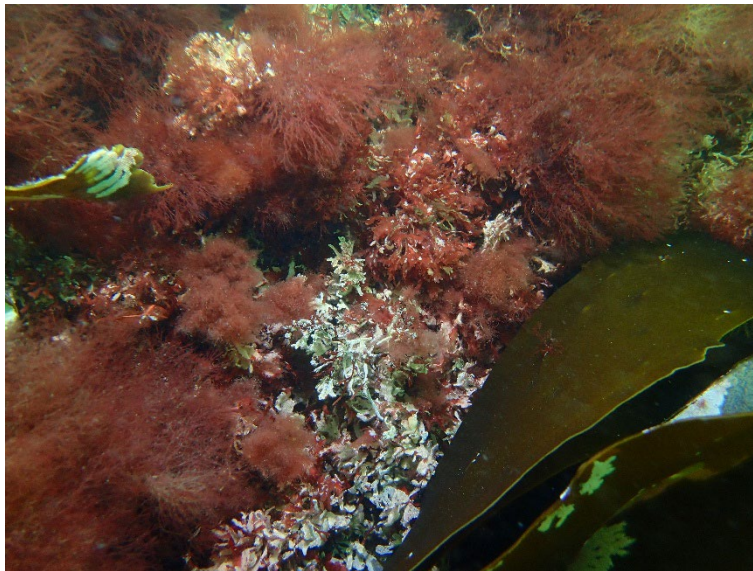


Assessment of proposed indicators on hard and mixed substrate habitats

An evaluation of the applicability of indicators on hard and mixed substrate habitats and the potential consequences of adopting the proposed methods

Scientific note from DCE – Danish Centre for Environment and Energy

Date: 28 Sept. 2026 | **53**



AARHUS
UNIVERSITY

DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

Scientific note from DCE – Danish Centre for Environment and Energy

Category: Scientific briefing

Title: Assessment of proposed indicators on hard and mixed substrate habitats
Subtitle: An evaluation of the applicability of indicators on hard and mixed substate habitats and the potential consequences of adopting the proposed methods

Authors: Ben Jamie Owen Robinson, Cordula Göke and Lasse Tor Nielsen
Institution: Aarhus University, Department of Ecoscience

Referee: Peter Anton Upadhyay Stæhr
Quality assurance, DCE: Camilla Uldal
Linguistic QA: Peter Anton Upadhyay Stæhr

Claimant: Miljøstyrelsen – The Danish Environmental Protection Agency

External comment: No comments

Please cite as: Robinson, B.J.O., Göke, C. and Nielsen, L.T. 2026. Assessment of proposed indicators on hard and mixed substrate habitats. An evaluation on the applicability of indicators on hard and mixed substate habitats and the potential consequences of adopting the proposed methods. Aarhus University, DCE - Danish Centre for Environment and Energy, 19 s. – [Scientific note no. 2026|53](#)

Reproduction permitted provided the source is explicitly acknowledged

Front page photo: Peter Anton Upadhyay Stæhr – boulder reef

Number of pages: 19

Contents

1	Introduction	4
1.	National mapping of hard and mixed bottom and known pressures	5
1.1	Quantification of Hard and Mixed Seabed Extent in Danish MSFD Regions	5
1.2	Additional data and alternative mapping	6
1.3	Confidence in Existing Mapping and Identification of Significant Data Gaps	8
1.4	Existing pressure factor maps	8
2	Assessment of ICES' proposed D6C5 indicators on hard and mixed substate BBHTs	12
2.1	ICES' proposed D6C5 indicators	12
2.2	Biomass/abundance measurements	12
2.3	Hard and mixed BBHTs heterogeneity	13
2.4	Trait information	14
2.5	Reference conditions and pressure	14
3	Conclusions and potential solutions	15
4	References	16
5	Appendix	19

1 Introduction

The technical group Seabed (TG Seabed) under EU's Marine Strategic Framework Directive (MSFD) is undertaking efforts to set quantitative indicators for the environmental state of the seafloor. To achieve this, the group has requested scientific advice from the International Council for the Exploration of the Sea (ICES). In response, ICES has proposed 5 indicators and corresponding methods for threshold setting for the seafloor integrity (MSFD Descriptor 6, Criteria 5 (D6C5)) in EU marine waters (ICES 2026a). These proposed indicators aim to support a more uniform assessment across all 22 benthic 'broad habitat types' (BBHT) of Good Environmental Status (GES) in all EU's sea basins and member states. The Commission Decision (EU) 2017/848 ('GES Decision') has set out the standards for determining Good Environmental Status (GES) and assessments on a more general level, and the new proposed methods from ICES constitutes a proposal for the more concrete operationalisation.

Along with the proposed indicators, ICES has provided a technical toolbox including code, guidance and instructions for the implementation of indicators and setting of D6C5 threshold values, with an exclusive focus on soft sediment fauna and pressure from fishing with bottom contacting gear. Hard substrates are not included in ICES' work, despite the fact they constitute 7 out of 22 of BBHTs, of which 6 are present within Danish waters. This potential scientific- and management gap is the focus of this scientific briefing, and the Danish Environmental Protection Agency has asked Aarhus University to evaluate whether the indicators proposed by ICES can be used on Danish hard- and mixed substrate habitats.

Hard substrate environments are key habitats for biodiversity, ecosystem functioning and commercial species (Lundsteen et al., 2008). Although relative rare in Danish waters (13.2 %), these habitats act as shelter, spawning areas and nursery grounds and are essential for many sessile species that are the foundation for entire trophic networks (Mikkelsen et al., 2013; Schwartzbach et al., 2020; Støttrup et al., 2017). Due to their importance, many types of hard and mixed substrate BBHTs, such as boulder reefs and biogenic mussel reefs, are protected under Natura 2000 (Naturstyrelsen, 2000). Ensuring GES of these hard and mixed substrate BBHTs is ecologically significant also because their ecological benefits spillover to adjacent waters, however further work is needed to define its importance (Van Hoey et al., 2024).

The purpose of this scientific brief is to assess the suitability of ICES' proposed indicators and threshold values on hard and mixed substrate BBHTs within Danish waters. To achieve this, we will:

1. Map the known extent of hard and mixed substrate BBHTs within Danish waters including confidence levels and pressure factors
2. Examine the extent to which ICES' proposed D6C5 indicators can be used on hard and mixed substrate BBHTs
3. If relevant, propose alternative pre-existing indicators and assessment methods that are suitable to hard and mixed substrate BBHTs

1. National mapping of hard and mixed bottom and known pressures

1.1 Quantification of Hard and Mixed Seabed Extent in Danish MSFD Regions

To quantify the extent of Hard and Mixed Seabed in Danish MSFD Regions, we used the EUSeaMap 2025 Broad-Scale Predictive Habitat Map for Europe (EUSeaMap, 2025) in combination with the MSFD regional delineations defined in Miljøministeriet (2019). Hard and mixed substrate habitats are defined as mixed sediment, rock, and biogenic reefs within MSFD BBHT. In the analysis, the Kattegat region was evaluated separately from the remaining North-East Atlantic region to better reflect its distinct environmental characteristics (Göke et al. 2025). The spatial delineations and resulting distributions of hard- and mixed substrates are shown in Fig. 1.1, while the areas (km²) are presented in Table 1.1.

