European Commission

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

Reefs (1170)

ATECMA

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Reefs (1170)

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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

Reefs (habitat 1170) are present in all EU Marine Regions. A general description, including listing of the main sub-types and distinguishing between geogenic and biogenic reefs 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.

A structured framework for the ecological characterization of habitat 1170 and the selection of appropriate variables for assessing their condition is set out in Section 1. Seventeen **key characteristics and corresponding variables essential for evaluating condition** of the habitat have been identified using the System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA), an international standard for ecosystem accounts adopted by the United Nations Statistical Commission (Section 1.2 and Table 2).

All twenty-two Member States that have reported habitat 1170 as present in their jurisdictions provide some information on the location and main characteristics of 'reefs' that have been given Natura 2000 status.

Specific methodologies for assessing and monitoring reefs are available from twelve Member States (DE, DK, ES, FR, HR, IE, IT, MT, NL, PL, RO, SI). There are also reports of reef 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 Estonia and Latvia). Out of the seventeen key characteristics of habitat 1170 described in Section 1, the most commonly recorded (by 12 Member States) concern epifaunal and infaunal communities (Table 5).

Sweden and Ireland have proposed variables for consideration when reporting on conservation objectives without distinguishing those which might be specifically used for assessment of structure and function. Also relevant are survey reports relating to this habitat type carried out in the waters of other EU Member States that can be, or have been used, to inform such assessments although not directly stated as a reason for the work e.g. Denmark and France.

The **reference values and thresholds** applied by Member States to obtain condition indicators for reefs 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. The exception is functional state characteristics where limited information is available on approaches taken.

A number of approaches are used to **aggregate data** to provide an assessment at local and national scales. There is no specific information on aggregation methods applied for reefs 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 reefs. Practical consideration, such as accessibility are important as are factors such as size, physical variability and diversity of the associated biological communities. Ideally monitoring takes place across the reef as well as focusing on any identifiable sub habitats such as biogenic reef types.

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

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 15). 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

Reefs are rocky marine habitats or biological concretions that rise from the seabed. They are generally subtidal but may extend as an unbroken transition into the intertidal zone, where they are exposed to the air at low tide. They are very variable in form and the communities they support. There are two main types of reefs; those which are defined by the substratum where animal and plant communities develop on rock or stable boulders and cobbles (geogenic reefs) and those which are defined by the presence of structures created by the animals themselves (biogenic reefs)[1].

The EU Interpretation Manual gives the following definition and clarifications for reefs (code 1170) (European Commission, 2013);

> "Reefs can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions."
>
> Clarifications:
>
> - "**Hard compact substrata**" are: rocks (including soft rock, e.g. chalk), boulders and cobbles (generally, >64 mm in diameter).
> - "**Biogenic concretions**" are defined as: concretions, encrustations, corallogenic concretions and bivalve mussel beds originating from dead or living animals, i.e. biogenic hard bottoms which supply habitats for epibiotic species.
> - "**Geogenic origin**" means: reefs formed by non-biogenic substrata.
> - "**Arise from the sea floor**" means: the reef is topographically distinct from the surrounding seafloor.
> - "**Sublittoral and littoral zone**" means: the reefs may extend from the sublittoral uninterrupted into the intertidal (littoral) zone or may only occur in the sublittoral zone, including deep water areas such as the bathyal.
> - Such hard substrata that are covered by a thin and mobile veneer of sediment are classed as reefs if the associated biota are dependent on the hard substratum rather than the overlying sediment.
> - Where an uninterrupted zonation of sublittoral and littoral communities exists, the integrity of the ecological unit should be respected in the selection of sites.
> - A variety of subtidal topographic features are included in this habitat complex such as: Hydrothermal vent habitats, sea mounts, vertical rock walls, horizontal ledges, overhangs, pinnacles, gullies, ridges, sloping or flat bed rock, broken rock and boulder and cobble fields.

Reefs typically provide an increase in structural complexity and a cryptic habitat which allows for the settlement of other species and provides refuge from predation, competition, and physical and chemical stresses. Reef habitats may also represent important food resources, providing food for juvenile fish and economically important fish stocks, as well as providing areas for foraging, refuge and nursery grounds (West et al., 2024).

[1] https://sac.jncc.gov.uk/habitat/H1170/

Schuhmacher & Zibrowius (1985) describe marine biogenic concretions or bioconstructions, or bioherms, as elevated structures made of living benthic organisms (bioconstructors) that overgrow the remnants (usually skeletons or shells) of their predecessors. Marine bioconstructions are biodiversity-rich, three-dimensional biogenic structures, regulating key ecological functions of benthic ecosystems worldwide (Ingrosso et al*.,* 2018)."

Hard substrata that are covered by a thin and mobile veneer of sediment are classed as reefs if the associated biota is dependent on the hard substratum rather than the overlying sediment. A variety of subtidal topographic features are included in this habitat complex such as: hydrothermal vent habitats, sea mounts, vertical rock walls, horizontal ledges, overhangs, pinnacles, gullies, ridges, sloping or flat bed rock, broken rock and boulder and cobble fields.

An important characteristic is that many reefs are made up of a mosaic of marine communities and habitats rather than being uniform. This is illustrated in Annex II of the Nature Restoration Law[2] which lists sub-habitats that may be present within some biogenic or geogenic reef types (macroalgal forests - group 2, shellfish beds - group 3, and sponge, coral and coralligenous beds - group 5) using the EUNIS habitat classification as a reference. A review by Oceana (Aguilar comm. pers.) lists reef types formed by cnidarians (including stony corals, black corals, soft corals and sea pens), molluscs (including mussels, oysters, clams and piddocks), annelids (polychaetes), crustaceans, sponges, tunicates, bryozoans, brachiopods and foraminifera as well as mixed reefs.

Reefs (code 1170) are listed in the Interpretation Manual under COASTAL AND HALOPHYTIC HABITATS and in the subcategory 'Open Sea and Tidal Areas'. They can be found in association with "vegetated sea cliffs" (habitats 1230, 1240 and 1250), "sandbanks which are covered by sea water all the time" (1110) and "sea caves" (habitat 8830). Reefs may also be present in habitat 1130 "estuaries" and habitat 1160 "large shallow inlets and bays"

The approach taken in these guidelines is not to cluster habitat 1170 with other marine habitat types because, even though there is some overlap in approaches to monitoring and assessment, the focus for this habitat is on investigating "hard compact substrata". In contrast, 'Estuaries' and 'Large Inlets and Bays' are habitat complexes and may include some areas of reef; however, in these cases soft sediments are a major component.

According to the 2022 EUNIS marine habitat classification the following EUNIS habitat types (level 3) may be present as components of habitat type 1170: MA12-15, MA22-25, MB12-15, MB22-25, MB43, MB44, MC12-15, MC22-25, MC43, MD12-15, MD22-25, ME12-15, ME22, ME24-25, MF12, MF14-15, MF22, MF24-25, MG12, MG14, MG15, MG22, MG24, MG25. These incorporate some of the habitats listed, (at EUNIS level 4) in Group 2 (macroalgal forests) Group 3 (Shellfish beds) Group 5 (sponge, coral and coralligenous beds) and Group 6 (vents and seeps) habitats on Annex II of the Nature Restoration Law.

'Reefs' are present in the following twenty-two Member States;

Belgium (BE), Bulgaria (BG), Cyprus (CY), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Croatia (HR), Ireland (IE), Italy (IT), Lithuania (LT), Latvia (LV), Malta (MT), Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Sweden (SE) and Slovakia (SL).

[2] REGULATION (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869

Diversity across de the regions

Geogenic and biogenic reefs are present in all the EU regional sea areas, in both coastal and offshore locations.

Geogenic reefs are found both intertidally and subtidally, in sheltered waters through areas moderately exposed to swell and wave action, to waters exposed to the full force of waves. They occur fringing coastal areas as well as offshore, and from shallow waters to significant depths around seamounts (e.g. Probert et al., 2007). Across this range, reefs may be subjected to strong tidal currents. The structure of reefs varies from bedrock to boulders or cobbles while topography ranges from horizontal to vertical and the reefs may have numerous ledges and crevices. The geology includes limestone, shale, granite, schists and gneiss and sometimes of volcanic origin. In the **North Sea** and the **Baltic Sea**, they may be elevations containing glacial debris and with mixed substrates (e.g. Marl, sands, muds). The North Eastern Atlantic archipelagos, of the **Macaronesian** region, comprise four groups of islands: the Azores, Madeira, the Canaries and Cape Verde. They are all of volcanic origin with both intertidal and subtidal rocky reefs where the underlying geology is basalt.

The associated marine communities on reefs vary depending on factors such as depth, light levels, exposure to wave action, availability of nutrients and geographical location (e.g. Templado et al., 2009). The communities may be dominated by vegetation, sessile animals and mobile species (e.g. molluscs, crustaceans and fish) that are either permanently or temporarily resident on reef habitats.

Biogenic reefs significantly alter their environment by enhancing its structural complexity, creating resources that support a richer diversity and abundance of species. There are many subtypes of biogenic reefs and it is important that these are distinguished in the assessments to be carried out. In European seas they may be formed by algae, bryozoans, cold water corals, coralligenous platforms, deep sea sponge grounds, shallow water sponge reefs, mollusc reefs and reefs formed by polychaete worms (e.g. Ingrosso et al., 2018; Silas et al., 2023).

The main types of biogenic reef that have been described in the **Black Sea** are those formed by mussels (*Mytilus galloprovincialis*), piddocks (Pholadidae) and tube worms (*Ficopomatus enigmaticus*). There are also reefs formed by the oyster (*Ostrea edulis*) in Bulgarian waters, but these are from historic rather than currently living populations and are now colonized by blue mussels and sponges as well as both red and brown algae (Todorova et al., 2009; Micu et al., 2007). *Ficopomatus enigmaticus* reefs (an invasive species) have developed in areas sheltered by waves with a slight current and variable salinity, whereas biogenic reefs of *M. galloprovincialis* consist of banks of mussels whose shells have accumulated over time, forming a hard support raised above the surrounding sediments. Other types of biogenic reefs in the region are clay banks in the form of plateaus with galleries dug by the burrowing species *Pholas dactylus* and *Barnea candida* (Micu et al., 2007).

Biogenic reefs in mediolittoral, infralittoral and circalittoral zones of the **Mediterranean Sea** are typically formed by mussels (*Mytilus galloprovincialis/edulis* and *Modiolus barbatus*) and oysters (*Neopycnodonte cochlear*). There are also worm reefs in the circalittoral zone formed by several species depending on the bottom composition. The most common are *Sabellaria spinulosa, Sabella pavonina* and to a lesser extent the *Filograna* spp./*Salmacina* spp. complex and *Sabella spallanzanii. Dendropoma petraeum* is endemic to the Mediterranean Sea, notable for creating both living and fossil reefs along warm, rocky coasts, which develop in the lower intertidal. Fossil *Dendropoma* reefs, preserved alongside living structures, are especially important as palaeoecological indicators, providing insights into past sea-level fluctuations and climate conditions in tectonically stable Mediterranean areas (Templado et al., 2016)

Coralligenous habitats, develop in dim light conditions where calcareous algae and different macroinvertebrate species (Bryozoans, scleractinians, serpulids and sponges) develop complex bioconstructions. They are found down to 200m and may develop on vertical walls and overhangs as well as horizontal and gently sloping seabed (Ballesteros, 2006; UNEP/MAP - RAC/SPA, 2014). The most widely studied are those of the **north-western Mediterranean** where the two main algal communities that have been distinguished are an assemblage dominated by *Halimeda tuna* and *Mesophyllum alternans* in relatively high light levels, and an assemblage dominated by encrusting corallines where light levels are low (UNEP/MAP - RAC/SPA, 2014). They may be relatively dense aggregation of colonies or individuals of one or more coral species. Reef forming hard corals (e.g. *Desmophyllum, Madrepora* and Caryophylliidae), may be present as small or scattered colonies. Whilst in deeper waters gorgonians, sea pens and black corals (Antipatharian species) may also form part of the reef features (Gubbay et al., 2016). In the Canary Islands, for example, the black coral *Antipathella wollastoni* is found around 40m and below, along with the gorgonian *Eunicella verrucosa* and the zoanthid *Antipathozoanthus macaronesicus* (Ocaña & Brito, 2004).

In the **Atlantic** biogenic reefs in the intertidal zones may be formed by species including the blue mussel (*Mytilus edulis*) the Mediterranean mussel (*Mytilus galloprovincialis*), which is found on the Portuguese coast as well as the Mediterranean (Boaventura et al., 2002) and the honeycomb worm (*Sabellaria alveolata*). The reefs can extend over significant areas, although often in patches. Two examples are the banks of *S.alveolata* that cover large areas of sandflats in the lower intertidal zone the Bay of Mont Saint-Michel (France) and some areas in the Portuguese coast (Dubois et al., 2006; Bertocci et al., 2012; Dias & Paula, 2001), and the patchy *M. galloprovincialis* reefs on rocky shores of the Portuguese coast. Sublittoral biogenic reefs in the region include those created by the polychaete worms *Serpula vermicularis, Sabellaria spinulosa, S.alveolata* and bivalves, such as mussels and oysters. In Belgium reefs formed by the sand mason work (*Lanice conchilega*) occur in shallow water close to the coast[3]. In deeper waters, cold water corals form reefs. The Porcupine Bank Canyon (Ireland), and Galicia Bank (Spain) are two such locations where *Desmophyllum pertusum, Madrepora oculata* and communities of black coral, bamboo coral and gorgonia sea fans have formed biogenic reefs (de la Torriente et al., 2015). There are also deep-water reef habitats on seamounts such as occur around the Canary Islands (Alvarez et al., 2015) and the Azores. Circalittoral coral reefs dominated by black coral and gorgonian communities occur around all three island groups in the **Macaronesian** region at depths of between 40m and at least 196m. This is a species rich and productive habitat providing diverse ecosystem services including fish habitat and nursery areas, nutrient cycling and benthic productivity[4].

In the **Baltic Sea**, biogenic reefs are typically formed by *Mytilus edulis, Modiolus modiolus* (common in the Kattegat) and the zebra mussel (*Dreissena polymorpha*) which is present in coastal lagoons and estuaries. All these species can form dense colonies and often create multi-layered beds on hard or soft substrata. They act as substratum for other animals and macrophytes. The animal and plant communities of reefs vary with the salinity, light penetration and exposition to water motion. In the northern **Baltic Sea** reefs are mainly of geogenic origin, and are often covered by macroscopic epibenthic communities dominated by *Mytilus* spp. (HELCOM, 2013).

[3] https://www.health.belgium.be/en/habitats-directive-areas-belgian-part-north-sea
[4] https://moveon-project.eu/results/deliverables/circalittoral-coral-reefs-a5-63/

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

Reefs are very variable in form and in the communities that they support. The **main characteristics** which determine the structure and function of reefs are;

- Degree of submergence/depth
- Substrate type/geology
- Topography
- Biogenic structures
- Exposure to current, wave action, scour and surge
- Temperature
- Turbidity
- Water quality

1.2.1 Abiotic characteristics

Abiotic characteristics describe both the physical and chemical state of the habitat. In the case of geogenic reefs, this will include the geology and topography of the underlying substrate, rugosity and characteristics of the water column.

The structure of such reefs varies from bedrock to boulders or cobbles while topography ranges from horizontal to vertical and the reefs may have numerous ledges and crevices. The geology includes limestone, shale, granite, schists and gneiss. In the North Sea and the Baltic Sea, reefs may be elevations containing glacial debris and with mixed substrates (e.g. Marl, sands, muds)[5]. There may be further variety associated with topographical features such as vertical rock walls, boulder fields, gully and canyon systems, outcrops from sediment, and rockpools on the shore[6]. As an example, see Table 1 which illustrates types of geogenic reefs in Ireland across differing substrata, depth, salinity and current regimes (West et al., 2024).

Table 1. Overview of the ecological and environmental requirements of geogenic reef habitat in Ireland

Reef Type	Distribution	Preferred Substratum	Temp. Range	Depth Range	Preferred Salinity	Preferred Current Speeds	References
Intertidal geogenic reef	Worldwide	Bedrock, boulders, cobbles, pebbles	-5°C - 30°C	Upper shore - 0 m	18-35‰	<1-6 kn	Hill et al., 1998; Connor et al., 2004
Infralittoral geogenic reef	Worldwide	Bedrock, boulders, cobbles, pebbles	0°C - 24°C	0-20 m	18-35‰	<1-6 kn	Birkett et al., 1998; Connor et al., 2004
Subtidal geogenic reef	Worldwide	Bedrock, boulders	5°C - 20°C	20-100 m	30-35‰	<1-6 kn	Connor et al., 2004; Marine Institute Ireland, 2019

[5] Eg. off the Jasmund peninsula in the German Baltic where reef structures are formed by rising chalk slabs (Herrmann et al., 2015)

[6] https://sac.jncc.gov.uk/habitat/H1170/

Potential physical indicators for monitoring geogenic reef habitat structure and function identified in a study of reefs in Ireland are habitat elevation, patchiness, extent, substrate type, wave exposure/currents, temperature change, and light attenuation (West et al., 2024).

The marine communities and typical species on reefs differ depending on the physical structure and location given that reefs may be present in the intertidal as well as infralittoral and circalittoral zones. Key physical factors that characterise the different communities present are morphology (including roughness and verticality), the structure of the substrate, bathymetry, hydrological conditions, tidal regime, as well as chemical characteristics such as transparency, thermal conditions, oxygen levels, salinity and nutrients (Jackson-Bué et al., 2024; Templado et al., 2009). Depth and the turbidity of the water will have an influence on the establishment of algae on a reef as well as the species, their abundance and any zonation patterns. The same applies in relation to currents and wave action. Where there is good water movement geogenic reefs may be colonised by large numbers of filter feeding organisms. Such conditions can also favour the development of biogenic reefs such as those formed by corals, bivalves and polychaete worms (e.g. *Cladocora caespitosa, Lophelia pertusa, Mytilus edulis, Neopycnodonte cochlear, Ostrea edulis, Serpula vermicularis*, and *Sabellaria alveolata*). Extremely exposed habitats may be dominated by a robust turf of sponges, anemones and foliose red seaweed, while in more sheltered locations they may support delicate or silt-tolerate filamentous algae[7]. Particularly distinct communities are associated with chalk and limestone[8].

