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

Mudflats and sandflats not covered by seawater at low tide (1140)

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

Mudflats and sandflats not covered by sea-water at low tide (1140)

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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

Mudflats and sandflats not covered by seawater at low tide (habitat 1140) are present in all EU Marine Regions. The most extensive examples are in the Atlantic biogeographical region in locations where there is a combination of sheltered conditions enabling deposition of sediment, gently sloping shores and significant tidal range. Due to the non-tidal nature of the Baltic Sea and the Black Sea, this habitat does not cover large areas in these two Regional Seas. In the Mediterranean, where there is a small, but regular tidal influence, this habitat type may be found within estuaries as well as within tidal lagoons.

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

A structured framework for the ecological characterization of habitat 1140 and the selection of appropriate variables for assessing their condition is set out in Section 1. Nineteen **key characteristics and corresponding variables essential for evaluating condition of the habitat** have been identified using the System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA), an international standard for ecosystem accounts adopted by the United Nations Statistical Commission (Section 1.2 and Table 1)

Nineteen Member States have reported habitat 1140 as present in their jurisdictions (BE, BG, CY, DE, DK, EE, ES, FR, GR, HR, IE, IT, LV, MT, NL, PT, RO, SE, SI). Some information has been collected about the location and description of the main characteristics of mudflats and sandflats by all the Member States that have reported habitat 1140 as present within their jurisdiction. **Specific methodologies** for assessing and monitoring intertidal flats are available from twelve Member States (BG, DE, DK, ES, FR, HR, IE, IT, NL, PL, RO, SI). There are also reports of mudflat/sandflat surveys and assessments carried out in these and other EU Member States that are relevant, and that can or have been used to inform such assessments although not directly stated as a reason for the work.

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 assemblages. Functional state characteristics are the least well covered. Primary production is specified as a monitoring programme variable in only one Member State, and there is no specific indication that food web parameters are recorded by any Member State (Table 4).

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

In most EU Member States, a common rather than habitat specific methodology is used to **aggregate data** on indicators at the local scale to provide a condition assessment at the level of the plot or monitoring locality. The Netherlands and Germany are two exceptions. No habitat specific methodologies were available on the aggregation of indexes to obtain the condition of intertidal flats at the biogeographical scale.

There is no standard approach to the identification of a number and distribution of **localities or sampling frequencies** to carry out the assessment and monitoring of intertidal flats. Practical consideration, such as accessibility are important as are factors such size, physical variability and diversity of the associated biological communities. Sampling stations may be along transects or distributed across known areas where different biotopes are present.

There is a broadly similar approach in **methodologies** used to describe and monitor this habitat type across Member States with differences in the detail depending on location, hydrographic conditions and size of the intertidal flats being monitored, the accessibility of sampling locations, and whether they are part of long-term studies. The variables monitored cover physical, chemical, composition, structural, functional, and landscape/seascape characteristics. Compositional state characteristics and in particular species and assemblages present are well represented in the monitoring schemes that were reviewed.

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 12). 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

Tidal flats exhibit a wide variety of forms. The sediments are generally composed of mud and sands; the mud content, however, is sufficiently high for the sediment to exhibit cohesive properties. Mudflats can be bounded by sandflats near the low tide mark, and above high-water neap tides by a zone of vegetation. Intertidal flats can have distinct zonation of flora and fauna which can be extremely numerous and productive (though often of low diversity) (Dyer et al., 2000). They can be extensive features, covering many square kilometres or exist in small patches with extent influenced by shore profile, exposure and tidal range.

Mudflats are usually located in the most sheltered areas of the coast where large quantities of silt from rivers are deposited in estuaries whereas sandflats occur on open coast beaches and bays where wave action or strong tidal currents prevent the deposition of finer silt (National Parks and Wildlife Services, 2007).

The Interpretation Manual description of this habitat type is (European Commission, 2013);

> "Sands and muds of the coasts of the oceans, their connected seas and associated lagoons, not covered by sea water at low tide, devoid of vascular plants, usually coated by blue algae and diatoms. They are of particular importance as feeding grounds for wildfowl and waders".

Sandflats and mudflats not covered by seawater at low tide (code 1140) are listed in the Interpretation Manual under COASTAL AND HALOPHYTIC HABITATS, and in the subcategory 'Open Sea and Tidal Areas'. This is a habitat type which can be found along sections of open coast but opportunities for development are most favourable in sheltered areas on gently sloping shores where there is a large tidal range. Consequently, the habitat is often most extensive when associated with estuaries (1130) and/or large shallow inlets and bays (1160) in the Atlantic biogeographical region.

There is some overlap in the monitoring and assessment requirements and methodologies for assessment of habitat type 1140 with habitat types 1130 and 1160. For example, the need to:

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

We consider that the methodologies used to investigate 1140 are largely a subset of those used to investigate the intertidal components of habitat types 1130 and 1160 as well as habitat of 1110 although the latter is fully subtidal. We therefore propose that whilst it is dealt with separately for the purposes of this review of the monitoring and assessment requirements, the recommendations for future action (Section 3) are presented jointly with those for habitat types 1110, 1130 and 1160.

According to the 2022 EUNIS marine habitat classification the following EUNIS habitat types (level 3) may be present as components of habitat type 1140: MA22, MA42 to MA45, MA52 to MA55, MA62 to MA 64. Of these, MA42, MA52 and MA62 are also listed in Group 7 (soft sediments above 1000m) of Annex II of the Nature Restoration Law. The broad habitat type

‘Mudflats and sandflats not covered by seawater at low tide’ is also listed in Annex 1; Group 1 -Wetlands of the Nature Restoration Law.

‘Sandflats and mudflats not covered by seawater at low tide’ have been reported from the following nineteen Member States: Belgium (BE), Bulgaria (BG), Cyprus (CY), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), France (FR), Greece (GR), Croatia (HR), Ireland (IE), Italy (IT), Latvia (LV), Malta (MT), Netherlands (NL), Portugal (PT), Romania (RO), Sweden (SE) and Slovakia (SI).

Diversity across the regions

This habitat is present in all the regional sea areas. The most extensive examples are in the **Atlantic** biogeographical region in locations where there is a combination of sheltered conditions enabling deposition of sediment, gently sloping shores and significant tidal range. The Wadden Sea, which borders the North Sea coastlines of Denmark and Germany and extends along part of the coastline of the Netherlands is, reported to be the largest unbroken system of intertidal sand and mudflats in the world[1].

Highly dynamic natural processes are uninterrupted across the vast majority of the Wadden Sea creating a variety of different barrier islands, channels, flats, gullies, saltmarshes and other coastal and sedimentary features. The area encompasses a multitude of transitional zones between land, the sea and freshwater environments, and is rich in species specially adapted to the demanding environmental conditions. The Wadden Sea is considered one of the most important areas for migratory birds in the world, and it is connected to a network of other key sites for migratory birds[2]. Other smaller examples which have developed within estuaries and bays include the Natura 2000 sites of Baie du Mont Saint Michel and the Gironde estuary in France, Doñana in Spain, the Tejo estuary in Portugal, and Dublin Bay and the Lower River Shannon in Ireland.