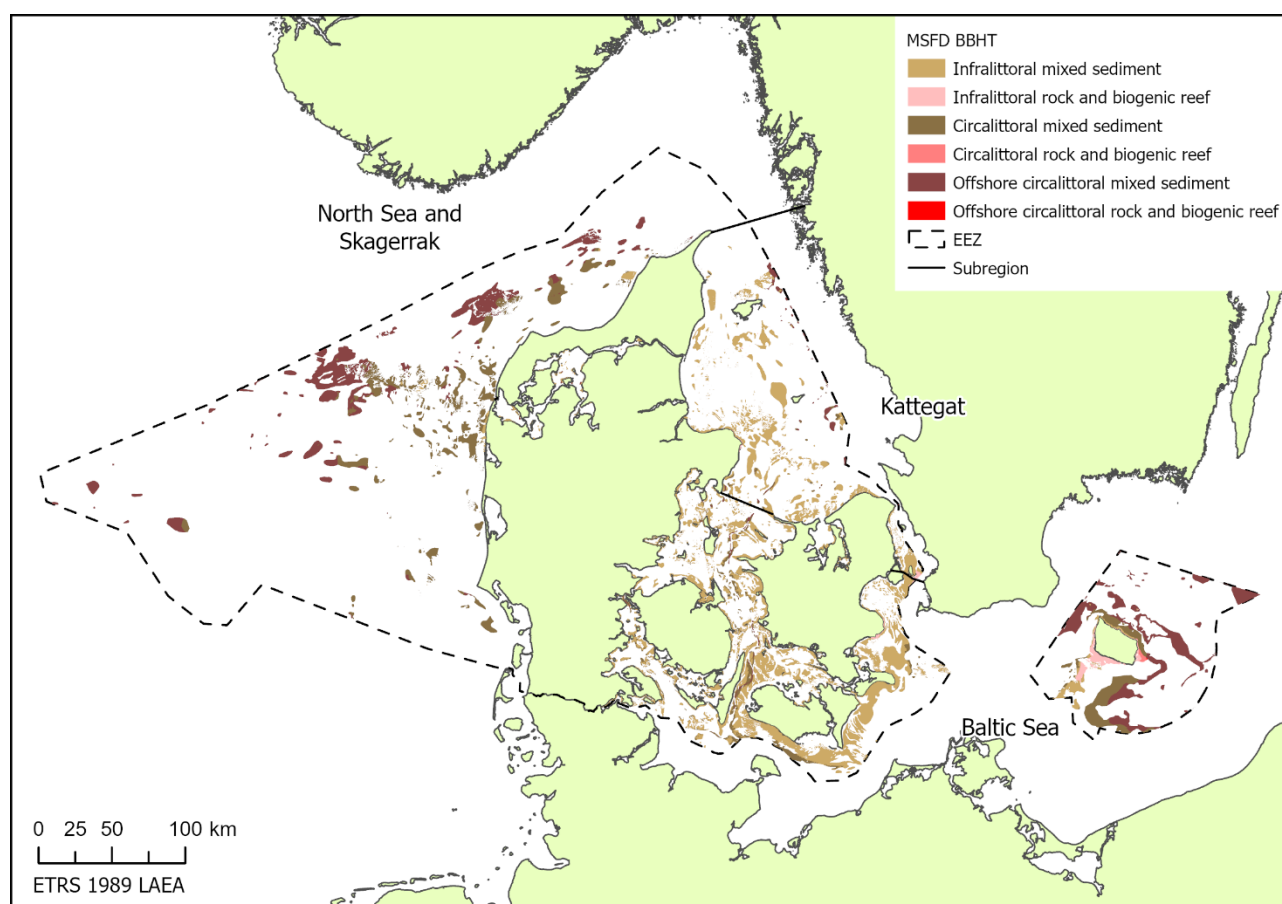


Figure 1.1. Extent of the mapped MSFD BBHTs *Mixed sediment, rock, and biogenic reef* in Danish MSFD Regions (EU-SeaMap, 2025 and Miljøministeriet, 2019).

Table 1.1. Extent of the mapped MSFD BBHTs *Mixed sediment, rock and biogenic reef* in Danish MSFD Regions (EUSeaMap, 2025 and Miljøministeriet, 2019). Values shown as 0 indicate a non-zero value smaller than the reported precision. Values in km².

MSFD BBHT	Atlantic			Danish Waters total
	Baltic Sea	Kattegat	North Sea and Skagerrak	
Circalittoral mixed sediment	1217	73	1990	3280
Circalittoral rock and biogenic reef	23	0	absent	23
Infralittoral mixed sediment	4515	2034	104	6653
Infralittoral rock and biogenic reef	226	25	absent	251
Offshore circalittoral mixed sediment	1370	148	2120	3638
Offshore circalittoral rock and biogenic reef	1	0	absent	1
Sum per region	7352	2280	4214	13847

1.2 Additional data and alternative mapping

The data in EUSeamap 2025 is based on sediment data acquired by Geological Survey of Denmark and Greenland (GEUS) through multiple public, private, and EU-funded initiatives. As no systematic seabed mapping program exists for Danish waters, data coverage and confidence levels vary spatially and the sediment information in EUSeamap 2025 do not include survey efforts later than approximately 2019 (Fig. 1.2).