1.2.2 Biotic characteristics

The main biotic characteristics of reefs are determined by the characteristic species present as well as their relative abundance, density, the structures they form, including niches for other species as well as provisions such as food, nursery/refuge areas. Species specific variables have also been proposed to assess biotic characteristics. In the case of fish, for example (Henriques et al., 2013) the following metrics were selected as the most suitable to detect changes on temperate reef fish assemblages: “density of generalist individuals”, “density of territorial individuals”, “density of large individuals with medium to high commercial value (>20 cm)”, “density of juveniles” and metrics relative to trophic guild (except zooplanktivores). For macroinvertebrates Henriques et al., (2014) suggest distinguishing different ecological groups using the AMBI Marine Biotic Index[9]. Potential biological indicators for monitoring reef habitat structure and function identified in a study of reefs in Ireland are species abundance/habitat extent, macroalgae, abundance of non-native species and recruitment (West et al., 2024).

Examples of variables that can be used to measure these characteristics when reporting on the condition of habitat type 1170 are summarised in Table 2. The classification of the ecological characteristic and associated variables follows the UN-SEEA ecosystem condition typology which has six classes: abiotic physical, abiotic chemical, biotic compositional, biotic structural, biotic functional and landscape/seascape characteristics (United Nations et al., 2021).

[7] https://sac.jncc.gov.uk/habitat/H1170/

[8] E.g. off the Jasmund peninsula in the German Baltic where reef structures are formed by rising chalk slabs (Herrmann et al., 2015)

[9] AMBI Marine Biotic Index https://ambi.azti.es/

Table 2. Ecological characterisation and selection of variables used to measure habitat condition of habitat 1170 (reefs)

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
		Substrate type/Geology	Mineral/rock/sediment type Proportions of cobbles, pebbles, boulders etc
		Topography/physical structure/habitat complexity	Physical dimensions Extent Longitude and latitudinal gradients Form/roughness/verticality
		Temperature	Water temperature
		Turbidity	Suspended particles Light transmission through water samples
		Hydrodynamics - Exposure to current, wave action, scour & surge	Location Aspect Water movement
	Chemical state characteristics	Water quality, nutrient status, hazardous substances	Various parameters including nitrates & phosphates
Biotic characteristics	**Compositional state characteristics**	Invertebrates - Epifaunal & infaunal communities including meiofauna	Number of biocenosis Presence & abundance of species (SACFO scale) Diversity indexes Biomass Density
		Vertebrates - Associated fish communities	Abundance Distribution Population structure
		Macrophytes, macroalgae, eelgrass	Spatial extent Taxonomic composition % cover
		Opportunistic/invasive species	Species distribution Species abundance/biomass
		Biogenic structures	Type Extent Volume/biomass
	Structural state characteristics	Characteristic species	Percentage cover Biomass Synthetic indicators (M-AMBI, BENTIX etc)
		Reef structure	Basal (encrusting), intermediate (bushes) and upper (erect) layer for coralligenous reefs
		Vegetation zones	Depth limit of angiosperms Belts of fucales
	Functional state characteristics	Bioerosion	Abundance of bioeroders e.g. sponges
		Bioconcretion	Cover of animal and algal builders
Landscape/ seascape characteristics		Connectivity/ Fragmentation	Presence of anthropogenic structures Patch size/distance between patches
Other		Disturbance	% free from damage due to human impact

1.2.3 Ecological processes that are relevant regarding proper functioning.

Wave exposure, water depth and water currents are key physical processes which influence the biological assemblages present on reefs. Other important factors such as recruitment/propagule supply, and processes which affect primary production, such as suspended sediments, light attenuation and water chemistry and temperature, are also key and act to influence the food sources consumed by the biological of the habitat, and the biological assemblages themselves (Coates et al., 2018). Biogenic reefs may stablish sands, gravels and stones they may provide a diversity of crevices, surfaces and sediments for colonisation. Accumulated faeces, pseudofaeces and other sediments may be an important source of food for other organisms. For these reasons many biogenic reefs have a very rich associated fauna and flora, which at least in terms of macrofauna is often much richer and more diverse than the surrounding areas (Holt et al., 1998).

Recruitment, grazing, and predation are key biological drivers affecting macroalgal assemblages whilst passive filter feeders such as sponges and anemones are dependent on water currents to bring microorganisms, particulate organic matter, plankton and detritus to them.

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. According to the guidelines for reporting under Article 17 (European Commission, 2023), typical species should be species which occur regularly (i.e. are ‘characteristic’) in a habitat type and 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. They also need to reflect the variety of biological communities/subtypes often found within reef habitats given that reefs are often made up of a mosaic of marine communities rather than being uniform.

The marine communities and typical species in this habitat differ depending on the type of reef, the stage of development, local conditions as well as global considerations such as sea temperatures and natural fluctuations, for example due to variations in the supply of planktonic propagules and survival following settlement. By way of example, a preliminary list of typical/indicator species occurring with coralligenous habitats along the Croatian part of the Adriatic Sea identifies potential indicator species in the following groups; algal builders, animal builders, ‘agglomerative’ animals (sponges and bryozoans), bioeroders (sponges, echinoids, molluscs), species of particular importance due to their abundance, sensitivity, architectural importance and economic value) and invasive species (*Caulerpa* spp. and red turf algae) (Kipson et al., 2014). Modelling work of sublittoral rock habitats identified the following key groups; macroalgae, temporarily or permanently attached active filter feeders; temporarily or permanently attached passive filter feeders; bivalves, brachiopods and other encrusting filter feeders; tube building fauna; scavengers/predatory fauna; non-predatory mobile fauna. Another approach, as used in Spain, is to consider selecting taxa that are typically of different zones of reefs: Coastal hard substrates, infralittoral hard substrates, hard circalittoral substrates, and bathyal hard substrates (Templado et al., 2009).

The species used to monitor the condition of this habitat type differ depending on the geographical location and characteristics. Table 3 indicates frequently present groups from which species for monitoring may be selected, and the types of changes in quality they could be used indicate. They may be drawn from any species group.

Table 3. Potential species groups from which to select typical species for monitoring habitat 1170 (reefs)

Species Group	Ecological notes	Sensitive to changes in condition
Macroalgae	Macroalgae may be present where light levels are sufficient.	Macroalgae are primary producers, absorbing nutrients, providing food, shelter and a surface for attachment by other species. The growth and viability of algae is affected by water movement, light levels and water quality.
Polychaetes	Reef building species (*S.spinosa*) may be present as well as infaunal polychaetes with species preferences depending on grain size, organic matter, and oxygen levels (Vanosmael et al., 1982). *S. spinulosa* tube density can reach high values, approximately 37,000 individuals/m2. *S. spinulosa* modifies, maintains and creates habitat, Ecosystem effects of reef structures created by these polychaetes include alteration of water flow and acting as sediment traps (Bruschetti, 2019).	Physical disturbance and changes in nutrient/organic matter levels can be indicated by monitoring species from this group.
Molluscs	Filter feeders and grazers. Molluscs can form the structure of biogenic reefs. 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 (Moraitis et al., 2018) and bioindicators of environmental contamination (Coelho et al., 2014; Velez et al., 2016).
Crustaceans	Sessile and mobile crustaceans have an important role in food webs on reefs as a link between benthic and pelagic organisms, fish and birds. They have an ecological role with different species as herbivores, detritivores, carnivores and omnivores. There can also be a significant role in planktonic ecology because of pelagic larval stages (Priones-Fourzán & Hendrickx, 2022)	Physical disturbance, Water quality, productivity
Echinoderms	Both infaunal and epifauna species of echinoderms are present in this habitat affecting reef structure and dynamics in various ways. Sea urchins, for example, can affect the structure of reefs through their grazing activity creating areas of bare rock for colonization; starfish can form dense aggregations feeding on and clearing areas of bivalve reefs, and sea cumbers act as deposit feeders contributing to nutrient recycling on reefs.	Physical disturbance and changes in nutrient/organic matter levels can be indicated by monitoring species from this group.
Anthozoans	Can form the structure of biogenic reefs. They may be slow-growing and fragile therefore vulnerable to mechanical damage. Sediment re-suspension can also have a detrimental effect on sessile filter feeders.	Turbidity, organic matter, productivity, disturbance
Fish	Reef fish can occupy a variety of trophic levels using such areas for feeding, rest/refuge, reproduction, nursery grounds and transit. They are useful indicators of environmental water quality because of their differential sensitivity to pollution.	Productivity, water quality, migration barriers, fisheries impact

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

Information has been collected about the location and description of the main characteristics of reefs by all the Member States that have reported habitat 1170 as present within their jurisdiction[10]. Specific methodologies for assessing and monitoring reefs are available from twelve Member States (DE, DK, ES, FR, HR, IE, IT, MT, NL, PL, RO, SI). There are also reports of reef 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 Estonia and Latvia) (e.g. Vaher et al., 2022; Armoškaitė et al., 2021). All these methodologies have been considered in the following review albeit distinguishing between what is being done by Member States for reporting on habitat condition under Article 17 and what has been done as part of other initiatives.

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

A summary of the ecological characteristics and main variables used to measure habitat condition of reefs is presented in Table 2 (Section 1). Examples of the characteristics and variables used by Member States as part of the assessment of conservation status are presented in Table 4 and a summary analysis is given in Table 5.

Table 5 shows that whilst the monitoring and assessment programmes from the twelve Member States where assessment methodologies were reviewed cover abiotic, biotic, landscape and other characteristics, there are differences in emphasis.

Nine of the twelve Member States that have specific monitoring programmes for reef habitats have identified the need to monitor variables relating to the **abiotic characteristics**. Of these topography/physical characteristic and water quality are the most frequently cited variables. Exposure to current/wave action/scour/surge is only specifically mentioned by France; however, like the other abiotic characteristics it is possible that they may be incorporated into other aspects of monitoring.

Biotic characteristics are well represented in the monitoring programmes being specifically mentioned by all twelve Member States. The most frequently cited being monitoring of epifaunal and infaunal assemblages. Five Member States specifically mention monitoring of biogenic structures, seven refer to macroalgae/macrophyte monitoring variables and only Ireland and Slovenia highlight monitoring of associated birds/fish/marine mammals. It is nevertheless possible that these variables may be considered by other Member States in their more general reporting of the abundance and condition of species.

Connectivity/fragmentation as a **landscape/seascape characteristic** that needs to be assessed is specifically mentioned by two Member States (France and Malta). Other two Member States (Germany and France) reference monitoring of disturbance albeit in different forms. In the case of Germany for example, this refers to disturbance of birds. Disturbance has been included in the category **other**.

[10] as evidenced by the submitted Standard Data Forms for designated sites where 1110 is a feature and Article 17 reporting for this habitat type.

Table 4. Examples of variables used by Member States to assess condition of habitat 1170 (reefs)

Description	Examples of variables used by Member States	Notes
1. Abiotic characteristics		
1.1 Physical state characteristics		
Degree of submergence / depth / tidal regime	FR - Reef boundaries including degree of submergence.	Whilst not necessarily highlighted in all assessment methodologies, these characteristics are usually included in the descriptions of Natura 2000 sites where habitat 1170 is present (e.g. in the SDFs). Depth is a standard variable which is recorded in acoustic surveys and site-specific sampling e.g. of seabed sediments and therefore likely to be noted in the supporting documentation of all assessments for habitat 1170 even if not specifically mentioned in the methodologies.
Substrate type/geology	DE- Geogenic reef structures & sediment FR - Substrate (limestone, granite, metamorphic rock, conglomerate…) IE – Sediment grain size	The rocky substratum of geogenic reefs is usually relatively stable however there may be some variation in any soft sediments present within and around the reefs.
Topography/physical structure/habitat complexity	FR – Morphology (continuous/big boulders/small boulders) HR – Structural complexity (basal, intermediate and upper layers of coralligenous habitats) RO – Relative distribution of habitat subtypes (ha)	The topographical features of habitat 1170 provide 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	DE – Hydrology (including exposure) FR - wave exposure	
1.2 Chemical state characteristics		
Water quality	DE - Total inputs compared to baseline year for N & P targets ES - Dissolved oxygen, pH, salinity, temperature	There is limited specific mention of water quality sampling for assessments of this habitat type. Much of the published guidance is general in nature although variables are mentioned in some cases.

Description	Examples of variables used by Member States	Notes
2. Biotic characteristics		
2.1 Compositional state characteristics		
Invertebrates - Epifaunal & infaunal communities including meiofauna	DE - Reference against lists of typical species DK - Species, number of individuals ES – Community/species inventory FR - % cover of species HR - Species composition and % cover IE - Number of marine community types NL - Presence of benthic species PL - Presence/absence, number of typical macroinvertebrate taxa RO - Number and abundance/average density of characteristic species	These characteristics are reported in all the Member States where this habitat is present, but the methodologies examined reveal some variation in the level of detail. In some cases, there is reference to compiling species lists, for example and in others to recording biocenosis or keystone communities.
Vertebrates - Associated fish communities	SI - Fish community inventory IE – Keystone communities including fish	These characteristics are not necessarily mentioned specifically in assessment methodologies but are likely to be covered during surveys to record species present
Macrophyte, macroalgae, eelgrass	DK - Max depth limit, spread and % cover of eelgrass, macroalgae species and % cover FR - Area of algae belts, upper and lower limits. IT - Presence of floristic elements PL - Presence/absence and number of typical macroalgae species RO - Extent of phytoplankton/macroalgae MT - Density of *Cystoseira* spp. (derived from % algal cover)	
Opportunistic/invasive species	HR - Invasive species abundance (from photoquadrats) IE - Presence and/or abundance of negative indicator species	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.
Biogenic structures	RO - Relative distribution of habitat subtypes SI - Stony coral (*Cladocora caespitosa*) density and colony size MT - Distributional range and extent (km), % cover of living organogenic trottoirs with *Lithophyllum* spp., including facies with vermetids	These characteristics are not necessarily mentioned specifically in assessment methodologies but are likely to be covered during surveys to record species and biocenoses present

Description	Examples of variables used by Member States	Notes
2.2 Structural state characteristics		
Characteristic species	DK - Biomass of fauna species covering reefs and bubble reefs ES - Relative abundance of species/unit area FR - Relative abundance of macrofaunal species groups, Health Status Index, diversity & % cover of upright macrofauna (gorgonian, sponges bryozoans) HR - Number/census of sea urchins along transects IE - Area of keystone communities MT - Relative abundance and presence of particularly sensitive and/or tolerant species	These characteristics are reported in all Member States where this habitat is present, but the methodologies examined reveal some variation in the variables measured. Abundance measures (e.g. % cover or biomass) are most common, but there are also condition measures (e.g. patchiness).
Reef structure	HR - Cover of encrusting calcareous algae and macroinvertebrates contributing to building up of coralligenous outcrops. IE - Area of keystone communities	
Vegetation zones	ES - Dry biomass per surface unit (g/m²) of the main species (defined as such by their representativeness or abundance). FR - Density of structuring algae (*Cystoseira* spp. and *Padina pavonica*)	
2.3 Functional state characteristics		
Bioerosion	HR - Estimate of the cover of boring sponge *Cliona* spp. and enumeration of bioeroding molluscs *Gastrochaena dubia* and *Lithophaga lithophaga*	
Bioconcretion	HR - Cover of encrusting calcareous algae and macroinvertebrates contributing to building up of coralligenous outcrops.	
3. Landscape/seascape characteristics		
Connectivity / Fragmentation	FR - Presence/absence of artificial structures and % cover of artificial surfaces MT - Patch size/distance between patches	
4. Other		
Disturbance	DE - Level of disturbance from fishing (professional, sport, recreational)	

Table 5. Main ecological characteristics and associated variables monitored in the assessment of structure and function of habitat 1170 (reefs) by EU Member States

Ecological characteristics	Variables	Metrics	DE	DK	ES	FR	HR	IE	IT	MT	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			■	■	■		■			■	■	
Substrate type / geology	Geogenic reef type	Mineral/Rock type, Proportions of cobbles, pebbles, boulders etc	■			■		■						
Topography / physical structure / habitat complexity	Physical dimensions; extent; longitude and latitudinal gradients; elevation; form and presence of features from a standardised list (e.g. gullies, caves)	Metres (m), degrees of slope (o), roughness/ verticality, physical features from a reference list			■	■	■		■			■	■	
Hydrodynamics - Exposure to current, wave action, scour & surge	Current speed; wave height, direction & frequency	Current speed (m/s) direction, height and extremes (m)	■			■								
1.2 Chemical state characteristics														
Water quality	Various substances (including chemicals listed in the WFD and EQSD, nitrates & phosphates, oxygen, chlorophyll, dissolved solids).	Temperature (ºC), pH, Chromophoric dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM), total dissolved solids (TDS), dissolved oxygen (mg/l), oxygen saturation (%)	■	■	■	■							■	

Ecological characteristics	Variables	Metrics	DE	DK	ES	FR	HR	IE	IT	MT	NL	PL	RO	SI
2. Biotic characteristics														
2.1 Compositional state characteristics														
Invertebrates -Epi-faunal & infaunal communities including meiofauna	Abundance and diversity of characteristic species from standardised lists.	Number of biocenosis/taxa, presence & abundance of species (SACFOR scale), diversity index, (Shannon-Wiener diversity index, AMBI index), biomass, estimated % cover, density												
Vertebrates -Associated fish communities	Abundance and diversity of characteristic species from standardised lists.	Number, population structure, trophic composition (e.g. % omnivores/piscivores), distribution.												
Macrophytes, macroalgae, eel-grass	Type; extent	Spatial extent (area and depth), taxonomic composition, % cover of substrate, density (no/m^2), average leaf length & width, leaf & rhizome biomass.												
Opportunistic / invasive species	Presence; distribution; abundance	Number, biomass, % cover, population structure												
Biogenic structures	Type; extent	Biomass, estimated % cover, of main taxa or morphological groups. Type; Geogenic or biogenic. basal (encrusting), intermediate (bushes) and upper (erect) layer for coralligenous reefs.												

Ecological characteristics	Variables	Metrics	DE	DK	ES	FR	HR	IE	IT	MT	NL	PL	RO	SI
2.2 Structural state characteristics														
Characteristic species	Condition	Percentage cover, biomass, density. Synthetic indicators (M-AMBI, BENTIX etc)												
Reef structure	Condition	Volume/biomass Basal (encrusting), intermediate (bushes) and upper (erect) layers												
Vegetation zones	Abundance; extent; condition	Spatial extent (area and depth), composition, % cover of substrate, density (no/m^2), average leaf length & width, leaf & rhizome biomass.												
2.3 Functional state characteristics														
Bioerosion	Type and abundance of bioeroders (e.g. sponges)													
Bioconcretion	Cover of animal and algal builders													
3. Landscape/Seascape characteristics														
Connectivity / fragmentation	Presence of anthropogenic structures and their % cover; patch size and distance between patches	Area (ha). % area directly affected by human activity												
4. Other														
Disturbance	Footprint of activity; number and intensity of negative pressures	Presence/absence, Length of modified banks (m), % area directly affected by human activity (e.g. by demersal fisheries or sand extraction, anthropogenic structures), pressures from a standardised list (graded High, Medium, Low, unknown).												