Due to the non-tidal nature of the **Baltic Sea** and the **Black Sea**, this habitat does not cover large areas in these two Regional Seas. Changes in sea water level are wind-induced and also partly depend on varying seasonal atmospheric pressure. The habitat is therefore only present as a very narrow strip, and is part of the hydrolittoral or mediolittoral zone which means that the sands and muds only dry out episodically (HELCOM, 2013; Zaharia, 2013). In some cases, the flats are bordered by banks of detritus including from seagrass.

In the **Mediterranean**, where there is a small, but regular tidal influence, this habitat type may be found within estuaries including the Ebro (Spain), Rhone (France) and Po (Italy) as well as within tidal lagoons such as the Ria Formosa (Portugal) and Venice lagoon (Italy). The intertidal sediments of the Ria Formosa are predominantly silts and clay, commonly covered with mats of green algae (Aníbal et al., 2007). The Ebro estuary on the NE Iberian Peninsula, by contrast, is a salt wedge or highlight stratified estuary. The substrate is predominantly sandy with the macrobenthos of the upper estuary dominated by freshwater taxa and the lower estuary by marine communities typical of shallow Mediterranean environments (Nebra et al., 2016).

[1] The Wadden Sea UNESCO World Heritage Sites extends over 1,143,403 ha. https://whc.unesco.org/en/list/1314
[2] http://world-heritage-datasheets.unep-wcmc.org/datasheet/output/site/the-wadden-sea/

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:

- Tidal range
- Exposure to currents, wave action, and scour
- Turbidity
- Sediment composition/distribution
- Water quality
- Sediment quality
- Infaunal and epifaunal assemblages
- Opportunistic/invasive species
- Associated fish, seabirds and marine mammals

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

1.2.1 Abiotic characteristics

Mudflats and sandflats are created by deposition in low energy environments therefore the degree of exposure to currents wave action and scour is key to their formation, stability and extent as well as having an influence on the formation of bedforms within the flats such as gullies and channels. Different zones can be identified depending on the tidal range and degree of submergence with the lower mudflat occurring between low spring tides and low neap tides, a middle flat between low neap tides, and high neap tides; and an upper flat between high tide and the lower saltmarsh (Dyer et al., 2000). Other attributes that can be used to classify the habitat include slope, sediment type, and exposure to waves (Dyer et al., 2000).

The hydrographical regime, including tidal, wind-induced and residual water movements, will influence the water retention properties, permeability and porosity, retention and degradation of organic matter and thus the sediment oxygen regime and redox characteristics (Elliott et al., 1998). There can be large differences in the sediment structure and density between and across mudflats with wave action transporting both mud and sand across the habitat. Intertidal flats of clean sands tend to be found in areas where wave action or strong tidal streams prevent the deposition of finer silt. Muddy sands develop where shelter from wave action is sufficient to allow the deposition of fine sediments but some water movement or the lack of supply of silt leads to a sandier substratum. Mudflats form in the most sheltered areas of coast usually where large quantities of silt derived from reivers are deposited in estuaries (Davies et al., 2001).

An important feature of this habitat is that there is a very intense coupling of biological, sedimentary and physical processes and hence of abiotic and biotic characteristics. For instance, diatom growth on mud surfaces can inhibit erosion, and macrophyte growth can aid trapping of sediment. Because of this there is likely to be considerable seasonal variation in the suspended sediment concentrations as the plants grow and die. High concentrations of mud in suspension increase the effective viscosity of the fluid and attenuate the waves, which are then less able to erode the sediment (Dyer, 1988).

Organic enrichment of the mud and sandflats by sewage and other organic discharges will impair functioning through the development of opportunistic populations and anoxic sediment which affect the composition and abundance of infauna. Such changes can also occur as a result of industrial discharges (Elliott et al., 1998).

1.2.2 Biotic characteristics

The diversity and types of communities associated with this habitat are determined particularly by sediment type together with a variety of other physical, chemical and hydrographic factors. The physical structure ranges from mobile, coarse-sand beaches on wave-exposed coasts, to stable, fine sediments in estuaries. The plant and animal communities vary according to the type of sediment, its stability and the salinity of the water and can have a distinct zonation of flora and fauna with both horizontal and vertical gradients. Upper flats are affected by the period of emersion rather than immersion and the flora and fauna have to be adapted to cope with drastic changes in temperature and salinity. Lower levels are less affected by atmospheric processes.

Mudflats are characterized by high biological productivity and abundance of organisms, but low diversity with few rare species. The main primary producers, microphytobenthos, are usually comprised of diatoms, euglenids, and cyanobacteria living in few millimetres of mudflat sediment. They can reach high levels of primary production which is also highly variable across the intertidal flats being influenced by elevation, tidal exposure, bottom shear stress and particle size of the sediment (Miller et al., 1996; Reddin et al., 2022).This makes them important feeding areas for shorebirds and some wildfowl during the low water period when the intertidal flats are exposed, and for diving ducks and fish during high water when they are submerged (Evans et al., 1999). This habitat may also act as a nursery areas for flatfish (JNCC, 2016).

The invasive species *Magallana gigas* (Pacific oyster), introduced for aquaculture but also dispersing naturally from such introductions, can colonise areas of intertidal mudflats. Where extensive their presence on the flats can change the original community structure, altering the balance of biotopes and loss of original species in intertidal areas (Mata et al., 2024). In the Wadden Sea, for example, blue mussel beds (*Mytilus edulis*) were the only major epibenthic biogenic structure on the sedimentary tidal flats until the early 2000s. Since then, *M. gigas* has become the main structural component of what are now mixed beds of mussels and oysters with mussels in the lower layers. This shift was accompanied by an increase in habitat heterogeneity due to newly constructed beds formed by the large-sized oysters. However, the associated species communities of former pure mussel beds and oyster beds are largely the same, including a high number of sessile organisms, which live directly attached to the shells of the bivalves (Buschbaum et al., 2016; Kochmann et al., 2008; Markert et al., 2010).

1.2.3 Landscape/Seascape characteristics

Intertidal mudflats and sandflats can form extensive features on gently sloping shorelines in areas where there is a large tidal range and sedimentation takes place. Large scale features may be visible such as channels through which water drains from the flats on a falling tide. They also provide a source of sediment to adjacent vegetated areas such as saltmarshes (Robins et al*.,* 2016).

Examples of variables used to measure these characteristics when reporting on the condition of habitat type 1140 are given in Table 1.

