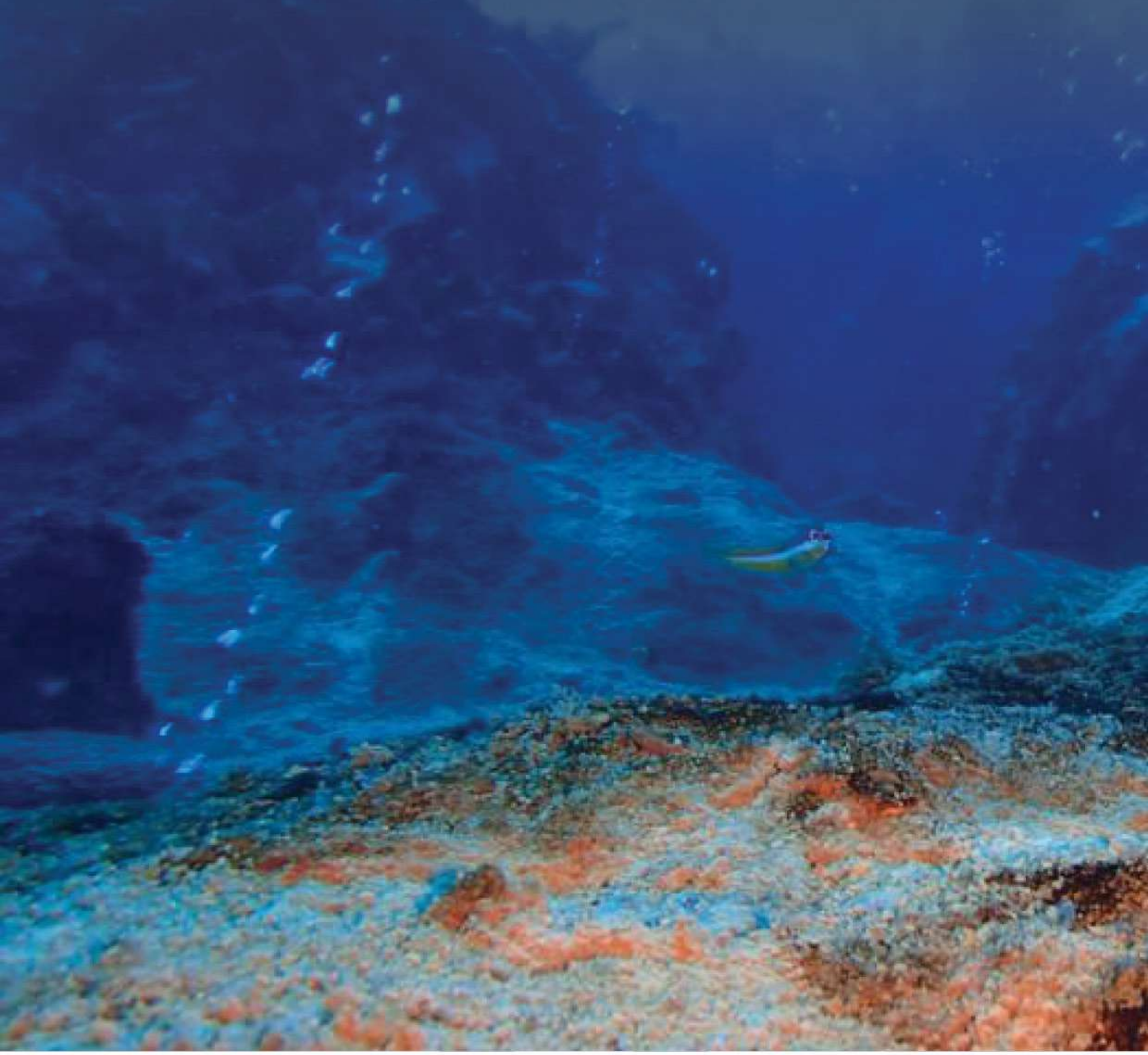
European Commission

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

Submarine structures made by leaking gases (1180)



ATECMA

DAPHNE
INŠTITÚT APLIKOVANEJ EKOLÓGIE

Institute for European Environmental Policy

EUROPEAN COMMISSION

Directorate-General for Environment
Directorate D — Biodiversity
Unit D3 — Nature Conservation

E-mail: nature@ec.europa.eu

European Commission
B-1049 Brussels

EUROPEAN COMMISSION

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Submarine structures made by leaking gases (1180)

Susan Gubbay and Alvaro Garcia Herrero (ATECMA)

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Contents

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Glossary and definitions

Habitats

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

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

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

Species

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

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

Variables

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

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

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

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

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

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

Abbreviations

EU: European Union

HD: Habitats Directive

IAS: Invasive Alien Species

MS: Member State

EU Member States acronyms:

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

MSFD: Marine Strategy Framework Directive

SEEA EA: System of Environmental Economic Accounting- Ecosystem Accounting

WFD: Water Framework Directive

Executive summary

Submarine structures made by leaking gas (habitat 1180) are present in all EU Marine Regions. A general description, including listing of the main sub-types is provided by way of introduction, including references to the definition in the Habitats Directive Interpretation Manual and EUNIS habitat types (level 4) and Annex I of the Nature Restoration Regulation.

A structured framework for the ecological characterization of habitat 1180 and the selection of appropriate variables for assessing their condition is set out in Section 1. Twelve **key characteristics and corresponding variables essential for evaluating condition of the habitat** have been identified using the System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA), an international standard for ecosystem accounts adopted by the United Nations Statistical Commission (Section 1.2 and Table 1).

All ten Member States that have reported habitat 1180 as present in their jurisdictions provide some information on the location and main characteristics of 'submarine structures made by leaking gases' that have been given Natura 2000 status.

Only three Member States (Spain, Italy and Romania) have published specific **methodologies** for the assessment of structure and function of habitat 1180. Out of the twelve key characteristics of habitat 1180 described in Section 1, only one of these (topography/physical characteristics) is specifically identified for recording in the methodologies of all these three Member States (Table 4).

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.

Specific **reference values and thresholds** are rarely defined for condition monitoring of this habitat at the present time by Member States. In some cases, the approach proposed is to report on trends in variables, such as extent, which are related to the conservation objectives of a site. In other cases, decisions about potential reference values are still subject to discussion, requiring further data.

There is no standard approach to the identification of a number and distribution of localities to carry out the assessment and monitoring of habitat 1180 or **sampling frequency**. Practical consideration, such as accessibility are important and most work to date has broad scale mapping with some detailed survey points across the habitat. There is a lack of information available on **aggregation methods** at a local scale or biogeographic scale specifically for this habitat type

A variety of **methodologies** and projects provide valuable information on assessing the structure and function of submarine structures made by leaking gases even though they may not be specifically aimed at Article 17 reporting. Many of the investigations in relation to the requirements of the Habitats Directive have focused on locating and mapping the distribution/extent/abundance, the method of formation and chemical characteristics as well as identifying and reporting threats/impacts to this habitat type. Although some examples of this habitat type are relatively well known as geological features, studies of biodiversity interest and associated biological communities are more recent. This is particularly the case when the habitat is in deep offshore waters.

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 and recommended condition variables** is presented covering abiotic, biotic, and landscape/seascape characteristics (Table 9). 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

The Interpretation Manual description of this habitat (European Commission, 2013) indicates that:

> "Submarine structures consist of sandstone slabs, pavements, and pillars up to 4 m high, formed by aggregation of carbonate cement resulting from microbial oxidation of gas emissions, mainly methane. The formations are interspersed with gas vents that intermittently release gas. The methane most likely originates from the microbial decomposition of fossil plant materials."

They are described as taking the form of "bubbling reefs/pillars" with examples in the Kattegat and Skagerrak, and/or "pockmarks" such as those described from the North Sea. Other forms of this habitat type, although not mentioned in the Interpretation Manual, include hydrothermal vents such as reported off the island of Santorini associated with the submarine volcano of Kolumbo (Nomikou et al., 2012), and the mud volcanoes, mud volcano-mud diapir complexes and diapiric ridges in the Gulf of Cadiz (Díaz del Río et al., 2014; Rueda et al., 2022).

The main subtypes described to date are:

- **Pillars/Bubbling reefs/Pavements**: structures produced by leaking gases with carbonate substrates of chemosynthetic origin.
- **Pockmarks:** formed due to the rapid expulsion of fluids, which is sometimes favored by the presence of faults.
- **Mud volcanoes**: these volcanoes usually present a simple cone with a circular morphology in the basis. The presence of extensive mud flows on the flanks are indicative of an extrusion process that took place in different phases, so their formation did not occur in a single event.
- **Diapir-mud volcano complex:** structures of diapiric origin mud volcanoes on the surface, generated as a consequence of the migration of fluids along the diapiric body, resulting in structures of different dimensions.
- **Diapir:** dome-shaped geological structures, which originate when a thick bed of evaporitic minerals (mainly common salt or halite) located at depth, is introduced vertically into the surrounding rock strata.
- **Diapiric dorsal:** diapiric ridges have been described in detail in recent years based on their morphological and morphosedimentary characteristics.
- **Collapsed depressions:** sometimes, mud volcanoes are surrounded at their base by depressions, which may be formed by collapse processes, due to active fluid escapes and the influence of deep currents.
- **Structures produced by leaking gases with chemosynthetic communities:** one of the most unique habitats, has been detected mainly on the tops of some mud volcanoes and diapir-mud volcanoes complexes.
- **Hydrothermal vents:** as described in Greek waters differ from other examples of this habitat type in having an active discharge of bubbles of CO_2 together with high temperature fluids (around 220° C)[1]. The vent chimneys stand up to 4m in height and are constructed of polymetallic massive sulfides and sulfates.

[1] Thalassia Periochi Koloumvo GR4220036

‘Submarine structures made by leaking gases’ (code 1180) are listed in the Interpretation Manual under COASTAL AND HALOPHYTIC HABITATS and in the subcategory ‘Open Sea and Tidal Areas’. ‘Reefs’ (code 1170) are also in this subcategory and there are some similarities in the characteristics, associated marine communities, as well as survey and monitoring techniques of ‘reefs’ and ‘bubbling reefs’, typically where hard substratum is present. Nevertheless, there are also significant differences. In particular, an underlying substrate of Methane-derived authigenic carbonate (MDAC) and the role of leaking gases (both current and historic), which can have a significant influence on the types of marine communities that develop on this habitat. We therefore do not propose clustering these two habitat types for the purposes of this review of the monitoring and assessment requirements or recommendations for future action (Section 3).