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

A summary of the ecological characteristics and main variables used to measure habitat condition of reefs is presented in Table 2 (Section 1) and a list of typically used methodologies in Table 6.

Table 6. Survey methods used to investigate key characteristics of habitat 1170 (reefs)

Abbreviations: ACDP - Acoustic Doppler Current Profiler, AGDS – Acoustic Ground Discrimination Systems, BRUVS – Baited Remoted Underwater Video Systems, DDV – Drop-down video, LIDAR – Laser Induced Detection and Ranging, MBES – Multi Beam Echo Sounders, ROV – Remotely Operated Vehicle, SBES - Single Beam Echo Sounder, SSS - Side Scan Sonar.

Key characteristics	Methodologies
Degree of submergence / depth / tidal regime	Diving, boat-based surveys, Acoustic methods (MBES, SBES, AGDS), tide gauge stations, remote sensing, modelling.
Topography/physical structure/habitat complexity **Substrate type/Geology**	Aerial survey (Satellite/Drone imagery/LIDAR), Acoustic surveys (SSS, AGDS, MBES), geological maps, modelling.
Hydrodynamics - Exposure to current, wave action, scour and surge	Hydrographic charts, modelling, Aerial survey (Satellite/Drone imagery), Current meters (ADCP), time-lapse photography.
Biogenic structures	Acoustic surveys (SSS, AGDS, MBES), photographic quadrats, video transects or visual census (diver, ROV or DDV), direct sampling.
Invertebrates - Epifaunal & infaunal assemblages including meiofauna	Photographic quadrats, video transects or visual census (diver, ROV or DDV), direct sampling (hand corer or suction sampler).
Macrophytes, macroalgae, eelgrass	Photographic quadrats, video transects or visual census (diver, ROV or DDV), direct sampling.
Vertebrates - Associated fish communities	Visual census (diver, boat-based surveys, ROV, DDV, BRUVS).

Acoustic techniques are widely used for mapping areas of seabed with the systems deployed depending on the survey objectives and scale of the area to be mapped as well as the resolution required. The technologies include Single-Beam Echosounders (SSS), Multi-Beam Echosounders (MBES), and Side Scan Sonars (SSS). Multibeam backscatter has been used to map both geogenic and biogenic reefs e.g. mussel reefs (Schulze et al*.,* 2022) as well as bedrock outcrops. MBES has the advantage of simultaneously acquiring bathymetry and backscatter data over a swath covering a wide range of angles and has been extensively used for large-scale surveying, producing high-resolution maps (Brown et al*.,* 2011).

These technologies have grown more robust, leading to the development of advanced analysis techniques that are now widely used (Menandro et al., 2023). More detailed information, particularly on biotopes present, epifauna and infauna may be acquired through combinations of direct sampling, photographic/acoustic techniques and visual census, for example using Drop-down video (DDV) or Remotely Operated Vehicles (ROVs).

Some of the non-invasive methods used to describe the biotic character are high-definition diver surveys/recording *in situ* (e.g. transects/quadrats for species & abundance estimates) and collection of high-definition imagery by ROV. Whilst direct observation is more applicable in shallow waters, the use of ROVs is particularly valuable in gathering information on reefs in deep water. One example is the mapping of oyster reefs (*Neopycnodonte cochlear)* in water depths greater than 100m in the Mediterranean (Angeletti & Taviani, 2020). Images collected by ROV surveys in this case revealed different typologies of the reefs in terms of shape and dimension as well as making it possible to identify macro and megabenthic associated fauna. Reefs can be topographically complex made up of a mix of features that can be observed at both large and small scales. At the landscape/seascape scale, for example, the underlying hard substrate may take the form of plateaus, pinnacles or outcrops surrounded by areas of soft sediment. A combination of aerial and underwater imagery can be used to map and indicate the extent of shallow/intertidal reef habitat. In clear, calm water conditions, for examples drone imagery can be a fast, low-cost method for fine scale mapping of reefs in shallow waters as used along the central Latium coast in Italy (Ventura et al., 2023).

In Germany a grid-based evaluation of backscatter mosaics of hydroacoustic recordings has been used to map the extent of reef features and to categorise them into reef types (Heinicke et al*.,* 2021).

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 reefs are variously; very specific, based on trends, use indices, rely on expert judgement or any combination of these. Table 7 gives some examples of the different approaches. Indicators and thresholds being developed under the auspices of other programmes, can also inform the assessment process for the Habitats Directive.

Table 7. Examples of reference values and approaches used for assessment of habitat 1170 (reefs)

Approach	Example of variable used	Method/metric and reference values	Country: Reference
Quantitative	Complexity of coralligenous habitat	Combining estimates of cover of 3 main layers of coralligenous habitats (encrusting, bushes and erect). Scores attributed depending on number of colonies/m^2 along transects using a specified methodology then combined to give layers per transect. Total score can range from 0 to 40 and used to record cover as null (0), low (1-10) medium (11-20) and high (>20). methodology	Croatia; Kipson et al., 2014
	% of communities present.	Surface area of communities with respect to potential coverage; 80-100% (FV), 40-80% (U1), <40% (U2)	Spain: Templado et al., 2009
	% of affected colonies	Visual census along 10 x 1m transect to evaluate cover of the erect layer and macrobioeroders. Quantification based on assessment of a minimum of 100 colonies. Conservation status of Gorgonian populations. Not affected (colonies with <10% injured surface); affected (colonies with >10% injured surface): naked axis/recent epibiosis; old epibiosis or combination of recent epibiosis and old epibiosis	Croatia: UNEP/MAP - RAC/SPA, 2014
Indices/ Additional	Relative abundance & presence of particularly sensitive and/or tolerant species	CARLIT index (CARtography of LITtoral and upper-sublittoral rocky communities) Definitions of high, good and moderate status as qualitatively agreed at the WFD Mediterranean Geographical Intercalibration group and therefore specific to the Mediterranean Ecoregion. Also intercalibrated EQRs (Environmental Quality Ratios) between Malta and Spain – High-Good Boundary =0.75, Good-Moderate boundary=0.60	Malta: Ballesteros et al., 2007
	Number of taxa present from a list of typical species	3=FV, 2=U1, 1 or 0 =U2	Poland: Baranska et al, 2022
	Number of macroalgal taxa,	Recording and scoring a range of physical characters for a given area of intertidal reef and assessing the range of macroalgal species within that area against the diversity of physical features recorded (the normalised number of macroalgal taxa). Reference values have been determined. Designed for assessing ecological status in transitional and coastal waterbodies but additional attributes also recorded for Habitats Directive assessments	Ireland; Scally et al., 2020
Scoring	Not specified but will cover, faunal and floristic components, state of health and character of sediment for soft substrates	Indicator compared to a threshold value to get a score which is then subtracted from a starting score of 100.	France; Delavenne & de Bettignies, 2023

Approach	Example of variable used	Method/metric and reference values	Country: Reference
Linked to other programmes – e.g. WFD, MSFD, EOBV	Typical macroalgal taxa	Field studies and information from other sources e.g. HELCOM COMBINE programme	Poland: Baranska et al., 2022; HELCOM, 2021
	Harmful substances	Measurement against OSPAR and HELCOM convention target to year 2020 to reduce input of synthetic harmful substances to zero and reduce naturally occurring harmful substances to concentrations that match background values.	Germany: Krause et al., 2008
	WFD rocky shore macroalgal species richness tool	Recording and scoring a range of physical characters for a given area of intertidal reef and assessing the range of macroalgal species within that area against the diversity of physical features recorded (the normalised number of macroalgal taxa). Reference values have been determined.	Ireland: WFD UK TAG, 2009
Trend	Hard beds associated with communities of photophilic algae (*Cystoseira* belts)	Range and extent of macroalgal assemblages characterised by *Cystoseira* species. 2008 survey data used as baseline	Malta: Ballesteros et al., 2007
	Criteria relating to reef structures, hydrology & morphology and vegetation zones. For example; Reef Structures: natural, unchanged; slightly changed (structures and sediment distribution of the geogenic or biogenic reefs changed temporarily and only in a few areas); changed more (structural losses in all areas or in individual areas of structures and sediment distribution significantly changed).	Evidence of change; use of suitable basic data and evaluations from monitoring for WFD	Germany: Krause et al., 2008

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 (TG SEABED, 2023). 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.

Indicators and thresholds being developed under the auspices of other programmes can also inform the process for the Habitats Directive. One example is the Dark Habitats Action plan (UNEP/MAP – SPA/RAC, 2021) which recommends common indicators for monitoring deep sea habitats including biogenic reefs such as those formed by anthozoans and sponges. One of these is an indicator of “condition of the habitat’s typical species” (Table 8).

Table 8. Condition of habitat’s typical species

Extract of assessment guidelines from the Dark Habitats Action Plan (UNEP/MAP – SPA/RAC, 2021)

General considerations	Assessment guidelines
Typical species: this concept emerges from the conservation status of natural habitats to their long-term natural distribution, structure and functions, as well as to the long-term persistence of their typical species within the territory. Typical species composition should be near/close to natural conditions for their habitat to be considered in natural condition. **Reference list of habitats**: not defined yet (in process). **Methods**: • Depend on the habitat type (and selected species) to be addressed. Large attached epibenthic species on hard substrates are preferably monitored using optical, non-destructive methods, such as underwater video. Endobenthic communities are sampled using standardized grabs or corers. • Several specific benthic biotic indices have been developed and have become operational. (see IMAP guidance, 2016), in particular to fulfil MED GIG (Mediterranean Geographical Intercalibration Group) requirements. They are all well methodologically defined but the way to combine these parameters in sensitivity/tolerance. classification or depending on structural, functional and physiological attributes is heterogeneous, depending on the issue (pressure type), habitat types or sub-region. *NOTE: Information about the typical and/or characteristic species of some habitats and their past state/conditions is often unavailable for southern and eastern sub-regions of the Mediterranean. The limited data availability may restrict the number of habitats that can be assessed with sufficient statistical confidence at present. Although benthic biotic indices are conceptually applicable in all sub-regions, adjustments might be required in order to cover biogeographic heterogeneity*.	Typical species lists: to be defined per sub-region (or bioregion) to allow for the consistent assessment of state/condition. Long-lived species and species with high structuring or functional value for the community should preferably be included; however, it should also contain small and short-lived species if they characteristically occur in the habitat under natural conditions as they can also be functionally very important for the community. Periodicity: This list should be updated every six years. Resources required: • Research vessels, suited to work in bathy l zones (below 150-200 m depth). • Adequate equipment (box core samplers, grabs, underwater camera systems, etc.) for sample collection. • Laboratory infrastructure to analyse samples (e.g. microscopes, weighing scales). • Qualified personnel for data processing analysis and interpretation. • Good taxonomy skills are essential for the adequate assessment of this indicator

2.3 Aggregation methods at the local scale

A generic rather than habitat specific methodology is generally used by Member States to aggregate data on variables measured at the local scale to provide a condition assessment at the level of the plot or monitoring locality/site. This is typically based on the number of variables that are considered 'favourable', either **scored and aggregated** (e.g. Germany, Spain), or with the overall assessment being based on the **lowest grading** of any variable e.g. Bulgaria (Table 9). They may use the same parameters for all habitat types e.g. Cyprus, or different parameters depending on the habitat type. Examples of the latter specifically for reefs as applied in France (Table 10, from Lepareur, 2011), Poland (Table 11, from Baranska et al., 2022) and Germany (Table 12, from Krause et al., 2008). Some countries have not specified the methodologies used (e.g. Lithuania and Italy) and the assessment of reefs in Latvia is based on expert judgement.

Table 9. Examples of aggregation methods used at the local scale for Reef assessments

Country	Aggregation method
France	Three parameters (surface, structure and functions and alterations) are assessed against several criteria, each represented by one or more indicators filled in or calculated from metrics collected in the field. Each indicator assessed is compared with a threshold value and scored with the total score subtracted from the starting score of 100. Final scores indicate the overall status along a gradient (Delavenne & de Bettignies, 2023). This generic approach across all habitat types is supplemented with a reef specific "health status index" (see Table 10).
Poland	Individual variables specific to reefs are rated (FV, U1, U2) with the lowest grading determining the aggregated result for 'structure & function'. An overall assessment for the site is the lowest grading given by aggregating results for the assessment of 'structure & function' with those for 'area' and 'future prospects' (See Table 11).
Germany	A common approach is applied to all the habitats. The results of the evaluation of individual variables are summarised by means of an accounting matrix to an overall evaluation for each individual sample plot. For reef habitats 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 (see Table 12).
Bulgaria	The status is favourable for structure and function when all parameters indicate "favourable" or when all parameters are indicated as "favourable" but where maximum up to 25% of the parameters have been assessed to have insufficient information available. If the assessment is "unfavourable – bad" for just one parameter, the overall assessment becomes unfavourable – bad. "unfavourable – inadequate" status is determined by any other combination of parameters.
Ireland	Aggregation at the local level is generally based on the number of assessed variables that fail to reach the good status (e.g. dune habitats: No failures = Favourable, 1-2 failures = Unfavourable - Inadequate, >3 failures = Unfavourable – Bad).
Netherlands	For reefs, 'Structure' scores are allocated for structure-determining species and for internal structure. Scoring for 'Function' is made up of scores relating to water (transparency and water quality), and processes. Scores are also allocated under a category of 'rest/food' which indicates suitability as a habitat for larval and juvenile fish being unaffected. In all cases the assessment must apply to at least 75% of the surface area of the habitat. The total gives a score for the Natura 2000 site (Jansen et al., 2014).
Spain	The status in a given locality is assessed as favourable for structure and function when all variables are considered favourable or, a maximum of 25% are unfavourable – inappropriate" and none considered "unfavourable bad". A site (SCI) is assessed as favourable where the locality assessments are predominantly favourable and there are no variables in the category "unfavourable bad".

Table 10. 'IS Health status index' used in France for assessment of reefs

To be informed	Collection methods	Collection scale
DF = Degree of fragmentation	1: the reef is composed of a single large block. 2: the reef is composed of several large blocks. 3: the reef is composed of blocks belonging to a broad size spectrum 4: the reef is composed of numerous small and medium blocks. 5: the reef consists only of very small blocks.	Mesh
BI = percentage of coverage of isolated balls	Estimated *in situ* on a grid of 75x75m	Mesh
SC = percentage of coverage of coalescent structures	Estimated *in situ* on a grid of 75x75m	Mesh
D = percentage of recovery of the degraded state	Estimated *in situ* on a grid of 75x75m	Mesh
BID = percentage of coverage of degraded isolated balls	Estimated *in situ* on a grid of 75x75m	Mesh
SCD = percentage of coverage of degraded coalescent structures	Estimated *in situ* on a grid of 75x75m	Mesh
RH = percentage of oyster recovery	Estimate on a 1m^2 quadrat (3 quadrats in each 75x75m mesh)	Quadrat
RM = mussels coverage percentage	Estimate on a 1m^2 quadrat (3 quadrats in each 75x75m mesh)	Quadrat
RU = percentage of recovery of Ulva	Estimate on a 1m^2 quadrat (3 quadrats in each 75x75m mesh)	Quadrat
R = percentage of reef within the 50 m^2 mesh	Estimated *in situ* on a grid of 75x75m	Mesh

Table 11. Reef specific variables used by Poland to assess structure and function

Parameter	Indicator rating		
	FV	**U1**	**U2**
Area	Area of the habitat is not decreasing and is not anthropogenically fragmented.	Area of the habitat shows a slowdown downward trend compared to previous studies or literature or is anthropogenically fragmented.	Area of the habitat shows a rapid downward trend compared to previous studies or literature or is highly anthropogenically fragmented.
Specific structure and functions			
Typical taxa of macroalgae	If there are 3 taxa from the list of typical taxa.	If there are 2 taxa from the list of typical taxa.	If there is 1 or no taxa from the list of typical taxa.
Typical taxa of fouling and phytophilous fauna	If there are 4 taxa from the list of typical taxa.	If there are 3 or 2 taxa from the list of typical taxa.	If there is 1 or no taxa from the list of typical taxa.
Conservation perspectives	The prospects for preserving the habitat are good to excellent, no significant conservation is expected impact or threatening factors.	The habitat's protection prospects are medium; the impact of threatening factors is expected.	The prospects for preserving the habitat are poor; a strong influence of threatening factors is observed, and the habitat cannot survive.

Table 12. Criteria and evaluating scheme for assessing the conservation status of habitat 1170 in Germany

Criteria	A: Excellent expression	B: Good expression	C: Medium to bad expression
Completeness of the typical habitat structures	Available	Largely present	Only partially present
Reef structures	natural, unchanged geogenic reefs: stable hard bottom structures in natural composition and sediment environment biogenic reefs: natural, stable composition of reef-forming species in natural sediment environment	slightly changed Structures and sediment distribution of the geogenic or biogenic reefs changed temporarily and only in a few areas	changed more significantly Loss of structure in all areas or in individual areas Structures and sediment distribution changed significantly
Hydrology and Morphology (including exposure)	natural, unchanged	minor changes in natural water exchange and soil relief	greater changes in natural water exchange and soil relief
Vegetation zones (if present under natural conditions)	natural	slightly changed	greatly changed, reduced
Where available, adoption of suitable basic data and assessments from monitoring for the WFD.			

