European Commission

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

Large shallow inlets and bays (1160)

ATECMA

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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

Large shallow inlets and bays (habitat 1160) are present in all EU Marine Regions and can include several physiographic types e.g. embayments, fjards, rias and voes. 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 1160 overlap with those used to investigate habitat types 1110 (shallow sublittoral sandbanks) 1130 (Estuaries), and 1140 (Mudflats and sandflats) 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 1160 and the selection of appropriate variables for assessing their condition is set out in Section 1. Seventeen **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)

Seventeen Member States have reported habitat 1160 as present in their jurisdictions (BG, DE, DK, EE, ES, FI, FR, GR, HR, IE, IT, NL, PL, PT, RO, SE, SI). Some information has been collected about the location and description of the main characteristics of large shallow inlets and bays by all the Member States that have reported habitat 1160 as present within their jurisdiction **Specific methodologies** for assessing habitat 1160 have been available for review from eleven Member States (BG, DE, ES, FR, HR, IE, IT, NL, PL, RO, SI) There are also reports of surveys and assessments of this habitat type 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 or exclusively a reason for the work.

There is consistent and 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. Abiotic, biotic and structural state characteristics are noted as relevant to monitoring structure and function of this habitat type with the most frequently specified variables being concerned with epifaunal and infaunal assemblages. Functional state characteristics are the least well covered with primary production specified as a monitoring programme variable in only two Member States, and no specific indication that food web variables are recorded by any Member State (Table 5).

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

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. Two exceptions in the case of inlets and bays are in Poland and Spain where habitat specific variables are scored and aggregated to give an overall score/assessment at the local level. There is a lack of information on how Member States have undertaken aggregation at the biogeographical scale specifically for this habitat type.

There is no standard approach across the Member States regarding the number and distribution of **localities, sampling frequencies and methodologies**, to carry out the assessment and monitoring of this habitat. However, there is much commonality in approach for example in defining the limits of the habitats or in sampling methods such as standardised collection of sediments, infauna and epifauna along transects. Typically monitoring takes place across the habitat trying to record the variety of features. This may be along transects, or distributed across known areas where different biotopes are present. In many cases relevant data collected under other programmes (e.g. WFD, MSFD and any regional/national schemes) are also used, as and when they become available. Variations in the methodologies used to assess and monitor large shallow inlets and bays are strongly influenced by accessibility, topographical type, hydrographic conditions, as well as the diversity of the habitat and the associated biological communities.

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 10). 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

Greenlaw et al. (2007) developed a classification system for coastal, marine bays based on GIS analyses of geophysical and oceanographic variables. These were freshwater input, exposure (fetch), intertidal area, depth, shoreline sinuosity, and topographic complexity. These factors were also used to predict fine substratum and biological communities within bays and were applied to the Nova Scotia's Atlantic shoreline. Three different inlet types were distinguished using the Nova Scotia Atlantic shoreline as the study area. These were morphological/hydrographic inlets, inlets with a dominant productivity regime (benthic, intermediate and pelagic) and complex inlets based on habitat heterogeneity (e.g. shoreline sinuosity, topographic seabed complexity).

The Interpretation Manual gives the following definition for large inlets and bays (code 1160) (European Commission, 2013);

> Large indentations of the coast where, in contrast to estuaries, the influence of freshwater is generally limited. These shallow indentations are generally sheltered from wave action and contain a great diversity of sediments and substrates with a well-developed zonation of benthic communities. These communities have generally a high biodiversity. The limit of shallow water is sometimes defined by the distribution of the *Zostera* and *Potamogeton* associations.

Several physiographic types may be included under this category providing the water is shallow over a major part of the area: embayments, fjards, rías and voes.

Large shallow inlets and bays (code 1160) are listed in the Interpretation Manual under COASTAL AND HALOPHYTIC HABITATS and in the subcategory 'Open Sea and Tidal Areas'. They are a habitat complex as is habitat type 1130 (estuaries) and 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).

Six different subtypes of this habitat have been described for the coasts of Spain (Carrillo de Albornoz et al., 2009).

Along the Mediterranean coast of Spain these are:

- **Closed bays:** The concavity of the coast limited by two capes, in which the distance in a straight line between the two capes is less than 2/3 of the maximum width of the interior of the bay. Shallow features (depth <10 m), with intense dynamics.
- **Open bays:** The concavity of the coast limited by two capes, in which the distance in a straight line between the two capes is greater than 2/3 of the maximum width of the interior of the bay. Depth >10m, not intense dynamics.
- **Coves:** short and submerged erosion valley taking into the processes that have intervened in its formation, such as karst, eustatic, paleo-karst. cos, fluvio-torrential and fracturing. It is considered that the ratio between the width of the mouth of the cove and its total length should be less than unity.

Sub-types identified on the Atlantic coast of Spain are:

- **Closed bays:** The concavity of the coast limited by two capes with the distance in a straight line between two capes is less than 2/3 of the maximum width of the interior of the bay. Shallow features (depth <10m), with intense dynamics.

- **Open bays:** The concavity of the coast limited by two capes, in which the distance in a straight line between the two capes is greater than 2/3 of the maximum width of the interior of the bay. Depth >10m, not intense dynamics.
- **Rías:** penetration that the sea forms on the coast, is due to the submergence of the coastal part of a river basin with more or less steep slopes. This has created an arm of the sea which goes into the coast, coinciding with the mouth of a river, which is also governed by the rise and fall of the tides.

In many tidal bays and inlets, the upper intertidal area contains areas of mudflats, perhaps with a landward wetland fringe. This stratification of habitats within the inlet and bay system can also be seen in the seabed sediments. Generally, the sediments will grade seawards into silts, sands and even gravels. This differentiation of seabed sediment is an important consideration as different sediment types have an influence on the associated species as well as their vulnerability to disturbance[1].

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

- Map the profile and extent of any intertidal/subtidal area largely composed 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 soft 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. Habitat 1170 (reefs) is not included in this cluster because although it may be present as a fringing habitat of large inlets and bays, and possibly as isolated examples within 1160, the methodologies for assessing these biogenic and/or geogenic structures will include some significantly different approaches.

An important characteristic of inlets and bays is that they are made up of a mosaic of marine communities and habitats rather than being uniform. According to the 2022 EUNIS marine habitat classification the following EUNIS habitat types (level 3) may be present as components of habitat type 1160: MA12 to MA15, MA22 to MA24, MA23, MA24, MA32 to MA35, MA42 to MA45, MA52 to MA55, MA62 to MA65, MB12 to MB15, MB22 to MB25, MB32 to MB35, MB42 to MB43, MB52 to MB55, MB62 to MB64, MC12 to MC15, MC23, MC32 MC35, MC42 to MC43, MC52 to MC55, MC62 to MC65. These incorporate some of the habitats listed, (at EUNIS level 4) in Group 1 (seagrass beds) Group 2 (macroalgal forests) Group 3 (shellfish beds), Group 4 (maërl beds), Group 5 (sponge, coral and coralligenous beds) of Annex II as well as EUNIS level 3 habitats in Group 7 (soft sediments above 1000m) of the Nature Restoration Law. Large inlets and bays have been reported from the following Member States; Belgium (BG), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Croatia (HR), Ireland (IE), Italy (IT), the Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Slovenia (SI) and Sweden (SE).