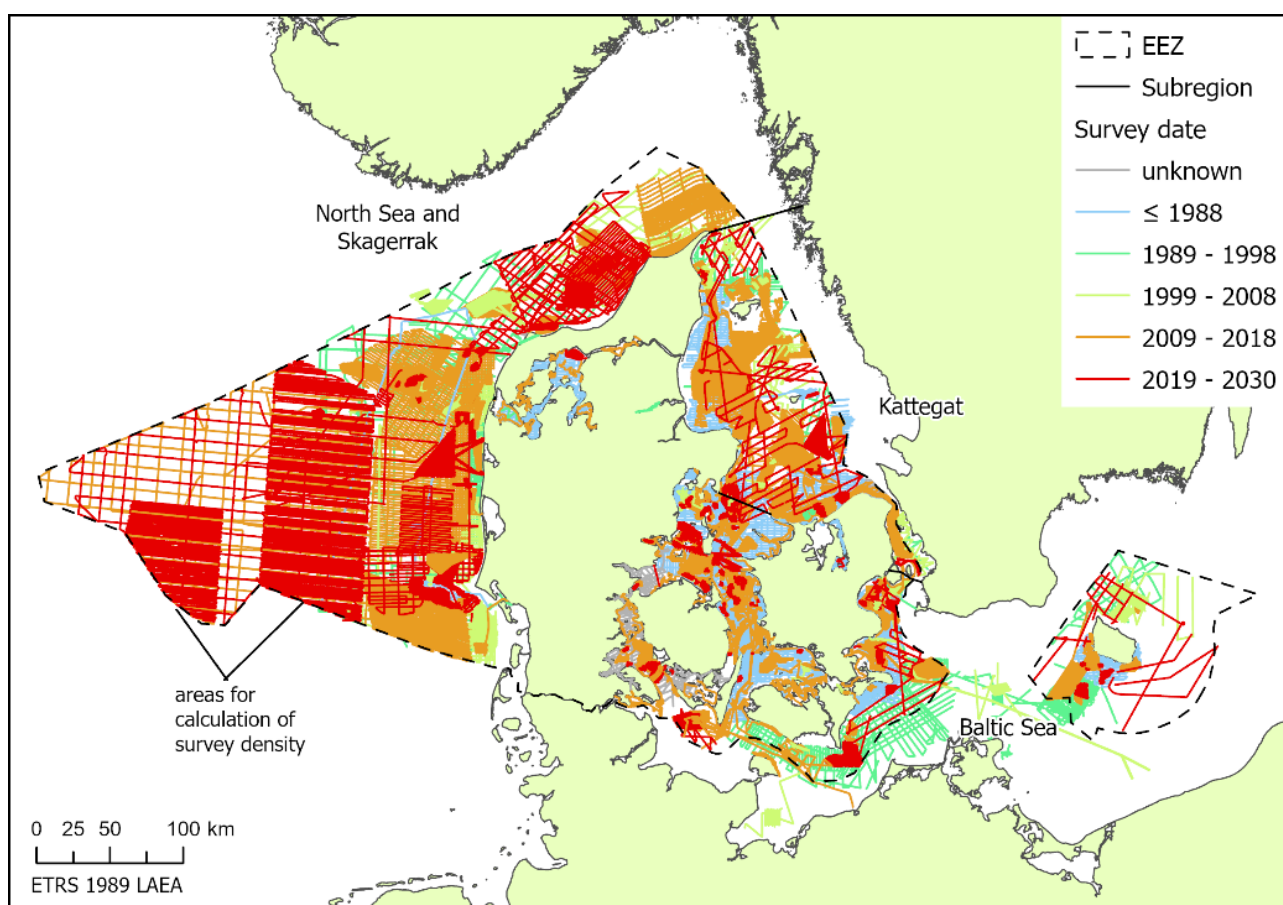


Figure 1.2. Seabed survey lines with data provided by GEUS

A central inventory of available sediment maps does not exist. Sediment mapping is available, for example for areas with planned offshore wind farm developments and other projects (see appendix 1 with the data collected by Göke et al., 2025). Additionally, GEUS is currently mapping the coastal zone using green LiDAR (maximum water depth depends on water clarity).

In Danish terminology, “sediment” describes deeper layers (approximately 50 cm), whereas “substrate” refers to the uppermost seabed layer (approximately top 10 cm), and the two are classified using different purposes and systems (Table 1.2).

The sediment information is used for the MSFD BBHT, except for the information of biogenic reefs, which stems from the substrate and habitat type mapping. Substrate and habitat type mapping does not provide full coverage of Danish waters. Substrate data is available for several EU habitat areas which are a subset of the Natura 2000 network, offshore wind survey sites, and the two areas in the North Sea which were mapped in 2019/20 (marked as number 9 in appendix figure 0.1). Habitat types are available in the EU habitat areas.

Within Danish substrate mapping, mixed sediments are covered by types 1c, 3 and 4 (Table 1.2). A common hard substrate habitat in Denmark is boulder reefs, which are defined by at least 25% larger stones (type 4) and can include areas of type 3. Consequently, despite their ecological function, a substantial proportion of Denmark's hard substrate is classified as BBHT Mixed sediment, because the stone density of the boulder reefs is too low for these habitats to be included within the BBHT Rock and biogenic reef. In areas of only sediment mapping, we lack a distinction between boulder reefs, biogenic reefs and other mixed sediments.

For most of the areas, where the substrate has been mapped, the raw data is reinterpreted to update the sediment map, but there are some exceptions. The sediment information, and therefore BBHT, in for example the habitat areas “Kims Top”, “Den Kinesiske Mur”, and “Lillebælt” are not consistent with the habitat types found in Miljøstyrelsen (2023).

Table 1.2. Comparison of sediment and substrate classes in the Danish waters to classes used in MSFD BBHT (shown only for the relevant classes). The sediment data is used as basis for the MSFD BBHT.

MSFD BBHT	Sediment	Substrate
Mixed Sediment	Quaternary clay and silt	1c: Patterned sandy bottom/solid clay with sand
	Till/diamicton	3: Gravel, sand and large stones 10- 25%
Rock and biogenic reef	Sedimentary rock	4: Gravel, sand and large stones > 25%

The results presented (in Fig. 1.1) reflect the current state of the data included in EUSeaMap 2025. However, ongoing mapping initiatives and the incorporation of already available seabed data will improve habitat delineations and are expected to result in updated estimates of habitat extent in future assessments. This will not address the fact that, under the Danish approach, boulder reef habitats are mostly classified within the BBHT Mixed sediment.

1.3 Confidence in Existing Mapping and Identification of Significant Data Gaps

A pragmatic approach to evaluate the uncertainty and coverage can be done by looking at the survey line density, while time and method of the survey and the density of ground truthing sampling points are also relevant.

The EUSeaMap 2025 dataset includes confidence information classified into three categories (appendix figure 0.2). Areas of high confidence are generally associated with dense survey lines before 2019 (fig. 1.2), although not all closely spaced surveys are reflected in the high-confidence class.

An improvement in mapping quality can likely be obtained, if more recent (after 2019) data by GEUS, other project data (as eg. shown in appendix figure 0.1), and data from the current coastal mapping with LiDAR are included into the sediment map.

In the area marked in figure 1.2 for a density analysis, the survey lines from 2019-2020 have approximately 1.8 km distance and a 200 m survey width, which means that only 14 % of the area gets surveyed. While the newer surveys reduce the distance between the survey lines in many areas, there are still areas with low coverage density and old data.

Most of the time, a conservative approach of mapping reefs and mussel beds is used, i.e. not extrapolating those types extending out of the surveyed area. As a result reefs and biogenic reefs are currently underestimated and absent from mapping. The unmapped reefs are likely found in areas extrapolated as sediment class Till/diamicton (or the BBHT mixed sediment), since these were formed in the last Weischel glacial and subsequent erosional processes (Mortensen et al., 2016) and thus are most likely to contain exposed stones with a large enough size to classify as reefs.

1.4 Existing pressure factor maps

Within this report, three pressure factors were considered: (1) Fishing with bottom-contacting gear, as this is the chief example and focus of the proposed indicators, however its relevance as a pressure varies greatly across mixed and hard substrate. (2) Oxygen depletion, a critical pressure factor within Danish waters across MSFD BBHTs, and (3) Stone fishing, a unique and historical pressure on boulder reef habitats. Additional anthropogenic pressures, e.g. extraction of raw materials, might also have been of relevance when assessing the environmental status of BBHTs in Danish waters. However, due to the limited scope of this evaluation, it was not possible to include any additional pressures.