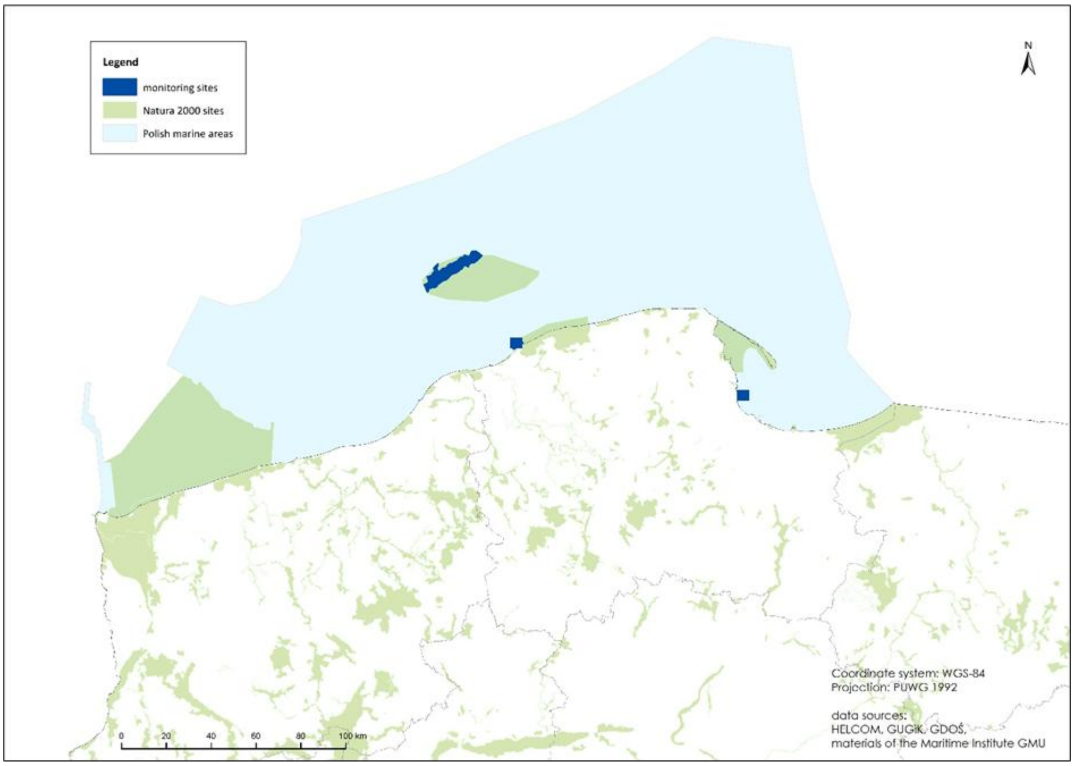
2.4 Aggregation at biogeographical scale

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

2.5 Selection of localities

There is no standardised approach across the Member States regarding the number and distribution of localities to carry out the assessment and monitoring of this habitat. Where a habitat has a limited occurrence and there have been comprehensive surveys to determine their occurrence, monitoring may take place in all the known locations. This is the case for example, with monitoring bioconcretions of *Lithophyllum* spp. along the **Maltese** coast which take place at all the sites known to host this community of the basis of a 2008 survey (Thibaut, 2011). The same applies for monitoring reef habitats in **Polish** marine areas which are only known from the Słupsk Bank boulder site, the Rowy boulder site and the Orłowo Reef. Poland recommends that five monitoring stations for macrophytes and macroinvertebrates should be located randomly in each monitoring locality (Baranska et al., 2022) (Figure 1).

Figure 1 Habitat monitoring sites for reefs in Poland



Source: Baranska et al., (2022)

In **Ireland** specific reef community types are sampled in each SAC with three stations within each community complex surveyed (Table 13) (Scally et al., 2020).

Table 13. Reef community types sampled on reefs in Ireland

Site	Marine Community Type
Kenmare River SAC	-Intertidal reef community complex -*Laminaria*-dominated community complex -Subtidal reef with echinoderms and faunal turf community complex
Galway Bay Complex SAC	-*Mytilus*-dominated reef community -Fucoid-dominated community complex -*Laminaria*-dominated community complex -Shallow sponge dominated reef community complex
Valencia Harbour/Portmagee Channel SAC	-*Fucus*-dominated intertidal reef community complex -*Laminaria*-dominated community -Echinoderm-dominated reef community complex
Kilkieran Bay and Islands SAC	-Intertidal reef community complex -Subtidal sponge and ascidian community complex -Deep water faunal crust and sponge community complex -Exposed to moderately exposed subtidal reef community complex -*Laminaria*-dominated community complex
Hook Head SAC	-Exposed to moderately exposed intertidal reef community complex -Echinoderm and sponge dominated community complex -*Laminaria*-dominated community
Mulroy Bay SAC	-*Laminaria*-dominated community complex -Reef community complex
Broadhaven Bay SAC	-Fucoid-dominated reef community complex -Subtidal reef community complex

Site	Marine Community Type
Mullet/Blacksod Bay Complex SAC	-Intertidal reef community complex -Sheltered subtidal reef community complex -*Laminaria*-dominated community complex
Tralee Bay and Magharees Peninsula, West to Cloghane SAC	-Intertidal reef community complex -Subtidal reef community complex -*Laminaria*-dominated reef community complex
Magharee Islands SAC	-Intertidal reef community complex -*Laminaria*-dominated community complex -Subtidal reef community complex
River Barrow and River Nore SAC	-*Sabellaria spinulosa* reef
Lower River Shannon SAC	-Fucoid-dominated intertidal reef community complex -Mixed subtidal reef community complex -Faunal turf-dominated subtidal reef community -Anemone-dominated subtidal reef community -*Laminaria*-dominated community complex

A generic sampling design has been set out in **Croatia** because of the spatial heterogeneity of the coralligenous habitats, lack of information on their distribution, as well as differing extents and depth ranges. The suggested approach is to define the main geographical areas characterized by their environment conditions and within each one, selected areas under different management regimes (e.g. Natura 2000 sites, MPAs). Out of 10 subtypes of 1170, monitoring should be concentrated (but not exclusively) on gorgonian dominated assemblages which are representative of reefs at same time as being very sensitive to disturbance. The number of monitoring sites should range from a minimum of 18 (one assemblage and 3 sites per condition) to a maximum of 108 (2 assemblages and 9 sites per condition) for each depth range considered (UNEP/MAP - RAC/SPA, 2014).

In **Spain** the number and distribution of sampling locations depend on the size and diversity of the reef habitat (Templado et al., 2009); **Romania** recommends stratified sampling except for rare habitats where subjective sampling should be used. The minimum sample size should be determined by conducting a pilot study, depending on the habitat type. In contrast, detailed methodologies, specifically for monitoring reefs have been set out by **Germany** (Heinicke et al., 2021) and **Italy** (Ministero dell'Ambiente e della tutela del Territorio e del Mare, 2010).

2.6 General monitoring and sampling methods

A six yearly cycle of reporting, as specified under Article 17, is required under the Habitats Directive. This includes reporting on the conservation status of habitats listed in Annex I 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.

Protocols and practice including identifying variables for monitoring the condition of deep-sea habitats, including deep sea reefs are not as well developed as those for continental shelf areas but this is changing. A review of approaches favoured by deep-sea scientists in a survey carried out by Danovaro et al. (2020) indicated a consensus on the need to prioritise macro and megafauna, and that monitoring of ecosystem functioning should focus on trophic structure and biomass production. A counter case has also been made for prioritizing microscopic organisms, notably eukaryotic and prokaryotic microbes, and meiofauna microbial given that heterotrophic and chemoautotrophic carbon production and elemental cycling are essential ecological variables to understand key processes that sustain the functioning of deep-sea food webs and biogeochemical cycles (Ingels et al., 2020). As in shallower waters, habitat degradation and recovery rates are identified as crucial features for monitoring deep sea ecosystem health.

In **Malta**, monitoring frequency of distributional range and extent is 6 yearly (ERA, 2015) with guidance that seasonal factors need to be taken into account. In the Maltese case it is recommended that the best period to carry out surveys of littoral reefs in the North-western Mediterranean is spring (April-June) over the shortest possible time to reduce the effect of the great seasonal variability in littoral communities in the region. More frequent sampling/monitoring is recommended for bio concretions of *Lithophyllum* spp. which have a limited distribution along the Maltese coast. Three yearly monitoring is also recommended for the small number of reef habitats in the **Polish** marine area (Baranska et al., 2022).

2.7 Other relevant methodologies

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

They include;

- Work carried out under Regional Seas Programmes such as the Quality Status Reports prepared by OSPAR and HELCOM (e.g. an assessment of benthic habitat quality in the Great North Sea using Relative Margalef diversity and the extent of physical disturbance to benthic habitats by fisheries and an assessment of eutrophication in the Baltic Sea (Wijnhoven et al., 2023; Matear et al*.,* 2023; HELCOM, 2009) and monitoring measures for Specially Protected Areas under the Barcelona Convention (United Nations, 1982)
- Reporting under other EU Directives, in particular the Water Framework Directive and the Marine Strategy Framework Directive[11]
- National monitoring programmes as in Denmark[12] or the United Kingdom (Alexander et al., 2015)
- Surveys/monitoring of developments/human activities/EIAs (Eg. Brunier et al*.,* 2022)

Some examples are; historical studies for example on the spatial extent and associated macrofauna species of oyster reef ecosystems along the coasts of France, Denmark, Ireland and the UK (Thurstan et al., 2024); characterisation of the fishes, algae and benthic macro invertebrates on the rocky reefs around the Macaronesian islands of Madeira and Selvagens (Friedlander et al., 2017); and impacts of offshore wind, nutrients and invasive species on reefs in the northeastern Baltic Sea (Estonia) (Vaher et al., 2022).

Variables and metrics have also been used to report on the condition of specific reef types. One example, shown in Table 14 relates to coralligenous reefs where at least sixteen different indices have been used to assessing their ecological status highlighting the need to align the methodologies and develop a unified index (de Camillo et al., 2023).

[11] Summaries available on the Marine Water Information System for Europe (WISE Marine); https://water.europa.eu/marine/data-maps-and-tools/map-viewers-visualization-tools/dashboards-on-marine-features-under-other-policies

[12] Eg. monitoring of seas and fjords in Denmark since the early 1970s as part of the adoption of the first Environmental Protection Act.

Table 14. Summary of indices (in chronological order) to assess the ecological status of coralligenous reefs (de Camillo et al., 2023)

Index	Reference
STVI - Scuba Trail Vulnerability Index	di Franco et al., 2009
CAI - Coralligenous Assemblage Index	Deter et al., 2012; Marre et al., 2020
CavEBQI - Cave Ecosystem-Based Quality Index	Rastorgueff et al., 2015; Boudouresque et al., 2020
ESCA - Ecological Status of Coralligenous Assemblages	Cecchi et al., 2014; Piazzi et al., 2017; 2021; Penna et al., 2018
ESCA – TA - ESCA Total Assemblage	Piazzi et al., 2017; 2021
COARSE index - Coralligenous Assessment by Reef-Scape Estimate	Gatti et al., 2015; Piazzi et al., 2017
MAES - Mesophotic Assemblages Ecological Status **q-MAES -** quick MAES	Canovas-Molina et al., 2016
OCI - Overall Complexity Index	Paoli et al., 2016
CBQI - Coralligenous Bioconstructions Quality Index	Ferrigno et al., 2017; Apolloni et al., 2020; Piazzi et al., 2022
INDEX-COR	David et al., 2014; Sartoretto et al., 2017
ISLA - Integrated Sensitivity Level of coralligenous Assemblages	Montefalcone et al., 2017
Index of 3D – Structural Complexity	Valisano et al., 2019
STAR – STAndaRdized coralligenous evaluation procedure	Piazzi et al., 2019a, b; Gennaro et al., 2020
MACS – Mesophotic Assemblages Conservation Status	Enrichetti et al., 2019; Moccia et al., 2021
MedSens sensitivity index	Turicchia et al., 2021
NAMBER	Piazzi et al., 2023

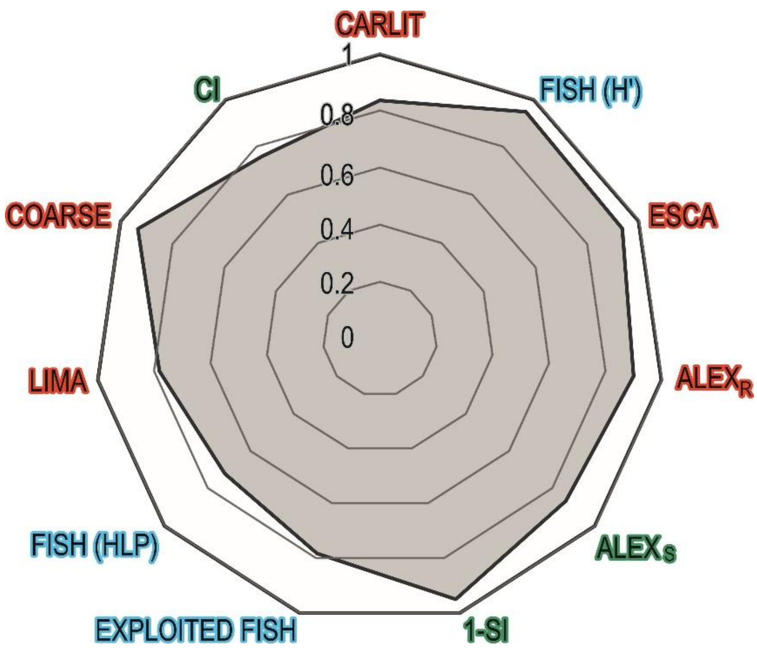
Member States link some of their marine monitoring and sampling methodologies to sampling and monitoring requirements under WFD and MSFD. In Denmark, for example, nature type monitoring complements similar monitoring related to WFD regarding soft-bottom fauna, flowering plants and macroalgae. Areas are typically visited once during an assumed 6-year programme however natural type monitoring for rocky reefs take place annually with the number of sampling stations/transects specified (Miljostyrelsen, 2022).

Co-ordination also takes place with other monitoring schemes. An example of the latter is monitoring of physical, chemical and biological variables in the Baltic Sea under the Helsinki Convention and as part of the Baltic Sea Action Plan. The HELCOM monitoring manual provides a catalogue describing and listing all marine monitoring carried out in the Baltic Sea and their links to indicators developed to assess progress towards Good Environmental Status (HELCOM, 2021). There are also links to national monitoring programmes for the Habitats Directive for the EU Member States around the Baltic Sea.

A Nested Environmental status Assessment Tool (NEAT) focusing on five MSFD descriptors (including Biodiversity (D1) and Seafloor integrity (D6)) has been the subject of a feasibility study for selected North Atlantic deep-sea ecosystems (Kazanidis et al., 2020). Twenty-four indicators were used across the five descriptors, including one for descriptor D1 and thirteen for D6. Conclusions included that three indicators (areal extent of human affected area, areal extent of biogenic/vulnerable habitats and density of biogenic reef forming species) should be considered in future regional assessments of deep-sea environmental status. There was good/moderate agreement with expert judgement but a number of issues that should prevent its use without advice from experts in the field of deep-sea ecology.

In Italy, a study using data from the Capo Carbonara MPA (SE Sardinia) compared the eleven biotic indices applied to different habitat types to assess whether they were consistent in defining the environmental status of the MPA. The reef component was assessed using the CARLIT method (Ballesteros et al., 2007) and was combined with an estimated Ecological Quality Ratio of indices for fish, non-indigenous species, exploited fish, food webs, seagrass habitat and seafloor integrity to give an overview of the condition of the site as a whole (Figure 2). This was presented using the graphical RESQUE (REsilience and QUality of Ecosystem) approach (Oprandi et al., 2023) with the benchmark describing the best conditions for the MPA, corresponding to a high environmental status would be when all indices reach their maximum value (i.e. equal to 1).

Figure 2. Polygon resulting from the EQR scores of all the indices for Capo Carbonara MPA (SE Sardinia, Italy)



Source: Oprandi et al., (2023).

Remote sensing techniques are constantly evolving. In recent years Structure from Motion (SfM) photogrammetry has been used to support rapid and accurate data collection through optical scanning of organisms and habitats. Multi-view cameras are used and image data sets processed using commercial or open-source software. This approach has been used in Italy (Portofino MPA) to estimate the biomass of the sponge *Sarcotragus foetidus* and abundance of the red coral *Corallium rubrum* (Palma et al., 2019).

There are also many examples of work assessing the condition of reefs in non-EU countries. In South Africa, for example, two types of metrics (composition and size-based) were used in a study to assess the condition of rocky reefs. The aim was to investigate potential approaches in the absence of baseline data for reference conditions and used no-take MPAs to identify suitable indicators using fish and benthic community data. Structural indicators for fish included species richness, evenness and total abundance and size-based indictors included trophic, biomass, and life stage of individual fish. Benthic metrics included percentage cover of morphologies (e.g. turf mat, upright branching, large fan). In this study fish and benthic community data (total biomass, average length and proportion of mature fish) were more responsive that total abundance or species richness to three levels of human pressures (Smit et al., 2023). A study in California also used reference sites – reefs that scored zero in the water quality index and below the 30th percentile in the fishing pressure index dating back to 1980 (Coates et al., 2018). Long term data sets have also been used in New Zealand, in this case to evaluate and improve monitoring of reef fish species using underwater visual census monitoring to quantify trends in their abundance. This revealed that greater site replication was required for more spatially heterogenous species/locations and also that the optimal monitoring approach changes through time, highlight the need for an adaptive approach to monitoring (Jones et al., 2015).

2.8 Conclusions

Some information has been collected about the location and description of the main characteristics of reefs by all the Member States that have reported habitat 1170 as present within their jurisdiction[13]. Specific methodologies for assessing and monitoring reefs are also available from twelve Member States (DE, DK, ES, FR, HR, IE, IT, MT, NL, PL, RO, SI). Also relevant are reports of reef surveys and assessments carried out in these and other EU Member States (BE, BG, CY, EE, ES, FI, GR, LT, LV, NL, PT, SE), that can or have been used to inform such assessments although not directly stated as a reason for the work.

There is much commonality in approach across Member States, from initial review of likely locations based on existing geological information and maps, followed by aerial surveys and further reconnaissance from boat and shore to gather more specific locational information. Abiotic and biotic characteristics and variables of the habitat are recorded, as well as aspects such as fragmentation and disturbance which are landscape/seascape characteristics of this habitat type. For example, physical state variables frequently recorded include the topography and extent of reefs as well as exposure to currents and wave action; compositional state variables typically involve recording epifauna and macroalgae assemblages, their abundance and distribution across reef features as well as the presence, condition and abundance of any subhabitats, including biogenic reefs. Variations in the methodologies used to assess and monitoring reefs are strongly influenced by accessibility, topographical type, hydrographic conditions, as well as the diversity of the habitat and the associated biological communities.

The reference values and thresholds applied by Member States to obtain condition indicators for reefs 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. The exception is functional state characteristics where limited information is available on approaches taken.

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

A number of approaches are used to aggregate data to provide an assessment at local and national scales. There is no specific information on aggregation methods applied for reefs 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 reefs. Practical consideration, such as accessibility are important as are factors size, physical variability and diversity of the associated biological communities. Ideally monitoring takes place across the reef as well as focusing on any identifiable sub habitats such as biogenic reef types.

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 reefs specifically for Habitats Directive reporting is more frequent (e.g. 3 yearly or 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.