[1] The sensitivity of large shallow inlets and bays: http://ukmpa.marinebiodiversity.org/uk_sacs/activities/recreation/r01_04.htm [accessed 06/02/2025]

Diversity across the regions

Large inlets and bays are widespread, being present in all the marine biogeographical regions. There are examples fringing the **North Sea** coasts of Denmark and the Netherlands, the Channel and Atlantic coasts of France, and the **Atlantic** coasts of Spain and Portugal. Rias are a particular feature of France and northern Spain.

In the **Mediterranean**, Natura 2000 sites have been designated for this habitat type along the mainland coasts of France, Croatia, and Greek as well as islands such as Corsica, Sardinia and Mallorca.

In the **Baltic Sea** large shallow inlets and bays are represented by coastal features such as fjords and/or fjord like bays, shallow bights, but also specific subtypes of Bodden (HELCOM, 2013). In the German Baltic, the largest example is the Greifswald Bodden.

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

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

- Topography/physical characteristics
- Hydrology- tidal range/currents/wave action/mixing
- Sediment composition and distribution
- Turbidity
- Water/sediment quality
- Characteristic species, epifaunal and infaunal assemblages
- Macrophytes/macroalgae/eelgrass
- Associated fish, birds, and marine mammals
- Sedimentation/sediment dynamics

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

1.2.1 Abiotic characteristics

The physical characteristics of inlets and bays, particularly the underlying geology and size, together with the tidal range, currents and wave action affects many aspects of this habitat type. They help determine the overall physical attributes as well as influencing patterns of erosion and deposition. The degree of shelter from wave action as well as strength, direction and consistency of currents also affects the distribution, erosion and deposition of sediments within the habitat while tidal range together with slope determines the extent of the intertidal area. All of these have a strong influence on the biocenoses and characteristic species of inlets and bays.

1.2.2 Biotic characteristics

Large shallow inlets and bays vary widely in habitat and species diversity according to their geographic location, size, shape, form and geology. There is considerable variation between hard (rock) and soft (sediment) coasts. The degree of wave exposure is a critical factor in determining habitat and species diversity, affecting communities both on the shore and in the sublittoral zone. The levels of exposure to wave action vary from sheltered through semi-exposed to exposed. This is reflected in the sediment type with mud or sandy mud occurring in the sheltered sites to mixed sediments on semi-exposed sites to coarser sediments in exposed sites. Very exposed conditions may result in shingle beaches, whilst less-exposed shores may consist of clean sand, and in sheltered conditions shores may consist of fine sand and mud. Animal-dominated rocky communities in the sublittoral zone also vary according to local conditions of wave exposure and tidal streams.

The variation in sediment types is reflected in the organic carbon content and numbers of species with maximum biological diversity in softer sediments and lowest diversity occurring in coarse material. The range of plants and animals associated with this habitat type is therefore very wide. The issue of site size is also important, as larger sites tend to encompass the greatest variety of constituent habitats and have the greatest potential for maintenance of ecosystem integrity[2].

1.2.3 Landscape/Seascape characteristics

Inlets and bays are landscape scale features that are constantly evolving with some of these changes best observed at a landscape scale. They are also habitat complexes which can include a variety of sub-habitats. Baie du Mont Saint-Michel (France) for example is fringed by large areas of saltmarshes with a very diverse morphology, and comprises sand/gravel beds of bivalves, reefs of *Sabellaria alveolata*, rocky islets, cliffs and dunes[3].

Examples of variables used to measure these characteristics when reporting on the condition of habitat type 1160 are given in Table 1.

Table 1. Ecological characterisation and selection of condition variables used to measure habitat condition of large inlets an bays

Ecological characteristics	Types	Description	Examples of associated variables
Abiotic characteristics	**Physical state characteristics**	**Degree of submergence / depth, tidal regime**	Depth in relation to chart datum. Tidal range.
		Topography / physical structure	Physical dimensions, extent, form, longitude and latitudinal gradients.
		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.
		Turbidity	Suspended particles.
	Chemical state characteristics	**Water quality**	Various parameters including nitrates & phosphates.
		Sediment quality	Redox potential in bottom sediment, organic carbon in sediment % dry matter.

[2] JNCC 1160 factsheet: https://sac.jncc.gov.uk/habitat/H1160/ [accessed 06/02/2025]
[3] Ramsar Sites Information Service – Baie du Mont Saint-Michel: https://rsis.ramsar.org/ris/709 [accessed 06/02/2025]

Ecological characteristics	Types	Description	Examples of associated variables
Biotic characteristics	Compositional state characteristics	**Epifaunal & infaunal assemblages, abundance and diversity of characteristic species**	Number of biocenosis, presence & abundance of species (SAFCO scale), diversity index, biomass
		Biogenic structures	Spatial extent, taxonomic composition, % cover
		Macroalgae / eelgrass / vegetation	Spatial extent, taxonomic composition, % cover
		Associated fish, birds & marine mammal	Abundance, distribution, population structure
	Structural state characteristics	**Abundance and condition of characteristic species including biogenic structures**	Percentage cover, biomass, Synthetic indicators (M-AMBI, BENTIX etc)
		Macrophytes / macroalgae / eelgrass condition	Depth limit of angiosperms, biomass of eelgrass
	Functional state characteristics	**Primary production**	Phytoplankton blooms (frequency/longevity Macroalgae/ angiosperm (growth rates, dry weight/m^2)
		Food webs	Number of species/functional groups and qualitative links Average energy transfer between trophic levels (%) Stable isotopes (^{13}C, ^{5}N, ^{34}S) Stomach content analysis
Landscape/ seascape characteristics		**Connectivity / Fragmentation**	Presence of anthropogenic structures and their % cover
Other		**Disturbance**	Footprint of activity, number and intensity of negative pressures.

1.2.4 Ecological processes that are relevant regarding proper functioning

The physical characteristics of inlets and bays are strongly influenced by factors such as underlying geology, aspect, and tidal range and are strongly influenced by coastal processes such as erosion, deposition and sediment movement. Features within an inlet or bay, such as sandbanks or reefs also affect both their physical characteristics, for example by providing areas sheltered from wave action, or highly dynamic areas of sediment moment, as well as the biological communities that may become established.

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). The sediment habitats and their communities within large shallow inlets and bays are very varied reflecting the broad sediment types that may be present. Typical species will vary depending on the depth, substrate and degree of exposure to wave action.