Table 1. Ecological characterisation and selection of condition variables

Ecological characteristics	Types	Description	Examples of associated variables
Abiotic characteristics	**Physical state characteristics**	Degree of submergence / depth, tidal regime	Depth in relation to chart datum Tidal range
		Topography	Physical dimensions Extent Longitude and latitudinal gradients Form
		Hydrodynamics - exposure to current, wave action, scour & surge	Current speed, direction, height, seasonal extremes
		Turbidity	Suspended particles
		Sediment composition / distribution / dynamics	Folk analysis Deposition/erosion rates & locations
	Chemical state characteristics	Salinity / freshwater influence / stratification	$^0/_{00}$
		Water quality	Various parameters: nitrates & phosphates, etc
		Sediment quality	Redox potential in bottom sediment Organic carbon in sediment % dry matter
Biotic characteristics	**Compositional state characteristics**	Epifaunal & infaunal communities, abundance and diversity of characteristic species	Number of biocenosis Presence & abundance of species (SACFO scale) Diversity indexes
		Biogenic structures	Type Extent Volume/biomass
		Presence of macrophytes / macroalgae / eelgrass	Spatial extent Taxonomic composition % cover
		Associated fish, birds & marine mammals	Abundance Distribution Population structure
		Opportunistic / invasive species	Species distribution Abundance/biomass
	Structural state characteristics	Abundance and condition of characteristic species including biogenic structures	Percentage cover Biomass Synthetic indicators (M-AMBI, BENTIX, etc)
		Condition of macrophytes / macroalgae / eelgrass	Depth limit of angiosperms Belts of fucales
	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, ^{15}N,^{34}S) Stomach content analysis
Landscape/ seascape characteristics		Connectivity / Fragmentation	% cover Patch size
Other		Disturbance	Footprint of activity

1.2.4 Ecological processes that are relevant regarding proper functioning

Currents, waves, tides, sediment availability and transport as well as the interactions between morphology, hydrodynamic processes and sediment transport are key to the location, formation and stability of mudflats and sandflats. They define physical characteristics of the habitat, such as mobility and sediment composition but also the associated species and biotopes.

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 infauna and epifauna of this habitat are characterised by communities of oligochaetes, polychaetes, crustaceans and bivalves often constituting more than 90% of the species and biomass (Gray & Elliott, 2009; McLachlan et al., 2018). The species present typically have short cycles of development that permit rapid colonisation and will vary according to the type of sediment, its stability and the salinity of the over-lying water. In areas of clean sands, the mobility of the sand and abrasion means that the species that inhabit such areas tend to be mobile and robust and include amphipod crustaceans, some polychaete worms and bivalve molluscs. Muddy sands are more stable and can support a wider range of species such as lugworms *Arenicola marina* and bivalve molluscs. Beds of the blue mussel may be present and areas of eel grass (*Zostera noltii, Z.angustifolia* and *Z.marina*). Mudflats, including areas of muddy sands often support very high densities of some infaunal species, where the high biomass of intertidal species provides an important food source for waders and wildfowl (Davies et al., 2001).

The species used to monitor the condition of this habitat differs depending on the geographical location and characteristics. Table 2 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 2. Potential species groups from which to select typical species for monitoring habitat 1140 (intertidal mudflats and sandflats)

Species group	Ecological notes	Sensitive to changes in condition
Angiosperms	Seagrass beds may be present on some mudflats. 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, (e.g. anchoring or 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.
Molluscs	Both infauna and epifauna. Benthic macrofauna have a pivotal role in the mixing, ventilation, oxygenation and irrigation of sediments (bioturbation). This improves nutrients cycling, substrate permeability, redistribution of food resources, buffering against nutrient enrichment and benthic-pelagic coupling (di Camillo et al., 2023).	Physical disturbance and changes in nutrient/organic matter levels can be indicated by monitoring species from this group. Molluscs have been used as biotic tools for ecological status assessment in the context of WFD status classification (Leshno et al., 2016; Nerlović et al., 2011), as ecological indicators (La Valle et al., 2011) and bioindicators of environmental contamination (Coelho et al., 2014; Velez et al., 2016). E.g., *Corbula gibba* has been proposed as a proxy of eutrophication with distribution influenced by *Chl a* (Moraitis et al., 2018).
Polychaetes	Reef building species (*Sabellaria alveolata* 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., 2005; Wrede et al., 2017).	Physical disturbance and changes in nutrient/organic matter levels can be indicated by monitoring species from this group.
Seagrass	Intertidal species.	Water quality, productivity.
Fish	Intertidal flats are important feeding grounds as well as nursery and spawning areas for some species of fish such as the Lesser weever *Echiichtyhys vipera* (Ellis et al., 2011), 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/increase in number of individuals, biomass, average size and age, as well as an expansion or contraction of their distribution range over time.
Seals	Feeding and using drying areas as haul out sites.	Human disturbance.
Birds	Resident and migratory waders, wildfowl feed and roost mudflats and sandflats.	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 mudflats and sandflats by all the Member States that have reported habitat 1140 as present within their jurisdiction[3]. Specific methodologies for assessing and monitoring intertidal flats are available from twelve Member States (BG, DE, DK, ES, FR, HR, IE, IT, NL, PL, RO, SI). There are also reports of intertidal surveys and assessments carried out in these and other EU Member States that are relevant, and that can or have been used to inform such assessments although not directly stated as a reason for the work (e.g. surveys carried out in Belgium (Bertels et al., 2011), the Netherlands (Conley et al., 2000; Chowdhury et al., 2023; Nascimento et al., 2021)[4] and Estonia (Torn et al., 2017). 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 the condition of habitat 1140 is presented in Table 1. Examples of the characteristics and variables used by Member States to report on intertidal flats, as part of the assessment of their conservation status are presented in Table 3 and a summary analysis is given in Table 4.

Table 4 shows that whilst the monitoring and assessment programmes from twelve Member States cover abiotic, biotic, landscape and other characteristics there are differences in emphasis. Seven of the twelve Member States that report on mudflats and sandflats specifically mention monitoring variables relating to the **physical characteristics** of the habitat. Of these, 'sediment composition and distribution' and 'topographical features' are most frequency covered. **Chemical characteristics** (water and sediment quality) are specifically mentioned by around half the Member States.

Biotic characteristics are well represented in the monitoring programmes being specifically mentioned by all twelve Member States that report on this habitat. The most frequently cited are 'epifaunal and infaunal assemblages', and 'abundance and condition of characteristic species. Nine Member States specifically refer to monitoring macrophytes/macroalgae or eelgrass and whilst only one Member State (Denmark) makes specific mention of monitoring seals it is likely associated fish, birds and marine mammals, as well as vegetation may be considered by other Member States in their more general reporting of the abundance and condition of species.

Structural state characteristics are monitored by eight 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 one Member State specifically refers 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**.