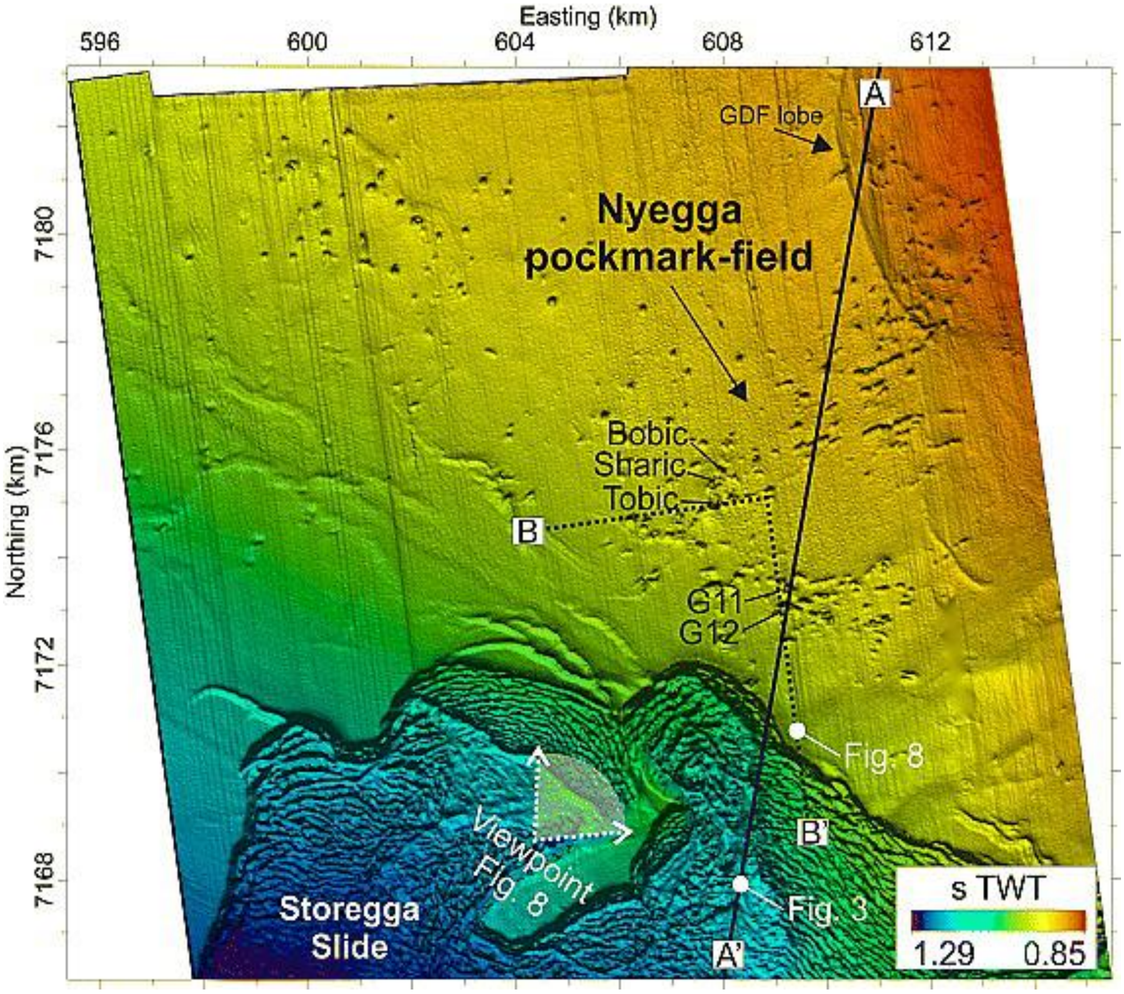
According to the 2022 EUNIS marine habitat classification the following EUNIS habitat types (level 4) may be present as components of habitat type 1180: MB128 and MC127. Both of these are also listed in group 6 (Vents and Seeps) of *Annex II* of the Nature Restoration Law.

Diversity across the regions

‘Submarine structures made by leaking gas’ have been reported from the following ten Member States; Bulgaria (BG), Cyprus (CY), Denmark (DK), Spain (ES), France (FR), Greece (GR), Ireland (IE), Italy (IT), Romania (RO), and Sweden (SE). This habitat is protected in those countries under 26 SCI/SAC through the European Union.

‘Bubbling reefs’, one type of this habitat, are present in the northern Kattegat and in the Skagerrak and follow a NW/SE direction parallel to the Fennoscandian fault line. There are examples, in **Danish** waters at depths of up to 30m which are dominated by algae communities in the shallows and by structuring faunal communities in the circalittoral zone (Seffel, 2010). In **Sweden** ‘bubbling reefs’ have been reported in areas of sandy seabed, often around fault zones which has enabled methane gas to migrate to the surface to form MDAC (Jensen et al., 1992). The reefs have become visible when the surrounding seabed has been eroded, exposing the hard sandstone structures. In some cases, the reefs are in the form of pillars 2-3 metres tall. In other cases, they take the form of lithified pavements covering large areas (Seffel, 2010; Lundälv, 2020, 2022). The largest continuous area with well-developed carbonate structures is located about 2 km NNE of the shallowest part of Stora Middelgrund in Swedish waters. This area has the largest individual bubble reef structures found to date in Swedish waters, with nearly 4 m high dome-shaped structures containing abundant cavities and cave formations, as well as a large number of smaller structures of varying shape and with intervening bacterial patches (Lundälv, 2022). ‘Pockmarks’, another sub type of this habitat are also present in **Swedish** waters with the most extensive being found in the Bratten area where there are at least 170 examples, covering a total area of 300km^2. An example of the Nyegga pockmark field on northern flank of the Storegga Slide of the mid-Norwegian continental margin is shown in Figure 1.

Figure 1. Location map of the Nyegga pockmark field on northern flank of the Storegga Slide of the mid-Norwegian continental margin



Source: Hustoft et al (2009)

In the **Black Sea**, bubbling reefs have been reported in Romania (Zaharia, 2013) and Bulgaria (Shnyukov & Yanko-Hombach, 2020) from both shallow and deep waters (down to 800m) and are therefore in the oxic and anoxic zones. In Romania, flat, pancake-like, structures have been found in 60m water depth, with larger concretions, up to 10 cm thick, at 110-130 m depth. At the top of the anoxic zone, at 190 m, the carbonates have formed coral-like concretions and at 230 m depth they have formed chimneys up to 1 m high. The highest density has been reported from the Danube Canyon which is in an area with important gas-hydrate deposits and a place of intense methane seepage in the anoxic water layer[2]. Pockmarks have been found in shallower waters (less than 100m) and may be surrounded by the sulfide oxidizing bacteria Beggiatoa spp. (Naudts et al., 2008). They are typically carbonate plates with holes through which the gas bubbles escape and are in areas of sandy and muddy sediment. The structures become more three dimensional with depth and reefs up to 2m tall have been report in deeper anoxic waters.

[2] Black Sea Marine Biogeographical Region. Regional workshop, October 27-30th 2020, Habitat Definitions and Favourable Reference Values.

In the **Mediterranean**, submarine structures made by leaking gases have been described from the northern and central Adriatic (Casellato et al., 2007; Gordini et al., 2023). Known locally as “tegnùe” “trezze” and “grèbeni”, these are rocky substrates of biogenic concretions, irregularly scattered across areas of sandy or muddy seabed. They are believed to have been formed by the precipitation of carbonates on beach sediments after methane, most likely from microbial decomposition of fossil plant material, has been released into the water.

A dense field of carbonate chimneys have also been reported at a depth of around 450m along the slope of the Montenegrin continental margin in the **South East Adriatic** (Angeletti et al., 2015). In Greece, underwater hydrothermal vents and structures off the island of Santorini include areas have been identified as habitat type 1180. They differ from other examples of this habitat type as there is an active discharge of bubbles of CO^2 together with high temperature fluids (around 220°C)[3]. Most of the volcanic cones are circular or concave, some with well-defined craters and others dome-shaped. The majority are in the depth range of 200-350m. The Gela Basin pockmark field in the strait of Sicily is another example of habitat type 1180 in the Mediterranean (Taviani et al., 2013). An example from the western Mediterranean can be found at the Illes Columbretes (Spain) in depths of around 40m (Erena, 2014). Also, some pockmark fields have been described in the Balearic Islands (Vázquez et al., 2022), Cabo de Palos seamount surrounding area and the Alboran Sea (Muñoz et al., 2008).

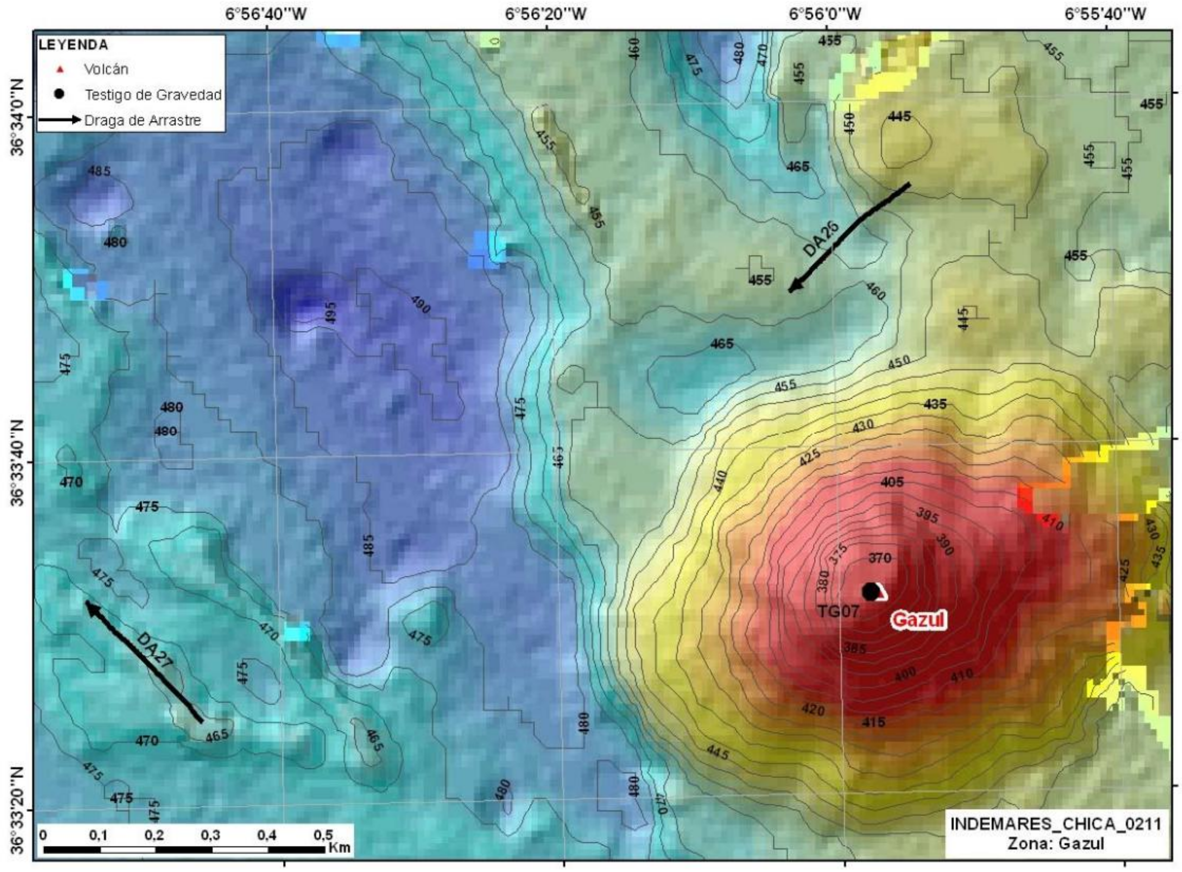
In the **Irish Sea** extensive areas of MDAC have been mapped in the vicinity of the Codling Fault Zone and in the Kish Bank Basin. Here they take the form of mounds standing 5-10m proud of the seabed and occupying areas >20,000 m^2. They are colonized by a diverse fauna which is richer than that found on the surrounding seabed and are far more extensive that the areas of bubbling reefs in the Kattegat and pockmarks described from in the North Sea (Judd et al., 2007).

MDAC pavements are present on the **Atlantic coast of France**, having been recorded along the edge of the continental shelf of Aquitaine between the canyons of Cap Ferret to the north and from Cape Breton to the south at depths ranging from 140-220m. Here the carbonate structures are in the form of low-lying blocks, mostly only a few centimeters above the surrounding seabed although in some cases up to 2m. The concentrations of endogenous meiofauna and macrofauna are very high in microbial mats in these locations (up to 30,000 nematodes/m^2 1000-5000 polychaetes/m^2) (La Rivière et al., 2022).

