ICES Special Request Advice
EU ecoregions
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EU request to advise on a seafloor assessment process for physical loss (D6C1, D6C4) and physical disturbance (D6C2) on benthic habitats

Advice summary

ICES advises that the assessment of both physical loss and physical disturbance of the seafloor and its habitats is performed within a single assessment process, as presented in this advice. The assessment process expresses the spatial extent and distribution of these pressures, both separately and in combination, in MSFD marine waters per (sub)region and per MSFD broad habitat type. This processs also provides an overarching regional approach that allows the benchmarking of national assessments against a regional assessment, thereby providing further consistency. Operational data flows for the assessment process have been identified and a demonstration assessment is provided, which includes examples of pressure distribution maps and tables.

Request

This advice is in response to two requests from the European Commission (DG ENV); one on D6C1 physical loss pressure and D6C4 habitat loss, and the other on D6C2 physical disturbance pressure. ICES was requested to:

Advise on appropriate methods to assess the spatial extent and distribution of physical loss and physical disturbance pressures on the seabed (including intertidal areas) in MSFD marine waters.

Demonstrate the application of the advice by providing estimates of the spatial extent of physical loss and physical disturbance per subdivision and per MSFD broad habitat type (where possible), together with associated distribution maps.

Provide information on gaps in data for physical loss and physical disturbance activities/pressures and/or habitat types and recommend key methodological improvements which may be needed.

The advice presented relates to criteria D6C1 (physical loss pressure) and D6C4 (habitat loss), as well as D6C2 (physical disturbance pressure) as laid down in Commission Decision (EU) 2017/848 (EU, 2017) under Descriptor 6 (D6 seafloor integrity) of the Marine Strategy Framework Directive (EU, 2008) that sets out the requirement that "sea-floor integrity is at a level that ensures that the structure and functions of ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected."

Amalgamation of these two requests was done as the opportunity to develop a single operational assessment process was identified.

Elaboration on the advice

To assess physical loss (D6C1 and D6C4) and physical disturbance (D6C2) on the seafloor, ICES advises the use of a single assessment process (Figure 1). This assessment process expresses the spatial extent and distribution of these pressures, both separately and in combination, and can be applied in MSFD marine waters per subdivision and (where possible) per MSFD broad habitat type. The assessment process presented in this advice facilitates the development of an overarching regional framework that also allows for the benchmarking of national assessments against regional assessments, thereby providing further consistency.

The assessment process consists of three stages to assess the criteria D6C1, D6C2, and D6C4 and is designed to accommodate for the assessment of criterion D6C3, should future elaboration be requested.