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

3.1 Selection of condition variables, metrics and measurement methods

Variables identified for monitoring programmes need to be robustly associated to the key characteristics and processes (functions) that determine habitat condition and must be sensitive to natural threats or human pressures that decrease favourable condition (Maes et al., 2023). A set of variables associated will to 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 type 1170 are presented earlier in this report. A proposed list of essential, recommended and specific condition variables is presented in Table 15. '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. 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 reef types (e.g. where biogenic reefs are present) or which may be particularly relevant in some Member States.

On the other hand, 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 MSs, which may determine the values of the variables characterizing the habitat condition as favourable. These factors include biogeographical gradients, historical, cultural and socio-economic background.

The main **abiotic characteristics** are physical (describing influencing factors of depth, tidal regime, geology, topographical characteristics, and exposure to currents, wave action, scour and surge, temperature and turbidity), and chemical (related to water quality).

The main **biotic characteristics** are compositional (e.g. epifaunal and infaunal communities, biogenic structures), structural (characteristic species, reef structure and vegetation zones) and functional (type and degree of bioerosion and bioconcretion). All of these are already subject to monitoring by Member States however monitoring biogenic structures has been listed in Table 15 as 'specific' as such structures are not always present. The same applies to macroalgae/eelgrass presence and condition. Monitoring the presence of opportunistic/invasive species is '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, 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 15. Proposals for condition variables for assessing and monitoring habitat 1170 (reefs)

The variables are included in the types recognized in the SEEA EA methodology. Metrics may show several options. 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, SBES - Single Beam Echo Sounders, SSS - Side Scan Sonar, TLP - Time Lapse Photography

Characteristics	Variables	Metrics	Application	Standardised measurement procedures	Considerations relating to methodologies
1. Abiotic characteristics					
1.1 Physical state characteristics					
Degree of sub-mergence/ depth/ tidal regime	**-Depth in relation to chart datum**	-Metres (m)	Essential if not positionally stable	SSS, SBES, MBES, AGDS, LIDAR Tide gauges	Depth, together with topographical characteristics and tidal regime have a significant influence on the form and extent of reef habitat types as well as on the development and stability some of the features within them such as gullies, overhangs and tidal pools.
Substrate type/ Geology	**-Type of rock (just for geogenic reefs)**	-Sediment type	Essential if not positionally stable	SSS, MBES, AGDS Modelling Aerial survey (Satellite/Drone imagery/LIDAR) Geological maps Seabed sediment sampling	Rock type together with topographical and hydrographical characteristics have a significant influence on the form and extent of reef habitat types as well as the associated biological communities (e.g. bivalves that can bore into soft rocks) and therefore in determining which other variables should be used for reef monitoring and evaluation.
Topography/ physical structure/ habitat complexity	**-Physical dimensions,** **-Extent** **-Longitude and latitudinal gradients** **-Form and features (e.g. gullies, caves)** **-Roughness/ verticality**	-Metres (m) -Degrees of slope (º) -Physical features from a reference list	Essential if not positionally stable	SSS, MBES, AGDS Aerial survey (Satellite/Drone imagery/LIDAR) Geological maps Modelling UW-Video	Most appropriate methodologies 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 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. For small scale habitat mapping, high resolution SSS, underwater photography, and grab sampling data can be combined for habitat mapping. LIDAR is particularly useful in shallow waters although affected by turbidity of the water.

Characteristics	Variables	Metrics	Application	Standardised measurement procedures	Considerations relating to methodologies
Hydrodynamics - Exposure to current, wave action, scour & surge	**-Current speed -Wave height -Direction -Frequency**	-Speed (m/s) -Metres (m)	Recommended	TLP Hydrographic charts Modelling Aerial survey (Satellite/Drone imagery) ADCP, wave riders, pressure sensors	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 (^{0}C)	Essential	CTD	Temperature is usually recorded as part of water quality sampling programmes.
Turbidity	**-Suspended particles -Light transmission through water samples**	Nephelometric turbidity units (NTU), formazin turbidity units (FTU)	Essential	Turbidity sensor, Secchi disc, water chemistry data loggers. Aerial survey (Satellite data). Direct sampling (sediment sampling, sediment traps).	Different turbidity units would be used depending on tools used, therefore the same instrument should be used for comparability of data over time. Colonising species can be an indirect indicator of turbidity. Complementary biological surveys may therefore be considered for monitoring and reporting on this characteristic.
1.2 Chemical state characteristics					
Water quality	**-Various substances (including chemicals listed in the WFD 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 depending on habitat type, pressures and threats	CTD with sensors to measure oxygen (saturated %) and dissolved (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 relevant and may already apply to some intertidal reefs. They include a requirement to monitor and set standards for general parameters such as oxygenation, nutrients, nitrogen, phosphorus, as well as chemical and physico-chemical quality elements.

Characteristics	Variables	Metrics	Application	Standardised measurement procedures	Considerations relating to methodologies
2. Abiotic characteristics					
2.1 Compositional state characteristics					
Invertebrates - Epifaunal & infaunal communities including meiofauna	**-Abundance of characteristic species from standardised lists** **-Diversity of characteristic species from standardised lists** **-Density of meiofauna**	-Number of biocenosis/taxa -Presence & abundance of species (SACFOR scale) -Diversity index (Shannon-Wiener diversity index, AMBI index) -Biomass -Estimated % cover -Meiofauna density (ind/10cm^2)	Essential	Photographic quadrats, video transects and visual census (ROV or DDV) Direct sampling (grab, core, dredge, suction)	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 present as well as factors such as their extent, location, and any seasonality.
Vertebrates - Associated fish communities	**-Abundance of characteristic species from standardised lists** **-Diversity of characteristic species from standardised lists**	-Number -Population structure -Trophic composition (e.g. % omnivores/ piscivores) -Distribution	Specific	Visual/boat-based surveys Photographic/satellite imagery *in situ* observations Nets & traps (fish) eDNA	Methodology will depend on the species.
Macrophytes, macroalgae, eelgrass	**-Type** **-Extent**	-Spatial extent -Taxonomic composition	Specific but Essential if present	Visual and acoustic surveys (e.g. covering presence, density, extent) Photographic quadrats, video transects, visual census (ROV or DDV) Direct sampling Remote sensing	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.

Characteristics	Variables	Metrics	Application	Standardised measurement procedures	Considerations relating to methodologies
Opportunistic / invasive species	**-Presence -Distribution -Abundance**	-Number -Biomass -% cover -Population structure	Recommended	Photographic quadrats, video transects and visual census (ROV or DDV) Direct sampling (grab, core, dredge, suction)	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 this habitat as well as some potential impacts on the physical structure.
Biogenic structures	**-Type -Extent**	-Biomass -Estimated % cover of main taxa or morphological groups -Type: Geogenic or biogenic, basal (encrusting), intermediate (bushes) and upper (erect) layer for coralligenous reefs.	Specific but Essential if present	Photographic quadrats, video transects and visual census (ROV or DDV) Direct sampling (grab or core) Hydroacoustic methods Aerial photography for intertidal reefs	Methodology will depend on the species. Non-destructive methods are likely to be favoured.
2.2 Structural state characteristics					
Characteristic species	**-Condition**	-Percentage cover -Biomass -Density -Synthetic indicators (M-AMBI, BENTIX etc)	Essential	Birds, marine mammals and fish: Visual census, aerial and boat-based surveys Epifaunal and infaunal assemblages: Photographic quadrats, video transects and visual census (ROV or DDV), direct sampling (grab, core) Meiofauna and microbiota: direct sampling (grab, core)	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.
Reef structure	**-Condition -Composition**	-Volume/biomass -Basal (encrusting), intermediate (bushes) and upper (erect) layer for coralligenous reefs	Essential	Photographic quadrats, video transects and visual census (ROV, DDV or towed sledge video data) Direct sampling (grab, core) AGDS, SSS Aerial/satellite photography Modelling	Non-destructive methods are likely to be favoured, and the methodology will depend on the reef forming species as well as factors such as extent and location.

Characteristics	Variables	Metrics	Application	Standardised measurement procedures	Considerations relating to methodologies
Vegetation zones	**-Abundance** **-Extent** **-Condition**	-Spatial extent (area and depth) -Composition -% cover of substrate -Density (no/m^2) -Average leaf length & width -Leaf & rhizome biomass	Specific but Essential if present	Visual and acoustic surveys (e.g. covering presence, density, extent) Photographic quadrats, video transects and visual census Direct sampling	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 change 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).
2.3 Functional state characteristics					
Bioerosion	**-Type of bioeroders** **-Abundance of bioeroders** **(e.g. sponges)**	-Composition -% cover	Recommended	Visual and acoustic surveys (e.g. covering presence, density, extent) Photographic quadrats, video transects and visual census Direct sampling	Comparisons of recording data will reveal temporal changes in the presence and/or condition of bioeroders. 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 either directly (e.g. removal) or indirectly (e.g. increasing turbidity of the water column).
Bioconcretion	**-Cover of animal** **-Cover of algal builders**	-% cover	Recommended	Visual and acoustic surveys (e.g. covering presence, density, extent) Photographic quadrats, video transects and visual census Direct sampling	Comparisons of recording data will reveal temporal changes in the presence and/or condition of bioconcretion. 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).
3. Landscape/Seascape characteristics					
Connectivity / Fragmentation	**-% cover** **-Patch size** **-Distance between patches**	-Area (ha) -Distance (m or km)	Recommended	Visual survey Mapping Aerial/satellite imagery	

Characteristics	Variables	Metrics	Application	Standardised measurement procedures	Considerations relating to methodologies
4. Other					
Disturbance	**-Presence of anthro-pogenic structures -Footprint of activity (ha)**	-Presence/absence -% area directly affected by human activity (e.g. by demersal fisheries or an-thropogenic structures).	Essential	Visual survey, Mapping Aerial/satellite imagery For physical disturbance on sublit-toral areas from activities such as trawling and dredging: SSS and MBS	Many different "types" of disturbance may be reported, and they can be categorised in a variety of ways (e.g. physi-cal/chemical/biological; presence/absence). The signifi-cance of any disturbance on the structure and function of the habitat may be related to aspects such as frequency, permeance, level and type of impact. There may be scope to use relevant results of MSFD assessments.

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

Table 16. 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

Source: Borja et al., 2012
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.

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 1)[14]

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

Box 1. Article 4 of Commission Decision (EU) 2017/848 (EU, 2017)

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

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

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

(b) be consistent with Union legislation;

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

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

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

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

(g) make use of best available science;

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

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

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

A 2022 review of the state of play with thresholds for MSFD criteria used by Member States indicated that progress has been made but also that there was some way to go before this is achieved for all eleven descriptors. For benthic habitats (relating to Descriptors 1 and 6) the following criteria are to be used to assess the extent to which GES is achieved:

- D6C1 Physical loss of the seabed
- D6C2 Physical disturbance to the seabed
- D6C3 Adverse effects of physical disturbance on benthic habitats (spatial extent)
- D6C4 Benthic habitat extent (extent of habitat loss from anthropogenic pressures)
- D6C5 Benthic habitat condition (extent of adverse effects from anthropogenic pressures)

No thresholds have been agreed as yet for D6 (sea floor pressures and impacts) however the Technical Group on Seabed Habitats and Sea-floor integrity (TG SEABED) have provided some advice on setting threshold values for D6C4 and D6C5 (Box 2) (TG SEABED, 2023).

Box 2. Technical Group on Seabed Habitats and Sea-floor integrity (TG SEABED) advice on setting threshold values on Good Environmental Status for descriptors D6C4 and D6C5.

TG's Seabed's advice is to set the threshold values as follows:

- The maximum proportion of a benthic broad habitat type in an assessment area that can be lost is 2% of its natural extent (≤2%) (D6C4).
- The maximum proportion of a benthic broad habitat type in an assessment area that can be adversely affected is 25% of its natural extent (≤25%). This includes the proportion of the benthic broad habitat type that has been lost (D6C5).
- 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 ecosystems processes) (D6C5)*.

Existing obligations for the protection and conservations of certain habitat types, such as those listed under Directive 92/43/EEC or international agreements such as Regional Sea Conventions, still apply and the thresholds defined here shall not be considered by Member States as alternative conservation values for these habitat types.

TG Seabed recommends that Member Stated use caution when applying these threshold values on very small and/or very large benthic broad habitats types in their marine waters and fully consider the practical implications of the accepted extent of habitat lost in environmental protection terms**.

Footnote: TG Seabed recognises that more work is required for the quantification of specific indicators of adverse effects before an overall threshold value can be proposed for D6C5-Quality. TG Seabed is developing a roadmap to ensure that the work on the quality threshold value is done in a defined timeframe. The group therefore recommends a qualitative description for D6C5-Quality that will guide the work on the selection and quantification of indicators of adverse effects and the adoption of an overall threshold value for D6C5-Quality.*

*Footnote**: For instance, a very small broad habitat type in an assessment area may need to conserve all of its extent to be in 'good' quality. On the other hand, the extent of loss of a very large broad habitat type in an assessment area may be so big that it threatens ecosystem functioning in the whole assessment area.*

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/E9).

All the variables identified for assessing the structure and function of habitat 1170 are covered in some way by the MSFD GES descriptors with the exception of substrate type/geology which is a contextual variable. 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 17 makes some initial recommendations for setting reference/threshold values for the proposed variables for assessing and monitoring the condition of habitat 1170.

Table 17. Considerations for setting reference/threshold values for habitat 1170 (reefs)

WFD Quality Elements: QE1 – Biological Quality Elements, 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), , QE3-1-2 Thermal conditions

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

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/ Thresholds	Relevant MSFD Descriptors
1. Abiotic characteristics					
1.1 Physical state characteristics					
Degree of submergence / depth / tidal regime	**-Depth in relation to chart datum (Essential*)**	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 habitat.	QE2 (QE2-1, QE2-3)	D7
Substrate type / Geology	**-Geogenic reef type (Essential*)**	Qualitative	This variable will be descriptive with no changes foreseen in the underlying geology, therefore no proposals for reference values are recommended.		
Topography / physical structure / habitat complexity	**-Physical dimensions -Extent -Longitude and latitudinal gradients -Form and presence of features from a standardised list which could be developed (e.g. gullies, caves) -Roughness / verticality (Essential*)**	Quantitative, Qualitative, expert judgement	Comparisons of imagery data over time can reveal gross changes in extent and 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 reefs 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 regarding knowledge of such changes. If sufficient historical data are available these could be used to set a reference value relative to a specific point in time.	QE2 (QE2-1, QE2-3)	D6, D7

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/ Thresholds	Relevant MSFD Descriptors
Hydrodynamics - Exposure to current, wave action, scour & surge	**-Current speed -Wave height -Direction -Frequency (Recommended)**	Quantitative, Trend	Aside from seasonal changes, natural variation in these variables is likely to be low. However, if major changes do occur, they are likely to lead to significant changes in the species colonising reef habitats. Whilst it would be possible to set quantitative reference values (e.g. a certain % change) trends are likely to be more informative as this is less likely to be skewed by single significant events.	QE2 (QE2-1)	D7
Temperature	**-Water temperature (Essential)**	Quantitative	Reference values for temperature might be carefully defined according to each subtype and the seasonal cycle. Furthermore, need to takes into account that 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 (Essential)**	Quantitative	Increasing turbidity can have an effect on the species that are present (e.g. reducing the number/extent of filter feeders) Reference levels relating to characteristic species and water quality would be complementary to this variable.	QE3 (QE3-1-1)	D6
1.2 Chemical state characteristics					
Water quality	**-Various substances (including chemicals listed in the WFD and EQSD, nitrates & phosphates, oxygen, chlorophyll, dissolved solids) (Essential*)**	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

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/ Thresholds	Relevant MSFD Descriptors
2. Biotic characteristics					
2.1 Compositional state characteristics					
Invertebrates - Epifaunal & infaunal communities including meiofauna	**-Abundance of characteristic species -Diversity of characteristic species -Density of meiofauna (Essential*)**	Quantitative, indices/additional, scoring.		QE1 (QE1-2-4, QE1-3)	D1, D4, D6
Vertebrates - Associated fish communities	**-Abundance of characteristic species -Diversity of characteristic species (Specific*)**	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.	QE1 (QE1-4)	D1, D3, D11
Macrophytes, macroalgae, eelgrass	**-Type -Extent (Specific*)**	Quantitative, trend, 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, diversity, 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
Biogenic structures	**-Type -Extent (Specific*)**	Quantitative, Trend	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. E.g. physical damage of some types of biogenic structures may be the result of storm events or human activity such as demersal trawling. Examples of natural variation include burial by sediment, responses to cyclical changes in predator/prey levels and specific natural events (storms or flooding). Indices have been used to assess ecological quality across reefs e.g. combining descriptors of sensitivity, diversity and heterogeneity of assemblages.		D1, D6
Opportunistic / invasive species	**-Presence -Distribution -Abundance (Recommended)**	Quantitative, indices			D1, D2

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/ Thresholds	Relevant MSFD Descriptors
2.2 Structural state characteristics					
Characteristic species	**-Condition (Essential)**	Quantitative, indices/additional, scoring, linked to WFD	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.	QE1 (QE1-2-4, QE1-3)	D1, D4, D6
Reef structure	**-Condition -Composition (Essential)**	Quantitative, indices/additional, scoring.	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 changes following storm events.	QE1 (QE1-3)	D1, D6
Vegetation zones	**-Abundance -Extent -Condition (Specific*)**	Quantitative, indices, linked to WFD	If vegetation zones are present, 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. 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 (QE1-2-2)	D1, D5, D6
2.3 Functional state characteristics					
Bioerosion	**-Type of bioeroders -Abundance of bioeroders (e.g. sponges) (Recommended)**		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 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 (QE1-3)	D1, D6

Characteristics	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values/ Thresholds	Relevant MSFD Descriptors
Bioconcretion	**-Cover of animal -Cover of algal builders (Recommended)**		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 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 (QE1-3)	D1, D6
3. Landscape/Seascape characteristics					
Connectivity/ Fragmentation	**-% cover -Patch size -Distance between patches (Recommended)**	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 regarding 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	**-Presence of anthropogenic structures -Footprint of activity (ha) (Essential)**	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.		D1, D8, D10

*: check Table 15 for further information

Table 18 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. In fact, 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 categorical (e.g. no alien species allowed), or quantitative variables which may obey linear or non-linear relationships with the condition (Jakobsson et al., 2020). The variables that are used can be directly standardized to apply aggregation procedures.