Habitat 1180 is also present on the **Atlantic coast of Spain** off the coast of Galicia and in the Gulf of Cadiz where there is sometimes an association with mud volcanoes (Mata et al., 2009; Vanreusel et al., 2009). One of these volcanoes, Gazul, is shown in Figure 2. In the Gulf of Cadiz, the habitat has formed it in an area of fluid leaks (mainly methane) because of tectonic movements related to the convergence of the African and European lithospheric plates. These leaks, together with microbial processes, create MDAC which has resulted in a great diversity of seabed features. Eight different types of structures have been identified associated with habitat type 1180 in the area; mud volcanoes, diapir-mud volcano complex, diapir, diapiric ridges, pockmarks, structures produced by leaking gases with chemosynthetic communities and structures produced by leaking gases with carbonate substrates of chemosynthetic origin (Rueda et al., 2022). Pockmarks have also been reported from the Rias Bajas, off the Spanish coast of Galicia but no carbonates have been found so far associated with them (García-Gil et al., 2000; Mata et al., 2009).

[3] Thalassia Periochi Koloumvo GR4220036

Figure 2. Gazul Volcano in the Gulf of Cadiz



Gazul Volcano from INDEMARES-CHICA 2011 campaign. The arrow shows the direction of dredge sampling of the campaign.

Source: Fernández-Salas et al. (2015)

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

The classification of the ecological characteristic and associated variables follows the UN-SEEA ecosystem condition typology (ECT), which has six classes: abiotic physical, abiotic chemical, biotic compositional, biotic structural, biotic functional and landscape/seascape characteristics (United Nations et al., 2021). Examples of biotic variables used to measure these characteristics when reporting on the condition of habitat type 1180 are summarised in Table 1.

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

- Gas emissions/methane seepage (on going and historic)
- Degree and form of Methane-Derived Authigenic Carbonate (MDAC), if present
- Exposure to current, wave action, scour and surge
- Geological characteristics
- Erosion and sedimentation around MDAC structures
- Oxygen levels (oxic or anoxic conditions)
- Epifaunal and infaunal assemblages
- Abundance and condition of characteristic species

1.2.1 Abiotic characteristics

Bubbling reefs are created through a process of precipitation (attributed to the oxidation of methane) whereby the carbonate cements the normal seabed sediment, forming rock-like concretions of 'Methane-Derived Authigenic Carbonate (MDAC). A fundamental requirement for the formation of these structures is therefore the presence of methane (Judd et al., 2007; 2020). Continuing emissions will enable the structures to develop further, but if this no longer takes place, they may be damaged or lost through erosion and sedimentation. Erosion of the surrounding bottom material may also expose the calcareous deposits, revealing complicated structures with many cavities the create many microhabitats supporting a rich fauna compared to the surrounding seabed (Lundälv, 2020). Whilst methane seeps and the formation of MDAC are key to the development of this habitat type continuing or continuous gas seepage is not necessary for its long-term viability. Instead, if gas seepage does occur, it will influence the types of marine communities associated with the structures that have formed.

Pockmarks form if the seabed is composed of fine-grained clay/silt sediments. They are thought to form by sudden gas or porewater eruption followed by long periods of quiescence or micro seepage (Croker et al., 2005; Hovland et al., 2005). Not all pockmarks contain carbonate structures but where present they may form blocks or slabs and, in some instances, may become covered by sediment or exposed by erosion. Sediment movement can change the physical characteristics of the feature as well as exposing or smothering associated epifauna especially in the case of low-profile features of pockmarks and pavements. Currents act semi permanently, transporting and depositing sediments on the seabed. The interaction of a mass of water with the relief of the seabed sometimes develops regional or local hydrodynamics that control the dominant sedimentary processes. For example, MDAC present different sizes and shapes and can be buried below sedimentary deposits. Currents expose these structures in a continuous process while gases leaking is still active. A comparison of two data sets from 2001 and 2012 of the Scanner Pockmark in the North Sea for example, revealed infilling of up to 1m in thickness, which is believed to have been the result of lateral collapse of the pockmark sidewalls (Gafeira & Long, 2015). On higher profile features, such as pillars, the epifauna may be dominated by filter feeding organisms (particularly anthozoans and sponges). Water movement and turbidity in the vicinity of such features are therefore key ecological processes that affect the character of this habitat type. normal

1.2.2 Biotic characteristics

Associated communities have a crucial role in this habitat. For example, chemosymbiotic species feed on any gas emissions, and suspension feeding species with a very slow growth and high sensitivity and ecological functionality colonize Methane-Derived Authigenic Carbonate (MDAC). Chemosynthetic microorganisms are the primary producers in cold seep food webs in the deeper waters along European margins, with non-symbiotic species present benefiting from the large biomass and productivity of chemosynthetic megafauna (Vanreusel et al., 2009). In shallower waters, such as the bubbling reefs on Stora Middelgrund and Röde Bank (Sweden) there can be a rich flora and fauna and elevated densities of fish populations compared to surrounding areas of seabed taking advantage of the many microhabitats created by the structures (Lundälv, 2020).

Disturbance of the seabed by human activity can affect the structures and associated species of this habitat[4]. Fishing equipment like bottom trawls are known to tear off pieces of the carbonate structures, thus destroying or damaging the habitat (Seffel, 2010). The direct effects of beam trawling on a submarine structure could include the loss of erect and sessile epifauna, smoothing of sedimentary bedforms and removal of taxa that produce structure. Trawl gear can crush, bury or expose marine flora or fauna and reduce structural diversity (Auster & Langton, 1999) while nets may become entangled in the irregular shapes of the carbonate structures. Anchoring in such areas may lead to similar damage (Lundälv, 2022).

Table 1. Ecological characterisation and selection of variables used to measure habitat condition of habitat 1180 (submarine structures made by leaking gases)

Ecological characteristics	Types	Description	Examples of associated variables
Abiotic characteristics	**Physical state characteristics**	Degree, form & location of MDAC, if present	High and low relief forms
		Erosion/sedimentation around MDAC	Presence/extent of surficial sediment, deposition/erosion rates and locations
		Topography/physical characteristics, depth	Physical dimensions, extent, longitude and latitudinal gradients, form, depth
		Hydrodynamics - Exposure to current, wave action, scour & surge	Current speed, wave height, direction, frequency
	Chemical state characteristics	Water quality/sediment quality	Dissolved oxygen, hazardous substances
		Geological, mineralogical and petrographical characteristics	Magnesium calcite and aragonite concentrations
		Gas emissions/methane seepage	Gas plumes/methane concentration
Biotic characteristics	**Compositional state characteristics**	Invertebrates - Epifaunal & infaunal assemblages, abundance and diversity of characteristic species	Number of biocenosis, presence & abundance of species (SACFO scale), diversity index.
	Structural state characteristics	Characteristic species, distribution of biocenoses	Percentage cover, biomass, Synthetic indicators (M-AMBI, BENTIX etc)
	Functional state characteristics	Presence and abundance of chemosynthetic communities (sulphide and/or methane-dependent biota)	Diversity, abundance
Landscape/ seascape characteristics		Connectivity/Fragmentation	Continuous/fragmented. Presence of anthropogenic structures and their % cover
Other		Disturbance	% area directly affected by human activity (e.g. demersal fisheries)

[4] E.g. Assessing Welsh Fisheries Activities Project https://naturalresources.wales/media/681826/beam-trawl-on-submarine-structures-made-by-leaking-gases.pdf

1.3 Selection of typical species for condition assessment

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

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

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

The marine communities and typical species present on and around habitat type 1180 differ depending on the type and form of the MDAC features, gas emissions, the hydrographic and oceanographic conditions, and the surrounding sediment type. The following description of marine life associated with bubbling reefs in the aphotic zone is provided by the Marine Life Information Network[5].

"The MDAC provides hard substratum for colonization by a diverse community of filter feeding and passive predatory epifauna typical of the sublittoral hard substrata in the surrounding area. The epifaunal community is reduced in immediate proximity to seeps gas outlets that penetrate the rock or where gas accumulates in caves within the rock. Some epifauna near the gas outlets are coated in methane-oxidizing bacteria. Mats of sulphide-oxidizing bacteria *Beggiatoa*, *Thiothrix* and *Thioplaca*, may form in areas in direct contact with the gas, which may support its own community of grazing ciliates and nematodes and predatory nematodes".

In Sweden, surveys of the bubbling reefs on Fladen, have indicated that the best developed bubble reefs have a rich flora and fauna and elevated densities of fish populations compared to the surrounding seabed (Lundälv, 2020; 2022). A species list from bubbling reefs in the Kattegat is shown in Table 2.

[5] https://www.marlin.ac.uk/habitats/detail/1163/bubbling_reefs_in_the_aphotic_zone (accessed 23/10/23)

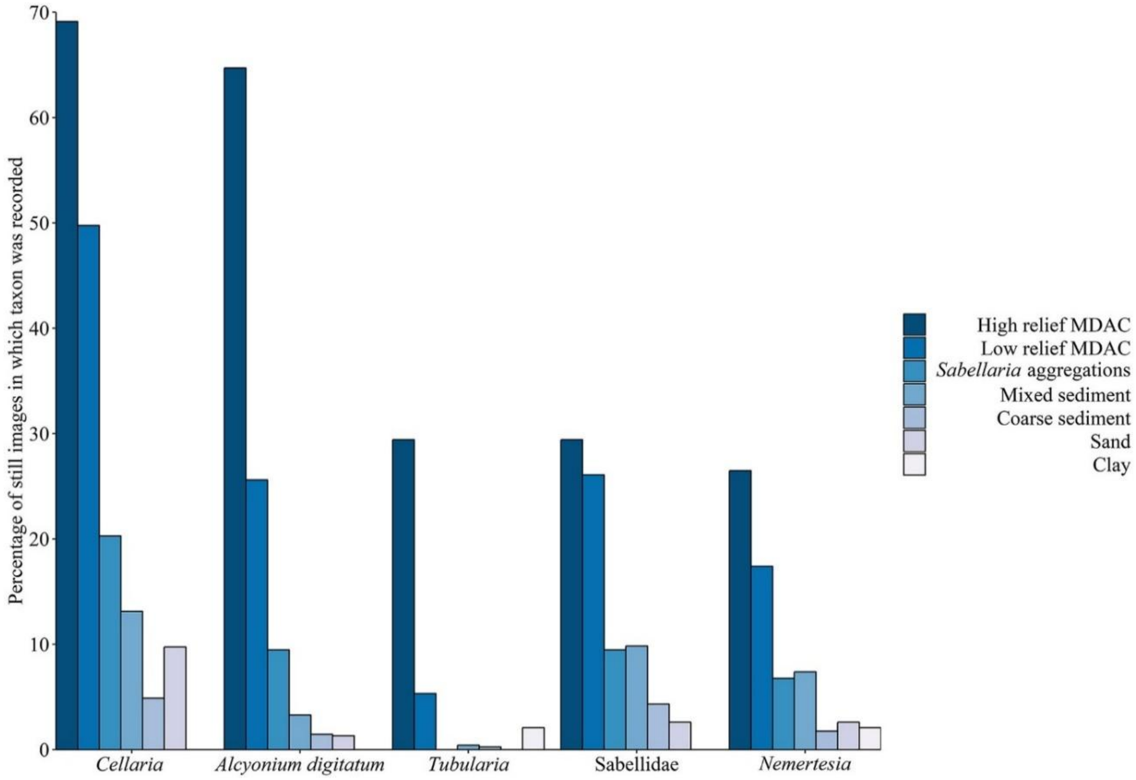
Table 2. Common macrofauna on the bubbling reefs in the Kattegat

*: Jansen et al. (1992) refer as common species.