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

[4] Eg. Estuarine monitoring in Flanders, Belgium https://www.gbif.org/dataset/702973cf-6935-45bf-ba31-cecee3571cf9

Table 3. Examples of variables used by Member States to assess condition of habitat 1140 (intertidal mudflats and sandflats)

Description	Examples of variables used by Member States	Notes
1. Abiotic characteristics		
1.1 Physical state characteristics		
Degree of submergence/depth/tidal regime	IT – morphobathymetry NL - tidal dynamics, morphodynamics 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 1140 is present (e.g. in the SDFs).
Topography	DE – morphology unchanged/slightly changed/disturbed NL - Morphodynamics	The gross morphology of habitat 1140 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	BE (Flanders) - Balance between basin storage and hydrodynamics	Whilst not necessarily highlighted in the assessment methodologies, these characteristics are typically included in the descriptions of the relevant Natura 2000 sites (e.g. SDFs) although the information may be very general.
Turbidity	RO - water transparency	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	DE - sediment distribution (e.g. proportion of mudflats) IE - proportion of grain size classes IT - particle size analysis RO - sediment particle diameter	Sandy or muddy sediments dominate habitat type 1140 by virtue of the definition but there may also be areas where finer or coarser sediment and even rocky outcrops are present. The distribution of sediments is unlikely to be static and it also has a major influence on the associated infauna and epifauna.
1.2 Chemical state characteristics		
Salinity/freshwater influence/stratification	ES - salinity and conductivity mg/l NL - salt dynamics RO - water salinity	Measurements of this variable is not specifically mentioned in most methodologies examined but is likely to be included in any water quality sampling.
Water quality	BG - Dissolved O_2 - mg/dm^3, O_2 saturation % ES - dissolved O_2 at surface and depth; mg/l nitrate, ammonium and phosphate water and sediment samples RO - nutrient status/concentration	Measurements of this variable is not specifically mentioned in all the methodologies examined but is likely to be included in any water quality sampling.
Sediment quality	FR - thickness of oxidised layer of silt. IT - nutrients in sediments PL - redox (bottom sediments)	Measurements of this variable is not specifically mentioned in the methodologies examined but is likely to be included in sediment sampling (see above).

Description	Examples of variables used by Member States	Notes
2. Biotic characteristics		
2.1 Compositional state characteristics		
Invertebrates - Epifaunal & infaunal assemblages	DE - completeness of habitat typical species inventory ES - benthic macroinvertebrates, number of taxa FR - presence/absence of characteristic species HR - abundance and coverage of species (Braun-Blanque method) IE - number of marine community types IT - presence of benthic macrofauna NL - number of species RO - number and abundance of identified species	These characteristics are reported in most of 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	IE - number and area of keystone species RO - biocenoses types	These characteristics are not highlighted in all the methodologies examined but may by picked up in surveys of epifaunal and infaunal assemblages (see above).
Macrophytes, macroalgae, eel-grass	DE - macroalgae cover DK – macroalgae species and % cover FR - presence/absence, volume and % coastline covered IT - presence of vegetation SI - presence of characteristic plant species	These characteristics are not highlighted in all the methodologies examined but if present are likely to also be picked up in surveys of characteristic species (see above).
Vertebrates - Associated fish, birds & marine mammals	DK – population estimates of seals	These characteristics are not necessarily mentioned specifically in assessment methodologies but may be picked up during surveys to record species present. This is especially the case in locations that are important resting, foraging or feeding area for fish birds, and marine mammals.
Opportunistic/invasive species	FR - % area covered by opportunist green algae (Enteromorpha, Cladophora, Ulva)	This characteristic is likely to be picked up in general species monitoring which is possibly the reason why it is not singled out for reporting in many methodologies. Specific guidance to do so is more to be expected in locations where it is considered likely to be a significant threat to habitat condition.

Description	Examples of variables used by Member States	Notes
2.2 Structural state characteristics		
Characteristic species condition including biogenic structures	HR - abundance and coverage of species NL - number of qualifying structural elements	These characteristics are frequently recorded, but the methodologies examined reveal some variation in the variables measured. They include abundance (e.g. % cover or biomass) and density.
Macrophytes, macroalgae, eel-grass	FR - presence/absence species associated with wrack zones	Several Member States make specific mention of monitoring variables for this characteristic. It may also be picked up under reporting of the 'abundance and condition of characteristic species' (see above).
2.3 Functional state characteristics		
Primary production	RO – extent of phytoplankton	
3. Landscape/seascape characteristics		
Connectivity/ Fragmentation	BG - % of anthropogenic structures fragmenting recording polygons RO - relative distribution of habitat sub-types	
4. Other		
Disturbance	DE - sediment extraction, shipping, leisure uses etc. FR - presence/absence of artificial structures and assessment of % of artificial areas IE - number of negative pressures (by intensity)	There are various approaches to assessing disturbance. In some cases, there is a focus on specific activities (e.g. footprint) and in others disturbance is gauged by reporting any resulting changes (e.g. changes in sediment structure, presence of hazardous substances).

Table 4. 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	DK	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 (km^2), degrees of slope (°), physical features from a reference list.												
Hydrodynamics - Exposure to current, wave action, scour & surge,	Current speed; direction; height; seasonal extremes	Current speed (Knots) direction, height and extremes (m).												
Turbidity	Suspended particles; light transmission through water; 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. Changes in % cover of different sediment fractions, sediment depth (mm) and rates of change (mm/year, -g/m^2).												

Ecological characteristics	Variables	Metrics	BG	DE	DK	ES	FR	HR	IE	IT	NL	PL	RO	SI
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, g MO(MS)/ m^2/day .												
2. Biotic characteristics														
2.1 Compositional state characteristics														
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), estimated % cover.												
Associated fish, birds & marine mammals	Abundance and diversity of characteristic species from standardised lists.	Number, population structure, trophic composition (eg. % omnivores/piscivores), distribution.												
Macrophytes, macroalgae, eelgrass	Type; abundance; extent	Biomass, estimated % cover.												
Opportunistic/invasive species	Species distribution Species abundance / biomass	Biomass, estimated % cover.												

Ecological characteristics	Variables	Metrics	BG	DE	DK	ES	FR	HR	IE	IT	NL	PL	RO	SI
2.2 Structural state characteristics														
Characteristic species including bio-genic structures	Abundance & condition, volume / biomass / frag-mentation	Percentage cover, biomass, density. Synthetic indicators (M-AMBI, BENTIX etc).												
Macrophytes, macroalgae, eelgrass	Condition; biomass; esti-mated % cover	Spatial extent (area and depth), taxo-nomic composition, % cover of sub-strate, density (no/m^2), biomass (dry weight/m^2) eelgrass average leaf length & width, leaf & rhizome bio-mass.												
2.3 Functional state characteristics														
Primary production	Frequency / longevity / strength of plankton blooms	Concentration of chlorophyll a (µg/ l), phytoplankton species, cyanobacteria volume.												
3. Landscape/Seascape characteristics														
Connectivity / Fragmentation	Continuous, fragmented, presence of anthropogenic structures and their % cover.	% cover, patch size.												
4. Other														
Disturbance	Footprint of activity	Presence / absence, Length of modi-fied banks (m), % area directly af-fected by human activity (e.g. by de-mersal fisheries or sand extraction, anthropogenic structures).												

