randomization of sampling plots location help to reduce bias and increase the reliability of the data.
- Randomized plot locations ensure that the sampling captures the natural variability within the habitat.

3.7 Use of available data sources, open data bases, new technologies and modelling

Data collection frameworks that integrate data from monitoring programmes are a useful source of monitoring data. Examples that focus of marine biodiversity and therefore relevant to monitoring all four of the habitats in this cluster (sandbanks, mudflat & sandflats, large inlets & bays and estuaries) are shown in Figure 13 (European Commission, 2023).

Figure 13. Data collection frameworks relevant to marine biodiversity in European Waters



Source: European Commission, 2023

Three relevant initiatives that provide an overview of research programs, types of data and methodologies used for marine monitoring are:

- **Biodiversa+**[10] European Biodiversity Partnership 'Mapping' the current state of research on biodiversity and associated ecosystem services in Europe in terms of projects, programmes and funding. This includes research projects on biodiversity and associated ecosystems services funded through research programmes in Europe.
- **EuropaBON**[11] current monitoring efforts to identify gaps, data and workflow bottlenecks, and analyse cost-effectiveness of different schemes. The results of this assessment will be used to inform the design of improved monitoring schemes able to integrate in-situ and remote sensing data through models, and using novel technologies, to deliver more complete and less biased biodiversity information with multiple benefits to users and society.
- **MarBioME**[12] **– Marine Biodiversity Monitoring in Europe**. A holistic and global review of European marine biodiversity projects and monitoring programmes, and collated information on marine biodiversity research gaps. Identifies 647 distinct monitoring programmes conducted in EU marine waters, the majority of which target assemblages or communities (European Commission, 2023).

Databases:

SeaAroundUs[13]: developed a preliminary global database of estuaries, the first to be designed at a global scale. It contains over 1,200 estuaries (including some lagoon systems and fjords),

[10] https://www.biodiversa.eu/
[11] https://europabon.org/
[12] https://op.europa.eu/en/publication-detail/-/publication/a09868c3-b721-11ed-8912-01aa75ed71a1/language-en
[13] SeaAroundUs estuaries database: https://www.seaaroundus.org/about-estuaries-database/

in over 120 countries and territories. Currently, our database is also available and viewable via the UNEP-WCMC Ocean Data Viewer.

Portuguese Coastal Monitoring Network (CoastNet): dataset from Mondego, Tejo and Mira estuaries, including multiparametric measurements during 2020 (Castellanos *et al.,* 2021)

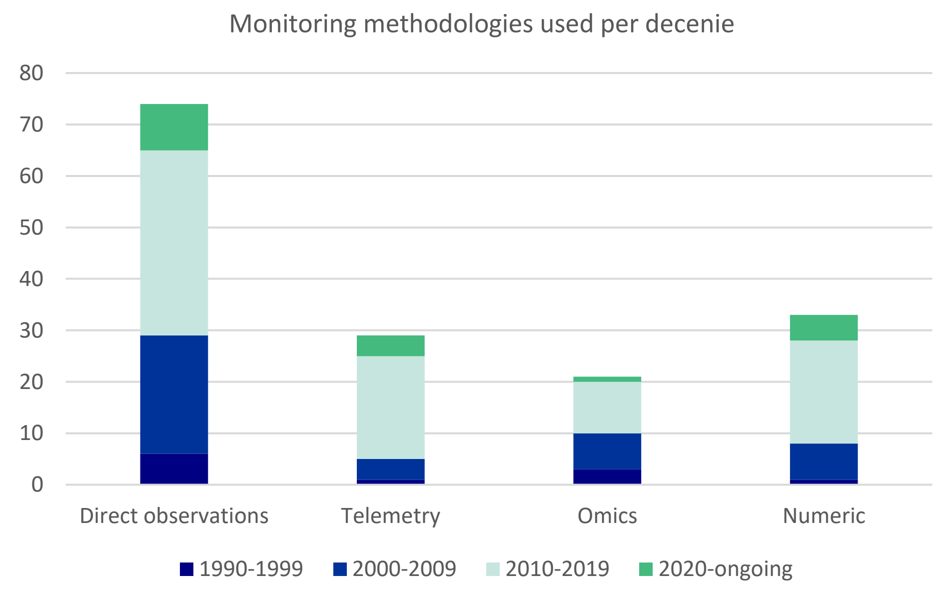
The Estuary Guide[14]: The Estuary Guide aims to provide an overview of how to identify and predict morphological change within estuaries in the UK, as a basis for sound management. It is not yet possible and, indeed, may never be possible to make absolute predictions. Rather, it is necessary to identify probable/possible outcomes, as a basis for guiding management actions.