PORIFERA	**OLIGOCHAETA**	**PANTOPODA**
**Cliona celata*	4 spp.	*Pallene brevirostris*
HYDROZOA	**GASTROPODA (-Nudibranchia)**	**CIRRIPEDIA**
Eudendrium arbuscula	*Acmaea virginea*	**Verruca stroemia*
Ectopleura larynx	*Gibulla cineraria*	*Balanus balanus*
ANTHOZOA	**Cingula striata*	
**Metridium senile*	*Crepidula fornicata*	**DECAPODA**
**Tealia felina*	**Alvania punctura*	*Eupagurus bernhardus*
**Alcyonium digitatum*	**Rissoa albella*	**Porcellana longicornis*
	**Rissoa parva*	**Cancer pagurus*
NEMERTEA	*Rissoa membranacea*	*Stenorhynchus rostratus*
**Emplectonema gracile*	*Hinia pygmaeus*	
Micrura fasciolata	**Chrysallida spiralis*	**ISOPODA**
Lineus bilineatus	**Odostomia plicate*	*Jamira maculosa*
Prostomatella obscura	*Odostomia eulimoides*	*Munna minuta*
	Retusa truncatula	
POLYCHAETA	*Philine denticulata*	**AMPHIPODA**
Lepidonotus squamatus		**Phtisica marina*
Harmothoe fragilis	**NUDIBRANCHIA**	**Corophium bonelli*
Harmothoe aff. *elisabethae*	**Goniodoris nodosa*	*Cressa dubia*
Scalisetosus sp.	*Ancanthodoris pilos*	*Microdeutopus propinquus*
Pholoe inornata	*Onchidoris muricata*	2 spp.
Eulalia viridis	*Archidoris pseudoargus*	
Nereimyra punctata	*Coryphella verrucosa*	**SIPUNCULIDA**
Typosyllis armillaris	*Cuthona foliata*	*Golfingia minuta*
Exogone hebes	*Doto coronata*	
Proceraea cornuta	*Jorunna tomentosa*	**BRYOZOA**
Nereis pelagica		*Conopeum seurati*
Sphaerodorum flavum	**BIVALVIA**	**Crisia eburnea*
Pherusa plumosa	*Mytilus edulis*	*Scrupocellaria scruposa*
Arenicola marina	*Modiolarca tumida*	*Acyonidium hirsutum*
**Promatoceros triqueter*	*Monia patelliformis*	*Electra pilosa*
Hydroides norwegica	**Heteronomia squamula*	*Membranipora membranacea*
Sabellaria spinulosa	**Hiatella sp.*	*Escharella immersa*
Heteromastus filiformis	*Parvacardium ovale*	*Plagioecia patina*
Autolytus prolifer	*Mysella bidentata*	
Nicolea zostericola	*Kellia suborbicularis*	**ECHINODERMATA**
Spirorbis spirillum		*Ophiopholis aculeata*
**Dodocaceria concharum*		**Ophiotrix fragilis*
Cirratulus incertus		*Asterias rubens*
Caulleriella aff. *Fragilis*		*Masthasterias glacialis*
Caulleriella aff. *killariensis*		
Lagisca externuata		**ASCIDIA**
Polydora ciliata		**Botrylloides leachii*
Polydora coeca		*Botryllus schlosseri*
Polycirrus norwegicus		*Styela coriacea*

The benthic communities of **pockmarks** are typically invertebrate specialists of hard marine substrata and are different from the surrounding (usually) muddy habitat. The are generally areas of 'low relief', therefore MDAC in such locations may be colonised by scour-resistant hydroids and bryozoans. The diversity of the infauna community in the muddy seabed surrounding the "pockmark" may also be high (HELCOM, 2013). Figure 3 summarises data on associated taxa from the Croker Slabs, Irish Sea.

Figure 3. Percentage occurrence frequency of MDAC associated taxa



Percentage occurrence frequency of MDAC associated taxa for different habitat classes, derived from still-image data (Croker Slabs, Irish Sea, UK).

Source: Noble James et al. (2020)

In the case of the **hydrothermal vents** in Greek waters, the exterior of most chimneys as well as large areas on the Kolumbo floor are covered with white, grey, and reddish/orange filamentous bacteria microbial mats. The acidic shallow-submarine Kolumbo hydrothermal vents nourish marine ecosystems in which nitrifying Archaea are important.

In the SCI Volcanes de fango del Golfo de Cádiz in Spain, the biodiversity of different areas has been studied in detail, especially the porifera, molluscs including those linked to fluid emissions, peracarid crustaceans, crustaceans linked to fluid emissions and bryozoans (Díaz del Río et al., 2014). The following characteristic species of several habitats-structures have been described;

- **Mud volcanoes**: Archaebacteria, sulphate-reducing bacteria, invertebrates with chemosymbionts, especially bivalve molluscs (*Solemya* sp., *Lucinoma* sp., *Acharax* sp.), frenulate polychaetes (*Siboglinum* sp.) and thalasinid decapods (*Calliax* sp.).
- **Pockmarks:** polychaetes species of genus *Siboglinum*.
- **Collapsed depressions:** Remains of chemosynthetic species as bivalves (*Lucinoma* sp., *Acharax* sp., *Isorropodon* sp., *Bathymodiolus* sp.).
- **Structures produced by leaking gases with chemosynthetic communities:** Bacteria (*Beggiatoa* sp., *Thioploca* sp., *Thiothrix* sp.), polychaetes (*Siboglinum* sp., *Bobmarleya gadensis*), bivalves (*Lucinoma asapheus, Solemya elarraichensis, Acharax gadirae, Thyasira* sp. *Isorropodon* cf. *megadesmus*, *Bathymodiolus mauritanicus*), thalasinid decapods (*Calliax* sp.)
- **Structures produced by leaking gases with carbonate substrates of chemosynthetic origin:** Archaebacteria and sulfate-reducing bacteria.

The species used to monitor the condition of this habitat type differ depending on the location (e.g. photic zone or deep circalittoral zone) and type of submarine structure. For example, it has been observed that seep assemblages in shallow water (0-200m) are less likely to contain seep-specialised taxa than at deep water sites, as strong competition from fauna that use photosynthetic carbon is expected in shallow depths (Noble-James et al., 2020 and references within). Chemosymbiotic organisms located mainly at the top of mud volcanoes and are useful to estimate a high fluid expulsion activity in some of them, whilst some species groups are also particularly useful as indicators of disturbance. In the Gulf of Cadiz, for example, aggregations of species such as Pennatulacea, *Isidella elongata*, *Radicipes fragilis* and *Pheronema carpenteri* as present in the Deep Field areas of the mud volcanoes are highly sensitive to bottom trawling (Rueda et al., 2022). Regarding bivalves, Oliver et al. (2011) conclude that, although there is considerable similarity at the genus level between seep/mud volcano fields in the Eastern Atlantic and Mediterranean, there is little overlap at the species level. This indicates a high degree of endemism within chemosymbiotic bivalve assemblages.

Table 3 indicates groups from which species for monitoring may be selected, and the types of changes in condition 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 1180 (submarine structures made by leaking gases)

Species group	Sub-Type: -Bubbling reefs (BR) -Pockmarks (P) -Hydrothermal vents (HV)	Ecological notes	Sensitive to changes in condition
Bacteria / Archaea	Pockmarks Hydrothermal vents	Chemoautotrophic bacterial mats may be present where there is active anaerobic oxidation of methane	Gas seepage
Algae	Bubbling reefs	Photic zone only	Nutrient levels, turbidity, light
Hydrozoa	Bubbling reefs Pockmarks	Opportunistic and can rapidly colonise exposed areas of structures produced by leaking gases	Physical abrasion
Porifera	Bubbling reefs Pockmarks Hydrothermal vents	Require water movement for filter feeding with low turbidity	Physical abrasion, area of hard substrate
Anthozoans	Bubbling reefs Pockmarks	Require water movement for filter feeding with low turbidity	Nutrient levels, turbidity, physical disturbance, area of hard substrate
Crustaceans	Bubbling reefs Pockmarks	High abundance sheltering around bubbling reefs in the Kattegat	Disturbance/fishing
Fish	Bubbling reefs Pockmarks	High abundance sheltering around bubbling reefs in the Kattegat	Disturbance/fishing

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

Some information has been collected on the location and main characteristics of 'submarine structures made by leaking gases' by all the Member States that have reported habitat 1180 as present within their jurisdiction however, only Spain, Italy and Romania have specified variables for assessment and monitoring (La Mesa, 2019; Mata et al., 2009; Zaharia, 2013). Sweden and Ireland (Seffel, 2010; NPWS, 2023) 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 (Jensen et al., 1992; Pierre et al., 2017; Croker et al., 2005; Judd et al., 2007; Judd et al*.,* 2020)). 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 habitat 1180 is presented in Table 1 (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, which indicates that only three Member States (Spain, Italy and Romania) have published methodologies specifically relating to habitat 1180.

Only three Member States have published methodologies specifically related to habitat 1180 (Spain, Italy and Romania). In the case of Spain (Mata et al., 2009) they are recommendations. Sweden and Ireland (Seffel et al., 2010; NPWS, 2023) have proposals for consideration when reporting on conservation objectives without specifying those which might be specifically used for assessment of structure and function. Surveys of the Fladen bubble reefs in Sweden between 2005 and 2018 have collected data on location, extent and some of the associated flora and fauna (Lundälv, 2022) however the Article 17 report for 2018 on this habitat type indicates that the overall assessment of structure and function (U1 – Unfavourable/inadequate) has been set mainly by expert assessment based on a limited amount of data (mainly physical disturbance).

There is no specific guidance of variables and metrics to use for monitoring and assessment of habitat 1180 in Denmark however 'control monitoring' is recommended. This specifies monitoring populations and their distribution for species, and monitoring species diversity, coverage levels and biomass. In the assessment of condition, physical and water chemical data collected in for the Water Framework Directive and Marine Strategy Framework Directive are also to be used.

Table 4. Examples of variables used by Member States to assess condition of habitat 1180 (submarine structures made by leaking gases)

Description	Examples of variables used by Member States	Notes
1. Abiotic characteristics		
1.1 Physical state characteristics		
Degree, form and location of MDAC, if present	ES - Geomorphological & physiographic characterisation of ocean floor (recommended). IT – Morphobathymetry	Whilst not necessarily highlighted in the assessment methodologies for this habitat type, these characteristics are usually included in the descriptions of Natura 2000 sites where habitat 1180 is present (e.g. in the SDFs).
Erosion/sedimentation around MDAC	ES - Characterisation of sediments and sedimentary dynamics. RO - Sediment characteristics	Whilst there are only two instances where this characteristic is highlighted in assessment methodologies for habitat 1180, some observations about this variable may be included in general descriptions of the habitat.
Topography/physical characteristics, depth	ES - Geomorphological & physiographic characterisation of ocean floor (recommended). RO - Depth	Whilst not necessarily highlighted in the assessment methodologies for this habitat type, these characteristics are usually included in the descriptions of Natura 2000 sites where habitat 1180 is present (e.g. in the SDFs). Depth is a standard variable which is recorded in acoustic surveys and therefore likely to be noted in the supporting documentation of all assessments for habitat 1180 even if not specifically mentioned in the methodologies.
Hydrodynamics - Exposure to current, wave action, scour & surge		Whilst not necessarily highlighted in the assessment methodologies for this habitat type, these characteristics may be included in the descriptions of Natura 2000 sites where habitat 1180 is present (e.g. in the SDFs).
1.2 Chemical state characteristics		
Water quality/ sediment quality	SE – Concentrations of hazardous substances in biota and sediment, water oxygen level in the benthic zone (ml/l) RO - Water transparency	
Geological, mineralogical and petrographical characteristics		Whilst not necessarily highlighted in the few assessment methodologies for this habitat type, these characteristics are usually described in at least general terms in Natura 2000 sites where habitat 1180 is present (e.g. in the SDFs).
Gas emission/ methane seepage	ES - Fluid emission activity (recommended)	Gas seepage, if present, is likely to be noted and reported in general surveys and descriptions of habitat 1180. In some instances, there may be sampling of the chemical components as well as estimations of the rate of seepage. Changes in seepage activity may also be described in general terms if there are obvious visual changes e.g. becoming inactive