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

Table 18. Some initial recommendations for setting thresholds for the proposed variables

Dark grey: Preferred approaches; Light grey: additional approaches

Description	Application	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 / tidal regime	Essential*						MSFD
Substrate type / Geology	Essential*						
Topography / physical structure / habitat complexity	Essential*						MSFD, WFD
Hydrodynamics - Exposure to current, wave action, scour & surge	Recommended						MSFD, WFD
Temperature	Essential						MSFD, WFD
Turbidity	Essential						WFD, MSFD

Description	Application	Comparison to undisturbed areas	Comparison to good condition areas	Hindcasting	Modelling	Expert judgement	EU Relevant existing reference values
1.2 Chemical state characteristics							
Water quality	Essential*						MSFD, WFD
2. Biotic characteristics							
2.1 Compositional state characteristics							
Invertebrates - Epifaunal & infaunal communities including meiofauna	Essential						MSFD, WFD
Vertebrates - Associated fish communities	Specific						MSFD, WFD
Macrophytes, macroalgae, eelgrass	Specific*						MSFD, WFD
Opportunistic / invasive species	Recommended						MSFD
Biogenic structures	Specific*						MSFD
2.2 Structural state characteristics							
Characteristic species	Essential						MSFD, WFD
Reef structure	Essential						MSFD, WFD
Vegetation zones	Specific*						MSFD, WFD
2.3 Functional state characteristics							
Bioerosion	Recommended						MSFD, WFD
Bioconcretion	Recommended						MSFD, WFD
3. Landscape/Seascape characteristics							
Connectivity / Fragmentation	Recommended						MSFD
4. Other							
Disturbance	Essential						MSFD

*: check Table 15 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 3).

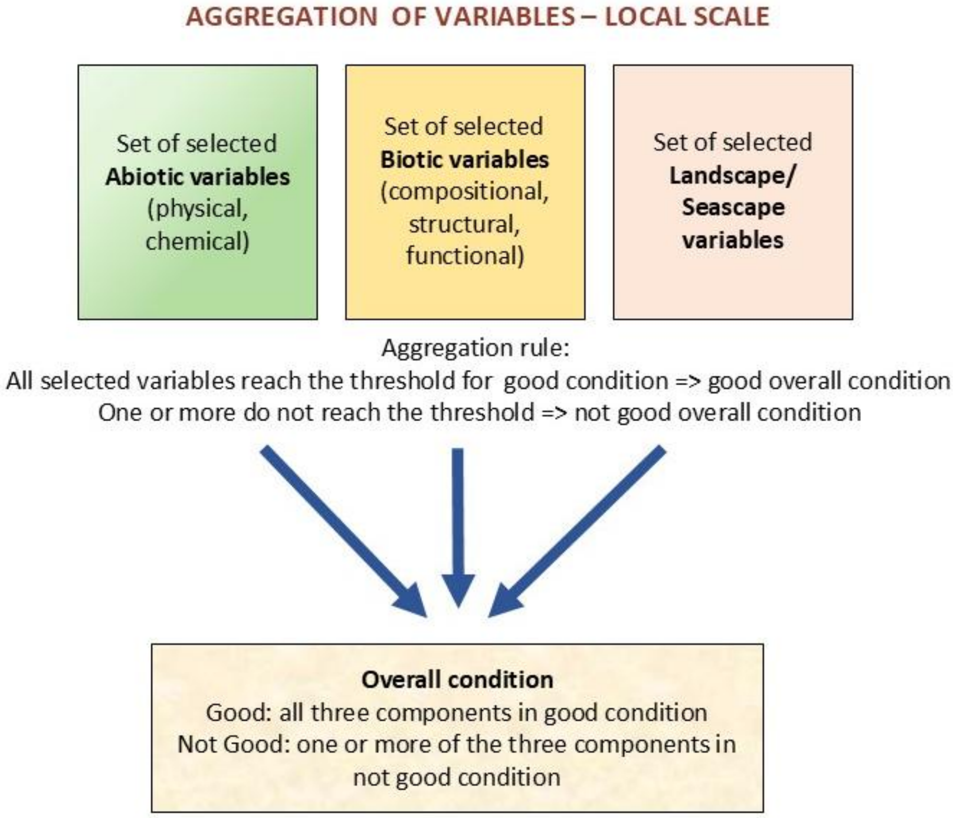
Step 1 – Aggregation of the variables measured in each group of characteristics

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 3. 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 MSs must follow the recommendations from the Art. 17 reporting guidelines for the period 2013-2018, which establish 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 characterization 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. However, this period can be completed through different approaches depending on the resources of Member States. Thus, 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, in order 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 our 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.

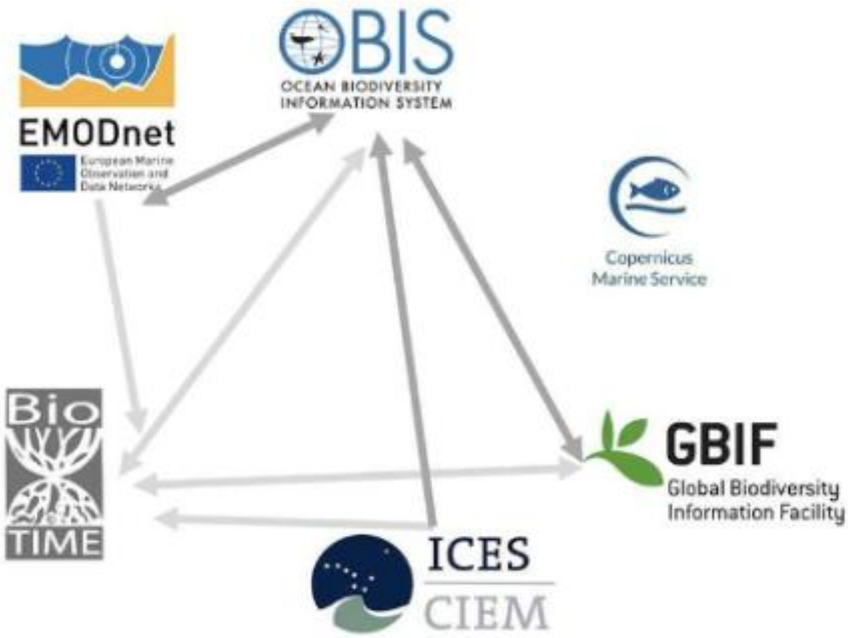
Replication and randomization:

- 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 are shown in Figure 4. (European Commission, 2023).

Figure 4. 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+**[15] European Biodiversity Partnership 'Mapping' the current state of research on biodiversity and associated ecosystem services in Europe in terms of projects, programmes and funding. This includes research projects on biodiversity and associated ecosystems services funded through research programmes in Europe. https://www.biodiversa.eu/
- **EuropaBON**[16] current monitoring efforts to identify gaps, data and workflow bottlenecks, and analyse cost-effectiveness of different schemes. The results of this assessment will be used to inform the design of improved monitoring schemes able to integrate in-situ and remote sensing data through models, and using novel technologies, to deliver more complete and less biased biodiversity information with multiple benefits to users and society.
- **MarBioME**[17] **– Marine Biodiversity Monitoring in Europe**. A holistic and global review of European marine biodiversity projects and monitoring programmes, and collated information on marine biodiversity research gaps. Identifies 647 distinct monitoring programmes conducted in EU marine waters, the majority of which target assemblages or communities (European Commission, 2023)

Other data sources include the following:

The **Marine Biodiversity Observation Network for Europe (MBON Europe**[18]**)** coordinates active monitoring of marine biodiversity by European organizations. It focuses on establishing long-term time series to recognize trends related to natural or human activities, especially climate change. MBON Europe aims to formalize coordination between organizations, harmonize methods, facilitate data publication, and develop strategies for improved coordination.

Copernicus Marine Data Store[19] offers data on sea temperature and anomalies, crucial for many types of reefs.

The **ADRIREEF** database provides a comprehensive collection of natural/artificial reefs and wrecks in the Adriatic Sea, collected as part of the Interreg Italy–Croatia project (Minelli et al., 2020).

Reef Check Med[20] exemplifies the growing field of citizen science in reef monitoring. It uses a set of indicator organisms to track human impact on coral reefs and ecological and socioeconomic changes. Their Mediterranean dataset includes abundance records of 43 marine species from 2001 to 2020, covering protected, non-indigenous, and climate-sensitive species.

The **Global distribution of cold-water corals**[21] dataset shows occurrences for eighty-six Families of Octocorallia and four Orders of Anthozoa, as well as the sub-Order Filifera in Class Hydrozoa.

The **Vulnerable Marine Ecosystems (VME**[22]**)** database, maintained by the Joint ICES/NAFO Working Group on Deep-water Ecology, provides data on VME distribution and abundance across the North Atlantic. There is certain relation between VMEs and 1170.

[15] Biodiversa +: https://www.biodiversa.eu/
[16] EuropaBON: https://europabon.org/
[17] MarBioME: https://op.europa.eu/en/publication-detail/-/publication/a09868c3-b721-11ed-8912-01aa75ed71a1/language-en
[18] MBON Europe: https://marinebon.org/mbon-europe
[19] Copernicus Marine Data Store: https://data.marine.copernicus.eu/products
[20] Reef Check Med: https://www.reefcheckmed.org/
[21] UNEP Cold-water corals dataset https://data.unep-wcmc.org/datasets/3
[22] Vulnerable Marine Ecosystems (VME): https://www.ices.dk/data/data-portals/Pages/vulnerable-marine-ecosystems.aspx

OSPAR Status Assessment 2022 covers various species associated with HIC 1170 Reefs, including coral gardens, deep-sea sponge aggregations, and oyster beds, among others (OSPAR, 2023).

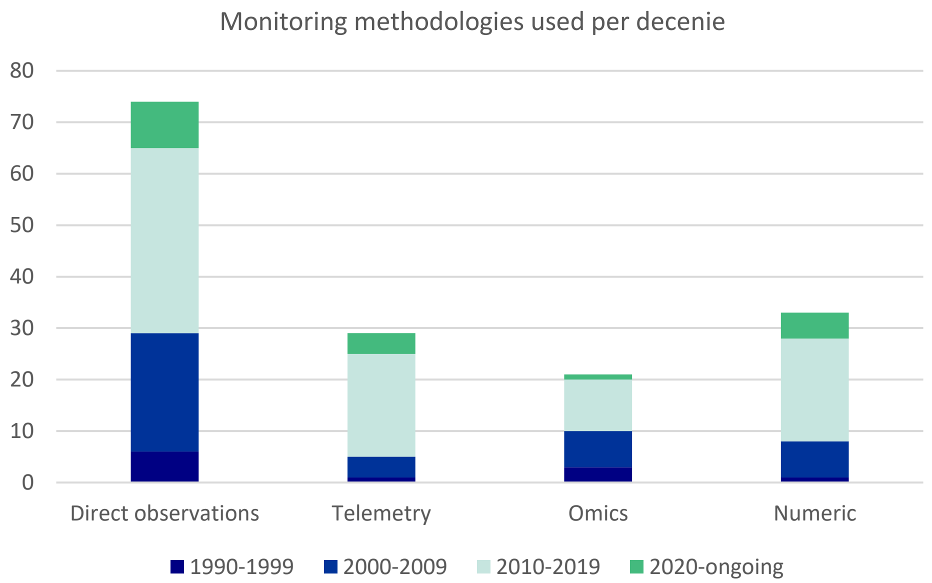
HELCOM State of the Baltic Sea a synthesis report that builds on, and integrates, results from a wide range of assessment products produced within the third HELCOM holistic assessment (HELCOM, 2023).

The **Reef Life Survey** offers an interactive digital tool for tracking reef ecosystem health globally (Hedley et al., 2016).

New technologies:

A review of the main methodologies used for the study of marine biodiversity monitoring since 1990 shows a dominance of direct observation but in recent years, an increase in the use of telemetry, omics[23] and numeric models (Figure 5).

Figure 5. Main categories of methodologies identified in relevant research projects for the study of marine biodiversity monitoring (adapted from 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
Source: European Commission (2023)

[23] Studies that focus on the structure, function and dynamics of molecules, such as genomes

New technologies used in reef monitoring:

Several authors have presented comprehensive reviews of new technologies used for coral reef monitoring in recent years. These reviews highlight the rapid advancement and diversification of tools available for reef research and conservation (Hedley et al., 2016; Hamylton, 2017; Madin et al., 2019; Obura et al., 2019; Apprill et al., 2023; Piñeros et al., 2024). Piñeros et al. (2024) provide a particularly detailed review of marine robotic vehicles used in reef monitoring. They discuss the features and capabilities of ROVs, AUVs, and other classes of underwater robots, including gliders, bio-inspired vehicles, and hybrid systems. This review highlights the diverse array of robotic platforms now available for reef research, each offering unique advantages for different monitoring scenarios.

New technologies such as structure for motion, multi-frequency backscatter analysis and analysis of point cloud data, are revolutionizing reef monitoring worldwide (especially coral reefs), offering improved capabilities for mapping, assessing, and tracking changes in reef habitats. **Remote sensing** technologies, including satellite imagery, have proven useful for large-scale reef monitoring and mapping. When combined with airborne imagery and LiDAR data, particularly from unmanned systems, these technologies enable unprecedented assessment of benthic habitats. Satellite observations can focus on environmental conditions affecting reefs or mapping reef habitats at landscape to global scales.

While remote sensing cannot match the detail of field surveys at individual points, it provides superior statistical power for inferring large-scale patterns due to complete areal coverage. Recent advances have improved spatial resolution, with sub-2m pixel multispectral satellite data now available for habitat mapping and bathymetry. Sea surface temperature products have also been upgraded to higher resolutions (Hedley et al., 2016).

Unmanned aerial vehicles (UAVs) are increasingly used for reef monitoring and mapping, often employing photogrammetry and hyperspectral/multispectral cameras. Underwater, remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) allow close-up monitoring of reefs. These can be equipped with various sensors (as inertial sensors, cameras, sonars, CTDs, chemical sensors, etc.), cameras, and sampling tools depending on their size and depth range to collect detailed data on reef conditions without human divers (Piñeros et al., 2024). Also, Baited Remote Underwater Video systems (BRUVs) are becoming standard for monitoring fish communities, including stereo applications for assessing benthic fish and habitat structure (Langlois et al., 2020; Bouchet et al., 2018). These technologies collectively offer powerful new tools for comprehensive, efficient, and cost-effective monitoring of HIC 1170, enabling improved management and conservation efforts.

Digital image processing and artificial intelligence techniques are enhancing the analysis of reef imagery. Artificial Intelligence (AI) methods are particularly useful for species classification, object detection in sonar images e.g. stones or traces/structures of human impact on the seafloor, identifying vulnerability patterns, and processing large image datasets. Machine learning approaches have shown robust performance in automated estimation of benthic composition, capable of detecting change and ensuring continuity with existing monitoring data (González-Rivero et al., 2020; Piñeros et al., 2024).

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 reef habitat monitoring in the EU Member States, comparing them with the main ecological characteristics of reefs, 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 reef habitats. 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 reef habitats given that reefs are often made up of a mosaic of marine communities rather than being uniform.

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

Finally, although there are many well established methods for **monitoring and sampling** reefs 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.

6 References

Alexander, D., Coates, D. A., Tillin, H. & Tyler-Walters, H. (2015). Conceptual Ecological Modelling of Sublittoral Rock Habitats to Inform Indicator Selection. Marine Ecological Surveys Ltd - A report for the Joint Nature Conservation Committee, JNCC Report No 560, JNCC Peterborough. 64pp. https://data.jncc.gov.uk/data/473b4f8c-b3cb-4224-8e59-c88cf433de6f/JNCC-Report-560-FINAL-WEB.pdf

Alvarez, H., Blanco, J., García, S., Marín, P., Perry, A. L., & Aguilar, R. (2015). Preliminary data on Deep-sea benthic habitats documented in four macaronesian seamounts. 14th Deep-Sea Biology Symposium, 31 Aug-4 Sep 2015, Aveiro, Portugal. https://oceana.org/wp-content/uploads/sites/18/oceana_macaronesian_seamounts.pdf

Angeletti, L., & Taviani, M. (2020). Offshore Neopycnodonte oyster reefs in the Mediterranean Sea. *Diversity*, *12*(3), 92. https://doi.org/10.3390/d12030092

Appolloni, L., Ferrigno, F., Russo, G. F., & Sandulli, R. (2020). β-Diversity of morphological groups as indicator of coralligenous community quality status. *Ecological Indicators*, *109*, 105840. https://doi.org/10.1016/j.ecolind.2019.105840

Apprill, A., Girdhar, Y., Mooney, T. A., Hansel, C. M., Long, M. H., Liu, Y., ... & Greene, A. (2023). Toward a new era of coral reef monitoring. *Environmental Science & Technology*, *57*(13), 5117-5124. https://doi.org/10.1021/acs.est.2c05369

Armoškaitė, A., Aigars, J., Andersone, I., Hansen, H. S., Schrøder, L., & Strāķe, S. (2021). Assessing change in habitat composition, ecosystem functioning and service supply in Latvian protected stony reefs. *Journal of Environmental Management*, *298*, 113537. https://doi.org/10.1016/j.jenvman.2021.113537

Ballesteros, E. (2006). Mediterranean coralligenous assemblages: a synthesis of present knowledge. *Oceanography and marine biology: an annual review*, *44*, 123-195.