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

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

Table 5. Example of survey methods used to investigate some of the key characteristics of habitat type 1140 (intertidal mudflats and sandbanks)

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
Hydrology - Tidal range/ currents/wave action	Hydrographic charts, modelling, aerial survey (Satellite/Drone imagery), Current meters (ADCP).
Salinity/stratification	Water chemistry data loggers
Turbidity/Sedimentation	Secchi disc, water chemistry data loggers, satellite data, sediment sampling, sediment traps
Oxygen levels	Water chemistry data loggers
Primary production	Chlorophyll A concentrations, sediment organic carbon concentrations, abundance/biomass data
Food webs	Stable isotopes (^{13}C, ^{5}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
Associated fish, seabirds, marine mammals	Visual census, aerial and boat-based surveys
Macrophytes/macroalgae	Photographic quadrats, video transects, visual census, direct sampling
Invertebrates - Epifaunal & infaunal assemblages	Photographic quadrats, video transects, visual census, drone imagery, direct sampling (grab, core). Multicorer or boxcorer to collect sediment samples for quantitative biological and trophic analyses

Some studies monitor and report on changes over a period of years, one example being data collection from ten marsh-mudflat sites in the Netherlands, Belgium and the UK. Multiple sensors were deployed for 9-20 months to give spatial and temporal coverage of changes in bed levels to understand the development of the intertidal habitat. This was synchronised with hydrodynamic data and measurements of chlorophyll *a* to reveal changes over daily as well as seasonal cycles (Hu et al., 2021). In the Danish Wadden Sea comparative studies of the macro zoobenthos of an intertidal mudflat the macrozoobenthos first investigated in the 1930s are another example (Jensen, 1992).

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 mudflats and sandflats are variously; very specific, based on trends, use indices, rely on expert judgement or any combination of these. Table 6 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 6. Examples of reference values and approaches used for intertidal mudflats and sandflats

Example of variable used	Method / metric and reference values	Country: Reference
Qualitative		
Marine community types	Area of marine community types; FV = ≥90% (of area shows) no change; U1 = 90-76% (of area shows) no change; U2 = ≤75% (of area) show(s) no change	Ireland: Scally et al., 2020
Nutrients	Nitrate, ammonium and phosphate from water and sediment samples, 1-6 Ultraoligotrophic, 6-10 Oligotrophic, 10-60 Mesotrophic, 60-100 Eutrophic	Spain: Morales et al., 2009
Habitat fragmentation	Presence of new fragmenting anthropogenic structures occupying up to 1% of the monitored polygons at the biogeographical level (FV), from 1.1% to 10% (U1), more than 10.1% (U2)	Bulgaria: MOEW, 2013[5]
Indices / Additional		
State of health of seagrass	Assessment of extent, density, leaf surface and biomass in quadrats of 0.1m^2 (4 replicates). one of the measures is degree of fragmentation. Proportion of sediment relative to the full extent of the area of seagrass - homogeneous (large and uniform within interruption) fragmented, or very fragmented	France: Lepareur, 2011
Number of species	Inventory of species from 3 species groups. 'High': if at least 8 qualifying species occur from at least two species groups; 'Middle': if 4-7 qualifying species occur; 'Low': if the criteria of the 'High' or 'Medium' classes are not met.	Netherlands: Bijlage, 2021
Scoring		
Assessment of function	Scoring for water quality, processes (variation in hydrodynamics not affected), connectivity/area (nursery function for N. Sea fish species not affected) and rest/food (disruption of resting and foraging functions for birds and marine mammals).	Netherlands: Jansen et al. 2014
Linked to other programmes – e.g. WFD, MSFD, OBV		
Various in Wadden sea Quality status report	Thematic reports include habitats and communities. E.g. seagrass, beds of blue mussels and pacific oysters and macrozoobenthos	Wadden Sea: Kloepper et al. 2017
Various in Scheldt monitor	Yearly reports on available scientific data for the Scheldt estuary, MONEOS reports (monitoring activities), six yearly evaluation reports (T-reports), development of 18 indicators for Long Term Vision Objectives. The latter include indicators that are directly relevant to monitoring and assessment for the Habitats Directive e.g. threats to biodiversity and the status of species and habitats.	Belgium / Netherlands[6]

[5] Information system for protected areas from the ecological network Natura 2000 – Bulgaria: https://natura2000.egov.bg/EsriBg.Natura.Public.Web.App/Home/Reports?reportType%20=Habitats

[6] Indicators of the Long term vision 2030 (LTV) for the Scheldt estuary: https://www.scheldemonitor.org/en/indicatoren.php

Example of variable used	Method / metric and reference values	Country: Reference
Trend + indices		
Presence/absence of keystone communities e.g. *Zostera* along video transect or walkover sites.	Change in *Zostera*-dominated community complex with reference to shoot density, fragmentation, physical damage, siltation or epiphytes on leaf blade, invasive alien species and opportunistic species. Favourable if >90% of keystone communities show not change, unfavourable - inadequate (90-76%) no change, and unfavourable bad if (75% or less show no change)	Ireland: Scally et al., 2020
Sediment characteristics	Change in the proportion of grain size classes that would result in change in classification of the sediment type, other than through natural processes. FV if >75% of stations with not change, U1 (74-51%) no change, and U2 if (50% or less show no change)	Ireland: Scally et al., 2020
Expert judgement		
Sediment supply	If available use data and assessment from WFD monitoring. If not, categorise as 'undisturbed', 'anthropogenically slightly disturbed' or 'heavily anthropogenically disturbed'	Germany: Krause et al., 2008
Disturbance; Macroalgae cover	Level of impairment of the tidal flat bottom due to excessive macroalgae cover – none, minor or severe degradation.	Germany: Krause et al., 2008
Under development		
Structural elements e.g. mudflats and sand, shellfish beds, seagrass and *Ruppia* fields	'High' if at least 3 qualifying structural elements are present. 'Medium' if 2-3 structural elements present, and 'Low' if criteria for 'High' and 'Medium' are not met. The final benchmark will be based more on the Water Framework Directive	Netherlands: Bijlage, 2021

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. 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.

2.3 Aggregation methods at the local scale

In most EU Member States, a generic rather than habitat specific methodology is used to aggregate data on indicators at the local scale to provide a condition assessment at the level of the plot or monitoring locality. For example, a general approach taken in France is illustrated in Box 1.

Box 1. Aggregation of indicators at a local scale - France

In France, for evaluation at the scale of Natura 2000 sites three parameters (surface, structure and functions and alterations) are assessed against several criteria, themselves represented by one or more indicators filled in or calculated from metrics collected in the field. In this "PatriNat" method, each indicator assessed is compared with a threshold value.Then each indicator is given a score (negative or zero) which is subtracted from the starting score of 100. A good indicator score will result in few points being subtracted, and a bad indicator score will result in more points being subtracted. Final scores indicate the overall status along a gradient (Table 7 & Figure 1 below).

Table 7. Example of scoring for three indicators A, B, C presenting different response modalities (from Delavenne & de Bettignies, 2023 and Lepareur et al., 2018)

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

Figure 1. Determination of conservation status based on its overall score

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

The Netherlands has developed a scoring system which brings together the findings on structure and function of Natura 2000 site designated for their intertidal mudflats and sandflats. They include areas in the Wadden Sea, Dunes and low land Texel, and the North Sea Coastal Zone. Scores are allocated under various headings (Table 8) and the total gives a score for that habitat for each of the applicable Netherlands Natura 2000 sites (Janssen et al., 2014).