Description	Examples of variables used by Member States	Notes
2. Biotic characteristics		
2.1 Compositional state characteristics		
Invertebrates - Epifaunal & infaunal assemblages	IT - Abundance and sessile species condition RO -Biocenoses types, abundance/average density of characteristic species SE - Number of species per unit area, species diversity of algae & fauna, presence of rare species	Some information about compositional state characteristics may be provided by Member States where habitat 1180 is present, but this mostly takes the form of general descriptions rather than detailed recording of a specific variable.
2.2 Structural state characteristics		
Condition of characteristic species	IT - Structure of populations of species RO - Extent of biocenoses and of characteristic communities, spatial distribution of biocenoses and characteristic communities, relative distribution of habitat subtypes. SE - Biomass of soft bottom fauna (dry weight/unit area), coverage by specific structural species of fauna	Some information about structural state characteristics may be provided by Member States where this habitat is present, but this mostly takes the form of general descriptions rather than detailed recording of a specific variable.
2.3 Functional state characteristics		
Presence and abundance of chemosynthetic communities	Diversity, abundance	Some information about functional state characteristics may be provided by Member States where this habitat is present, but this mostly takes the form of general descriptions rather than detailed recording of a specific variable.
3. Landscape/seascape characteristics		
Connectivity / Fragmentation	RO - Habitat extent SE - Habitat area	Mapping the extent provides information about connectivity/fragmentation. This will be available where detailed surveys have been carried out even if not specified as a variable for assessing habitat condition, although to different degrees of detail, and depending on repeat surveys. Although a significative change is unlikely except under anthropogenic pressures, periodical monitoring is necessary.
4. Other		
Disturbance	SE - Ratio (%) of physical damage and/or sedimentation; ratio (%) of unaffected area	Measuring the extent of physical damage is one of a number of potential variables proposed by Sweden that could be used to determine whether conservation objectives. The presence of marine litter or seabed disturbance caused by demersal trawling may be noted in general observations about a site rather than being measured as a specific variable.

Table 5. Main ecological characteristics and associated variables monitored in the assessment of structure and function of habitat 1180 (submarine structures made by leaking gases) by EU Member States

Ecological characteristics	Variables	Metrics	ES	IT	RO
1. Abiotic characteristics					
1.1 Physical state characteristics					
Degree & form of MDAC	High and low relief forms	Form/types from a reference list, density of seeps/km^2, area covered by seeps (km^2)			
Erosion/sedimentation around MDAC	Presence/extent of surficial sediment	Changes in % of different sediment fractions, sediment depth (mm) and rates of change (mm/year, g/m^2), oxidised layer (mm)			
Topography/physical characteristics, depth	Physical dimensions, extent, longitude and latitudinal gradients, elevation, form, depth	Metres (m), physical features from a reference list			
Hydrodynamics - Exposure to current, wave action, scour & surge	Current speed, wave height, direction & frequency	Knots (kn), Metres (m)			
1.2 Chemical state characteristics					
Water quality/sediment quality	Oxygen concentration, Redox potential	ml/l, Concentration/dissolved oxygen (% saturation)			
Geological, mineralogical and petrographical characteristics	Magnesium calcite and aragonite concentrations				
Gas emissions/methane seepage	Gas plumes/ methane concentration	gas flux (l/min), methane flux (m^3/yr)			
2. Biotic characteristics					
2.1 Compositional state characteristics					
Invertebrates - Epifaunal & infaunal assemblages	Assemblage abundance and diversity of characteristic species from standardised lists.	Biomass (dry weight/unit area), number of species/unit area. Number of biocenosis/taxa, presence & abundance of species (SACFO scale), diversity index, (Shannon-Wiener diversity index, AMBI index) biomass, estimated % cover			
2.2 Structural state characteristics					
Characteristic species	Type, extent	Percentage cover, biomass, density. Synthetic indicators (M-AMBI, BENTIX etc)			
2.3 Functional state characteristics					
Presence and abundance of chemosynthetic communities	Diversity, abundance	Percentage cover, biomass, density.			

Ecological characteristics	Variables	Metrics	ES	IT	RO
3. Landscape/Seascape characteristics					
Connectivity / Fragmentation	Continuous/fragmented. Presence of anthropogenic structures and their % cover	Area (ha/km^2), % area directly affected by human activity			
4. Other					
Disturbance	Footprint of activity, number	Presence/absence, % area directly affected/unaffected by human activity (e.g. by demersal fisheries or sand extraction, anthropogenic structures), pressures from a standardised list (graded High, Medium, Low, unknown).			

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

Accessibility including depth, has a major influence on data gathering, including the level of detail in which the variables are recorded. Table 6 lists some of the typical methodologies used to gather information on the key characteristics of this habitat type.

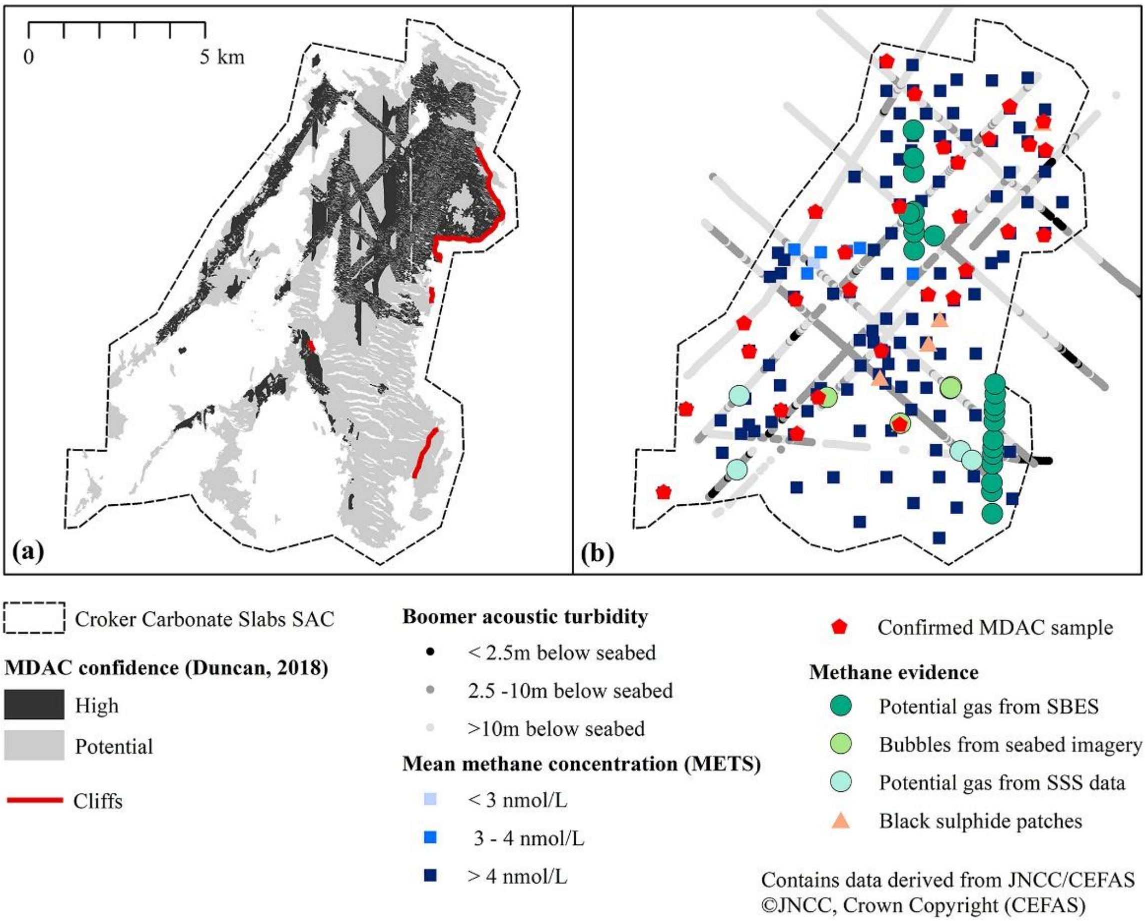
Table 6. Survey methods used to investigate key characteristics of habitat type 1180.

Key characteristics	Methodologies
Extent	Acoustic data, seabed imagery
Degree & form of MDAC	Acoustic data, seabed imagery, mineralogical and petrographical characterisation, isotope analysis & dating, grab samples
Erosion/sedimentation around MDAC	Acoustic data, seabed imagery, grab & core samples, sub bottom profiling
Water quality	Pore water chemistry, sea water samples
Gas emissions	Seabed imagery, acoustic data,
Methane seepage	Water samples, pore water chemistry, acoustic data, seabed imagery
Epifaunal & infaunal assemblages	Seabed imagery, grab & core sampling
Abundance of characteristic species	Seabed imagery, grab & core sampling

The extent to which these different methods are used by Member States depends on existing knowledge of potential locations of the habitat, as well as the depth and remoteness of the features to be studied. These considerations also have a bearing on the complexity of the required logistics and the level of detail, which in turn influences decisions about the most appropriate methodologies to use.

Direct sampling/ground truthing, by taking sediment cores, provide fine scale data about the habitat (e.g. substrate type) and associated infauna. Figure 4 (Noble-James et al., 2020). shows how data gathered by these different techniques can be combined to give an overview, in this case of the Croker Slabs bubbling reefs in the UK sector of the Irish Sea, which extend over an area of around 116km^2 in water depths ranging from 65-109m below Chart Datum.

Figure 4. Combined multidisciplinary evidence for (a) high confidence and potential MDAC extent and (b) active methane release.



Combined multidisciplinary evidence for (a) high confidence and potential MDAC extent and (b) active methane release within the Croker Carbonate Slabs SAC (UK).

Source: Noble James et al. (2020)

Abiotic characteristics describe both the physical and chemical state of the habitat. The physical state characteristics of bubbling reefs typically provide context and locational information. Acoustic methods such as side scan sonar and multibeam echosounders provide data on location and spatial extent, as well as topographical features of the habitat. Seabed imagery (e.g. using drop cameras, towed cameras and ROVs), provides for a more detailed overview of the physical characteristics of the habitat as well as the possibility of identifying associated epifaunal biotopes.

For example, in the Gulf of Cadiz, the project LIFE INDEMARES/CHICA developed several campaigns in the area the Shallow Field of Fluid Expulsion (SEFE). Bathymetric data was acquired with a multibeam echosounder (Kongsberg Simrad EM-710) and processed to produce a 15 × 15 m bathymetric grid model; very high-resolution seismic profiles were acquired with a Topographic Parametric Sounding system (TOPAS PS018); near-bottom current speed measurements were carried out using a Lowered Acoustic Doppler Current Profiler (LADCP) (Palomino et al*.,* 2016).

In Sweden, surveys to investigate the extent of bubble reefs around Fladen and on Lilla Middelgrund have been carried out using echo sounding and sonar mapping together with video and photo documentation using ROVs (Lundälv, 2020; 2022).

Chemical characteristics, determined from water sampling as well as samples taken from the reef structures themselves as well as surrounding sediment, are used to understand the formation, activity and condition of bubbling reefs.