The species used to monitor the condition of this habitat type differ depending on the geographical location and characteristics. Spain, for example, has identified potential indicator species from nine different groups (Table 2) (Carrillo de Albornoz et al., 2009).

Table 2. Characteristic and diagnostic species of habitat 1160 identified by Spain

Characteristics and diagnostic species	
Angiosperms Taxon 1: *Zostera marina* Taxon 2: *Zostera nana* or *Zostera noltii* Taxon 3: *Cymodocea nodosa* Taxon 4: *Posidonia oceanica* Taxon 5: *Halophila decipiens*	**Arthropoda**
Algae Taxon 1: *Padina Pavonica* Taxon 2: *Jania rubens* Taxon 3: *Udotea petiolata* Taxon 4: *Acetabularia acetabulum* Taxon 5: *Halimeda tuna* Taxon 6: *Caulerpa prolifera, C. racemosa, C. taxifolia*	**Echinodermata** Taxon 1: *Holoturia tubulosa* Taxon 2: *Paracentrothus lividus* Taxon 3: *Astropecten* sp. Taxon 4: *Echinaster sepositus* Taxon 5: *Asterina pancerii*
Porifera Taxon 1: *Dysidea avara* Taxon 2: *Crambe crambe* Taxon 3: *Adocia varia* (Sarà) = *Haliclona simulans* (Johnston)	**Annelida**
Cnidaria	**Chordata** Taxon 1: *Labrus viriis, L. merula* Taxon 2: *Coris julis* Taxon 3: *Sympodus* sp. Taxon 4: *Diplodus* sp. Taxon 5: *Salpa salpa* Taxon 6: *Serranus* sp. Taxon 7: *Chromis chromis* Taxon 8: *Thalassoma pavo* Taxon 9: *Torpedo torpedo* Taxon 10: *Hippocampus* sp.
Mollusca Taxon 1: *Pinna nobilis* Taxon 2: *Venus verrucosa* Taxon 3: *Rissoa* sp. Taxon 4: *Sepia officinalis* Taxon 5: *Octopus macropus* and *O. vugaris* Taxon 6: *Mytilus edulis* Taxon 6: *Mytillus galloprovincialis*	**Birds** Taxon 1: *Larus cachinans* Taxon 2: *Larus audoinii* Taxon 3: *Phalacrocorax aristotelis*

Table 3 indicates frequently present groups from which species for monitoring may be selected, and the types of changes in quality they could be used indicate. They may be drawn from any species group.

Table 3. Potential species groups from which to select typical species for monitoring habitat 1160 (large shallow inlets and bays)

Species group	Ecological notes	Sensitive to changes in condition
Angiosperms	Fringing saltmarsh and seagrass may be present. 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., 2022).	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	Reef building species (*Sabellaria 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.	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
Fish	Large inlets and bays can act as feeding grounds as well as nursery and spawning areas for some species of fish such as the Lesser weever E*chiichtyhys vipera* (Ellis et al., 2010), plaice and dab (Atalah et al., 2013). Sandeels *Ammodytes* spp. where present are an important food source for seabirds	Physical disturbance, productivity. 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.
Birds	Shore and seabirds.	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 inlets and bays by all sixteen Member States that have reported habitat 1160 as present within their jurisdiction[4]. Specific methodologies for assessing and monitoring large shallow inlets and bays from eleven Member States (BG, DE, ES, FR, HR, IE, IT, NL, PL, RO, SI) have been available for review. There are also reports of surveys and assessments of this habitat type carried out in these and other EU Member States (e.g. Belgium, Portugal, Denmark[5]) that are relevant, and that can or have been used to inform such assessments although not directly or exclusively a reason for the work. 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 used to measure habitat condition of inlets and bays is presented in Table 1 (Section 1). Examples of the characteristics and variables used by Member States to report this habitat type, as part of the assessment of their conservation status are presented in Table 4 and a summary analysis is given in Table 5. Table 5 shows that whilst the monitoring and assessment programmes from eleven Member States cover abiotic, biotic, landscape and other characteristics there are differences in emphasis.

Within the **abiotic characteristics**, nine of the eleven Member States with available methodologies for assessing this habitat type specifically mention monitoring variables relating to the physical characteristics of the habitat. Of these, 'degree of submergence' and 'topographical features' are most frequency covered. Chemical characteristics (water and sediment quality) are specifically mentioned six Member States.

Biotic characteristics are well represented in the monitoring programmes being specifically mentioned by eleven Member States with available methodologies. All consider 'epifaunal and infaunal assemblages', and 'abundance and condition of characteristic species and some (7) specifically refer to monitoring macrophytes/macroalgae or eelgrass. Only two Member States (Germany and Poland) make specific mention of monitoring associated fish, birds and marine mammals, although this may well be covered by other Member States in their more general reporting of the abundance and condition of species. Structural state characteristics are monitored by six Member States. Of the two functional state variables identified for this habitat (primary production and food webs) there is no indication of monitoring food webs and only two Member State specifically referring to monitoring primary production.

Connectivity/fragmentation as a **landscape/seascape characteristic** is not highlighted for monitoring by many Member States but given that both can affect the structure and function of this habitat, they may be covered indirectly. Disturbance has been included under the category **other**.

[4] as evidenced by the submitted Standard Data Forms for designated sites where 1160 is a feature and Article 17 reporting for this habitat type

[5] Eg. Danish National Aquatic Monitoring and Assessment Program (DNAMAP), Santos et al., 2019

Table 4. Examples of variables used by Member States to assess condition of habitat 1160 (large inlet and bays)

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 IT - Coastline morphobathymetry from satellite images or high-resolution photographs RO - Water depth	Whilst not necessarily highlighted in all assessment methodologies, these characteristics are usually included in the descriptions of Natura 2000 sites where habitat 1160 is present (e.g. in the SDFs).
Topography	DE – Morphology FR - Total surface area IT - Coastline morphobathymetry from satellite images or high-resolution photographs PL – Area RO - Habitat extent	The gross morphology of habitat 1160 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.
Hydrodynamics - Exposure to current, wave action, scour & surge	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 1160 is present, at least in general terms.
Turbidity	RO - Water clarity, Sechi disc 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/dynamics	BG - Bottom substrate type DE – Relationship between erosion and sedimentation ES - Sediment accretion/erosion g(MS)/m^2 day using benthic sediment traps FR - Granulometric analysis RO - Sediment particle diameter	Measurements of this variable are not specifically mentioned in all the methodologies examined but may be included as part of water quality sampling or considered, at least in general terms, when describing the physical characteristics of the habitat.
1.2 Chemical state characteristics		
Water quality	BG - Dissolved oxygen mg/dm^3, oxygen saturation %, pH	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	ES - Hydrogen sulphide concentration in the sediment (μM) FR - Organic matter content	There is some mention of hazardous substances as a pressure/threat relevant to this habitat, but it is not necessarily included as an assessment variable.