Table 8. Scoring system for structure and function of intertidal mudflats and sandflats used by the Netherlands

Note that in the publication 1140A regards Mudflats and sandbanks in the tidal area of Wadden Sea, and 1140B regards Mudflats and sandbanks in the tidal area of the North Sea coastal zone

I. Structure **(H1140A: a = 7-6 points, b = 5-4-3 points, c = 2-1-0 points** **H1140B: a = 4 points, b = 3-2 points, c = 1-0 points)**	**II. Function** **(a = 5-4 points, b = 3-2 points, c = 1-0 points)**
A: Structure-determining species 1 point = presence of seagrass and/or *Ruppia* fields (H1140A) 1 point = presence of shellfish concentrations at all suitable locations (H1140A) 1 point = presence of mussel beds of different ages (H1140A) 1 point = presence of concentrations of tube worms at suitable locations **B. Internal structure** 1 point = sufficient supply of sediment guaranteed 1 point = variation in sediment composition not affected 1 point = variation in water depth not affected **C. Landscape setting:** *not used* **D. Fauna:** *not used*	**A. Water** 1 point = good water quality (no high concentration of fertilizers and toxins) 1 point = oxygen deficiency is limited to natural depth **B. Air**: *not used* **C. Soil:** *treated under structure* **D. Processes** 1 point = variation in hydrodynamics (due to wave action or tidal currents) not affected **E. Connectivity/Surface** 1 point = nursery function for North Sea fish species not affected **F. Rest/Food** 1 point = no disruption of resting and foraging function for birds and marine mammals

In **Germany**, the focus is on sediments, hydrology, morphology together with seagrass (if present) and with reference to a habitat-typical species inventory if present. The assessment is qualitative, using expert judgement (Table 9) (Krause et al*.*, 2008).

Table 9. Criteria and evaluating scheme for assessing the conservation status of habitat 1140 in Germany

	A. Excellent expression	**B. Good expression**	**C. Medium to poor expression**
Completeness of habitat structures typical of the habitat	**Present**	**Largely present**	**Only partially present**
Sediment structures and distribution	Natural to near-natural characteristics of the sediment structure and the distribution of mud, sand and mixed mudflats	Characteristic structures intact, but slightly changed in terms of sediment distribution (e.g. reduced mudflat proportion)	Characteristic structures severely restricted, strong change in sediment distribution (e.g. mudflats only present in fragments)
Sediment supply	Undisturbed	Sediment balance slightly disturbed by anthropogenic factors	Sediment balance severely disturbed by anthropogenic factors

	A. Excellent expression	B. Good expression	C. Medium to poor expression
Oxidation layer	Typical sediment, natural to near-natural appearance	Slightly changed	Redox layer close (a few mm) under the sediment surface
Hydrology and morphology	Natural, unchanged	Slightly changed	Disturbed
Seagrass populations (if present)	Natural to near-natural development of the seagrass meadows	Slightly changed	Fragmentary development or former occurrence extinct
Where available, adoption of suitable basic data and assessments from monitoring for the WFD			

2.4 Aggregation at biogeographical scale

To assess 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 standardised approach across the Member States regarding the number and distribution of localities to carry out the assessment and monitoring of this habitat.

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 types of habitats 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.

For tidal flats associated with estuaries it is recommended that monitoring points are in each area of influence (river, mixed and marine). For tidal flats associated with bays and coastal lagoons at least two sampling stations are recommended (La Mesa, 2019).

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.

Where the habitat is extensive sampling protocols may be needed within each site to assess the condition of the whole feature. A stratified approach may be adopted for extensive sites where the available resources only permit a few locations to be investigated in detail and the results must be extrapolated to the whole site. This should include a series of 'spot checks' throughout the site to ensure that any extrapolated results are representative of the condition of the entire site (Davies et al., 2001). Sampling/recording along transects also helps to build a picture of the extent, distribution, and other characteristics of the biotopes and sediment characteristics of intertidal mudflats and sandflats.

In **Italy** 3-yearly surveys are recommended to record the extent of the habitat, variations and possible colonisation by plant species. The survey period should be from the beginning of May to the end of October and surveys carried out during exceptionally low tides. The survey frequency should be annual, varying the position of the survey areas from year to year, returning to the same area once every 3 years. Survey sites should be selected using existing cartographic data, on a regional scale so as to be representative of different environmental conditions and impacts of different intensities, taking into account the monitoring already being carried out e.g. for the WFD (La Mesa, 2019).

In **Spain**, evaluation is carried out in accordance with WFD criteria although work is also being carried out to establish optimal quality conditions that serve as a reference in each type of water body. Several sampling points are established in each area of community of importance. At each point all biological and physical-chemical factors are to be determined periodically with the frequency depending on what is being investigated and the perceived level of risk based on pressures and impacts (Table 10). It is also necessary to take into account that different measurements must be made throughout the year, taking into account the biological cycles of the species (Morales et al., 2009).

Table 10. Periodicity in sampling physical-chemical and biological parameters in tidal flats

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

	Biological			Physical-Chemical
	Macro-invertebrates	Macrophytes	Phytobenthos	
No risk*	2 years	2 years	2 years	Seasonal
At risk*	1 year	1 year	1 year	Monthly

Where several countries are involved, there may be differences in the detailed methodology. This is the case with monitoring seagrass in the Wadden Sea where, because the spatial distribution as well as size and density of the intertidal seagrass beds are extremely uneven, different monitoring methods are used in the Netherlands, Lower Saxony, Schleswig Holstein, and Danish parts of the Wadden Sea (Dolch et al., 2017).

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 intertidal flats which overlap with monitoring requirements under the Water Framework Directive (WFD) as they may occur in 'transitional waters' (most likely fringing estuaries). Under WFD this requires monitoring of phytoplankton, macrophytes, benthic invertebrates, and ichthyofauna. Monitoring for the Habitats Directive may therefore be additional. This is the case in Denmark, for example, which has a "supplementary control monitoring programme" for seas and fjords (Miljøstyrelsen, 2022). The reverse also applies with monitoring data collected for the Habitats Directive used to inform other initiatives, one example being in the Wadden Sea Quality Status Reports (Kloepper et al., 2017).

2.7 Other relevant methodologies

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

They include;

- Work carried through Regional Seas Programmes such as the Quality Status Reports prepared by OSPAR and HELCOM and monitoring measures for Specially Protected Areas under the Barcelona Convention[7]
- The Trilateral Monitoring and Assessment Programme for the Wadden Sea, carried out by the Netherlands, Germany and Denmark[8].
- Reporting under other EU Directives, in particular the Water Framework Directive and the Marine Strategy Framework Directive[9].
- Surveys/monitoring of developments/human activities/EIAs

Traditional on the ground surveying techniques are increasingly being supported by remote sensing as a means of provide topography maps more frequently with a lower cost and higher coverage. Interpretation methods are also evolving. For example, an automated derivation of Digital Elevation Models from spaceborne remote sensing as trailed on Arcachon Bay and the Bay of Veys on the French coast (Salameh et al.,2020). In Portugal aerial imagery collected by a UAV has been used in conjunction with an unmanned ground vehicle with a drilling tool, making up a "robotic team" to take sediment cores from the intertidal mudflats of the Tagus albeit guided by a human expert (Deusdado et al., 2016).