Other countries such as the United States[15], Australia[16] or New Zealand[17] have also developed their own estuaries related databases.

New technologies:

A review of the main methodologies used for the study of marine biodiversity monitoring since 1990 shows a dominance of direct observation but in recent years, an increase in the use of telemetry, omics[18] and numeric models (Figure 14) (European Commission, 2023).

Figure 14. Main categories of methodologies identified in relevant research projects for the study of marine biodiversity monitoring. (European Commission, 2023)



The height of each column represents the total amount of research projects that used each category of methodology. Stacked coloured categories depict the number of studies used in each category of methodology per specific decade. Research projects that used more than one methodological category are represented in multiple counts.

[14] The Estuary Guide (UK): https://www.estuary-guide.net/search/estuaries/
[15] Estuarine Species Database (United States): https://coastalscience.noaa.gov/project/estuarine-species-database-noaa-estuarine-living-marine-resources-program/
[16] Australian Estuaries Database (Australia): https://fed.dcceew.gov.au/datasets/erin::australian-estuaries-database-camris/explore?location=-24.518198%2C-46.449988%2C4.51
[17] Estuaries Spatial database (New Zealand): https://www.doc.govt.nz/nature/habitats/estuaries/estuaries-spatial-database/
[18] Studies that focus on the structure, function and dynamics of molecules, such as genomes.

- **Optical fibre sensors:** have become extremely attractive for use in natural environments to monitor different parameters of biological interest, due to their intrinsic small weight and size and low reactivity to chemical and biological parameters (Pereira et al., 2005).
- **Real-time monitoring systems:** in the Hudson River estuary (United States), a new real-time monitoring system is being developed using multiparameter and multiscale real-time environmental monitoring. The system incorporates a complex array of sensor technologies encompassing the physical, chemical, and biological measurement domains (Kolar et al., 2009).
- **Unmanned Aerial Vehicles (UAVs):** To analyse changes, UAV is used to collect very high-resolution images in sandbanks from Taiwan (Andaru et al., 2022). Also, they analyse potential, problems and challenges of using AUVs in monitoring. UAV offers new opportunities for scale-appropriate measurements of corridor-shaped study areas. UAV utilization for mapping purpose has recently emerged since it offers operational flexibility, high spatial and temporal resolutions, and low-cost budget with acceptable accuracy. In particular, to map sandbank morphologies, the common photogrammetry structure-from-motion multiview stereo (SfM-MVS) algorithm can be applied. In the Seine Estuary (France), Jaud et al. (2016) aims to show the potential of light UAVs for monitoring sedimentary hydrodynamics at different spatial scales. For each UAV mission an orthophotograph and a Digital Elevation Model (DEM) are computed. From repeated surveys the diachronic evolution of the area can be observed via DEM differencing.
- **Remote sensing:** Remote sensing (RS) techniques have emerged as invaluable tools for acquiring spatial environmental information, enabling the monitoring of large areas with consistent temporal resolution (Macintyre et al., 2020). Traditional platforms, including satellite and aerial systems, have been extensively employed for regional studies such as mapping tidal marshes (Byrd et al., 2018). Optical satellite remote sensing can gather critical data for understanding historical changes into coastal decision-making. These satellites collect reflectance data across the visible and infrared spectrum, which is used to calculate spectral indices (SIs). For instance, water indices combined with hydrodynamic modelling have successfully mapped digital elevation models (DEM) in intertidal areas (González et al., 2023).