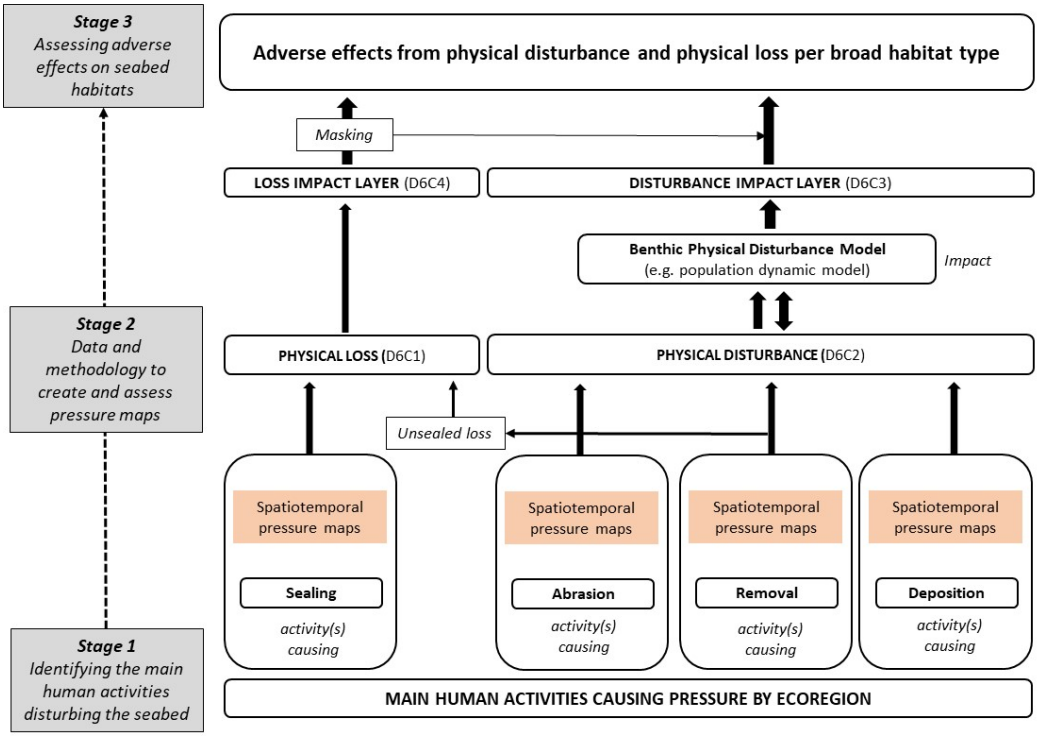

Figure 1 Seafloor assessment process.

Stage 1. Identifying the main human activities disturbing the seabed

To identify the main human activities that disturb the seabed, four pressure subtypes were identified as the pathways through which physical loss and physical disturbance operate. These physical pressure subtypes were identified by ICES as the only pathways from activities to physical loss or physical disturbance. ICES defines these four pressure subtypes as:

- **Abrasion**: the scraping of the substrate (e.g. by a trawl door or an anchor). Whilst abrasion could result in the mixing of sedimentary substrates, any sediment removal is considered a "Removal" pressure subtype. The abrasion pressure subtype can result in physical loss and/or physical disturbance.

- **Removal:** the net transference of substrate away from the seabed resulting from human activities (e.g. either directly by human activities or indirectly through the modification of hydrodynamics). This pressure subtype can result in physical loss and/or physical disturbance.

- **Deposition**: the movement of sediment and/or particulates to a new position on top of or in existing substrates (e.g. directly by human activities such as dredge disposal or indirectly through the modification of hydrodynamics). This pressure subtype can result in physical disturbance.

- **Sealing**: the capping of the original substrate with structures (e.g. metal pilings, concrete footings, or blankets) or substrates (e.g. rock or stone fills, dredge disposal) which in and of themselves change the physical habitat. This pressure subtype can result in physical loss.

For each pressure subtype, the main contributing human activities were identified based on the extent of their footprint and the severity of effects. In cases where activities had a small spatial extent, they were considered less important, unless they covered a large area of a specific (and certainly if sensitive) MSFD broad habitat type.

Table 1 Main human activities that affect the seabed through the four pressure subtypes (for further detail see Annex 1).

Pressure subtype	Main human activities
Abrasion	Fishing with mobile bottom-contacting gears.
Removal	Aggregate extraction (removal of sediment for use elsewhere) and dredging (removal of sediment to clear/maintain an area).
Deposition	Dredge disposal and fishing with mobile bottom-contacting gears.
Sealing	Placement of permanent structures during a variety of activities (e.g. oil and gas extraction, renewable energy, harbours and coastal defence, tourism/recreation, pipelines and cables, wrecks, artificial reefs).

Although the main activities that disturb the seabed through these pressure subtypes were found to be the same across regions, other activities and their pressure subtypes may be of concern to EU Member States. The assessment process allows for the incorporation of such locally important activities, providing these disturb the seabed through any of the four pressure subtypes.

Stage 2. Data and methodology to create and assess pressure maps

Assessing physical disturbance and physical loss consists of six generic steps: (1) identify the competent authorities who may hold or have access to suitable physical disturbance and physical loss data, (2) request spatial data and attribute information for each main human activity, (3) produce the combined footprint of physical disturbance and physical loss, (4) assess and document the level of confidence for each feature in the attribute table, (5) manage data according to the FAIR principles (see Annex 1 on data management), and (6) assess the spatial extent in terms of surface area (e.g. km²) and/or as a proportion (%) of the total surface of the assessed area or of habitat type. The assessment of physical loss also requires the incorporation of the historical loss of habitat.