Ballesteros, E., Torras, X., Pinedo, S., García, M., Mangialajo, L., & De Torres, M. (2007). A new methodology based on littoral community cartography dominated by macroalgae for the implementation of the European Water Framework Directive. *Marine pollution bulletin*, *55*(1-6), 172-180. https://doi.org/10.1016/j.marpolbul.2006.08.038

Barańska A., Michałek M., Kruk-Dowgiałło L., Brzeska-Roszczyk P., Osowiecki, A. (2022). 1170 - Reefs. Methodological guide https://morskiesiedliska.gios.gov.pl/images/1170_Rafy_OST.pdf

Barnard, S & Strong, J. (2014). Reviewing, refining and identifying optimum aggregation methods for undertaking marine biodiversity status assessments. JNCC Report No. 536. The Institute of Estuarine and Coastal Studies, University of Hull report for JNCC Peterborough. https://nora.nerc.ac.uk/id/eprint/521593/1/Report_536_Print.pdf

Bertocci, I., Araújo, R., Incera, M., Arenas, F., Pereira, R., Abreu, H., ... & Sousa-Pinto, I. (2012). Benthic assemblages of rock pools in northern Portugal: seasonal and between-pool variability. *Scientia Marina*, *76*(4), 781-789. https://scientiamarina.revistas.csic.es/index.php/scientiamarina/article/view/1411/1521

Boaventura, D., Ré, P., Cancela da Fonseca, L., & Hawkins, S. J. (2002). Intertidal rocky shore communities of the continental Portuguese coast: analysis of distribution patterns. *Marine Ecology*, *23*(1), 69-90. https://doi.org/10.1046/j.1439-0485.2002.02758.x

Borja, Á., Dauer, D. M., & Grémare, A. (2012). The importance of setting targets and reference conditions in assessing marine ecosystem quality. *Ecological Indicators*, *12*(1), 1-7. https://doi.org/10.1016/j.ecolind.2011.06.018

Borja, A., Prins, T. C., Simboura, N., Andersen, J. H., Berg, T., Marques, J. C., ... & Uusitalo, L. (2014). Tales from a thousand and one ways to integrate marine ecosystem components when assessing the environmental status. *Frontiers in Marine Science*, *1*, 72. https://doi.org/10.3389/fmars.2014.00072

Bouchet, P., Meeuwig, J., Huveneers, C., Langlois, T., Letessier, T., Lowry, M., ... & Whitmarsh, S. (2018). Marine Sampling Field Manual for Pelagic Stereo BRUVS (Baited Remote Underwater Videos). *Field Manuals for Marine Sampling to Monitor Australian Waters*, Version 1. http://dx.doi.org/10.11636/9781925297669

Boudouresque, C. F., Astruch, P., Bănaru, D., Blanchot, J., Blanfuné, A., Carlotti, F., ... & Thibaut, T. (2020). The management of Mediterranean coastal habitats: a plea for a socio-ecosystem-based approach. In *Evolution of Marine Coastal Ecosystems under the Pressure of Global Changes: Proceedings of Coast Bordeaux Symposium and of the 17th French-Japanese Oceanography Symposium* (pp. 297-320). Springer International Publishing. https://doi.org/10.1007/978-3-030-43484-7_20

Briones-Fourzán, P. & Hendrickx, M. E. (2022). Ecology and diversity of marine decapod crustaceans. *Diversity* 14(8): 614. https://doi.org/10.3390/d14080614

Brown, C. J., Smith, S. J., Lawton, P., & Anderson, J. T. (2011). Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. *Estuarine, Coastal and Shelf Science*, *92*(3), 502-520. https://doi.org/10.1016/j.ecss.2011.02.007

Brunier, G., Oiry, S., Gruet, Y., Dubois, S. F., & Barillé, L. (2022). Topographic analysis of intertidal polychaete reefs (*Sabellaria alveolata*) at a very high spatial resolution. *Remote Sensing*, *14*(2), 307. https://doi.org/10.3390/rs14020307

Bruschetti, M. (2019). The role of reef-building, ecosystem engineering polychaetes in shallow water ecosystems. *Diversity*, 11(9):68. https://doi.org/10.3390/d11090168

Cánovas-Molina, A., Montefalcone, M., Bavestrello, G., Cau, A., Bianchi, C. N., Morri, C., ... & Bo, M. (2016). A new ecological index for the status of mesophotic megabenthic assemblages in the Mediterranean based on ROV photography and video footage. *Continental Shelf Research*, *121*, 13-20. https://doi.org/10.1016/j.csr.2016.01.008

Cecchi, E., Gennaro, P., Piazzi, L., Ricevuto, E., & Serena, F. (2014). Development of a new biotic index for ecological status assessment of Italian coastal waters based on coralligenous macroalgal assemblages. *European Journal of Phycology*, *49*(3), 298-312. https://doi.org/10.1080/09670262.2014.918657

CIS (2003). Overall approach to the classification of ecological status and ecological potential. *Water Framework Directive Common Implementation Strategy Working Group*, *2*, 28. https://uicnmed.org/web2007/cdflow/conten/5/pdf/5_1_2/EcologicaStatus/EcologicalGuidance.pdf

Coates, J. H., Schiff, K., Mazor, R. D., Pondella, D. J., Schaffner, R., & Whiteman, E. (2018). Development of a biological condition assessment index for shallow, subtidal rocky reefs in Southern California, USA. *Marine Ecology*, *39*, e12471. https://doi.org/10.1111/maec.12471

Coelho, J. P., Duarte, A. C., Pardal, M. A., & Pereira, M. E. (2014). *Scrobicularia plana* (Mollusca, Bivalvia) as a biomonitor for mercury contamination in Portuguese estuaries. *Ecological indicators*, *46*, 447-453. https://doi.org/10.1016/j.ecolind.2014.07.015

Czúcz, B., Keith, H., Maes, J., Driver, A., Jackson, B., Nicholson, E., ... & Obst, C. (2021). Selection criteria for ecosystem condition indicators. *Ecological Indicators*, *133*, 108376. https://doi.org/10.1016/j.ecolind.2021.108376

Danovaro, R., Fanelli, E., Aguzzi, J., Billett, D., Carugati, L., Corinaldesi, C., ... & Yasuhara, M. (2020). Ecological variables for developing a global deep-ocean monitoring and conservation strategy. *Nature Ecology & Evolution*, *4*(2), 181-192. https://doi.org/10.1038/s41559-019-1091-z

David, R., Dubois, S., Erga, Z., Guillemain, D., de Ville d'Avray, L. T., Arvanitidis, C., ... & Feral, J. P. (2014). CIGESMED's protocol and network (Coralligenous basEd. Indicators to evaluate and monitor the "Good Environmental Status" of Mediterranean coastal waters). In *5th International Symposium Monitoring of Mediterranean coastal areas: problems and measurement techniques* (Vol. 5, pp. 828-843).

de la Torriente, A., Serrano, A., Druet Vélez, M., Gómez-Ballesteros, M., Acosta-Yepes, J., Parra-Descalzo, S., ... & Tello-Antón, M. O. (2015). Banco de Galicia. Áreas de estudio del proyecto LIFE+ INDEMARES. Centro Oceanográfico de Santander. https://www.indemares.es/sites/default/files/banco_de_galicia.pdf

Delavenne, J. & de Bettignies, T. (2023). Assessment of the conservation status of natural marine habitats at the scale of a Natura 2000 site. Methodological guide. Patrinat – OFB/MNHN/CNRS/IRD, 41 pp. https://mnhn.hal.science/mnhn-04089730/file/Delavenne%20%26%20de%20Bettignies_2023_Guide%20m%C3%A9thodologique.pdf

Deter, J., Descamp, P., Ballesta, L., Boissery, P., & Holon, F. (2012). A preliminary study toward an index based on coralligenous assemblages for the ecological status assessment of Mediterranean French coastal waters. *Ecological indicators*, *20*, 345-352. https://doi.org/10.1016/j.ecolind.2012.03.001

di Camillo, C. G., Ponti, M., Storari, A., Scarpa, C., Roveta, C., Pulido Mantas, T., ... & Cerrano, C. (2023). Review of the indexes to assess the ecological quality of coralligenous reefs: towards a unified approach. *Frontiers in Marine Science*, *10*, 1252969. https://doi.org/10.3389/fmars.2023.1252969

di Franco, A., Milazzo, M., Baiata, P., Tomasello, A., & Chemello, R. (2009). Scuba diver behaviour and its effects on the biota of a Mediterranean marine protected area. *Environmental Conservation*, *36*(1), 32-40. https://doi.org/10.1017/S0376892909005426

Dias, A. S., & Paula, J. (2001). Associated fauna of *Sabellaria alveolata* colonies on the central coast of Portugal. *Journal of the Marine Biological Association of the United Kingdom*, *81*(1), 169-170. https://doi.org/10.1017/S0025315401003538

Dubois, S., Commito, J. A., Olivier, F., & Retière, C. (2006). Effects of epibionts on Sabellaria alveolata (L.) biogenic reefs and their associated fauna in the Bay of Mont Saint-Michel. *Estuarine, Coastal and Shelf Science*, *68*(3-4), 635-646. https://doi.org/10.1016/j.ecss.2006.03.010

Enrichetti, F., Bo, M., Morri, C., Montefalcone, M., Toma, M., Bavestrello, G., ... & Bianchi, C. N. (2019). Assessing the environmental status of temperate mesophotic reefs: A new, integrated methodological approach. *Ecological Indicators*, *102*, 218-229. https://doi.org/10.1016/j.ecolind.2019.02.028

Environment & Resources Authority (2015). Malta's Marine Monitoring Programme – First Cycle. Biodiversity – Seabed Habitats factsheet. Malta, October 2015. https://era.org.mt/wp-content/uploads/2019/05/MonitoringFactsheet_D1_D4_D6_Seabed-Habitats.pdf

European Commission, DG Environment (2013). Interpretation Manual of European Union Habitats, EUR 28. https://cdr.eionet.europa.eu/help/natura2000/Documents/Int_Manual_EU28.pdf

European Commission. DG Environment. (2023). Reporting under Article 17 of the Habitats Directive: Guidelines on concepts and definitions – Article 17 of Directive 92/43/EEC, Reporting period 2019-2024. Brussels. Pp 104. https://reportingdirettivahabitat.isprambiente.it/documents/Guidelines%20Art%2017.pdf

European Commission: Directorate-General for Research and Innovation, Jessop, A., Chow, C., Dornelas, M., Pereira, H. et al., (2023) *MarBioME – Overview and assessment of the current state of Marine Biodiversity Monitoring in the European Union and adjacent marine waters*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2777/57760

Ferrigno, F., Russo, G. F., & Sandulli, R. (2017). Coralligenous Bioconstructions Quality Index (CBQI): A synthetic indicator to assess the status of different types of coralligenous habitats. *Ecological Indicators*, 82, 271-279. https://doi.org/10.1016/j.ecolind.2017.07.020

Forman, R. T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press.

Friedlander, A. M., Ballesteros, E., Clemente, S., Gonçalves, E. J., Estep, A., Rose, P., & Sala, E. (2017). Contrasts in the marine ecosystem of two Macaronesian islands: a comparison between the remote Selvagens Reserve and Madeira Island. *PLoS One*, *12*(11), e0187935. https://doi.org/10.1371/journal.pone.0187935

Gatti, G., Bianchi, C. N., Morri, C., Montefalcone, M., & Sartoretto, S. (2015). Coralligenous reefs state along anthropized coasts: Application and validation of the COARSE index, based on a rapid visual assessment (RVA) approach. *Ecological Indicators*, *52*, 567-576. https://doi.org/10.1016/j.ecolind.2014.12.026

Gennaro, P., Piazzi, L., Cecchi, E., Montefalcone, M., Morri, C., & Bianchi, C. N. (2020). Monitoraggio e valutazione dello stato ecologico dell'habitat a coralligeno. *Il coralligeno di parete. ISPRA, Manuali e Linee Guida*, (191). https://www.isprambiente.gov.it/files2020/pubblicazioni/manuali-e-linee-guida/mlg-191-2020-ec.pdf

Gonzalez-Rivero, M., Beijbom, O., Rodriguez-Ramirez, A., Bryant, D. E., Ganase, A., Gonzalez-Marrero, Y., ... & Hoegh-Guldberg, O. (2020). Monitoring of coral reefs using artificial intelligence: A feasible and cost-effective approach. *Remote Sensing*, *12*(3), 489. https://doi.org/10.3390/rs12030489

Gubbay, S., Sanders, N., Haynes, T., Janssen, J. A. M., Rodwell, J. R., Nieto, A., ... & Borg, J. (2016). *European red list of habitats. Part 1: Marine habitats*. European Union. https://edepot.wur.nl/404542

Hamylton, S. M. (2017). Mapping coral reef environments: A review of historical methods, recent advances and future opportunities. *Progress in Physical Geography*, *41*(6), 803-833. https://doi.org/10.1177/0309133317744998

Hargis, C. D., Bissonette, J. A., & David, J. L. (1998). The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape ecology*, *13*, 167-186. https://doi.org/10.1023/A:1007965018633

Hedley, J. D., Roelfsema, C. M., Chollett, I., Harborne, A. R., Heron, S. F., J. Weeks, S., ... & Mumby, P. J. (2016). Remote sensing of coral reefs for monitoring and management: a review. *Remote Sensing*, *8*(2), 118. https://doi.org/10.3390/rs8020118

Heinicke, K., Bildstein, T., Reimers, H. C., & Boedeker, D. (2021). Leitfaden zur großflächigen Abgrenzung und Kartierung des Lebensraumtyps Riffe in der deutschen Ostsee:(EU-Code 1170; Untertyp: geogene Riffe). https://bfn.bsz-bw.de/frontdoor/deliver/index/docId/1035/file/Skript612.pdf

HELCOM (2009). Eutrophication in the Baltic Sea – An integrated thematic assessment of the effects of nutrient enrichment and eutrophication in the Baltic Sea region. *Balt. Sea Environ. Proc.,* 115B. https://helcom.fi/wp-content/uploads/2019/08/BSEP115B-1.pdf

HELCOM (2013). Biotope information sheet – 1170 Reefs. https://helcom.fi/wp-content/uploads/2019/08/HELCOM-Red-List-1170-Reefs.pdf

HELCOM (2021). HELCOM monitoring guidelines of mobile and sessile epifauna. Sea-based Pressures Group manuals and guidelines. https://helcom.fi/wp-content/uploads/2021/06/HELCOM-Monitoring-guidelines-of-mobile-and-sessile-epifauna.pdf

HELCOM (2023). State of the Baltic Sea. Third HELCOM holistic assessment 2016-2021. Baltic Sea Environment Proceedings n°194. 134pp. https://helcom.fi/post_type_publ/holas3_sobs

Henriques, S., Pais, M. P., Batista, M. I., Costa, M. J., & Cabral, H. N. (2013). Response of fish-based metrics to anthropogenic pressures in temperate rocky reefs. *Ecological indicators*, *25*, 65-76. https://doi.org/10.1016/j.ecolind.2012.09.003

Henriques, S., Pais, M. P., Batista, M. I., Teixeira, C. M., Costa, M. J., & Cabral, H. (2014). Can different biological indicators detect similar trends of marine ecosystem degradation?. *Ecological indicators*, *37*, 105-118. https://doi.org/10.1016/j.ecolind.2013.10.017

Herrmann, C., von Weber, M. & Zscheili, K. & Gosselck, F. (2015). Underwater National Park – Marine Habitats in the Baltic Sea and Bodden.

Holt, T. J. (1998). *Biogenic reefs: an overview of dynamics and sensitivity characteristics for conservation management of marine SACs*. UK Marine SACs Project. http://ukmpa.marinebiodiversity.org/uk_sacs/pdfs/biogreef.pdf

Ingels, J., Vanreusel, A., Pape, E., Pasotti, F., Macheriotou, L., Arbizu, P. M., ... & Zeppilli, D. (2021). Ecological variables for deep-ocean monitoring must include microbiota and meiofauna for effective conservation. *Nature ecology & evolution*, *5*(1), 27-29. https://doi.org/10.1038/s41559-020-01335-6

Ingrosso, G., Abbiati, M., Badalamenti, F., Bavestrello, G., Belmonte, G., Cannas, R., ... & Boero, F. (2018). Mediterranean bioconstructions along the Italian coast. *Advances in marine biology*, *79*, 61-136. https://doi.org/10.1016/bs.amb.2018.05.001

Irving, R. (2009). *The identification of the main characteristics of stony reef habitats under the Habitats Directive*. Summary report of an inter-agency workshop 26-27 March 2008. JNCC Report No. 432 https://doi.org/10.13140/2.1.2278.5283

Jackson-Bué, T., Evans, A. J., Lawrence, P. J., Brooks, P. R., Ward, S. L., Jenkins, S. R., ... & Davies, A. J. (2024). Habitat structure shapes temperate reef assemblages across regional environmental gradients. *Science of the Total Environment*, *906*, 167494. https://doi.org/10.1016/j.scitotenv.2023.167494

Jakobsson, S., Töpper, J. P., Evju, M., Framstad, E., Lyngstad, A., Pedersen, B., ... & Nybø, S. (2020). Setting reference levels and limits for good ecological condition in terrestrial ecosystems–Insights from a case study based on the IBECA approach. *Ecological Indicators*, *116*, 106492. https://doi.org/10.1016/j.ecolind.2020.106492

Janssen, J. A. M., Weeda, E. J., Schippers, P., Bijlsma, R. J., Schaminée, J. H. J., Arts, G. H. P., ... & Jak, R. G. (2014). *Habitattypen in Natura 2000-gebieden: beoordeling van oppervlakte, representativiteit en behoudsstatus in de Standard Data Forms (SDFs)* (No. 8). WOT Natuur & Milieu. https://edepot.wur.nl/314180

JNCC (2004). Common Standards Monitoring Guidance for Estuaries. Version August 2004. 29pp. https://data.jncc.gov.uk/data/9b4bff32-b2b1-4059-aa00-bb57d747db23/CSM-Estuaries-2004.pdf

Jones, T., Davidson, R. J., Gardner, J. P., & Bell, J. J. (2015). Evaluation and optimisation of underwater visual census monitoring for quantifying change in rocky-reef fish abundance. *Biological Conservation*, *186*, 326-336. https://doi.org/10.1016/j.biocon.2015.03.033

Kazanidis, G., Orejas, C., Borja, A., Kenchington, E., Henry, L. A., Callery, O., ... & Roberts, J. M. (2020). Assessing the environmental status of selected North Atlantic deep-sea ecosystems. *Ecological Indicators*, *119*, 106624. https://doi.org/10.1016/j.ecolind.2020.106624

Keith, H., Czúcz, B., Jackson, B., Driver, A., Nicholson, E., & Maes, J. (2020). A conceptual framework and practical structure for implementing ecosystem condition accounts. https://doi.org/10.3897/oneeco.5.e58216

Kipson, S., Kaleb, S., Kruzic, P., et al., (2014). Croatian coralligenous monitoring protocol: the basic methodologic approach. In: Bouafif, C., Langar, H., & Ouerghi, A. (Eds). UNEP/MAP – RAC/SPA. Proceedings of the second Mediterranean Symposium on the conservation of Coralligenous and other Calcareous Bio-Concretions. https://doi.org/10.13140/2.1.2070.3681

Kirwan, M. L., & Megonigal, J. P. (2013). Tidal wetland stability in the face of human impacts and sea-level rise. *Nature*, *504*(7478), 53-60. https://doi.org/10.1038/nature12856

Krause, J., von Drachenfels, O., Ellwanger, G., Farke, H., Fleet, D. M., Gemperlein, J., ... & Zscheile, K. (2008). Bewertungsschemata für die Meeres-und Küstenlebens-raumtypen der FFH-Richtlinie. *Download*, *14*(23), 2021-09.