The potential for information derived from Environmental DNA (eDNA) to become an additional monitoring tool in estuaries is a developing field and would incorporate data from intertidal flats where they are present bordering estuaries. This methodology can be used to detect single or a small number of species, or on whole communities of species. A trial, using the San

[7] Eg.https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/intertidal-mudflats/
[8] https://www.waddensea-secretariat.org/trilateral-monitoring-and-assessment-programme-tmap
[9] 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

Francisco Estuary (California, USA) as an example was conducted to see if it could assist modernising the monitoring of this estuary which is subject to multiple monitoring programmes collected by several agencies (Nagarajan et al., 2022). A number of potential management questions that could benefit from eDNA based sampling were identified (Table 11) (Nagarajan et al., 2022), although it was also recognised that there were limitations in using this technique at present. For example, eDNA assays are not available for all the species of most concern, identified by the various agencies.

Table 11. Potential management questions that could benefit from eDNA-based sampling

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

2.8 Conclusions

Some information has been collected about the location and description of the main characteristics of mudflats and sandflats by all the Member States that have reported habitat 1140 as present within their jurisdiction. Specific methodologies for assessing and monitoring intertidal flats are available from twelve Member States (BG, DE, DK, ES, FR, HR, IE, IT, NL, PL, RO, SI). There are also reports of intertidal surveys and assessments carried out in these and other EU Member States that are relevant, and that can or have been used to inform such assessments although not directly stated as a reason for the work. They include work carried through Regional Seas Programmes such as the Quality Status Reports prepared by OSPAR and HELCOM, the Trilateral monitoring and Assessment Programme for the Wadden Sea, and reporting for the Water Framework Directive and the Marine Strategy Framework Directive.

There is a broadly similar approach to describing and monitoring this habitat type across Member States with differences in the detail depending on location, hydrographic conditions and size of the intertidal flats being monitored, the accessibility of sampling locations, and whether they are part of long-term studies. The variables monitored cover physical, chemical, composition, structural, functional, and landscape/seascape characteristics. Compositional state characteristics and in particular species and assemblages present are well represented in the monitoring schemes that were reviewed.

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

In most EU Member States, a common rather than habitat specific methodology is used to aggregate data on indicators at the local scale to provide a condition assessment at the level of the plot or monitoring locality. The Netherlands and Germany are two exceptions. No habitat specific methodologies were available on the aggregation of indexes to obtain the condition of intertidal flats at the biogeographical scale.

There is no standard approach to the identification of a number and distribution of localities to carry out the assessment and monitoring of intertidal flats. Practical consideration, such as accessibility are important as are factors such size, physical variability and diversity of the associated biological communities. Sampling stations may be along transects, or distributed across known areas where different biotopes are present.

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 intertidal flats specifically for Habitats Directive reporting is more frequent (e.g. 3 yearly or even annually). Relevant data collected under other programme (e.g. WFD, MSFD and any regional/national schemes) are also used as and when they become available. This is especially relevant in the case of intertidal flats in 'transitional waters' which overlap with monitoring requirements under the Water Framework Directive.

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 with 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 12. '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 biogeographical as good condition of the same habitat may vary across biogeographical regions. Salinity is a good example of this given the different salinity profiles of the different Regional Seas.

Table 12 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 12 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 12. Proposals for essential, recommended and specific condition variables for habitats 1110, 1130, 1140, and 1160

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The analysis carried out by Borja et al. (2012) (summarized in Table 13) 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 13) was that whilst using pristine or minimally impacted conditions was the best single method, others were also adequate when combined with expert judgement.

Table 13. 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 professional 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 (MSFD) 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 2)[10].

[10] 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 2. 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 14 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 14. Agreed thresholds setting methods and values for Descriptor 5 (Eutrophication) criteria

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

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

The Water Framework Directive (WFD) requires Member States to protect and where necessary restore water bodies in order to reach good status (chemical and ecological) and to prevent deterioration. Standards for priority substances and certain other pollutants are set out in the Environmental Quality Standards Directive (2008/105/EC)[11].

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

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

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

Table 15 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.

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

Characteristics	Variables	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/ Thresholds	Relevant MSFD Descriptors
1. Abiotic characteristics					
1.1 Physical state characteristics					
Degree of sub-mergence / 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	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	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/ Thresholds	Relevant MSFD Descriptors
Sediment com-position / distri-bution / dynam-ics	**-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 dif-ficult 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 / fresh-water 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 (in-cluding chemicals listed in the WFD and EQSD, nitrates & phosphates, oxygen, chlo-rophyll, dissolved solids)**	Quantitative, Trend, Indices, linked to WFD	The parameters and Environmental Quality Standards that apply under the WFD for transitional waters (e.g. in relation to chemical and physico-chemical quality elements) are particularly relevant to determining water quality for this cluster of habitats and are already being used as reference values/thresholds by Member States.	QE3 (QE3-1)	D5, D8
Sediment quality	**- Inorganic and organic chemical contaminants - Organic carbon**	Quantitative, Trend, Indices, Scoring			D8
Oxygen levels	**- Oxygen levels measured at surface and depth.**	Quantitative, Trend, linked to WFD	The parameters and Environmental Quality Standards that apply under the WFD for transitional waters (eg. in relation to chemical and physico-chemical quality elements) are particularly relevant to determining water quality for this cluster of habitats and are already being used as reference values/thresholds by Member States.	QE3 (QE3-1-3)	D5

Characteristics	Variables	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	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	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 16 indicates possible approaches for establishing thresholds and reference values applicable to the proposed variables, based on the procedures followed by Member States and the existing literature. A combination of approaches is suggested to better inform the setting of reference levels or thresholds, given the degree of uncertainty when setting reference levels. The different approaches described are not exclusive, they are often combined. For example, expert judgement is necessary when establishing reference cases for good condition or for certain decisions on modelling the relationship between variables and condition. Modelling-based approaches complement those based on good condition or undisturbed cases and can also be combined with statistical approaches.

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

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

Table 16. Some initial recommendations for setting thresholds for the proposed variables

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

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

Dark grey: Preferred approaches; Light grey: additional approaches
*: Check Table 12 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 2).