ICES has identified existing data flows and locally held data sources that serve the assessment process. These are shown to be operational within demonstration products (see Annex 2). However, gaps remain in the data availability for certain regions and for certain activities, especially activities relating to deposition.

To define and quantify pressures in a way that allows their use in the assessment of adverse effects on seabed habitats, pressures need to be relatable to changes in biological processes, e.g. growth and mortality of populations of benthic invertebrates. Hence, intensity of physical disturbance should reflect mechanisms through which activities affect benthic ecosystems, and are quantified in ways relevant to the subsequent assessment of adverse effects (e.g. swept-area ratio vs. fishing hours, gravel extraction spatial extent vs. weight of extracted sediments). This consideration is not needed for physical loss because by definition physical loss leads to a complete loss or removal of the natural habitat.

Stage 3. Assessing adverse effects on seabed habitat

The physical loss map is appropriate for the assessment of contemporary total loss under D6C4 (extent of habitat loss). For criterion D6C3 (adverse effects of physical disturbance on habitats), the above provides the input to an assessment of the extent of adverse effects by physical disturbance onto the seabed. The latter assessment, however, is not part of the advice request and has not been elaborated further in this advice.

Definitions

ICES advises based on the following definitions of physical disturbance and physical loss:

Physical loss is defined as any human-induced permanent alteration of the physical habitat from which recovery is impossible without further human intervention. An alteration of the physical habitat refers to a change from one EUNIS level 2 habitat type to another EUNIS level 2 habitat type. Recovery indicates the re-establishment of the original natural EUNIS level 2 habitat by means of a human intervention. Two types of physical loss are identified:

- Sealed physical loss results from the placement of structures in the marine environment (e.g. wind turbines, port infrastructure) and from the introduction of substrates that seal off the seabed (e.g. dredge disposal).

- Unsealed physical loss results from changes in physical habitat, either from human activities or from the indirect effects of the placement of man-made structures (e.g. aggregate extraction or a structure causing changes in water flows, ultimately changing the EUNIS level 2 habitat type).

Physical disturbance is defined as a pressure that disturbs benthic biota but does not permanently change the habitat from one EUNIS level 2 habitat type to another EUNIS level 2 habitat type. With sufficient time, recovery can be expected without human intervention.

Physical disturbance to physical loss can be regarded as a continuum, where the intensity of a physical disturbance may lead, in time, to a permanent change from one EUNIS level 2 habitat type to another and hence physical loss.

Basis of the advice

Background

The assessment of both physical loss and physical disturbance on the seabed is performed within a single assessment process; this produces spatial extent and percentage estimates of loss (D6C1/C4) and physical disturbance (D6C2), both separately and in combination. Human activities affecting the seafloor are introduced into the process through four main pressure subtypes: abrasion, removal, deposition, and sealing. The main human activities, contributing most towards each pressure subtype, have been identified based upon technical work undertaken in developing this advice (ICES, 2018a, 2019b, 2019c). These activities are: abrasion caused by fishing with bottom-contacting gears (physical disturbance/loss), removal caused by aggregate extraction and dredging (physical disturbance/loss), deposition caused by dredge disposal and fishing with mobile bottom-contacting gears (physical disturbance/loss), and sealing caused by the placement of hard structures (physical loss) (see Table 1 and Annex 1).

The assessment process is designed so that it can be coupled with the benthic physical disturbance model (ICES, 2017, 2018b) to convert disturbance pressure subtypes from activity data into adverse effects (D6C3). At this stage of the assement process the aggregated loss layers are removed, i.e. “masking”. Within each relevant pressure subtype, cases where physical loss occurs, both unsealed and sealed are aggregated into a single loss layer.