Fishing with bottom contacting gear

The pressure from fishing with bottom contacting gear was characterized using swept area ratio (SAR) data, which were provided for the period 2021–2024 by Olsen & Egekvist, 2025. Fisheries employing bottom-contacting gears predominantly operate on soft-bottom habitats. However, some spatial overlap with the MSFD BBHTs *Mixed sediment* and *Rock and biogenic reefs* occurs in all subregions of the Danish waters (fig. 1.3). Hence, fisheries with bottom-contacting gear, can be expected to influence the fauna and flora on mixed and hard sediments in Danish water to some degree.

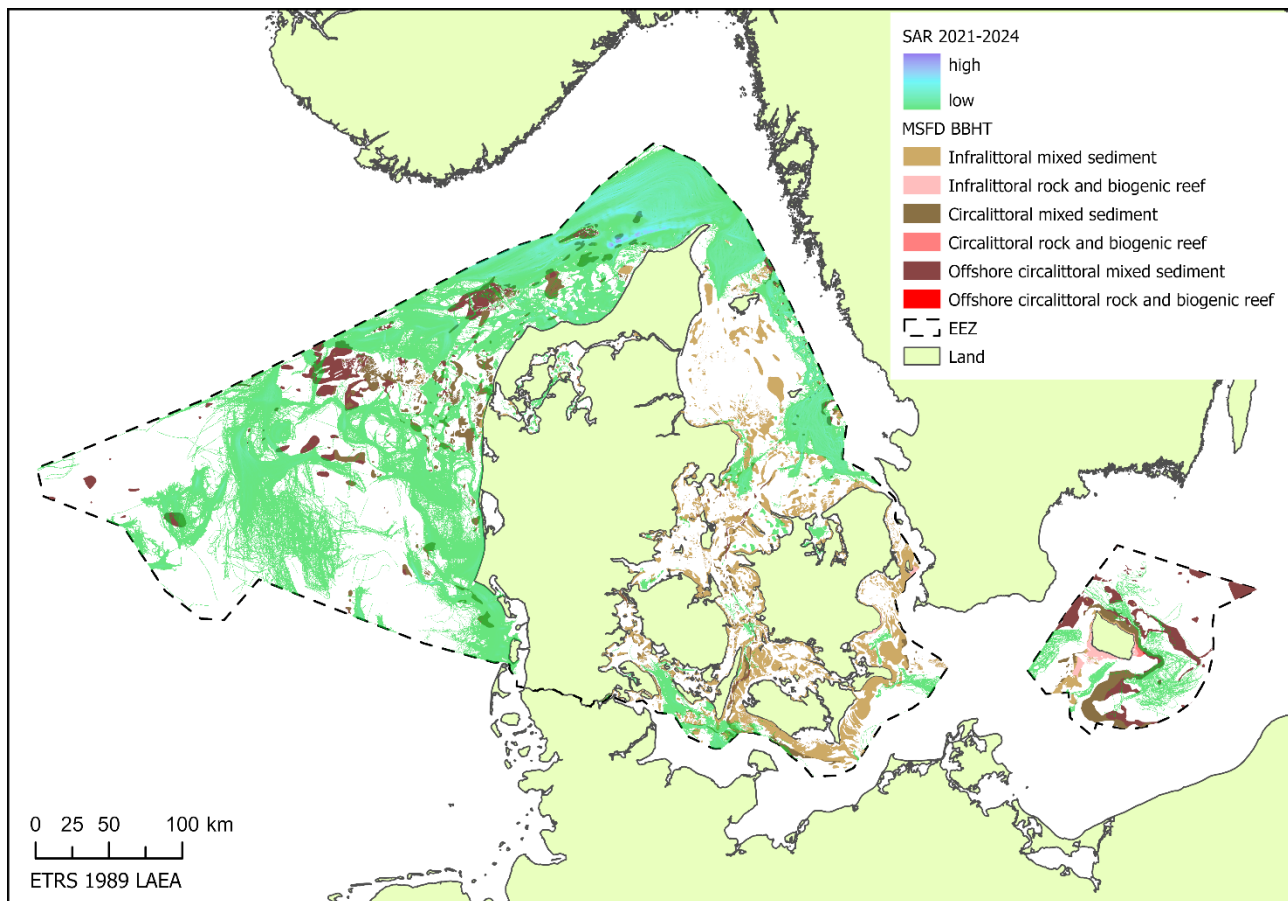


Figure 1.3. Danish bottom fishing activity (swept area ratios 2021-2024) aggregated from Olsen & Egekvist (2025).

Oxygen depletion

Oxygen depletion, the ultimate result of nutrient enrichment, has been one of the major threats to marine ecosystem health for more than 30 years (Ryther & Dunstan 1971). Nutrient enrichment will initially increase species diversity and biomass, followed by a shift in community towards suspension and detritus feeders. At progressively high enrichment, species diversity and biomass is expected to decrease and opportunistic species to be favoured, until oxygen depletion eventually leads to mass mortality and further species reduction (Ærteberg et al., 2003). These pressure responses present a particular challenge for the potential indicators as neither structure, biomass or diversity change in a uniform manner in response to the pressure.

It was not possible to develop a spatial multiannual metric of oxygen deficiency within the limited scope of this scientific briefing, with which to compare the spatial extent of the various mixed and hard substrates. Instead, we compare with the modelled extents of low oxygen concentrations in August 2025, one of the several reports published on this every autumn (fig. 1.4). From this comparison, it can be seen, that many areas with mixed sediments in the inner Danish waters are exposed to oxygen concentrations $<6\text{mg O}_2\text{ l}^{-1}$. Some areas with mixed sediment is also exposed to even lower oxygen concentrations (<4 or $<2\text{ mg O}_2\text{ l}^{-1}$). The model domain covers only the inner Danish waters, and not all of the Danish EEZ around Bornholm in the Baltic Sea. Although the extent of low oxygen concentrations may thus range beyond the model domain, areas in the North Sea are typically not influenced by detrimentally low oxygen concentrations.