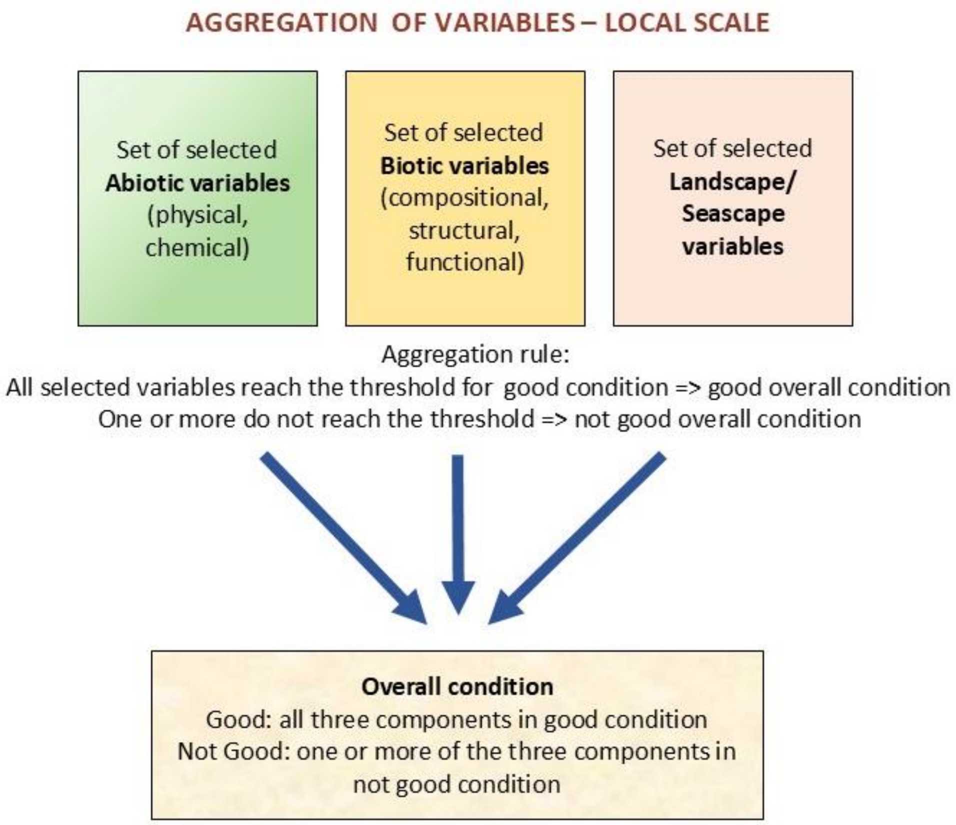
Step 1 – Aggregation of the variables measured in each group of characteristics

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 2. 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.

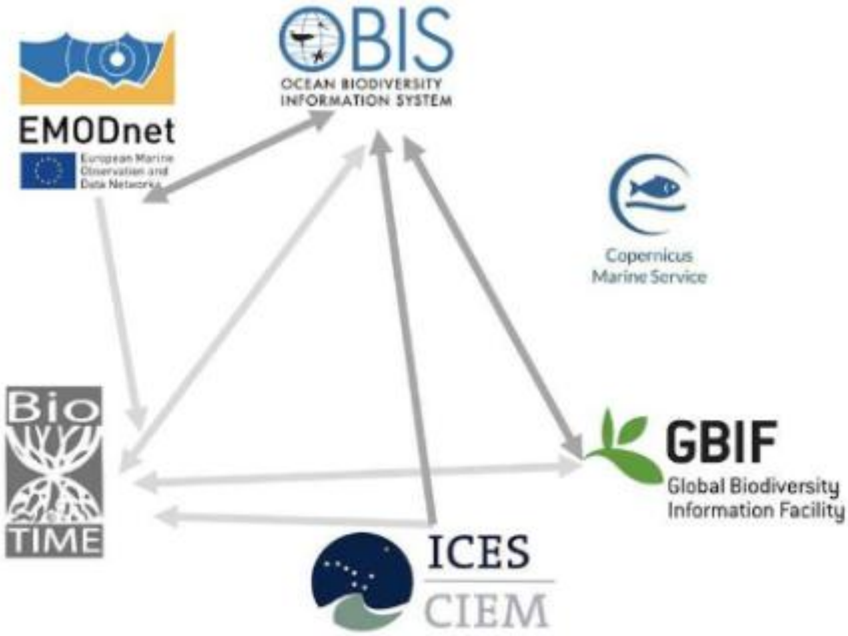
Replication and randomization:

- 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 3 (European Commission, 2023).

Figure 3. Data collection frameworks relevant to marine biodiversity in European Waters



Source: European Commission, 2023

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

- **Biodiversa+**[12] 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**[13] 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**[14] **– 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[15]: 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),

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

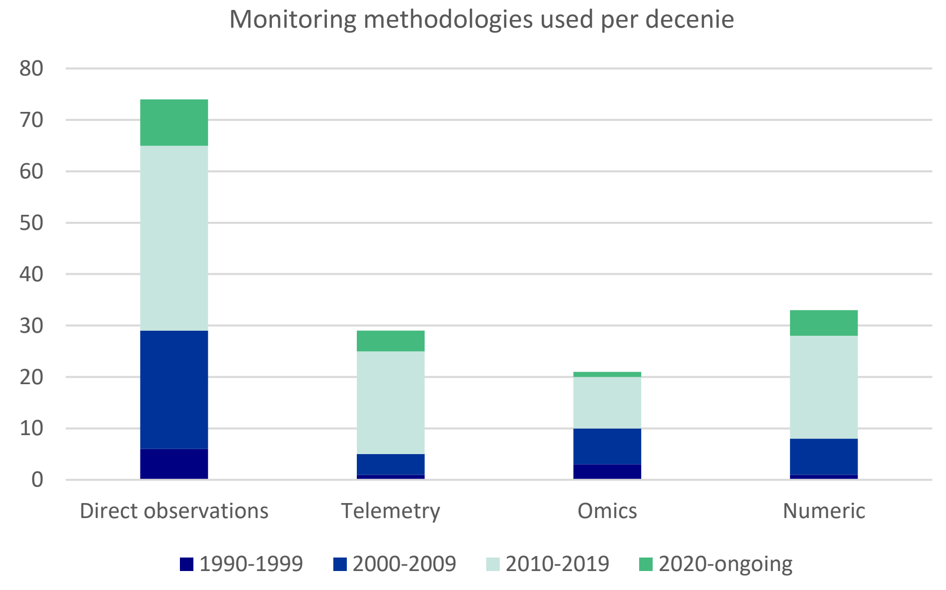
The Estuary Guide[16]: The Estuary Guide aims to provide an overview of how to identify and predict morphological change within estuaries in the UK, as a basis for sound management. It is not yet possible and, indeed, may never be possible to make absolute predictions. Rather, it is necessary to identify probable/possible outcomes, as a basis for guiding management actions.

Other countries as the United States[17], Australia[18] or New Zealand[19] 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[20] and numeric models (Figure 4) (European Commission, 2023).

Figure 4. 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.

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

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

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

4 Guidelines to assess fragmentation at appropriate scales

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

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

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

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

Fragmentation metrics

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

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

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

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

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

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

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

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

5 Next steps to address future needs

This document provided an analysis of the methodologies used for monitoring mudflats and sandflats in the EU Member States, comparing them with the main ecological characteristics of mudflats and sandflats, 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 mudflats. 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 mudflats given that they may be made up of a mosaic of marine communities rather than being uniform.

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

The **reference values and thresholds** applied by Member States to obtain condition indicators for mudflats and sandflats are variously; very specific, based on trends, use indices, 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** mudflats and sandflats 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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