Description	Examples of variables used by Member States	Notes
2. Biotic characteristics		
2.1 Compositional state characteristics		
Invertebrates - Epifaunal & infaunal assemblages, characteristic species	IE - Number of marine community types NL - Presence/absence, number of taxa of typical benthic macroinvertebrates L - Presence of characteristic species PL – Presence of typical taxa of macrozoobenthos	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	NL - Presence and coverage of structural elements (includes shellfish banks and tubeworm banks)	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	DE - Completeness of habitat-typical species inventory PL - Typical species of fish, and adult and juvenile individuals of viable populations of some typical fish species	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.
Macrophytes, macroalgae, eelgrass	ES - Depth limit of marine angiosperm meadows HR - Abundance and coverage of individual plant species (Braun-Blanque method) PL - Ration of length of coast cover with reed to length of whole coastal zone within the habitat, presence of typical taxa of macrophytes	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).
2.2 Structural state characteristics		
Abundance and condition of characteristic species including biogenic structures	FR - Condition of maërl (proportion of surface live/dead maërl from 3-5 samples) NL – Number of qualifying structural elements RO - Average density of characteristic species, relative distribution of habitat subtypes	These characteristics are reported in all 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	FR - Fragmentation of eelgrass. Proportion of envelope not covered by eelgrass. Density of eelgrass (% cover of substrate)	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).

Description	Examples of variables used by Member States	Notes
2.3 Functional state characteristics		
Primary production	BG – Presence/absence of phytoplankton blooms RO – Extent of phytoplankton/macroalgae	
3. Landscape/seascape characteristics		
Connectivity/ fragmentation	BG - Habitat fragmentation. Presence of new (after mapping) anthropogenically created structures (buildings, ports, roads, etc.) fragmenting the polygon FR – Fragmentation of eelgrass beds	
4. Other		
Disturbance	FR - Presence/absence of artificial structures (e.g. embankments, pipes, port facilities, concrete). PL - % share of total length of anthropogenically transformed coast to total length of coast within habitat, non-indigenous species NL - % of banks anthropogenic alteration vs total bank length from aerial photos or field survey	

Table 5. Main ecological characteristics and associated variables monitored in the assessment of structure and function of cave habitats by EU Member States

Ecological characteristics	Variables	Metrics	BG	DE	ES	FR	HR	IE	IT	NL	PL	RO	SI
1. Abiotic characteristics													
1.1 Physical state characteristics													
Degree of submergence / depth / tidal regime	Depth in relation to chart datum.	Metres (m), maximum & minimum with seasonal patterns.	■	■	■		■		■	■		■	
Topography	Physical dimensions; extent; longitude and latitudinal gradients; elevation; form and features (e.g. sandbanks, islands)	Area (km2), degrees of slope (o), physical features from a reference list.		■		■	■		■	■	■	■	
Hydrodynamic - 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; 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).	■	■	■	■		■				■	
1.2 Chemical state characteristics													
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.			■	■							

Ecological characteristics	Variables	Metrics	BG	DE	ES	FR	HR	IE	IT	NL	PL	RO	SI
2. Biotic characteristics													
2.1 Compositional state characteristics													
Invertebrates - Epifaunal & infaunal assemblages including biogenic structures	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													
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.											
Macrophytes, macroalgae, eelgrass	Type; abundance; extent	Biomass, estimated % cover.											
2.2 Structural state characteristics													
Characteristic species including biogenic structures	Abundance & condition; volume; biomass; fragmentation	Percentage cover, biomass, density. Synthetic indicators (M-AMBI, BENTIX etc).											
Macrophytes, macroalgae, eelgrass	Condition; biomass; estimated % cover	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 bloom; angiosperms/macroalgae	Concentration of chlorophyll a (μg/ l), phytoplankton species, Plant/macroalgae growth rates, dry weight/m^2.											

Ecological characteristics	Variables	Metrics	BG	DE	ES	FR	HR	IE	IT	NL	PL	RO	SI
3. Landscape/Seascape characteristics													
Connectivity/ Fragmentation	Continuous; fragmented; presence of anthropogenic structures and their % cover	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), pressures from a standardised list (graded High, Medium, Low, unknown).											

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 6 lists some of the typical methodologies used to gather information on the key characteristics of this habitat type.

Table 6. Examples of survey methods used to investigate key characteristics of habitat 1160 (large shallow inlets and bays)

Abbreviations: ACDP - Acoustic Doppler Current Profiler, AGDS – Acoustic Ground Discrimination Systems, DDV – Drop-drown video, 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
Tidal regime, exposure to currents, wave action	Hydrographic charts, modelling, Aerial survey (Satellite/Drone imagery), Current meters (ADCP).
Salinity/ freshwater influence/ stratification	Water chemistry data loggers
Turbidity	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 imagery
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 or boxcorer for biological components and organic matter composition
Invertebrates - Epifaunal & infaunal assemblages	Photographic quadrats, video transects, visual census, direct sampling (grab, core, trawl), ROV or DDV data.
Vertebrates - Associated fish, seabirds, marine mammals	Visual census, aerial and boat-based surveys
Macrophytes, macroalgae, eelgrass	Photographic quadrats, video transects, visual census, direct sampling (grab, core). Multicorer or boxcorer (depending on water depth) to collect sediment samples for quantitative biological and trophic analyses.

In some cases, relevant data is available from continuous monitoring programmes. One example, from the Balearic Islands (Spain) is the Sistema de Observación y Predicción Costero de las Illes Balears (SOCIB)[6]. A beach monitoring facility provides real time data on beach images and weather variables as well as periodic information on waves, sediments and beach morphology at four locations enabling analysis of coastline evolution as well as nearshore waves, sediments and beach bathymetry.

[6] https://www.socib.es/?seccion=observingFacilities&facility=beachMonitoring

Methodologies are also evolving. For example, traditional on the ground surveying techniques are increasingly being supported by remote sensing as a means of provide topography maps more frequently at a lower cost and higher coverage. This may be by using drones[7] but also satellite imagery e.g. remote sensing as used in trials at Arcachon Bay and the Bay of Veys on the French coast (Salameh et al., 2020).

2.2 Definition of ranges and thresholds to obtain condition indicators

The reference values and thresholds applied by Member States to obtain condition indicators for inlets and bays are variously; very specific, based on trends, use indices, rely on expert judgement or any combination of these. Table 7 gives some examples of the different approaches. Indicators and thresholds being developed under the auspices of other programmes can also inform the process for the Habitats Directive.