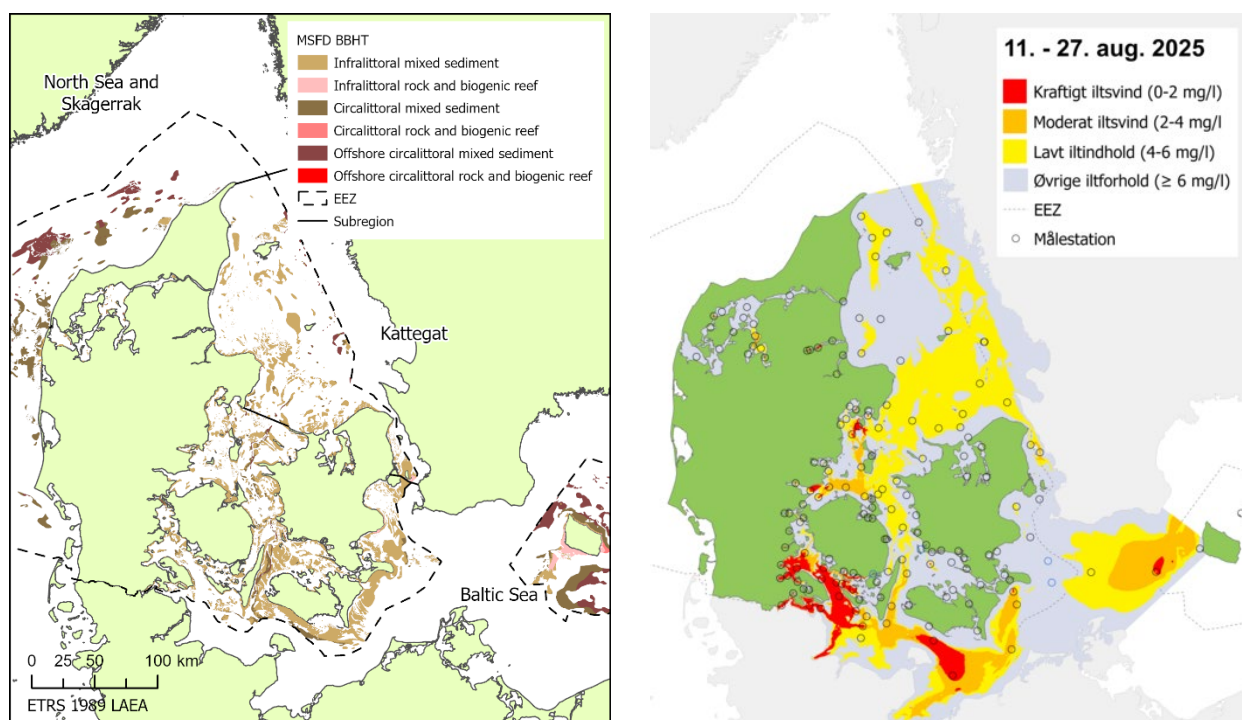


Figure 1.4. Left: distribution of mixed and hard BBHT, right: Oxygen depletion in the period 11 – 27 August 2025, Source: <https://dce.au.dk/aktuelt/nyheder/nyhed/artikel/tidligt-og-kraftigt-iltsvind-1>

Stone fishing

Although stone extraction is no longer an ongoing pressure, historical stone extraction (stone fishery) is particularly relevant to the MSFD BBHTs *Mixed sediment* and *Rock and biogenic reefs*, having removed substantial quantities of hard substrate from shallow reef areas (approximately <10 m depth).

Stone fishing was unregulated until 1972, after which regulatory measures were introduced. While a complete legal ban on stone extraction did not come fully into force until 2009, commercial extraction activities had effectively ceased by 1999 (Petersen et al., 2024).

Information on the spatial extent and intensity of stone fishery is limited. Available data sources include designated extraction areas, reported locations of extraction activities, and information compiled through interviews (Petersen et al., 2024, Figure 1.5). Additional information from logbooks is available, but time consuming to extract and does often not contain a precise position for the extraction.

Since the stone extraction dates back more than a century, a major uncertainty in assessing the historical impact of stone extraction is the lack of baseline information on reef extent and sediment composition prior to exploitation. Consequently, it is unknown whether former stone reefs are represented in contemporary sediment as *Mixed sediment* and *Rock and biogenic reefs*. In general, it is well documented however, that vast quantities of large stones and boulders have been removed from the seafloor many places in the inner Danish waters, constituting a potential issue when evaluating the current condition of the seafloor ecosystems.

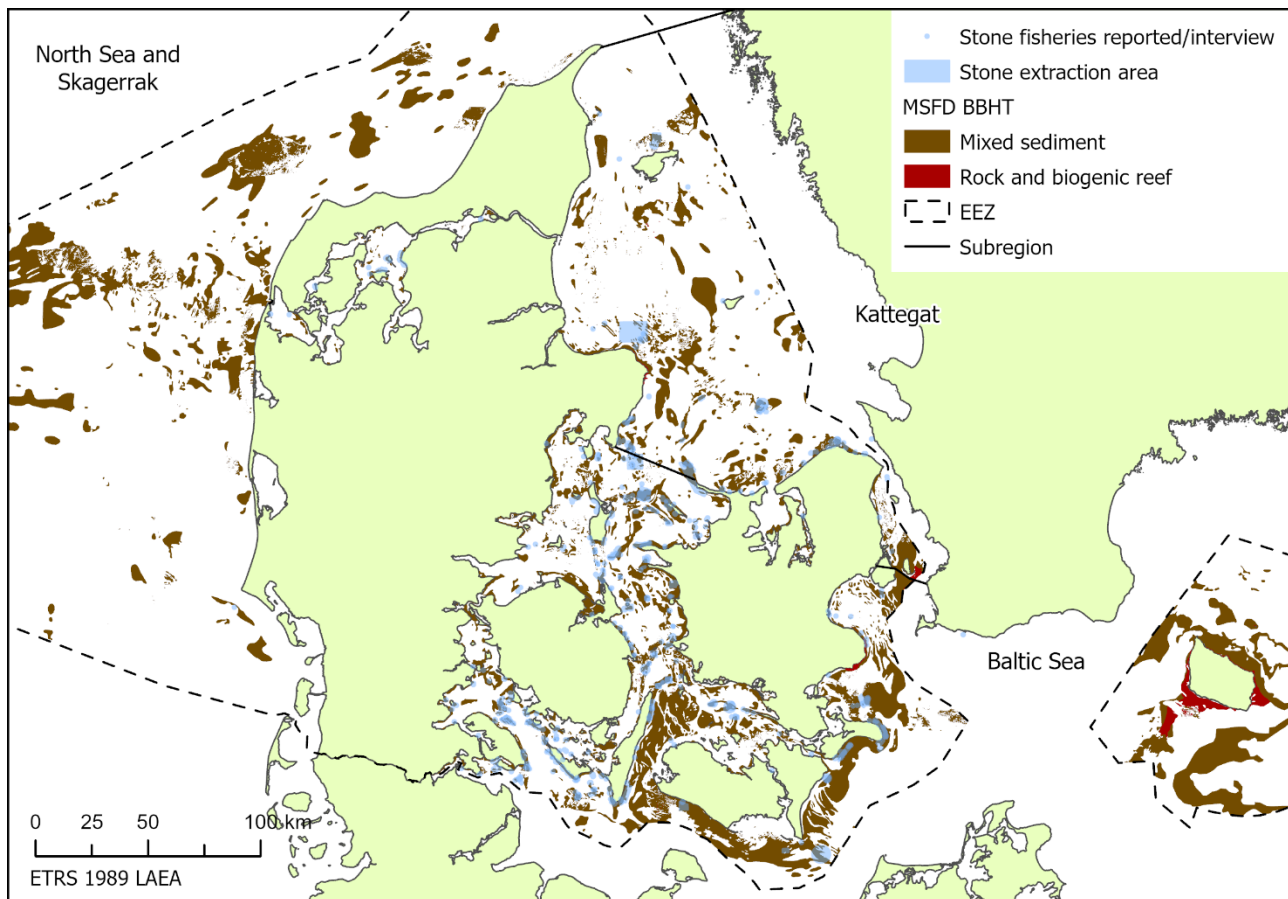


Figure 1.5. Known locations of stone fisheries (Petersen et al., 2024) on top of the selected BBHTs aggregated to “Mixed sediment” and “Rock and biogenic reef”.