There are differences in the **biotic characteristics** and specifically the biological communities and species associated with this habitat type depending on their location, particularly depth but also proximity to other areas of hard substrate as well as type and whether there are ongoing gaseous emissions. Sampling to describe the epifauna is usually not a favoured option because of the potential to damage the structures themselves. Instead, photography, particularly with the use of ROVs (Palomino et al*.,* 2016), is typically used to describe the biotic characteristics, although some sampling may take place, for example of associated bacterial mats. Core samples may be taken to investigate the infaunal communities in the surrounding sediments. Analysis of perturbance in the Gulf of Cadiz in Spain includes Benthos Sensitivity Index to Trawling Operations - BESITO index (González-Irusta et al., 2018).

Submarine structures made by leaking gases may be individual isolated features but are more often found in clusters and may even occur as dense fields across areas of current or historic gas emissions. In the latter cases they can cover hundreds of square kilometres creating distinctive **topographical/landscape scale features** on the seabed. Individual features, such as pockmarks, can also be large[6]. Acoustic methods and seabed imagery are used to map these features at a landscape scale revealing chimneys, pockmarks, and pavements in areas surrounded by soft sediments.

2.2 Definition of ranges and thresholds to obtain condition indicators

Reference values are generally not defined for condition monitoring of this habitat type due to limited baseline data. In part, this may be related to significant costs associated with acquiring such data when the habitat occurs in deep offshore waters.

In Spain, for example, the availability of specific technology, such as ROVs that can operate at great depths (500-1000m) has been identified as a constraint (Mata et al*.,* 2009). Another option for condition monitoring is to record trends in variables. At the Codling Fault zone (Irish Sea), for example, the habitat would be considered to be in favourable conservation condition if the area of MDAC and distribution of the submarine structures made by leaking gases is stable or increasing, subject to natural processes. Similarly, the structural integrity of MDAC features should be maintained and the MDAC community complex to be in a natural condition, subject to natural processes (NWPS, 2023).

In Sweden there are proposals for a mix of specific reference levels consistent with other environmental requirements, set levels, and indications of a possible approach but with no specific levels agreed to date (see Table 7). There has however been some reporting of trends with a comparison of the first documented bubble reef at the south west part of Fladen between 2005 and 2018 indicating that some species have declined sharply during this period[7] and that the number of fish has also decreased in number and size (Lundälv, 2022).

[6] E.g. 300m in diameter in the Bratten field (Sweden)

[7] https://www.havet.nu/havsutsikt/artikel/bubbelrev

Table 7. Examples of reference values and approaches proposed for assessment of habitat 1180 (submarine structures made by leaking gases) by Ireland and Sweden

Approach	Example of variable used	Method/metric and reference values	Reference
Quantitative	Ratio in % of un-affected area	95% of the structure/seabed in the Natura 2000 habitat shall be free from damage due to human impact (e.g. caused by chains and fishing gear, sedimentation & dredging)	Sweden; Seffel et al., 2010
Linked to other programmes - e.g. WFD, MSFD, national standards	Oxygen levels in the benthic zone (ml/l)	Water oxygen level at the benthic zone shall not be lower than environmental quality standards according to SFS 2004:660	Sweden; Seffel et al., 2010
Trend	Hectares	The permanent area of MDAC features is stable or increasing subject to natural change	Ireland; NWPS, 2023
Trend	Occurrence	The distribution of MDAC structures is stable or increasing subject to natural processes.	Ireland; NWPS, 2023
Under development	Dry weight per unit area	Biomass of soft bottom fauna does not decrease and is at least X gram/m^2	Sweden; Seffel et al., 2010

2.3 Aggregation methods at the local scale

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

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

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

Then each indicator is given a score (negative or zero) which is subtracted from the starting score of 100. A good indicator score will result in few points being subtracted, and a bad indicator score will result in more points being subtracted. Final scores indicate the overall status along a gradient (Table 8 & Figure 5 below).

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

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

Figure 5. Determination of conservation status based on its overall score

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

No examples have been found of aggregation methods at a local scale to assess structure and function of habitat 1180 for Article 17 reporting.

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). This level of detail may however not be possible at the present time due to limited baseline and monitoring data for this habitat.

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. Practical considerations play a large part, particularly for examples of this habitat type in deep or offshore waters.

Some also extend over very large areas as in the case of mud volcanoes of the Gulf of Cadiz (Spain) which occur across a depth range of 363-1123m and occupy just over 23,661ha (Rueda et al., 2022). In Romania the recommendation (for all marine Annex 1 habitat types) is to use a stratified random sampling strategy, except where monitoring rare or special habitats/species, the distribution of which is already known in which case a selective strategy should be used. Pilot studies are also one method of helping to determine the optimal sampling with availability of resources (Zaharia, 2013).

2.6 General monitoring and sampling methods

A six yearly cycle of reporting, as specified under Article 17, is required under the Habitats Directive. This includes reporting on the conservation status of habitats listed in Annex 1 of the Directive. It applies throughout the territory of the Member State concerned, not only where the habitat occurs within Natura 2000 sites. To inform this reporting, six-yearly monitoring of the relevant habitats would be the minimum required. There is a limited information on the frequency for monitoring this habitat, but it is assumed that it is linked to the regular Article 17 reporting requirements.

In Italy it is recommended that monitoring activities must be carried out at least every 5 years (La Mesa et al., 2019) and undertaken according to the monitoring guidelines for coralligenous habitats set out for implementation of Article 11 of the MSFD (Ministero dell'Ambiente e della tutela del Territorio e del Mare, 2016). These include guidance that habitats and populations present should ideally be identified in three survey sites in each area. The usual monitoring technique is based on the collection of images from part of underwater detectors, when this habitat is at accessible depths, or with ROVs in deeper waters. The images are collected at fixed stations or along transects with the aim of evaluating the presence and the state of conservation of typical species and those forming part of associated biocenoses. The characteristic chemosymbiotic species are part of the infauna and can only be sampled using buckets and dredgers; the use of such destructive methods for their collection must therefore be limited to specific research activities. The gas emission is monitored through the use of acoustic instruments such as echo sounders multibeams that record the overlying water column and using typical geophysical instruments such as sub-bottom profiler depth sounders.

In Denmark monitoring of 'bubbling reefs' is prioritised, and the recommendation is for annual monitoring (Miljøministeriet Miljøstyrelsen, 2022). Annual monitoring is also recommended for the two Natura 2000 sites in Romania which have been designated for this habitat type (Zaharia, 2013).

2.7 Other relevant methodologies

A variety of methodologies and projects provide valuable information on assessing the structure and function of submarine structures made by leaking gases even though they may not be specifically aimed at Article 17 reporting. They include:

- Work carried out under Regional Seas Programmes such as HELCOM[8]
- Reporting under other EU Directives, in particular the Water Framework Directive and the Marine Strategy Framework Directive[9]
- Scientific research, surveys/monitoring projects[10]

This habitat type has been subject to monitoring and assessment in UK waters. For the Croker Carbonate Slabs (UK, Irish Sea) it is recommended that the monitoring programme focuses on the physical structure and extent of MDAC, typical species, diversity, structure of communities associated with MDAC. There is however a cautionary note on using the extent of MDAC as an indicator of condition due to sediment movement that can cover previously exposed features (e.g., Gafeira et al., 2016; Gordini et al., 2023; Jensen et al., 1992) and also due to the difficulties of revisiting exact locations of outcropping pavements. The recommendations for condition monitoring are to focus on anthropogenic pressures, by analysis up-to-date pressures and activities maps. For this location the recommendation is that frequent monitoring is unlikely to be required unless a new pressure to which the features are vulnerable is identified within the site.

Sediment samples to investigate changes in sediment composition or movement of veneers over time are proposed as well as targeted sampling of bacterial mats or seep-associated meiofauna if required. Focus should be on epifaunal data via video and still imagery which will directly related to the MDAC features. Stratified sampling between outcropping and pavement MDAC can be used to further investigate differences in epifaunal assemblage composition between the different forms of the features.

There is a recommendation that future monitoring events should consider in-situ environmental monitoring, including tidal current meters and sediment traps, to improve understanding of hydrodynamics, erosion, sediment loads and deposition rates, and the associated impact on biological communities This information would allow a greater understanding of the amount of change which can be attributed to natural variability.

2.8 Conclusions

Some information has been collected on the location and main characteristics of ‘submarine structures made by leaking gases’ by all the Member States that have reported habitat 1180 as present within their jurisdiction however, only Spain, Italy and Romania have specified variables for assessment and monitoring (La Mesa, 2019; Mata et al., 2009; Zaharia, 2013). Sweden and Ireland (Seffel, 2010; NPWS, 2023) 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

[8] OSPAR HELCOM submarine structures made by leaking gases metadata catalogue https://metadata.helcom.fi/geonetwork/srv/eng/catalog.search#/metadata/3cef63ee-9a44-481f-8869-ea9b977df747
[9] Summaries available on the Marine Information System for Europe; https://water.europa.eu/marine/data-maps-and-tools/map-viewers-visualization-tools/dashboards-on-marine-features-under-other-policies
[10] Eg. LIFE IP INTEMARES project

used to inform such assessments although not directly stated as a reason for the work (e.g. Denmark and France (Jensen et al., 1992; Pierre et al., 2017; Croker et al., 2005; Judd et al., 2007; 2020)).

Many of the investigations in relation to the requirements of the Habitats Directive have focused on locating and mapping the distribution/extent/abundance, the method of formation and chemical characteristics as well as identifying and reporting threats/impacts to this habitat type. Although some examples of this habitat type are relatively well known as geological features, studies of biodiversity interest and associated biological communities are more recent. This is particularly the case when the habitat is in deep offshore waters.

The starting point for gathering information on this habitat type is typically acoustic surveys of areas where it is believed to be present, using tools such as single/multi-beam echo sounders and boomers (for sub-bottom profiles). Once located and depending on the extent of the habitat and depth of occurrence, this may be followed up with seabed imagery from video and stills photography (transects and/or fixed stations) using Remotely Operated Vehicles (ROVs), towed and drop-down cameras. In shallower waters, whilst these methods may be used direct observation/recording and photography is possible using SCUBA.

If undertaken, information for the assessment and monitoring of the biological characteristics of the habitat, including typical species, is also usually gathered by a combination of remote means and direct observation. Photographic images are used to get some an overview of the distribution and extent of associated epifaunal communities and, also identify characteristic species if they are visually dominant. Infaunal macrofaunal communities and species in areas of soft sediment are identified by analysis of core/grab samples. Photographic methods may be used to record more mobile species such as fish aggregating around reef structures.

Specific reference values are rarely defined for condition monitoring of this habitat at the present time by Member States. In some cases, the approach proposed is to report on trends in variables, such as extent, which are related to the conservation objectives of a site. In other cases, decisions about potential reference values are still subject to discussion, requiring further data.

There is no standard approach to the identification of a number and distribution of localities to carry out the assessment and monitoring of habitat 1180. Practical consideration, such as accessibility are important and most work to date has broad scape mapping with some detailed survey points across the habitat.

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. More frequent monitoring has however been proposed for ‘bubbling reefs’ in Denmark which is prioritized and is monitored annually. Romania also recommends annual monitoring at the two Natura 2000 sites where habitat 1180 is present. In general, detailed and repeat monitoring and assessment of this habitat type is limited at the present time with much remaining to be done (Noble-James et al., 2020; Mata et al., 2009; Lundälv, 2020; 2022).

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 1180 are presented earlier in this report. A proposed list of essential, recommended and specific condition variables is presented in Table 9. '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.

Table 9 is based on the main characteristics of the habitat (described in section 1.2.1), together with the information provided by Member States about the assessment of the condition of the habitat, and habitat specific literature. This list aims to be a prototype to be further defined by expert panels. The proposed metrics are intended to be easily but reliably obtained.