ICES defines the activity, pressures, and impact/adverse effect as follows:

- **Activity**: basic human activities to satisfy the needs of societal drivers; e.g. aquaculture or tourism. One activity may cause many different pressures with different scales of impacts (as defined below).
- **Pressure**: is considered as the mechanism through which an activity has an actual or potential effect on any part of the ecosystem, e.g. for demersal trawling activity, one pressure would be abrasion of the seabed. It should be noted that one pressure may be caused by many different activities (e.g. abrasion from fishing, aggregate extraction, dredging) with different extents, frequencies, and impacts, and that one activity may be responsible for multiple pressures (e.g. other non-physical pressures by fishing such as spread of non-indigenous species, mortality/injury to wild species, and inputs of litter). Pressures can cause multiple and progressive biological (e.g. lethal and various sub-lethal changes through damage and stress) and physio-chemical state changes (e.g. sediment homogenization, changes in sediment topography, and compaction) at any level (e.g. communities and habitats).
- **Impact/adverse effect**: within the assessment process ICES defines impact as a possible adverse change, influencing or affecting an environmental component, caused by a pressure related to one or more anthropogenic activities.

<u>Assigning physical loss/disturbance to activities</u>

Human activities are introduced into the assessment process through four main pressure subtypes: abrasion, removal, deposition, and sealing. These physical pressure subtypes were identified by ICES as the only pathways from activities to physical loss or physical disturbance. They are easily communicated and understood. The main activities contributing to these four pressure subtypes were identified and ranked by ICES through expert opinion. For each pressure subtype, the main activities were identified and prioritized for each ecoregion based on the extent of their footprint and severity of effects (Annex 1, Tables A1.1–A1.5). The ranking approach used for each activity–pressure pathway considered the extent

of the footprint (e.g. from widespread to site-specific), its distribution within this footprint (e.g. the extent of an activity within an area of operation), and the severity of the effect (severe biomass depletion/impairments to minor biomass reduction/impairments). The activities contributing most to physical loss and physical disturbance are:

- Abrasion: Fishing with mobile bottom-contacting gears.
- Removal: Aggregate extraction (removal of sediment for use elsewhere) and dredging (removal of sediment to clear/maintain an area).
- Deposition: Dredge disposal and fishing with mobile bottom-contacting gears.
- Sealing: Placement of permanent structures during a variety of activities (e.g. oil and gas extraction, renewable energy, harbours and coastal defence, tourism/recreation, pipelines and cables, wrecks, artificial reefs).

Established data flows relevant to the pressure subtypes

To operationalize the assessment process a standardized procedure relating to the collection, collation and storage of data should be adopted (Figure 2). These should follow FAIR data principles ("Data management" section in Annex 1).