Conclusion on pressures

Hard and mixed substrate habitats throughout Danish waters are exposed to multiple concurrent pressures. Bottom-contacting fishing gears operate at all depths with biggest impact on circalittoral and offshore circalittoral zones including mixed and hard substrates. Oxygen depletion affects mixed sediment areas in inner Danish waters, while historical boulder extraction predominantly reduced infralittoral mixed and hard substrates. Hence, mixed and hard BBHTs in Danish waters have been, and continue to be, under significant disturbance from various sources of anthropogenic pressures.

2 Assessment of ICES' proposed D6C5 indicators on hard and mixed substate BBHTs

2.1 ICES' proposed D6C5 indicators

ICES's proposed D6C5 indicators are organised into 3 categories: Traits, Diversity and Biomass (Table 2.1). To account for the limitations of each indicator, the advice from ICES is to include at least one indicator from each category, to assess seafloor integrity and evaluate GES. The requirement to implement multiple indicators would make it difficult, or even impossible, to assess hard and mixed substrate BBHTs if some of the proposed indicators are incompatible with the existing data for these BBHTs. In the following we discuss several considerations relating to the potential adoption of the proposed indicators for the assessment of hard and mixed BBHTs in Danish waters. The considerations are of a general nature, and are not specific to Danish waters or data, and hence we expect them to be relevant for many other EU countries as well.

Table 1.1. The five indicators of benthic habitat condition proposed by ICES.

Category	Purpose	Indicator	Summary Description
Traits	Structure and sensitivity	Sentinels of the Seabed (SoS)	Index of community composition based on the abundance or biomass of a subset of typically, or frequently encountered sensitive species in a sampled assemblage
		Long-lived fraction of biomass (Lf)	The biomass fraction of long-lived species in a sampled assemblage (corresponds with RBSsens)
Diversity	Structure	Relative Margalef diversity index	Species richness index compensating for numbers of individuals in the sampled assemblage and re-scaled relative to reference conditions
Biomass	Structure and function	Total biomass	Total biomass of fauna in the sampled assemblage (corresponds with RBStot)
		Total numeric abundance	Total numbers of individuals in the sampled assemblage

2.2 Biomass/abundance measurements

A critical concern with hard and mixed substrate habitats is that sampling and monitoring is traditionally completed with percentage cover using imagery or direct SCUBA observations. This contrasts with soft sediment BBHT investigations, that typically deploy cores, grabs and trawls and provide abundance and biomass measurements. The Danish monitoring program has quantified macroalgae and fauna on hard substrate environments annually with percentage cover for the last 30 years. Soft sediment methods are not compatible with hard and mixed BBHTs, since the few samples that could potentially be recovered would be from patches of soft sediment within the larger habitat, ignoring the biology on the gravel, cobbles and boulders. Mixed sediment BBHTs fall into this category with some soft sediment method samples being able to be recovered, however these samples are not representative of the whole habitat. As recovering soft sediment samples within hard and mixed substrate BBHTs, excludes the significant proportion of biomass and species diversity are found on the hard substrate and within the interstitial spaces between boulders.

On a single occasion, the WKBENTH4 report (ICES 2026b), as part of this scientific briefing, mentions the use of percentage cover (%) data: “also % cover may potentially be used”, however, there is currently no guidance in the technical toolbox or code scripts to allow percentage cover to be implemented as a metric. The lack of guidance presents unresolved methodological issues with using percentage cover, including how to interpret image-based and/or direct survey-based metrics, and how to resolve different growth forms. Many important species such as bryozoans (e.g. *Electra pilosa*) sponges (e.g. *Halicondra panacea*) and macroalgae (*Delesseria sanguinea*) violate many assumptions behind abundance/biomass-based indicators. Of particular concern are species that are colonial, encrusting, borrowing and/or canopy forming species that are common on hard substrate habitats. These can be incompatible with the concept of “individuals”, do not correlate with biomass and may respond differently to pressures.

Ultimately the concern with the lack of biomass/abundance measurements within all hard and mixed bottom habitats prevents the implementation of all five proposed indicators in their current state.

2.3 Hard and mixed BBHTs heterogeneity

Another potential issue is that hard and mixed substrate BBHTs contain a multitude of distinct habitats which poses a challenge for all the proposed indicators, and particularly indicators that rely on trait-based analysis such as SoS and Lf (table 2.1). These habitats are often complex and are affected by many environmental and abiotic factors that are not directly categorised in the MSFD BBHTs and therefore lead to very heterogeneous habitats being grouped together. For example, infralittoral rock and biogenic reefs BBHTs which encompasses in Danish waters shallow, shallow boulder reefs, chalk bedrock and Mussel (*Mytilus edulis*) beds, would likely have very few species in common, have no similar community structure and have drastically different biomass. This would mean any potential indicators and thresholds would grant or remove GES based entirely on the habitat rather than any information on ecological health.

The heterogeneity of hard and mixed BBHTs can also be broken down to the further with changes in light availability, exposure, hydrodynamics, depth, nutrient status, sedimentation, grazing pressure, reef structure and biogeographic location. All these factors prevent the proposed indicators and thresholds from working on these broad ecological groupings. Many of these diverse communities such as horse mussel reefs, bubbling reefs, kelp forests and red macroalgae (rhodophytes) reefs are already protected, and therefore GES is a clear priority.

A solution presented in the ICES advice is the inclusion of ‘other habitat types (OHT)’: where the EU Member States can add OHTs to their assessment. This solution would likely require adoption of EUNIS Level 5/6 biotopes (Davies et al., 2004) across all hard and mixed sediment BBHTs. This is consistent with the logic of EUNIS where levels 5-6 describe the biological coherent communities. However, the requirements for greater habitat resolution are detailed mapping of hard and mixed BBHTs, larger reference databases and unique thresholds for most EUNIS Level 5/6 habitats. This would need very substantial work before it could be implemented.

2.4 Trait information

Indicators that rely on trait information such as SoS and Lf (for full details see Serrano et al., 2022 and Bolam et al., 2014 respectively) rely on life history traits which are poorly described within most reef organisms. Species such as sponges, anemones, bryozoans and macroalgae often have no to little information on longevity, growth rates or their vulnerability to various pressures. Hence, it would most likely prove very difficult to select relevant key species with certain traits – or trait combinations – based on the currently available knowledge.