  AV sensors include high-resolution photogrammetry cameras and other advanced techniques like thermography, multispectral, LiDAR, and hyperspectral sensors. Three RS techniques show great promise for high-quality monitoring of saltmarshes: photogrammetry, which produces topographic products via Structure-from-Motion (SfM) (Westoby et al., 2012); Light Detection and Ranging (LiDAR) (Brock & Purkis, 2009), which generates reliable 3D point clouds for high-resolution topography and DEM creation; and multispectral techniques, which provide critical data for vegetation mapping. The combination of multispectral and LiDAR sensors mounted on UAVs yields excellent results for assessing the extent, cover, and canopy height of halophytes in intertidal environments at a landscape scale (Curcio et al., 2024).
- **Review of technology in marsh ecology** (Kimball et al., 2021)**:** This perspective highlights current and potential applications of novel research technologies for marsh ecology. These are summarized under several themes: (1) imagery — sophisticated imaging sensors mounted on satellites, drones, and underwater vehicles; (2) animal tracking — acoustic telemetry, passive integrated transponder (PIT) tags, and satellite tracking, and (3) biotracers — investigation of energy pathways and food web structure using chemical tracers such as compound-specific stable isotopes, isotope addition experiments, contaminant analysis, and eDNA.

4 Guidelines to assess fragmentation at appropriate scales

Fragmentation is a significant ecological issue resulting from both human activities and natural processes potentially leading to habitat loss and altered hydrology as well as changes in biodiversity and carbon storage capacity.

Lawrence et al. (2021), considering fragmentation of terrestrial Natura 2000 habitats, define it as a landscape-scale process that includes (a) reduction in total habitat area, (b) increase in the number of habitat patches, and (c) decrease in sizes of habitat patches. This would lead to a progressive deterioration of the habitat and, therefore the reduction of occupied surface (Mariotti & Fagherazzi, 2010; Kirwan & Megonigal, 2013).

Responses to habitat fragmentation in marine systems may be expected to differ to those in terrestrial systems. For example, many marine species have a relatively open population structure due to the large dispersal distances of marine organisms during their larval life stages. Also, energy and nutrients may be readily carried across habitat boundaries by water flow (Yeager et al., 2020)

A review and analysis carried out by Yeager et al. (2020) found that the effects of fragmentation were highly variable across marine ecosystems. Habitat fragmentation that restricts the movement of water could lead to rapid shifts in environmental conditions within remaining fragments was most notable for having a negative effect. Some positive effects were reported in relation to species abundance/diversity but there is need for further research on this topic including examining differences between patch scale and landscape scale effects of fragmentation.

Fragmentation metrics

Habitat fragmentation can be assessed statically to characterize fragmentation at a specific point in time or dynamically by comparing fragmentation indices based on past data with the same indices based on the current data. Forman (1995) uses as the minimum spatial unit the patch, which is defined as a homogeneous area (polygon in GIS) that differs from its surroundings The landscape metrics used for the assessment of fragmentation can be divided into three groups (Hargis et al., 1998, Wang et al., 2014):

1. **Patch-level metrics** measure characteristics of individual habitat patches. Common patch-level metrics include:
   - Patch area: calculate the size of individual mire patches. Smaller patches are generally more vulnerable to degradation and edge effects.
   - Patch perimeter: The length of the patch boundary.
   - Edge density: The length of the patch edge per unit area.
   - Shape Metrics
   - Shape index: Compares the patch perimeter to the perimeter of a circle with the same area. A higher value indicates a more complex shape.
   - Fractal dimension: Measures the complexity of the patch boundary.
2. **Class-level metrics** assess fragmentation at the landscape level. They provide a broader perspective on habitat fragmentation by considering the overall distribution and configuration of habitat patches within a landscape. They include:
   - Landscape shape index: Measures the complexity of the landscape configuration. Higher values indicate a more complex and fragmented landscape.

- Fractal dimension: Quantifies the complexity of the landscape pattern. Higher values suggest a more irregular and fragmented landscape.
- Patch density: The number of patches per unit area. Higher density indicates greater fragmentation.
- Patch size distribution: Describes the distribution of patch sizes within the landscape. This information can reveal whether there are a few large patches or many small ones.
- Edge density: The total length of edges per unit area. Higher values indicate a more fragmented landscape with increased edge effects.