Langlois, T., Goetze, J., Bond, T., Monk, J., Abesamis, R. A., Asher, J., ... & Harvey, E. S. (2020). A field and video annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages. *Methods in Ecology and Evolution*, *11*(11), 1401-1409. https://doi.org/10.1111/2041-210X.13470

Lawrence, A., Friedrich, F., & Beierkuhnlein, C. (2021). Landscape fragmentation of the Natura 2000 network and its surrounding areas. *PLoS One*, *16*(10), e0258615. https://doi.org/10.1371/journal.pone.0258615

Lepareur F. (2011). Evaluation de l'état de conservation des habitats naturels marins à l'échelle d'un site Natura 2000 – Guide méthodologique - Version 1. Février 2011. Rapport SPN 2011 / 3, MNHN, Paris, 55 pages. https://inpn.mnhn.fr/telecharge-ment/documentation/natura2000/evaluation

Leshno, Y., Benjamini, C., & Edelman-Furstenberg, Y. (2016). Ecological quality assessment in the Eastern Mediterranean combining live and dead molluscan assemblages. *Marine Pollution Bulletin*, *104*(1-2), 246-256. https://doi.org/10.1016/j.marpolbul.2016.01.014

Madin, E. M., Darling, E. S., & Hardt, M. J. (2019). Emerging technologies and coral reef conservation: Opportunities, challenges, and moving forward. *Frontiers in Marine Science*, *6*, 727. https://doi.org/10.3389/fmars.2019.00727

Maes, J., Bruzón, A. G., Barredo, J. I., Vallecillo, S., Vogt, P., Rivero, I. M., & Santos-Martín, F. (2023). Accounting for forest condition in Europe based on an international statistical standard. *Nature Communications*, *14*(1), 3723. https://doi.org/10.1038/s41467-023-39434-0

Mariotti, G., & Fagherazzi, S. (2010). A numerical model for the coupled long-term evolution of salt marshes and tidal flats. *Journal of Geophysical Research: Earth Surface*, *115*(F1). https://doi.org/10.1029/2009JF001326

Marre, G., Braga, C. D. A., Lenco, D., Luque, S., Holon, F., & Deter, J. (2020). Deep convolutional neural networks to monitor coralligenous reefs: operationalizing biodiversity and ecological assessment. *Ecological Informatics*, *59*, 101110. https://doi.org/10.1016/j.ecoinf.2020.101110

Matear, L., Vina-Herbon, C., Woodcock, K. A., et al. (2023). Extent of Physical Disturbance to Benthic Habitats (BH3a): Fisheries. In: OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London. OSPAR Benthic

Habitats Expert Group, Intersessional Correspondence Group on the Coordination of Biodiversity Assessment and Monitoring, OSPAR Biodiversity Committee. https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/indicator-assessments/phys-dist-habs-fisheries/

Micu, D., Zaharia, T., Todorova, V., & Niţă, V. (2007). Romanian marine habitats of European interest. *Editura Punct Ochit, Constanta*.

Miljøstyrelsen (2022). NOVANA Det nationale overvågningsprogram for vandmiljø og natur 2022. Miljøministeriet Miljøstyrelsen. https://www2.mst.dk/Udgiv/publikationer/2022/05/978-87-7038-419-3.pdf

Minelli, A., Ferrà, C., Spagnolo, A., Scanu, M., Tassetti, A. N., Ferrari, C. R., ... & Fabi, G. (2020). The ADRIREEF database: a comprehensive collection of natural/artificial reefs and wrecks in the Adriatic Sea. *Earth System Science Data Discussions*, *2020*, 1-29. https://doi.org/10.5194/essd-13-1905-2021

Moccia, D., Cau, A., Carugati, L., & Follesa, C. (2021). Assessing the Environmental Status of five Sardinian black corals forests via Mesophotic Assemblages Conservation Status Index (MACS). In *2021 International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea)* (pp. 204-208). IEEE. https://doi.org/10.1109/MetroSea52177.2021.9611628

Montefalcone, M., Morri, C., Bianchi, C. N., Bavestrello, G., & Piazzi, L. (2017). The two facets of species sensitivity: Stress and disturbance on coralligenous assemblages in space and time. *Marine Pollution Bulletin*, *117*(1-2), 229-238. https://doi.org/10.1016/j.marpolbul.2017.01.072

Moraitis, M. L., Tsikopoulou, I., Geropoulos, A., Dimitriou, P. D., Papageorgiou, N., Giannoulaki, M., ... & Karakassis, I. (2018). Molluscan indicator species and their potential use in ecological status assessment using species distribution modeling. *Marine environmental research*, *140*, 10-17. https://doi.org/10.1016/j.marenvres.2018.05.020

Nerlović, V., Doğan, A., & Hrs-Brenko, M. (2011). Response to oxygen deficiency (depletion): Bivalve assemblages as an indicator of ecosystem instability in the northern Adriatic Sea. *Biologia*, *66*(6), 1114-1126. https://doi.org/10.2478/s11756-011-0121-3

Obura, D. O., Aeby, G., Amornthammarong, N., Appeltans, W., Bax, N., Bishop, J., ... & Wongbusarakum, S. (2019). Coral reef monitoring, reef assessment technologies, and ecosystem-based management. *Frontiers in Marine Science*, 6, 580. https://doi.org/10.3389/fmars.2019.00580

Ocaña, O., & Brito, A. (2004). A review of Gerardiidae (Anthozoa: Zoantharia) from the Macaronesian islands and the Mediterranean Sea with the description of a new species. *Revista de la Academia Canaria de Ciencias*, *15*(3-4), 159-189.

OECD (1993). OECD Core set of indicators for environmental performance reviews: a synthesis report by the Group on the State of the Environment. OECD, Environment Monographs, 83: OECD/GD (93)179. https://www.ecoshape.org/app/uploads/sites/2/2020/06/OECD_1993.pdf

OSPAR (2023). OSPAR status assessment 2023. https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesements/mytilus-edulis-beds/

Oprandi, A., Atzori, F., Azzola, A., Bianchi, C. N., Cadoni, N., Carosso, L., ... & Montefalcone, M. (2023). Multiple indices on different habitats and descriptors provide consistent assessments of environmental quality in a marine protected area. *Frontiers in Marine Science*, *10*, 1111592. https://doi.org/10.3389/fmars.2023.1111592

Palma, M, Pavoni, G., Pantaleo, U., et al., (2019). Effective SFM-based methods supporting coralligenous benthic community assessment and monitoring. In Langar, H., &

Ouerghi, A., (Eds). UNEP/MAP – SPA/RAC, 2019. Proceedings of the 3rd Mediterranean Symposium on the conservation of Coralligenous & other Calcareous Bio-Concretions. 135 p. https://www.rac-spa.org/sites/default/files/symposium/proceedings_mscc_2019_final.pdf

Paoli, C., Morten, A., Bianchi, C. N., Morri, C., Fabiano, M., & Vassallo, P. (2016). Capturing ecological complexity: OCI, a novel combination of ecological indices as applied to benthic marine habitats. *Ecological Indicators*, *66*, 86-102. https://doi.org/10.1016/j.ecolind.2016.01.029

Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K. N., & Smith, C. J. (2016). DPSIR—two decades of trying to develop a unifying framework for marine environmental management?. *Frontiers in Marine Science*, *3*, 177. https://doi.org/10.3389/fmars.2016.00177

Penna, M., Gennaro, P., Bacci, T., Trabucco, B., Cecchi, E., Mancusi, C., ... & Cicero, A. M. (2018). Multiple environmental descriptors to assess ecological status of sensitive habitats in the area affected by the Costa Concordia shipwreck (Giglio Island, Italy). *Journal of the Marine Biological Association of the United Kingdom*, *98*(1), 51-59. https://doi.org/10.1017/S0025315417001485

Piazzi, L., Bianchi, C. N., Cecchi, E., Gatti, G., Guala, I., Morri, C., ... & Montefalcone, M. (2017). What's in an index? Comparing the ecological information provided by two indices to assess the status of coralligenous reefs in the NW Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(6), 1091-1100. https://doi.org/10.1002/aqc.2773

Piazzi, L., Gennaro, P., Montefalcone, M., Bianchi, C. N., Cecchi, E., Morri, C., & Serena, F. (2019a). STAR: An integrated and standardized procedure to evaluate the ecological status of coralligenous reefs. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(2), 189-201. https://doi.org/10.1002/aqc.2983

Piazzi, L., Cecchi, E., Cinti, M. F., Stipcich, P., & Ceccherelli, G. (2019b). Impact assessment of fish cages on coralligenous reefs through the use of the STAR sampling procedure. *Mediterranean Marine Science*, *20*(3), 627-635. https://doi.org/10.12681/mms.20586

Piazzi, L., Gennaro, P., Cecchi, E., Bianchi, C. N., Cinti, M. F., Gatti, G., ... & Montefalcone, M. (2021). Ecological status of coralligenous assemblages: Ten years of application of the ESCA index from local to wide scale validation. *Ecological Indicators*, *121*, 107077. https://doi.org/10.1016/j.ecolind.2020.107077

Piazzi, L., Ferrigno, F., Guala, I., Cinti, M. F., Conforti, A., De Falco, G., ... & Ceccherelli, G. (2022). Inconsistency in community structure and ecological quality between platform and cliff coralligenous assemblages. *Ecological Indicators*, *136*, 108657. https://doi.org/10.1016/j.ecolind.2022.108657

Piazzi, L., Turicchia, E., Rindi, F., Falace, A., Gennaro, P., Abbiati, M., ... & Ponti, M. (2023). NAMBER: A biotic index for assessing the ecological quality of mesophotic biogenic reefs in the northern Adriatic Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *33*(3), 298-311. https://doi.org/10.1002/aqc.3922

Piñeros, V. J., Reveles-Espinoza, A. M., & Monroy, J. A. (2024). From Remote Sensing to Artificial Intelligence in Coral Reef Monitoring. *Machines*, *12*(10), 693. https://doi.org/10.3390/machines12100693

Probert, P. K., Christiansen, S., Gjerde, K. M., Gubbay, S., & Santos, R. S. (2007). Management and conservation of seamounts (Chapter 20): 442-475. *Seamounts: Ecology, Fisheries and Conservation. Blackwell Publishing, Oxford, UK. XXIV+ 527p*.

Rastorgueff, P. A., Bellan-Santini, D., Bianchi, C. N., Bussotti, S., Chevaldonné, P., Guidetti, P., ... & Personnic, S. (2015). An ecosystem-based approach to evaluate the ecological quality of Mediterranean undersea caves. *Ecological Indicators*, *54*, 137-152. https://doi.org/10.1016/j.ecolind.2015.02.014

Rice, J., Arvanitidis, C., Borja, A., Frid, C., Hiddink, J., Krause, J., et al. (2010). Marine Strategy Framework Directive–Task Group 6 Report Seafloor integrity. *EUR 24334EN*, Luxembourg: Joint Research Centre; Office for Official Publications of the European Communities.73pp

Sartoretto, S., Schohn, T., Bianchi, C. N., Morri, C., Garrabou, J., Ballesteros, E., ... & Gatti, G. (2017). An integrated method to evaluate and monitor the conservation state of coralligenous habitats: The INDEX-COR approach. *Marine pollution bulletin*, *120*(1-2), 222-231. https://doi.org/10.1016/j.marpolbul.2017.05.020

Scally, L., Pfieffer, N., & Hewitt, E. (2020). The monitoring and assessment of six EU habitats directive annex I marine habitats. *Irish wildlife manuals*, 118. https://www.npws.ie/sites/default/files/publications/pdf/IWM118.pdf

Schuhmacher, H., & Zibrowius, H. (1985). What is hermatypic? A redefinition of ecological groups in corals and other organisms. *Coral reefs*, *4*, 1-9. https://doi.org/10.1007/BF00302198

Schulze, I., Gogina, M., Schönke, M., Zettler, M. L., & Feldens, P. (2022). Seasonal change of multifrequency backscatter in three Baltic Sea habitats. *Frontiers in Remote Sensing*, *3*, 956994. https://doi.org/10.3389/frsen.2022.956994

Shin, Y. J., Bundy, A., Shannon, L. J., Blanchard, J. L., Chuenpagdee, R., Coll, M., ... & IndiSeas Working Group. (2012). Global in scope and regionally rich: an IndiSeas workshop helps shape the future of marine ecosystem indicators. *Reviews in Fish Biology and Fisheries*, *22*, 835-845. https://doi.org/10.1007/s11160-012-9252-z

Silas, P. et al., (2023). MPA Europe Deliverable 3.3 Publish maps and models of biogenic habitat distribution in Europe on EMODnet. https://zenodo.org/records/10422129

Smit, K. P., Bernard, A. T., Sink, K. J., Dyer, A., Lombard, A. T., & Heyns-Veale, E. (2023). Identifying suitable indicators to measure ecological condition of rocky reef ecosystems in South Africa. *Ecological Indicators*, *154*, 110696. https://doi.org/10.1016/j.ecolind.2023.110696

Technical Group on Seabed Habitats and Sea-floor Integrity (TG SEABED) (2023). Setting of EU Threshold Values for extent of loss and adverse effects on seabed habitats. Recommendations from the Technical Group on Seabed Habitats and Sea-floor Integrity (TG Seabed). MSFD Common Implementation Strategy. 15pp. https://circabc.europa.eu/sd/a/54beb651-0991-4fc2-8ceb-26fe3572f76f/SEABED_3-2020-09_AdverseEffects.docx

Templado, J., Capa, M., Guallart, J. & Luque, A., (2009). 1170 Arrecifes. En: Bases ecológicas preliminares para la conservación de los tipos de hábitat de interés comunitario en España. Madrid: Ministerio de Medio Ambiente, y Medio Rural y Marino. 142 p. https://www.jolube.net/Habitat_Espana/documentos/1170.pdf

Templado, J., Richter, A., & Calvo, M. (2016). Reef building Mediterranean vermetid gastropods: disentangling the *Dendropoma petraeum* species complex. *Mediterranean Marine Science*, 17(1), 13-31. https://doi.org/10.1017/S0025315400041606

Thibaut, T. (2011). Ecological Status of the Rocky Coast of Malta, May 2008.

Todorova, V., Micu, D., & Klisurov, L. (2009). Unique oyster reefs discovered in the Bulgarian Black Sea. *Comptes Rendus de l'Academie bulgare des Sciences*, *62*(7), 871-874.

Turicchia, E., Cerrano, C., Ghetta, M., Abbiati, M., & Ponti, M. (2021). MedSens index: The bridge between marine citizen science and coastal management. *Ecological Indicators*, *122*, 107296. https://doi.org/10.1016/j.ecolind.2020.107296

UNEP/MAP - RAC/SPA (2014). Monitoring Protocol for Reefs - Coralligenous Community. By Garrabou J, Kipson S, Kaleb S, Kruzic P, Jaklin A, Zuljevic A, Rajkovic Z, Rodic P, Jelic K, and Zupan D. Ed. RAC/SPA - MedMPAnet Project, Tunis. 35 pages + annexes. https://www.haop.hr/sites/default/files/uploads/dokumenti/03_prirodne/monitoring_prog/monitoring_protocol_coralligenous_croatia.pdf

UNEP/MAP – SPA/RAC (2021). Action Plan for the conservation of habitats and species associated with seamounts, underwater caves and canyons, aphotic hard beds and chemo-synthetic phenomena in the Mediterranean Sea. Dark Habitats Action Plan. Ed. RAC/SPA. 32 pp. https://rac-spa.org/sites/default/files/action_plans/p_a_habitats_en.pdf

United Nations (1982). Protocol concerning Mediterranean Specially Protected Areas. https://wedocs.unep.org/bitstream/handle/20.500.11822/14030/82ig35_final_act_spaprotocol_eng.pdf

United Nations et al. 2021. System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). https://seea.un.org/ecosystem-accounting

Vaher, A., Kotta, J., Szava-Kovats, R., Kaasik, A., Fetissov, M., Aps, R., & Kõivupuu, A. (2022). Assessing cumulative impacts of human-induced pressures on reef and sandbank habitats and associated biotopes in the northeastern Baltic Sea. *Marine Pollution Bulletin*, *183*, 114042. https://doi.org/10.1016/j.marpolbul.2022.114042

Valisano, L., Palma, M., Pantaleo, U., Calcinai, B., & Cerrano, C. (2019). Characterization of North–Western Mediterranean coralligenous assemblages by video surveys and evaluation of their structural complexity. *Marine Pollution Bulletin*, *148*, 134-148. https://doi.org/10.1016/j.marpolbul.2019.07.012

Vanosmael, C., Willems, K. A., Claeys, D., Vincx, M., & Heip, C. (1982). Macrobenthos of a sublittoral sandbank in the Southern Bight of the North Sea. *Journal of the Marine Biological Association of the United Kingdom*, *62*(3), 521-534. https://doi.org/10.1017/S002531540001972X

Velez, C., Teixeira, M., Wrona, F. J., Soares, A. M., Figueira, E., & Freitas, R. (2016). Clam Ruditapes philippinarum recovery from short-term exposure to the combined effect of salinity shifts and Arsenic contamination. *Aquatic Toxicology*, *173*, 154-164. https://doi.org/10.1016/j.aquatox.2016.01.007

Ventura, D., Grosso, L., Pensa, D., Casoli, E., Mancini, G., Valente, T., ... & Rakaj, A. (2023). Coastal benthic habitat mapping and monitoring by integrating aerial and water surface low-cost drones. *Frontiers in Marine Science*, *9*, 1096594. https://doi.org/10.3389/fmars.2022.1096594

Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG) (2009). Macroalgae – rocky shore reduced species list. UKTAG coastal water assessment methods macroalgae. 16pp. https://wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/CW%20Intertidal%20Rocky%20Shore%20Macroalgal%20Index%20UKTAG%20Method%20Statement.PDF

Wang, X., Blanchet, F. G., & Koper, N. (2014). Measuring habitat fragmentation: An evaluation of landscape pattern metrics. *Methods in ecology and evolution*, *5*(7), 634-646. https://doi.org/10.1111/2041-210X.12198

West, V., Maher, E. & Alexander, D. (2024). Reef Habitat in Irish Intertidal and Near-shore Waters. Irish Wildlife Manuals, No. 150. National Parks and Wildlife Service, Department of Housing, Local Government and Heritage, Ireland. https://www.npws.ie/sites/default/files/publications/pdf/IWM150.pdf

Wijnhoven, S. (2023). Protocol Benthic Indicator Species Index (BISI): Protocol BISI for generic application (BISI v3). Version v170424. Ecoauthor Report Series 2023-01, Heinkenszand, the Netherlands. http://ecoauthor.net/bisi/

Yeager, L. A., Estrada, J., Holt, K., Keyser, S. R., & Oke, T. A. (2020). Are habitat fragmentation effects stronger in marine systems? A review and meta-analysis. *Current Landscape Ecology Reports*, *5*(3), 58-67. https://doir.org/10.1007/s40823-020-00053-w

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