2.5 Reference conditions and pressure

Within Danish waters, the extent of the impact of historical stone fishing, particularly in the shallows, is unknown. Therefore, identifying good reference reefs with which to compare potentially impacted sites presents a unique challenge. A challenge that would be further compounded by the adoption of EUNIS level 5/6 across hard and mixed substrate BBHTs, as each biotope would require its own reference site(s), pressure assessments and threshold values.

The focus on impacts of fishing with bottom contacting gear within the ICES work is understandable, as the majority of data and tools are focused on this pressure. However, fishing with bottom contacting gear is often avoided or is banned from areas of (un)known hard substrate making many of the underlying assumptions, of the effects of pressure on indicators not applicable. Total biomass/abundance may work well in soft sediment environments where trawling is the main controlling pressure. However, its equivalent percentage cover (%) is not necessarily a good indicator of pressure, even ignoring all the complexities introduced by myriad growth forms. Hard and mixed BBHTs in poor environmental conditions may have 100% percentage cover of opportunistic algae (for example *Ulva*, *Enteromorpha* or *Ectocarpus*), which can be disastrous for biogenic reefs, smothering mussel beds (Clemente & Thomsen 2023). Comparably, chalk bedrock reefs, or perennial macroalgae reefs, may have little to no cover due to natural erosion or the season, respectively.

Our scientific assessment of the potential use of each of the five indicators proposed by ICES on hard and mixed BBHTs in Danish waters is summarized in table 2.2.

Table 2.2 Indicators proposed by ICES and a summary of our scientific evaluation of each of them.

Indicator	Summary
Sentinels of the Seabed (SOS)	Could be well suited due to many conspicuous taxa in the various heterogenous habitats. However, requires greater habitat resolution, taxa trait information and percentage cover guidance and code modification within the indicators' documentation.
Long-lived fraction of biomass (Lf)	Missing critical taxa trait information and percentage cover guidance and code modification within the indicator's documentation.
Relative Margalef diversity index	Incompatible with % cover, as it requires absolute abundance.
Total biomass	Incompatible with % cover, as not equivalent to total biomass. Furthermore % cover does not respond uniformly to pressure factors.
Total numeric abundance	Incompatible with % cover, as it requires absolute abundance. Furthermore % cover does not respond uniformly to pressure factors.

3 Conclusions and potential solutions

The indicators proposed by ICES do not conform with the available data from hard and mixed BBHTs. As a result, if the indicators were adopted as currently suggested, EU members states may need to alter their current methodology and approach to monitoring hard and mixed BBHTs. Changing methodology presents challenges in identifying and assessing reference states, particularly as it may be incompatible with historical records. This would need to be combined with detailed mapping of hard and mixed BBHTs, larger reference databases and unique thresholds for most EUNIS Level 5/6 habitats. Adapting code and guidelines to accept percentage cover (%) unfortunately does not address the underlying issue that abundance and biomass are not interchangeable with regards to pressure factor relationships. Furthermore, functional trait data for many hard and mixed BBHT species and their responses to pressure factors would need to be investigated, assessed and adopted.

Previous work has identified total cover and cumulative cover of erect macroalgae as reasonable indicators of ecological quality in open shallow water boulder reefs in Denmark (Dahl & Carstensen, 2008). This was further refined to include functional groups within the algae community, such as perennial species richness and relative cover of opportunistic algae (Carstensen et al., 2008, Carstensen et al., 2020). However, it is worth noting that these only address macroalgae dominated reefs, whereas circalittoral reefs, biogenic reefs and bubbling reefs would likely need their own new indicators, since these are dominated by epifauna.

The adoption of the indicators proposed by ICES, and currently under discussion in TG Seabed, in their current state would lead to several complications and concerns regarding hard and mixed substrate BBHTs. Hence, it is our scientific advice, not to use the proposed indicators to assess hard and mixed substrate BBHTs at this stage, as substantial modifications and rigorous testing and reference setting would be needed before they could be implemented. Even if solutions were presented to overcome the technical issues that prevents the indicators from being calculated for hard and mixed bottom substrate data, there is a very high likelihood, that the resulting GES assessments would be of little, or no, value. This would be due to the described issues with lacking trait information, relevant reference setting and relations to the various anthropogenic pressures.

4 References

Ærtebjerg, G., Andersen J. H., & Hansen, O. S. (2003). "Nutrients and eutrophication in Danish marine waters." A challenge for science and management. National Environmental Research Institute: 126.

Bolam, S.G., Coggan, R.C., Eggleton, J., Diesing, M. and Stephens, D. (2014). Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: a biological trait approach. *Journal of Sea Research*, 85, pp.162-177.

Carstensen J. (2020). Macroalgae indicators for assessing ecological status in Danish WFD water bodies. Aarhus University, DCE – Danish Centre for Environment and Energy, 74 pp. Technical Report No. 170.

Carstensen, J., Krause-Jensen, D., Dahl, K. & Henriksen, P. (2008). Macroalgae and phytoplankton as indicators of ecological status of Danish coastal waters. National Environmental Research Institute, University of Aarhus. 90 pp. - NERI Technical Report No. 683

Clemente, K. J. E., & Thomsen, M. S. (2023). High temperature frequently increases facilitation between aquatic foundation species: A global meta-analysis of interaction experiments between angiosperms, seaweeds and bivalves. *Journal of Ecology*, 111, 1340–1361. <https://doi.org/10.1111/1365-2745.14101>

Dahl, K. & Carstensen, J. 2008: Tools to assess conservation status on open water reefs in Nature-2000 areas. National Environmental Research Institute, University of Aarhus. 25 pp. – NERI Technical Report No. 663.

Davies, C. E., Moss, D. & Hill, M.O. (2004). EUNIS Habitat Classification Revised 2004. European Environment Agency / European Topic Centre on Nature Protection and Biodiversity.

EUSeaMap (2025). *EUSeaMap 2025 Broad-Scale Predictive Habitat Map for Europe – Metadata*. ICES. Available at: <https://gis.ices.dk/geonet-work/srv/eng/catalog.search#/metadata/cec07b5e-3a9c-4492-b115-126a17c08697> (accessed 15 July 2026).

Göke, C., Robinson, B. J. O., & Dahl, K. (2025). Environmental mapping and screening of the offshore wind potential in Denmark: Sensitivity mapping: Benthic habitats and associated biological communities. Aarhus University, DCE - Danish Centre for Environment and Energy. Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi Vol. 2025 No. 642 https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Videnskabelige_rapporter_600-699/SR642.pdf

ICES (2026a). EU request to advise on seafloor integrity thresholds (MSFD D6C5): operational methods and application to the Nature Restoration Regulation. ICES Advice: Special Requests. Report. <https://doi.org/10.17895/ices.advice.32244633.v1>

ICES (2026b). Workshop to evaluate options for setting seafloor quality thresholds (WKBENTH4). ICES Scientific Reports. Report.
<https://doi.org/10.17895/ices.pub.31898953.v1>

Lundsteen, S., Dahl, K., & Tendal, O. S. (2008). Biodiversity on boulder reefs in central Kattegat.