Table 7. Examples of reference values and approaches used for large shallow inlets and bays

Example of variable used	Method / metric and reference values	Country: Reference
Quantitative		
Erosion/accretion of sediment in *Zostera* spp. and *Cymodocea nodosa* meadows	Depth of burial of leaves. FV (*Zostera* species burial average between 0-4cm, *C.nodosa* between -1cm and 4cm). U1 (Zostera sp. between 4-10cm and *C.nodosa* average between 4-7cm and between -1 to -1.5cm (if the horizontal rhizome is still buried). U2 (*Zostera* sp. average burial >10cm and, in the presence of erosion negative values. *C.nodosa* burial >7cm and less than -1.5cm or whenever the rhizome is visible).	Spain: Carrillo de Albornoz et al., 2009
Presence of typical fish species	FV (All species typical of this habitat present and no stocking in the period for which the assessment was carried out); U1 (3 of the listed species typical of the habitat are present with stocking of at least one of these); U2 (2 or less of listed typical species present).	Poland: Michałek et al., 2022
Reed community	% cover of the coastal zone (>23% =FV, 20.5-23% = U1, <20.5% = U2)	Poland: Michałek et al., 2022
Density of infauna characteristic of the intertidal zone	Scored between 0-2; 2(>20 individuals/m2), 1 (5-20 individuals/m2); 0 < 5 individuals/m2). Measured with grids of 50 x 50cm or 1 x 1m.	Spain: Aranda et al., 2019
Presence of new fragmenting anthropogenic structures.	Occupying up to 1% of monitored polygons at the biogeographic level (FV), 1.1-10% (U1), >10.1% (U2)	Belgium: MOEW, 2013
Indices		
Vulnerability index (IVT)	Unweighted average of three partial vulnerability indices; morphosedimentary factors (FM) (up to 12 points); ecological and vegetation cover factors (FE) (maximum 4 points) and management and conservation factors (GF) (maximum 10 points). IVT = (IVP_FM + IVP_FE + IVP_FG) / 3. Value is between 0 and 1. FV (0.67-1.00) U1 (0.33-0.66) and U2 (0- 0.32). The quality of the evaluation is based on the number of variables considered.	Spain: Aranda et al., 2019

[7] Eg. https://www.aqua.dtu.dk/english/news/2024/01/drones-for-monitoring-eelgrass

Example of variable used	Method / metric and reference values	Country: Reference
Qualitative		
Sedimentary structure	Undisturbed (natural diversity of sediments and structures in the inlets and bays); slightly changed (all natural sediments and structures present but partially altered); changed more (partial loss of natural sediments and structures greatly altered).	Germany: Krause et al., 2008
Trend		
Number of Marine Community types specified in conservation objectives	FV: all community types listed in the site, specific guidance document is present; U1: increase or decrease in MCTs present; U2: ≤50% of MCTs are present.	Ireland: Scally et al., 2020
Expert judgement		
Physical disturbance / Anthropogenic structures	Presence/absence of artificial structures (e.g. groynes, concreting) noted and expert opinion given on the influences on the state of conservation	France: Lepareur, 2011
Sediment structures	A: Undisturbed Natural diversity of sediments and structures of inlets and bays present; B: Low altered All natural sediments and structures present, but partially altered; C: More severely altered Partial loss of natural sediments and structures or majority severely altered	Germany: Krause et al., 2008

Site specific reference levels have been developed in the Netherlands for habitat 1160 using a Benthic Indicator Species Index (BISI) (Wijnhoven, 2023). These are either obtained from recent data of reference areas for which the possible presence of significant pressures can be ruled out, or, are based on recent maximum observations of year averages as observed from recent historic monitoring data of the area of assessment itself, that are, doubled and/or increased with the standard deviation. The methodology therefore depends on the availability of (recent) historic data. In case of poor historic data availability, there are no better options than using maximum observations from suboptimal techniques, in which case a reference of half the observed maximum is sometimes used. There are cases that indicator species have not been present in the monitoring data of the area of assessment (as densities were too low) during recent years. The reference values indicated are specific to the monitoring technique and sample area although different techniques can be used for different species or combined.

Threshold values for a seabed habitat to be considered in Good Environmental Status (GES), were agreed in 2023. This states that no more than 25% should be adversely affected by human pressures, including no more than 2% that should be irreversibly lost[8]. A benthic broad habitat type is adversely affected in an assessment area if it shows an unacceptable deviation from the reference state in its biotic and abiotic structure and functions, e.g. typical species composition, relative abundance and size structure, sensitive species or species providing key functions, recoverability and functioning of habitats and ecosystem processes. It is however noted that these recommendations should not be considered by Member States as alternative conservation values for these habitat types under for example, the Habitats Directive.

[8] Descriptors under the Marine Strategy Framework Directive: https://environment.ec.europa.eu/topics/marine-environment/descriptors-under-marine-strategy-framework-directive_en#descriptor-6-seabed-integrity

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 variable measured at the local scale to provide a condition assessment at the level of the plot or monitoring locality/site. Two exceptions relating to habitat 1160 are from Poland and The Netherlands.

In **Poland** individual variables specific to habitat type are rated (FV, U1, U2) at the level of the site and then worked up for an overall assessment of the habitat type at a biogeographic level. The lowest grading determines the aggregated result for 'structure & function'. The variables considered for habitat type 1160 are divided into cardinal indicators (e.g. ecological status according to the WFD) and auxiliary indicators (e.g. typical species of ichthyofauna and typical taxa of macrophytes). 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'.

In the **Netherlands**, the conservation status of a particular Natura 2000 site is determined by aggregating scores (specific to this habitat) for Structure (structure-determining species, internal structure & scenic setting); Function (water, processes, connectivity); and Area. These give an overall score for the applicable Netherlands Natura 2000 site such as the Oosterschelde (Janssen et al., 2014) (Table 8).

Table 8. Example of methodology for conservation status assessment of Oosterchelde

I. Structure (a = 8-6 points, b = 5-3 points, c = 2-0 pints)	II. Function (a = 4 points, b = 3-2 points, c = 1-0 points)
A: Structure-determining species • 1 point = presence of seagrass and/or *Ruppia* fields • 1 point = presence of locations with shellfish concentrations • 1 point = presence of littoral mussel beds • 1 point = presence of algae or "film" layer with diatoms and blue algae **B. Internal structure** • 1 point = varied altitude with permanently dry and tidal flats and permanently flooded parts. • 1 point = natural variation in high and low dynamics parts (as a result of hydrodynamics due to tidal action), leading to a variation in sediment composition. • 1 point = presence of a natural channel system. **C. Landscape setting** • 1 point = natural spatial distribution of adjacent salt marshes and marshes **D. Fauna:** *not used*	**A. Water** • 1 point = good water quality (no high conc. Toxins) • 1 point = clear water **B. Air:** *not used* **C. Bottom:** *treated under structure* **D. Processes** • 1 point = Presence of tidal current • 1 point = Natural sedimentations and erosion processes
Scoring for Structure: 0+1+0+1+0+0+1+1 = b	**Scoring for Function:** 1+1+1+0 = b
Total Scores for 118 Oosterschelde 'Structure and function': b	

In **Spain**, the overall conservation status of the structure and function of habitat 1160 at a monitoring station is determined according to the conservation status of the following environmental and biological variables (Carrillo de Albornoz et al., 2009);

Environmental variables:

- Erosion/accretion of sediment
- Temperature
- Oxygen
- Total sedimentation
- Organic sedimentation
- Concentration of nutrients in the water

Biological variables:

- Soft substrate benthic macroinvertebrates
- Phytoplankton/*Chl-a* concentration
- Maximum and minimum depth limits of angiosperm meadows
- Presence of invasive macroalgae.