3. **Connectivity metrics** evaluate the degree of connectivity between habitat patches. They include:

   - Mean patch isolation: The average distance between patches. Higher values indicate greater isolation.
   - Connectivity index: Measures the degree of connectivity between patches. Higher values suggest better connectivity.

Fragmentation may be assessed in a variety of ways. These include;

- Ecological impact assessment to assess species richness and composition in fragmented versus continuous patches, or changes in hydrology due to fragmentation.
- Trend analysis comparing current fragmentation levels with historical data to identify trends over time. Determine if fragmentation is increasing, decreasing, or stabilizing
- Assessing the role of human activity in driving fragmentation and evaluating the impact

Based on fragmentation assessments, it may be possible to identify hotspots i.e. priority areas for conservation, restoration, or connectivity enhancement, determine where restoration efforts could reconnect fragmented patches, improve habitat quality, or re-establish hydrological processes and develop policy recommendations to mitigate further fragmentation and protect existing ecosystems, including conservation strategies at a landscape scale to maintain and enhance connectivity.

5 Next steps to address future needs

This document provided an analysis of the methodologies used for estuary monitoring in the EU member states, comparing them with the main ecological characteristics of estuaries, and proposed a common approach for the harmonisation of habitat monitoring across the EU. Although this proposal is based on extensive information and a review of experiences included in the national habitat monitoring manuals, it is not meant to be definitive and prescriptive. It is highly recommended that this is evaluated by national experts and practitioners in habitat monitoring for its feasibility and appropriateness in different EU member states and different contexts.

Given the ecological and geographical variability of the Annex I habitat types, it is not realistic to have recommended lists of **typical species**, even for a biogeographical or marine region. Indeed, even within one Member State different species may be present in different parts of the range of a habitat type or in different subtypes, or even presents different biogeographical regions within the country, with the need to adapt the thresholds to every region in order to have a reliable methodology. Furthermore, given the variability of habitat types across their range, even within a single biogeographical marine region, it is also very unlikely that all typical species will be present in all examples of the habitat. For this reason, the report only identifies potential groups from which to select typical species for monitoring estuaries. Further work is needed to identify the most relevant typical species for the task. This may take place at a national level but should also reflect any biogeographical and regional differences and ideally link to relevant existing monitoring programmes.

When making such a selection it should also be borne in mind that the priority is for good indicators of favourable structure and function and that as such, they may not be the most dominant species. Species selected also need to reflect the variety of biological communities/subtypes often found within estuaries given that they are often made up of a mosaic of marine communities rather than being uniform.

A summary of the **ecological, physical and chemical characteristics and main variables** used to measure the habitat condition of estuaries is presented in this report together with a review and an analysis of variables which are specified in the national habitat monitoring manuals of EU Member States. There is much commonality but also potential to explore whether this can be standardized across Member States in at least some cases. Equally important is to make sure that there is consistency with variables being used for reporting of MSFD descriptors and the Nature Restoration Law whilst noting that there are differences in the scale of the habitats to be assessed. Also relevant are the metrics which are used to monitor the different variables. Many considerations make it unlikely that the metrics could be standardized even for commonly agreed variables (e.g. due to the variations in this habitat across its range, practical considerations, measurement methods) but it is worth exploring whether there is any scope for intercalibration.

The **reference values and thresholds** applied by Member States to obtain condition indicators for estuaries are variously; very specific, based on trends, use indices, based on region characteristics or rely on expert judgement or any combination of these. Given the variability of habitat across its range, even within a single biogeographical marine region, it is unlikely that the same ranges and thresholds can be applied in all circumstances. The scope to have a common or favoured approach to setting reference values and thresholds for particular variables could usefully be investigated. Equally important is to make sure that there is consistency with ranges and thresholds being used for reporting of MSFD descriptors and the Nature Restoration Law.

Finally, although there are many well established methods for **monitoring and sampling** estuaries, new techniques are constantly being developed. It is particularly important to keep alert to these for harder to access locations (depth, conditions, nature of habitat etc.) which is where many advances may be made.

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