Mikkelsen, L., Mouritsen, K. N., Dahl, K., Teilmann, J., & Tougaard, J. (2013). Re-established stony reef attracts harbour porpoises *Phocoena phocoena*. Marine Ecology Progress Series 481, 239-248

Miljøministeriet (2019) Danmarks Havstrategi II Første del God miljøtilstand Basisanalyse Miljø-mål. Udgiver: Miljøministeriet, April 2019. ISBN: 978-87-93593-73-2, https://mim.dk/media/p4negqko/hsii_foerste_del_-_endelig_udgave.pdf

Miljøstyrelsen (2023). NP3_2022 Marine naturtyper (2004-2018). Geodata-info.dk metadata record. Published 14 February 2023. Available at: <https://geodata-info.dk/srv/dan/catalog.search#/metadata/2b155452-9f74-43c1-b803-7ccae24f7d31>

Naturstyrelsen (2000) Danske naturtyper i det europæiske NATURA 2000 netværk. Miljø-og Energiministeriet, Skov-og Naturstyrelsen

Olsen, Jeppe and Egekvist, Josefine (2025). Danish bottom fishing activity (swept area ratios 2021-2024). Technical University of Denmark. Dataset. <https://doi.org/10.11583/DTU.29242337>

Petersen, J. K., Helmig, S. A., Geitner, K. J., & Rosenskjold, H. (2024). *Foreløbige optegnelser over lokaliteter for stenfiskeri i indre danske farvande*. Center for Marin Naturgenopretning. <https://orbit.dtu.dk/en/publications/foreloebige-optegnelser-over-lokaliteter-for-stenfiskeri-i-indre-d/>

Ryther, J. H., & Dunstan, W.M. (1971). Nitrogen, phosphorus, and eutrophication in the coastal marine environment. – Science 171: 1008–1013.

Schwartzbach, A., Behrens, J. W. & Svendsen, J. C. (2020). Atlantic cod *Gadus morhua* save energy on stone reefs: implications for the attraction versus production debate in relation to reefs. Marine Ecology Progress Series 635, 81-87

Serrano, A., de la Torriente, A., Punzón, A., Blanco, M., Bellas, J., Durán-Muñoz, P., Murillo, F.J., Sacau, M., García-Alegre, A., Antolínez, A. and Elliott, S. (2022). Sentinels of Seabed (SoS) indicator: Assessing benthic habitats condition using typical and sensitive species. Ecological indicators, 140, p.108979.

Støttrup, J. G., Dahl, K., Nienmann, S., Stenberg, C., Reker, J., Stamphøj, E. M., Göke, C., & Svendsen J. C. (2017). Restoration of a boulder reef in temperate waters: Strategy, methodology and lessons learnt. Ecological Engineering 102, 468-482

Van Hoey, G., Feary, D.A., Brown, E.J., Buyse, J., Mangi, S.C., Vallina, T., van Kooten, T., Abreu, S., Aranda, M., Bergstrom, U., Castro, N., Kleiven, P.J.N., Mosnier, P., Peat, W., Rakowski, M., Robert, M., Stacy, R., Uriarte, A., Whitley,

C., Wakeford, R.C., Quirijns, F.J. 2024. Assessing spillover from marine protected areas to adjacent fisheries. Baltic and North Seas, Atlantic EU Western Waters and Outermost Regions (SPILLOVER). Final Report. Annex 6. Publication Office of the European Union, , doi: 10.2926/384994

5 Appendix

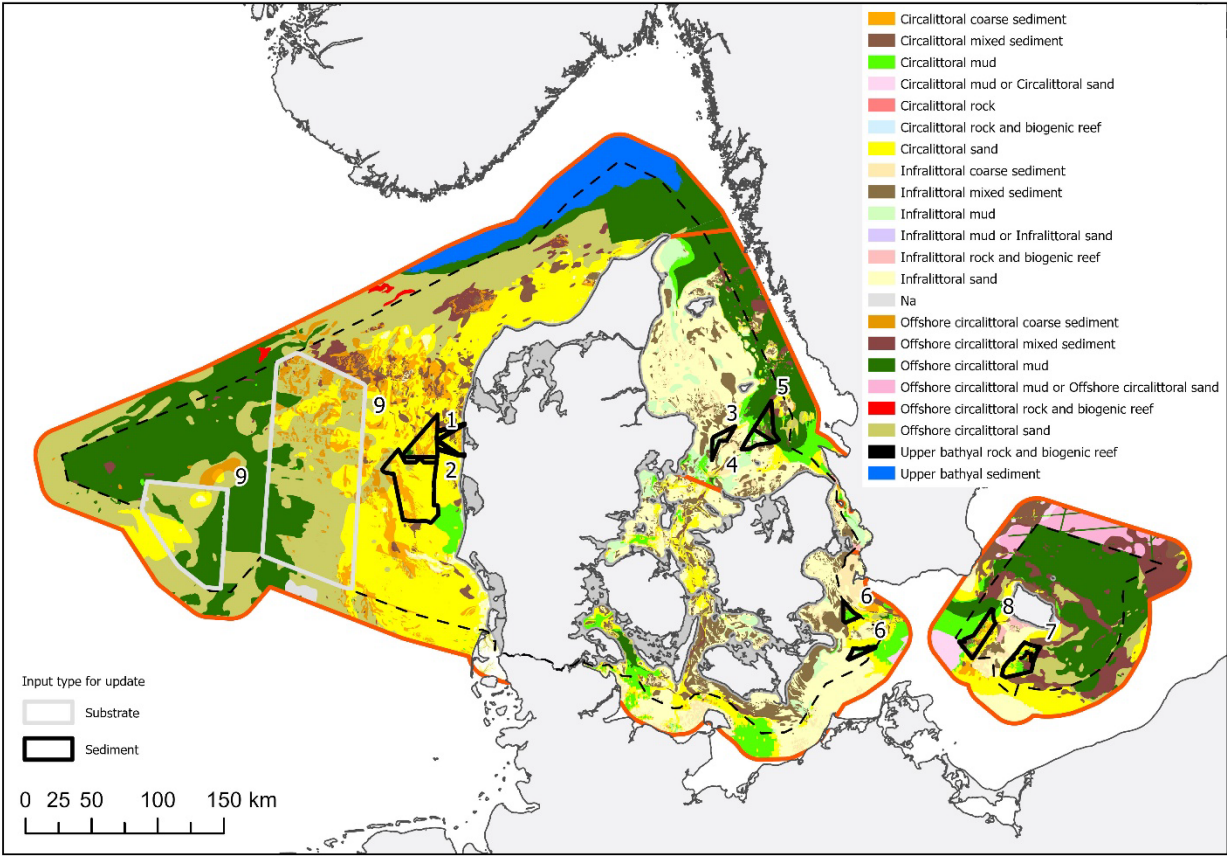


Figure 5.1 Broad habitat types and the nine areas where the sediment information was updated for the sensitivity mapping of benthic habitats and associated biological communities (Göke et al., 2025). The data is currently not included in EUSeaMap (2025).

Figure 5.2 EMODNET confidence. Source: EUSeaMap (2025)