The sampling station is considered to have a 'favourable' conservation status if all the environmental and biological variables are classed as favourable; 'unfavourable' if some are classed as favourable and others are unfavourable inappropriate; or if all are classed as unfavourable – inappropriate. The sampling station is classed as 'unfavourable – bad' if at least one of the variables is classified as unfavourable – bad.

At the level of the site, it is classified as favourable if the status of all the stations if favourable, unfavourable – inadequate if some are favourable and others unfavourable-bad and classified as unfavourable bad if the state of at least two stations is unfavourable – bad.

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 inlets and bays 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. Sites with moving boundaries may require more detailed remote sensing (Zaharia, 2013). In Poland, each inlet and bay have a designated station where measurements and water quality tests are carried out.

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):

- Representativeness within the Natura 2000 Network and the Protected Area Networks.
- Statistical significance. A minimum number of monitoring locations is necessary so that the assessment can be extrapolated from local to regional level.
- Number of habitat types of Community interest (THIC) present in the location.
- 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.

Guidance is provided for monitoring different variables (Aranda et al., 2019). In the case of infauna density assessments, for example, pilot studies are recommended, and samples should be taken perpendicular to the coast spaced 50m apart.

In **Romania**, a stratified random sampling strategy is recommended for monitoring Annex I habitat types except when monitoring rare or special habitats/species, the distribution of which is already known, in which case a selective strategy should be used. A split sampling program at different spatial levels aimed at capturing key physical attributes and characteristic biota needs to be carried out. In other words, the monitoring programme must be structured in such a way that a detailed sampling in a certain number of areas reduced in area allows the assessment of the entire feature (Zaharia, 2013).

Poland has only one site where habitat 1160 is present (Puck Lagoon and the Outer Puck Bay). The recommended frequency of studies is once every three years with the timing depending on the indicator being considered. For example, for macrophytes and macrozoobenthos the recommendation is for surveys in June, for ichthyofauna in the summer season (June-September) and for anthropogenic pressures in June or in the first half of September (Osowiecki & Błeńska, 2010).

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 inlet or bay. 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 protocols may be needed within each site to assess the condition of the whole feature. Sampling/recording along transects also helps to build a picture of the extent, distribution, and other characteristics of the biotopes and sediment characteristics of this habitat.

Sampling frequency is likely to vary depending on the variable being examined (Table 9). and there may be a process of compilation. In Spain, for example, annual monitoring of inlets and bays is proposed with the six-yearly evaluation being an average of the annual values so that interannual variability is taken into account (Aranda et al., 2019).

Table 9. Recommended sampling frequence or data collection for structure and function variables on beaches in Spain (from Aranda et al., 2019)

	Variables of Structure and function	Frequency of sampling
Morphosedimentary and oceanographic factors	**1.** Dimensions of the beach (width of the dry beach)	Yearly
	2. Sedimentary contribution	Yearly
	3. Tide range	-
	4. Frequency of energetic waves	-
	5. Rockiness	Yearly
	6. Beach slope	Yearly
Ecological and vegetation cover factors	**7**. Organic contributions of marine origin	Semester
	8. Density of infauna in the intertidal zone	Semester
Management and protection factors	**9.** Removal of accumulated marine debris	Weekly, during the summer
	10. Mechanized cleaning of the beach	Weekly, during the summer
	11. Regeneration of the beach	Yearly
	12. Occupation range of the beach	Weekly, during the summer
	13. Presence of engineering structures	Yearly

Co-ordination also takes place with other monitoring schemes both to inform Habitats Directive reporting and to support other reporting schemes. This is especially relevant in the case of inlets and bays which overlap with monitoring requirements under the Water Framework Directive as they occur in ‘transitional waters’. One example is the work undertaken by the Danish National Aquatic Monitoring and Assessment Program (DNAMAP).

2.7 Other relevant methodologies

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

Published data from research projects and programmes provide supplementary data. They include;

- Work carried out under Regional Seas Programmes such as the Quality Status Reports prepared by OSPAR and HELCOM (e.g. an assessment of benthic habitat communities in relation to nutrient and/or organic enrichment and the extent of physical disturbance to benthic habitats by fisheries and an assessment of eutrophication in the Baltic Sea) (Lizinska & Guerin, 2023; Wijnhoven et al., 2023; Matear et al., 2023; HELCOM, 2009) and monitoring measures for Specially Protected Areas under the Barcelona Convention[9].
- Reporting under other EU Directives, in particular the Water Framework Directive and the Marine Strategy Framework Directive[10].
- Scientific publications (eg. Schratzberger & Larcombe, 2014; Beerman et al., 2023)
- Surveys/monitoring of developments/human activities/EIA[11] (e.g. Frias et al., 2024; Kermorvant et al., 2017)

Eel grass, which may be present in large shallow inlets and bays is typically monitored by direct observations and video-based surveys, but there is also growing interest in newer technologies using Autonomous Underwater Vehicles (AUVs), unmanned aerial vehicles (UAVs) and remotely operated vehicles (ROVs). The use of these platforms for data collection on eelgrass beds in Natura 2000 sites has, for example, been trialled Denmark where the investigators concluding that they can provide data of high spatial resolution and accuracy in a labour and time efficient way. Their potential may be greatest where large areas need to be covered and in deep or turbid waters (Nielsen et al., 2023). A combination of UAVs for shallow waters and ROVs or traditional in water methods such as towed cameras to cover deeper waters were considered to be an effective methodology for eelgrass mapping on a water basin scale.

Norway has developed a tool for GIS modelling of inlets and bays using identifiable and re-examinable geophysical criteria based on work carried out in Norway and Sweden (Bekkby & Isæus, 2008). This used indentation, wave exposure and depth as criteria for modelling the habitats. In other areas freshwater influence may be a relevant criterion.

2.8 Conclusions

Some information has been collected about the location and description of the main characteristics of inlets and bays by all the Member States that have reported habitat 1160 as present within their jurisdiction[12]. Specific methodologies for habitat 1160 have been available for review from eleven Member States (BG, DE, ES, FR, HR, IE, IT, NL, PL, RO, SI) There are also reports of surveys and assessments of this habitat type 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 or exclusively a reason for the work.