The main **abiotic characteristics** proposed for monitoring are physical (describing the degree and form of MDAC where present, topography/physical structure) and chemical (related to the geological, mineralogical and petrographical characteristics and gas emissions/methane seepage where present. The main **biotic characteristics** proposed for monitoring are compositional (associated species), structural (presence and condition of species). Disturbance, and in particular the footprint of any activities and number and intensity of negative pressures should be noted. The main **landscape/seascape characteristic** is 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 mandatory monitoring. Connectivity and form provide more detail and are therefore recommended monitoring variables.

Table 9. Proposals for condition variables for assessing and monitoring habitat 1180 (submarine structures made by leaking gases)

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 & form of MDAC	**-High and low relief forms**	Form/types from a reference list, density of seeps/km^2, area covered by seeps (km2)	Essential	SSS, SBS, MBES, AGDS, LiDAR DDV, ROV, Seabed surficial sediment charts.	The extent to which these different methods are used by Member States depends on existing knowledge of potential locations of the habitat, as well as the depth and remoteness of the features to be studied. Comparisons of imagery data over time can reveal gross changes degree and form of MDAC.
Erosion / sedimentation around MDAC	**-Presence/extent of surficial sediment**	% of three classes of particle size (mm), oxidised layer (mm)	Recommended	SSS, SBS, MBES, AGDS, LiDAR DDV, ROV, Seabed surficial sediment charts. Direct sampling (benthic grab/core, suction)	Variation in sediment composition can occur naturally and over both small and large distances. A systematic and consistent approach to sampling will therefore be required to give sufficient overview of this characteristic across the habitat as well as identifying boundary areas and any locations with particularly different/distinctive sediment composition.
Topography / physical characteristics, depth	**-Physical dimensions -Extent -Longitude and latitudinal gradients -Elevation -Form -Depth**	Metres (m), physical features from a reference list	Essential	SSS, SBS, MBES, AGDS, LiDAR DDV, ROV, Seabed surficial sediment charts	The extent to which these different methods are used by Member States depends on existing knowledge of potential locations of the habitat, as well as the depth and remoteness of the features to be studied. Comparisons of imagery data over time can reveal gross changes in topography of the habitat

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**	Knots (kn), Metres (m)	Recommended	Scour - SSS, MBES, TLP Hydrographic charts, modelling, ADCP	Seasonal changes and storm events may be apparent when recording these variables.
1.2 Chemical state characteristics					
Water quality / sediment quality	**-Oxygen concentration -Redox potential**	ml/l, Concentration/ dissolved oxygen (% saturation)	Specific	Dissolved oxygen meters, optical sensors	
Geological, mineralogical and petrographical characteristics	**-Magnesium calcite concentration -Aragonite concentration**		Essential	SSS, SBS, MBES, AGDS Direct sampling (core)	The extent to which these different methods are used by Member States depends on existing knowledge of potential locations of the habitat, as well as the depth and remoteness of the features to be studied.
Gas emissions/methane seepage	**-Gas plumes/methane concentration**	gas flux (l/min), methane flux (m^3/yr)	Essential	Gas chromatography SSS, SBS, MBES, AGDS	
2. Abiotic characteristics					
2.1 Compositional state characteristics					
Invertebrates – Epifaunal & Infaunal assemblages	**-Abundance of characteristic species from standardised lists. -Diversity of characteristic species from standardised lists.**	Biomass (dry weight/unit area), number of species/ unit area. Number of biocenosis/taxa, presence & abundance of species (SACFO scale), diversity index, (Shannon-Wiener diversity index, AMBI index) biomass	Essential	Seabed imagery, video transects, visual census (ROV, DDV) Direct sampling (grab, core, dredge, suction)	Allows quantitative data on macro and meiofauna and identification of mega epibenthos. Presence of chemoautotrophic bacteria may be detected from imagery as well as grab samples. Non-destructive methods are likely to be favoured and the methodology will depend on the species as well as factors such as the extent and location.

Characteristics	Variables	Metrics	Application	Standardised measurement procedures	Considerations relating to methodologies
2.2 Structural state characteristics					
Characteristic species	**-Type** **-Extent**	Percentage cover, biomass, density. Synthetic indicators (M-AMBI, BENTIX etc)	Essential	Birds, marine mammals, fish -Visual census, aerial and boat-based surveys Epifaunal and infaunal assemblages - Photographic quadrats, video transects, visual census (ROV, DDV) Direct sampling (grab, core)	
2.3 Functional state characteristics					
Presence and abundance of chemosynthetic communities	**-Diversity** **-Abundance**	Percentage cover, biomass, density.	Specific	Direct sampling (grab, core) Seabed imagery, video transects, visual census (ROV, DDV)	
3. Landscape/Seascape characteristics					
Connectivity/ Fragmentation	**-Presence of anthropogenic structures** **-% cover**	Area (ha/km^2), % area directly affected by human activity	Recommended	SSS, SBS, MBES, AGDS	The extent to which these different methods are used by Member States depends on existing knowledge of potential locations of the habitat, as well as the depth and remoteness of the features to be studied. Comparisons of imagery data over time can show fragmentation/connectivity.
4. Other					
Disturbance	**-Footprint of activity** **-Number and intensity of negative pressures**	Presence/ absence, % area directly affected/ unaffected by human activity (e.g. by demersal fisheries or sand extraction)	Essential	Visual survey Mapping Aerial/satellite imagery (remote sensing) For physical disturbance on sublittoral areas from activities such as trawling and dredging (SSS and MBES)	Many different "types" of disturbance may be reported, and they can be categorised in a variety of ways e.g. physical/chemical/biological; presence/absence. The significance of any disturbance on the structure and function of the habitat may be related to aspects such as frequency, permanence, level and type of impact.

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

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

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

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

Establishing reference values and thresholds is therefore essential to determine whether habitats are in good 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 their 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) 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 in 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) (summarized in Table 10) was that whilst using pristine or minimally impacted conditions was the best single method, others were also adequate when combined with expert judgement.

Table 10. Evaluation of target and reference condition setting methods, regarding different issued

	Reference conditions			Best professional judgement	Targets		
	Pristine areas	**Historical data**	**Modelling**		**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	Moderated (2)	High (1)	High (1)	Low (3)	Moderate (2)	Moderate (2)	Moderate (2)
Scientific robustness	High (3)	Moderate (2)	Moderate/high (2.5)	High (3)	High (3)	High (3)	High (3)
Confidence of the method	High (3)	Moderate (2)	Moderate/high (2.5)	High (3)	Moderate (2)	High (3)	Moderate (2)
Applicability	High (3)	Low (1)	High (3)	High (3)	Moderate (2)	Moderate (2)	Moderate (2)
Practicality of the method within available time scales	High (3)	Moderate (2)	High (3)	High (3)	Moderate (2)	Moderate (2)	Moderate (2)
Transparency and comprehensibility	High (3)	High (3)	Low (1)	Low (1)	High (3)	High (3)	High (3)
Total scores	**17**	**11**	**13**	**16**	**14**	**15**	**14**

Note that scores are high: 3, moderate: 2, and low: 1, except in the case of data needs, which are opposite (the lowest data need the highest score). WFD: Water Framework Directive; HD: Habitats Directive; CWA: Clean Water Act; OSPAR: Oslo-Paris Convention. From Borja et al., (2012)

General guidance on setting environmental thresholds is included in the Marine Strategy Framework Directive (MSFD) which requires that Good Environmental Status (GES) should be achieved in EU marine waters as described by eleven environmental Descriptors. At the core of the GES assessment lies the need for threshold values which enable a quantitative assessment of environmental status for the indicators and elements used for each GES Criterion. Principles and guidelines on how these thresholds should be set are specified in Article 4(1) of Commission Decision (EU) 2017/848 (European Union, 2017[11]) (Box 2).

Box 2. Article 4 of Commission Decision (EU) 2017/848 (EU, 2017)

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

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

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

[11] 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) Art 13.

(b) be consistent with Union legislation;

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

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

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

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

(g) make use of best available science;

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

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

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

A review of the state of play with thresholds for MSFD criteria used by Member States, published in 2022, shows the progress but it also indicates there is still some way to go before this is achieved for all eleven descriptors (Vasilakopoulos et al., 2022). No thresholds or methods for assessing thresholds have been agreed as yet for D6C3 for example ("*Spatial extent of each habitat type which is adversely affected, through change in its biotic and abiotic structure and its functions, e.g., through changes in species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species*"), which is particularly relevant to assessing the condition of habitat 1180.

The Water Framework Directive (WFD) requires Member States to protect and where necessary restore water bodies in order to reach good status (chemical and ecological) and to prevent deterioration. Standards for priority substances and certain other pollutants are set out in the Environmental Quality Standards Directive (2008/105/EC)[12].

Apart from geology and gas emissions, all of the variables identified for assessing the structure and function of habitat 1180, are covered in some way by the MSFD GES descriptors. Some WFD Environmental Quality Standards are also directly applicable. A consistent approach, cross-referencing agreed thresholds for MSFD descriptors and WFD thresholds, with those that are also relevant to assessing the condition of the structure and function of marine and coastal habitats covered by the Habitats Directive is clearly desirable.

Table 11 makes some initial recommendations for setting reference/threshold values for the proposed variables for assessing and monitoring the condition of habitat 1180 (submarine structures made by leaking gases).

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

Table 11. Considerations for setting reference/threshold values for habitat 1180 (submarine structures made by leaking gases)

WFD Quality Elements: QE1 – Biological Quality Elements, QE1-2-4 – Phytobenthos, QE1-3 - Benthic invertebrates, QE2 – Hydromorphological quality elements, QE2-1 – Hydrological or Tidal regime – QE2-3 – Morphological conditions, QE3 - Chemical and physico-chemical quality elements, QE 3-1-3 – Oxygenation conditions

MSFD Descriptors: D1 – Marine biodiversity, D4 – Food webs, D5 – Human-induced eutrophication, D6 – Seabed integrity, D7 – Hydrographical conditions, D8 – Contaminants, D10 – Marine litter

Description	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 & form of MDAC	**-High and low relief forms (Essential)**	Qualitative, Trend, Expert judgement	Lack of baseline data and limited understanding of natural variation in this habitat type make it difficult to set quantitative reference values. Under such circumstances, trends, expert judgement and a qualitative approach are therefore more likely to be appropriate.		D6
Erosion / sedimentation around MDAC	**-Presence/extent of surficial sediment (Recommended)**	Qualitative, Trend, Expert judgement	Lack of baseline data and limited understanding of natural variation in this habitat type make it difficult to set quantitative reference values. Under such circumstances, trends, expert judgement and a qualitative approach are therefore more likely to be appropriate.		D7
Topography / Physical characteristics, depth	**-Physical dimensions -Extent -Longitude and latitudinal gradients -Elevation and form -Depth (Essential)**	Quantitative, Qualitative, expert judgement	Lack of baseline data and limited understanding of natural variation in this habitat type make it difficult to set quantitative reference values. Under such circumstances, trends, expert judgement and a qualitative approach are therefore more likely to be appropriate.	QE2 (QE2-1, QE2-3)	D7
Hydrodynamics - Exposure to current, wave action, scour & surge	**-Current speed -Wave height -Direction & frequency (Recommended)**	Quantitative, Trend		QE2 (QE2-1)	D7