There is much commonality in approach across Member States, from initial review of likely locations based on existing geological information and maps, followed by aerial surveys and

[9] https://wedocs.unep.org/bitstream/handle/20.500.11822/14030/82ig35_final_act_spaprotocol_eng.pdf
[10] Summaries available on the Marine Information System for Europe; https://water.europa.eu/marine/data-maps-and-tools/map-viewers-visualization-tools/dashboards-on-marine-features-under-other-policies
[11] SOCIB monitoring of beaches https://www.socib.es/?seccion=observingFacilities&facility=beachMonitoring [accessed 06/02/2025]
[12] as evidenced by the submitted Standard Data Forms for designated sites where 1110 is a feature and Article 17 reporting for this habitat type

further reconnaissance from boat and shore to gather more specific locational information. There is consistent and 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. Abiotic and biotic characteristics and variables of the habitat are recorded, as well as aspects such as fragmentation and disturbance which are landscape/seascape characteristics of this habitat type. For example, physical state variables frequently recorded include dimensions, depth, and sediment type; compositional state variables typically involve recording epifaunal and infaunal assemblages, their abundance and distribution within and across inlets and bays as well as the presence, condition and abundance of eelgrass beds. Variations in the methodologies used to assess and monitor large shallow inlets and bays are strongly influenced by accessibility, topographical type, hydrographic conditions, as well as the diversity of the habitat and the associated biological communities.

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

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. Two exceptions in the case of inlets and bays are in Poland and The Netherlands where habitat specific variables are scored and aggregated to give an overall score/assessment at the local level. No aggregation method specific to inlets and bays has been identified for habitat 1160.

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 for example in defining the limits of the habitats or in sampling methods such as standardised collection of sediments, infauna and epifauna along transects. Typically monitoring takes place across the habitat trying to record the variety of features. This may be along transects or distributed across known areas where different biotopes are present.

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 inlets and bays specifically for Habitats Directive reporting is more frequent (e.g. 3 yearly) but in many cases relevant data collected under other programme (e.g. WFD, MSFD and any regional/national schemes) are also used as and when they become available.

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 10. '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 characterising the habitat condition as favourable, particularly biogeography 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 10 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 10 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 10. 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 runoff. 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 11) 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 (MSFD) and the Water Framework Directive (WFD).

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 11) was that whilst using pristine or minimally impacted conditions was the best single method, others were also adequate when combined with expert judgement.

Table 11. 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 robustness	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 comprehensibility	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 1)[13].

[13] 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 1. 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 12 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 12. 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
D5C1	Open sea	Nutrient concentration in surface water or in the water column	From 7 to 14 MSs reported TVs for the different nutrient categories	Strong input of WFD in coastal waters, some MSs TVs still missing, especially in the open sea.	WFD
D5C2	Coastal waters	Chlorophyll-a in the water column	15 MSs reported TVs	Strong input of WFD in coastal waters.	WFD
D5C2	Open sea	Chlorophyll-a in the water column	17 MSs reported TVs	Strong input of WFD in coastal waters.	WFD
D5C3	Coastal waters	Harmful algal blooms in the water column	Only Baltic MS reporting a cyanobacteria bloom index	No index (e.g. red tides) in other marine regions	
D5C3	Open sea	Harmful algal blooms in the water column	Only Baltic MS reporting a cyanobacteria bloom index	No index (e.g. red tides) in other marine regions	
D5C4	Coastal waters	Photic limit (transparency) of the water column	11 MSs reported TVs		WFD
D5C4	Open sea	Photic limit (transparency) of the water column	11 MSs reported TVs		WFD
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
D5C5	Open sea	Dissolved oxygen at the bottom of the water column	14 MSs reported TVs	For some regions, TVs from project results and WFD are combined with expert evaluation. D5C5 may be substituted by D5C8.	WFD
D5C6	Coastal waters	Opportunistic macroalgae of benthic habitats	3 MSs reported TVs		WFD
D5C6	Open sea	Opportunistic macroalgae of benthic habitats	None		WFD
D5C7	Coastal waters	Macrophyte communities of benthic habitats	5 MSs reported TVs	Availability of TVs across regions is challenging	WFD
D5C7	Open sea	Macrophyte communities of benthic habitats	None	Availability of TVs across regions is challenging	WFD
D5C8	Coastal waters	Macrofaunal communities of benthic habitats	9 MSs reported TVs A	Availability of TVs across regions is challenging	WFD
D5C8	Open sea	Macrofaunal communities of benthic habitats	None	Availability of TVs across regions is challenging	WFD

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)[14].

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 appropriate.
- 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 13 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.

[14] 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 13. Considerations for setting reference/threshold values for habitats 1110, 1130, 1140 and 1160

Characteristics	Variables (application)	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 (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 (QE3-1-3)	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 14 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 standardised 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 14. Some initial recommendations for setting thresholds for the proposed variables

Description	Appli-cation	Compar-ison to undis-turbed areas	Comparison to good condition areas	Hind-casting	Model-ling	Expert judge-ment	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	Appli-cation	Compar-ison to undis-turbed areas	Comparison to good condition areas	Hind-casting	Model-ling	Expert judge-ment	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	Recom-mended						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	Recom-mended						MSFD
4. Other							
Disturbance	Essential						MSFD

Dark grey: Preferred approaches; Light grey: additional approaches
*: Check Table 10 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 1).

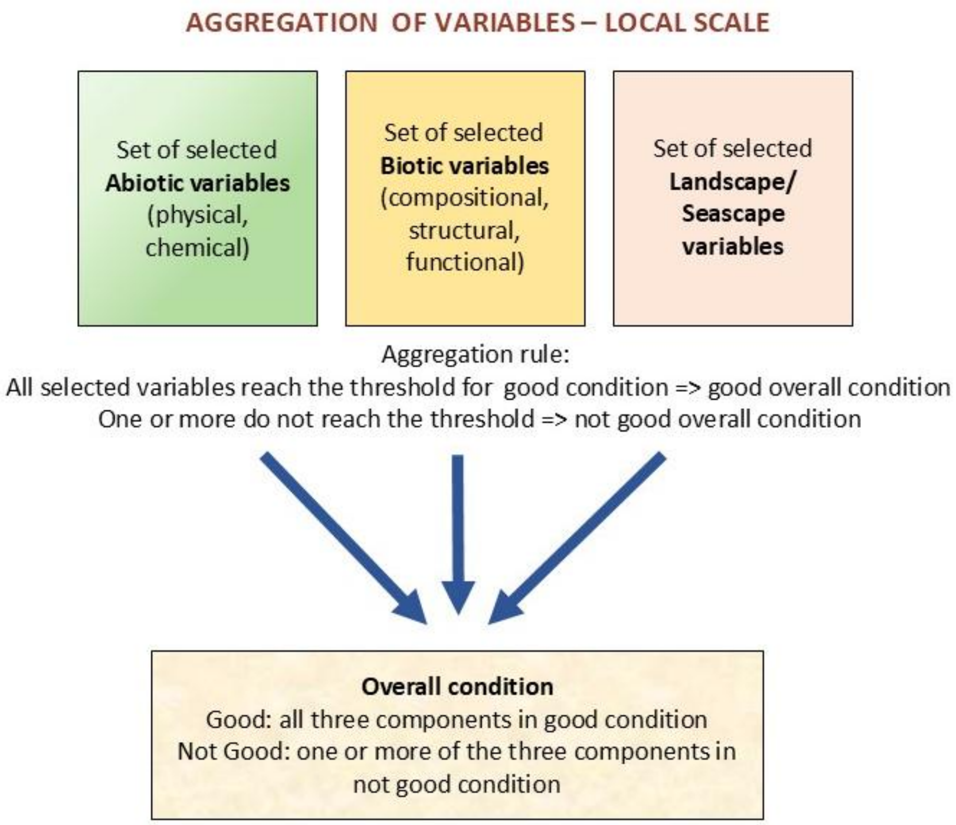
Step 1 – Aggregation of the variables measured in each group of characteristics

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 1. 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

Harmonized monitoring protocols are crucial for assessing habitat conditions across Europe. These protocols should offer standardized 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.

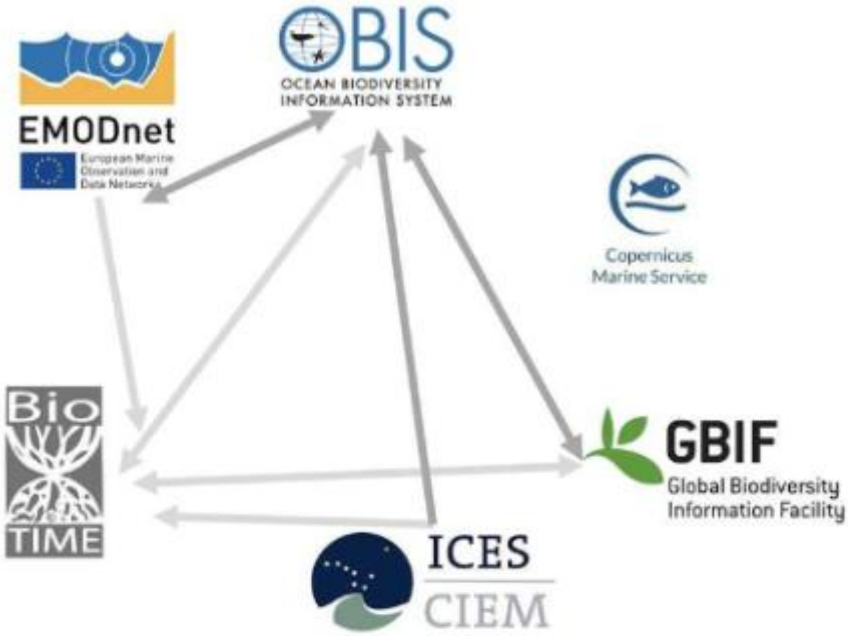
Replication and randomization:

- 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 2 (European Commission, 2023).

Figure 2. Data collection frameworks relevant to marine biodiversity in European Waters



Source: European Commission, 2023
© European Union, 2023

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

- **Biodiversa+**[15] 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**[16] 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**[17] **– 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[18]: 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),

[15] https://www.biodiversa.eu/
[16] https://europabon.org/
[17] https://op.europa.eu/en/publication-detail/-/publication/a09868c3-b721-11ed-8912-01aa75ed71a1/language-en
[18] 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)

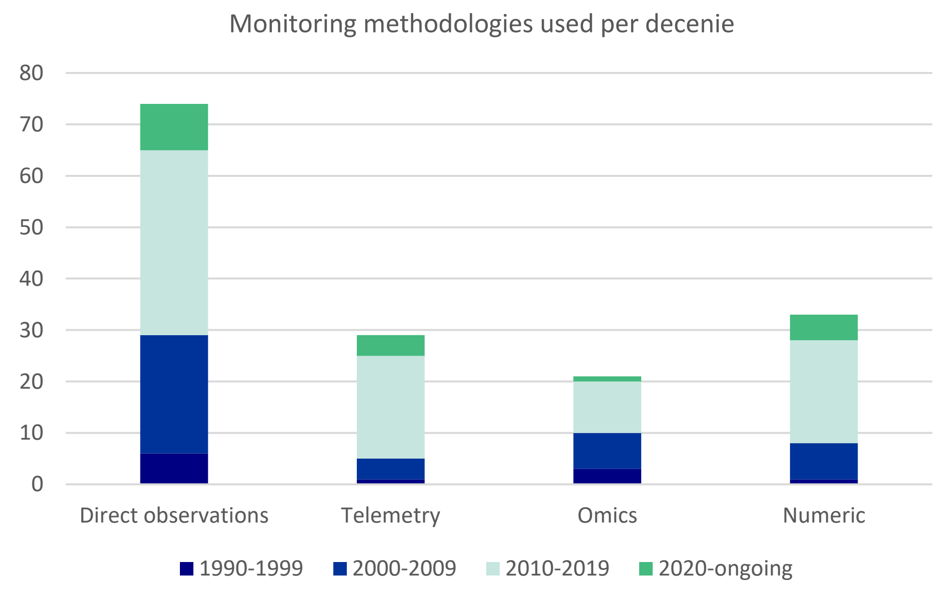
The Estuary Guide[19]: The Estuary Guide aims to provide an overview of how to identify and predict morphological change within estuaries in the UK, as a basis for sound management. It is not yet possible and, indeed, may never be possible to make absolute predictions. Rather, it is necessary to identify probable/possible outcomes, as a basis for guiding management actions.

Other countries as the United States[20], Australia[21] or New Zealand[22] 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[23] and numeric models (Figure 3) (European Commission, 2023).

Figure 3. 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.

[19] The Estuary Guide (UK): https://www.estuary-guide.net/search/estuaries/
[20] Estuarine Species Database (United States): https://coastalscience.noaa.gov/project/estuarine-species-database-noaa-estuarine-living-marine-resources-program/
[21] Australian Estuaries Database (Australia): https://fed.dcceew.gov.au/datasets/erin::australian-estuaries-database-camris/explore?location=-24.518198%2C-46.449988%2C4.51
[22] Estuaries Spatial database (New Zealand): https://www.doc.govt.nz/nature/habitats/estuaries/estuaries-spatial-database/
[23] 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 characterise 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 monitoring inlets and bays in the EU member states, comparing them with the main ecological characteristics of inlets and bays 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 inlets and bays. 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 habitat 1160 given that inlets and bays often made up of a mosaic of marine communities rather than being uniform.

A summary of the **ecological characteristics, physical and chemical characteristics and main variables** used to measure the habitat condition of inlets and bays 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 the 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 inlets and bays 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** inlets and bays, 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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