Description	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values / Thresholds	Relevant MSFD Descriptors
1.2 Chemical state characteristics					
Water quality / sediment quality	**-Oxygen concentration -Redox potential (Specific)**	Quantitative, Trend		QE3 (QE3-1-3)	D5
Geological, mineralogical and petrographical characteristics	**-Magnesium calcite concentration -Aragonite concentration (Essential)**	Quantitative, Trend	This variable will be descriptive with no changes foreseen in the underlying geology, therefore no proposals for reference values are recommended		
Gas emissions / methane seepage	**-Gas plumes/methane concentration (Essential)**	Quantitative, Trend	Lack of baseline data and limited understanding of natural variation in this habitat type make it difficult to set quantitative reference values. Under such circumstances, trends, expert judgement and a qualitative approach are therefore more likely to be appropriate.		
2. Biotic characteristics					
2.1 Compositional state characteristics					
Invertebrates – Epifaunal & infaunal assemblages	**-Abundance of characteristic species from standardised lists -Diversity of characteristic species from standardised lists (Essential)**	Quantitative, indices, Trend, expert judgement		QE1 (QE1-2-4, QE1-3)	D1, D4, D6
2.2 Structural state characteristics					
Characteristic species	**-Type -Extent (Essential)**	Quantitative, indices, Trend, expert judgement	Lack of baseline data and limited understanding of natural variation in this habitat type make it difficult to set quantitative reference values. Under such circumstances, trends, expert judgement and a qualitative approach are therefore more likely to be appropriate.	QE1 (QE1-2-4, QE1-3)	D1, D4, D6

Description	Variables (application)	Reference/ Threshold type	Considerations relating to Reference Values	Relevant WFD EQS for Reference Values / Thresholds	Relevant MSFD Descriptors
2.3 Functional state characteristics					
Presence and abundance of chemosynthetic communities	**-Diversity -Abundance (Specific)**	Quantitative, Trend	Lack of baseline data and limited understanding of natural variation in this habitat type make it difficult to set quantitative reference values. Under such circumstances, trends, expert judgement and a qualitative approach are therefore more likely to be appropriate.	QE1	D1
3. Landscape/seascape characteristics					
Connectivity / Fragmentation	**-Presence of anthropogenic structures -% cover (Recommended)**	Quantitative, qualitative, expert judgement	Lack of baseline data and limited understanding of natural variation in this habitat type make it difficult to set quantitative reference values. Under such circumstances, trends, expert judgement and a qualitative approach are therefore more likely to be appropriate. Where seabed imagery is available, and the full extent of the habitat is known, quantitative reference values may be possible. For example, under the MSFD 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).		D6
4. Other					
Disturbance	**-Footprint of activity -Number and intensity of negative pressures (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. Where seabed imagery is available, and the full extent of the habitat is known, quantitative reference values may be possible. For example, under the MSFD 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).		D6, D8, D10

Table 12 illustrates approaches for establishing thresholds and reference values applicable to the proposed variables for the purpose of harmonisation, based on the procedures followed by MSs and the existing literature. In fact, a combination of approaches is recommended 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. Nevertheless, it is common practice to define more than two categories in the assessment of each variable, e.g. good, medium, bad, as observed in the analysis of methodologies used by the MSs. 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 to linear or non-linear relationships with the condition (Jakobsson et al., 2020). This assimilation of the values (quantitative or categorical) of the variables to the condition categories (i.e., good and not good, or good, medium and bad) would correspond to the scaling necessary to later evaluate them jointly, through aggregation procedures, as described in the following section. So, these condition variable categories can be translated to values, such as good=2, medium=1, bad=0. Alternatively, when quantitative values for the variables are available, they can be directly standardized to apply aggregation procedures.

Owing to the different metrics 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.

In the assessment of habitat condition, each characteristic and associated variable is likely to involve use of different measurement units. These are normalised using reference levels and reference conditions and hence can be compared with each other. The values obtained from the measurement for the variables are scaled according to their reference levels, thus normalised to a common scale and direction of change, and can then combined to form a composite index or to obtain an overall result of the assessment using appropriate aggregation approaches (see further details in Section 3.3. on Aggregation).

Table 12. Some initial recommendations for setting thresholds for the proposed variables

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 & form of MDAC	Essential						MSFD
Erosion / sedimentation around MDAC	Recommended						MSFD
Topography / physical characteristics, depth	Essential						MSFD, WFD
Hydrodynamics - Exposure to current, wave action, scour & surge	Recommended						MSFD, WFD
1.2 Chemical state characteristics							
Water quality / sediment quality	Specific						MSFD, WFD
Geological, mineralogical and petrographical characteristics	Essential						
Gas emissions /methane seepage	Essential						
2. Biotic characteristics							
2.1 Compositional state characteristics							
Invertebrates - Epifaunal & infaunal assemblages	Essential						MSFD, WFD
2.2 Structural state characteristics							
Characteristic species	Essential						MSFD, WFD
2.3 Functional state characteristics							
Presence and abundance of chemosynthetic communities	Specific						MSFD, WFD
3. Landscape/Seascape characteristics							
Connectivity / Fragmentation	Recommended						MSFD
4. Other							
Disturbance	Essential						MSFD

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 6).

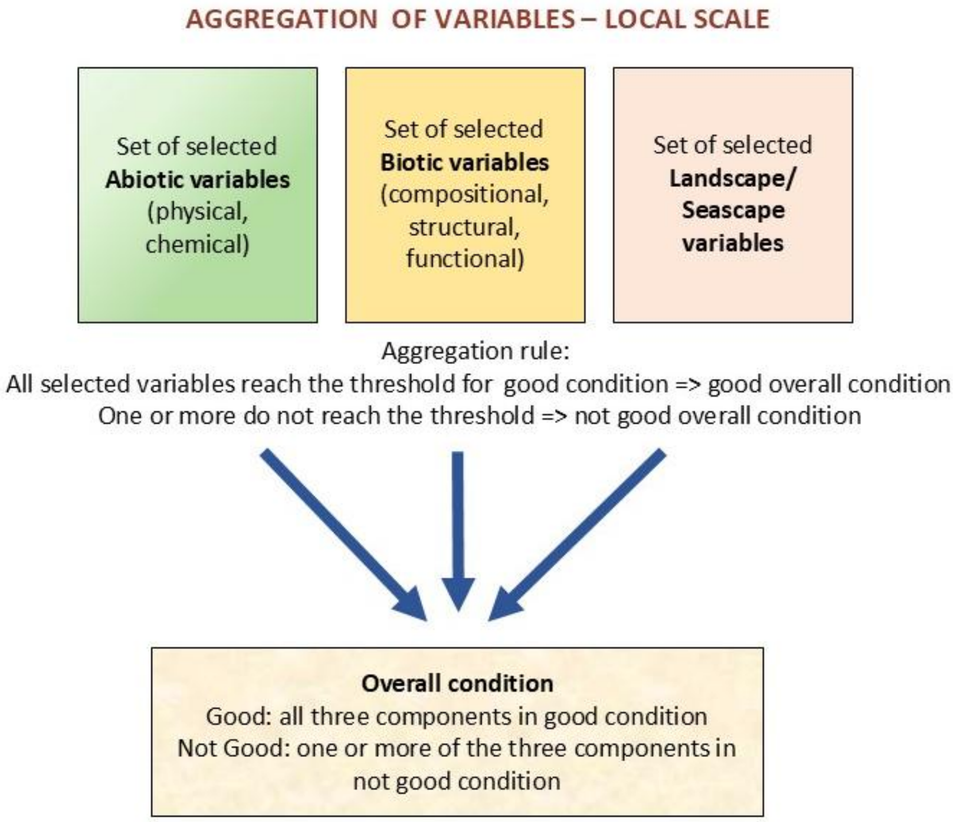
Step 1 – Aggregation of the variables measured in each group of characteristics

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 6. 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

Recent technological advancements have significantly enhanced our ability to research and monitor structures associated with habitat 1180. Dubois et al. (2015) have leveraged improvements in acoustic technologies, particularly side-scan sonars and multibeam echosounders, to enhance the mapping of benthic habitats. These advanced acoustic techniques have led to improved detection and characterization of seabed features, including pockmark fields, which are often associated with habitat 1180. Building on this progress, Baltzer et al. (2014; 2017) have employed sonar and seismic profiling techniques to investigate the presence of extensive pockmark fields in the Bay of Concarneau, Southern Brittany. Their research has focused on water depths ranging from 20 to 40 meters, demonstrating the effectiveness of these technologies in relatively shallow coastal environments.

The Spanish Institute of Oceanography has been conducting in-depth studies of the SCI Volcanes de fango del Golfo de Cádiz over the past decades. They combine classic methodologies (such as benthic dredges) and new technologies to analyse, among other things, the identification of habitat 1180 within the SCI, and the spatial distribution of geomorphological and sedimentary characteristics of the area. Among these technologies, the use of multibeam sonar stands out for obtaining bathymetry and reflectivity data, as well as the TOPAS parametric sounder, which provides data for identifying structures related to habitat 1180 and its internal structure (Fernández-Salas et al., 2021, Rueda et al., 2022).

In addition to acoustic and seismic technologies, other cutting-edge tools are now available for studying habitat 1180 and associated structures. Autonomous Underwater Vehicles (AUVs) equipped with high-resolution cameras and sensors can conduct detailed surveys of large areas with minimal human intervention. Hyperspectral imaging systems mounted on underwater platforms can detect subtle changes in seafloor composition and identify areas of gas seepage. Advanced ROVs with manipulator arms and sampling capabilities allow for precise collection of biological and geological samples from these unique habitats. Furthermore, environmental DNA (eDNA) analysis techniques are emerging as powerful tools for assessing biodiversity in marine environments without the need for direct observation or capture of organisms.

4 Guidelines to assess fragmentation at appropriate scales

Due to the complexity of habitat 1180 and the diversity of structures that may be present, the analysis of fragmentation and connectivity has not been extensively developed to date. Only a few studies have focused on this aspect, and some reflect the importance of developing this line of investigation.

In Spain, specifically in the SCI Volcanes de fango del Golfo de Cádiz, Díaz del Río et al. (2014) have highlighted the need for further investigation of the species associated with mud volcanoes and other structures included within 1180, in order to understand their connectivity and dependence, explore their conservation status, and publicise the importance of their protection.

Also, in the Gulf of Cadiz, Cunha et al. (2013) have carried out detailed studies of macrofaunal assemblages across spatial scales. The multivariate analyses revealed significant differences between mud volcanoes from a shallow area (<700 m) and a deeper one (>1.300m). Environmental conditions of the shallower mud volcanoes make them highly permeable to colonisation by background fauna leading to high diversity of the assemblages that are present.

Pachiadaki & Kormas (2013) have analysed the prokaryotic biological components connecting geographically isolated mud volcano systems, including the Hakon Mosby (Barents Sea), Gulf of Cadiz, and eastern Mediterranean mud volcanoes/pockmarks (Anaximander area and Nile Fan). The research provides valuable insights into prokaryotic community distribution and connectivity in deep-sea mud volcano environments.

5 Next steps to address future needs

This document provided an analysis of the methodologies used for monitoring submarine structures made by leaking gases in the EU member states, comparing them with the main ecological characteristics of habitat 1180, and proposed a methodology 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 needs to be 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. 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 habitat 1180. 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 the habitat given that they may be made up of a mosaic of marine communities rather than being uniform.

A summary of the **ecological characteristics and main variables** used to measure the habitat condition of habitat 1180 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. 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 habitat 1180 are variously; very specific, based on trends, use indices, rely on expert judgement or any combination of these. Given the variability of habitat across its range, even within a single biogeographical marine region, it is unlikely that the same ranges and thresholds can be applied in all circumstances. The scope to have a common or favoured approach to setting reference values and thresholds for particular variables could usefully be investigated. Equally important is to make sure that there is consistency with ranges and thresholds being used for reporting of MSFD descriptors and the Nature Restoration Law.

Finally, although there are **methods for monitoring and sampling** habitat 1180, 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. In the future, connectivity studies are another aspect to consider as this are poorly studied if at all, at present.

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