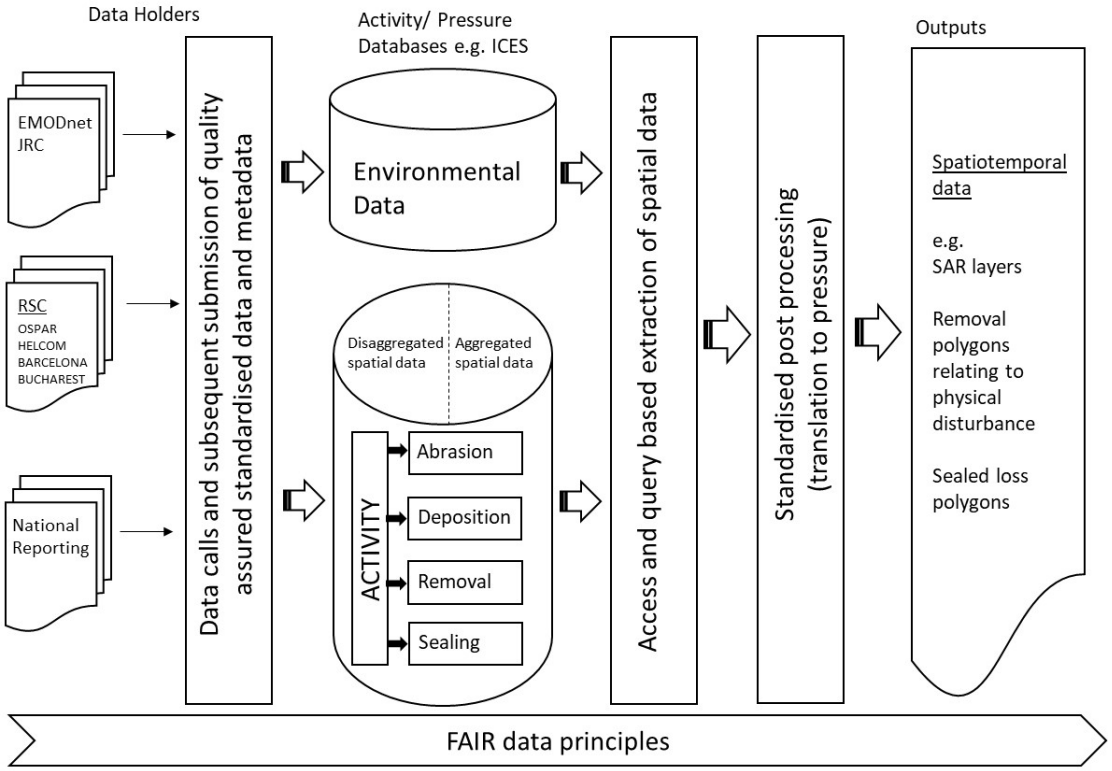

Figure 2 Conceptual diagram of data holders and the required data flows underpinning the assessment process. Data management practice follows FAIR principles outlined in the "data management" section of Annex 1.

Reporting at the level of MSFD broad habitat types

ICES advises that assessments of physical loss and physical disturbance, expressed as a spatial extent and a percentage of the total area of the assessed unit, can be reported for the (sub)region and at the level of MSFD broad habitat types. MSFD broad habitat types (Table 2 in Decision (EU) 2017/848; EU, 2017) are based on the EUNIS level 2 habitat types, but some EUNIS level 2 habitat types are merged into one MSFD broad habitat type. For reporting purposes, merging of EUNIS level 2 habitat types may be required; but their similarity in classification makes this possible.

ICES also notes that MSFD broad habitat maps are based on modelled data and may therefore be subject to change. The process outlined in the assessment process can accommodate such changes and, in addition, can provide hindcasts based on updated classification.

D6C1–D6C4 Physical loss

Defining physical loss under D6C1 and D6C4

Physical loss is defined as any human-induced permanent alteration of the physical habitat from which recovery is impossible without further human intervention. Within this definition, ICES advises that an alteration of the physical habitat refers to a change from one EUNIS level 2 habitat type to another EUNIS level 2 habitat type (Evans *et al.*, 2016) as this is consistent with MSFD assessment requirements. Alternative classifications could, however, be accommodated within the assessment process laid out in this advice.

The use of EUNIS level 2 habitat type classification relates to the Commission Decision (EU) 2017/848 (EU, 2017) which notes that physical loss may also arise from permanent changes in seabed morphology. As this can be open to interpretation relating to scale, ICES has constrained the definition only to changes between EUNIS level 2 habitat types. This approach will facilitate a European sea-wide assessment that is both comparable and replicable. The physical pressure subtypes that are relevant to physical loss are abrasion, removal, and sealing.

Sealed and unsealed loss
For the purposes of the assessment process, ICES distinguishes between two types of physical loss; sealed physical loss and unsealed physical loss. Sealed physical loss results from the placement of structures in the marine environment (e.g. wind turbines, port infrastructure) and from the introduction of substrates that seal off the seabed (e.g. dredge disposal). Unsealed physical loss results from changes in physical habitat resulting from activities, and from the indirect effects of placement of man-made structures (e.g. aggregate extraction or a structure causing changes in water flows that ultimately change the EUNIS level 2 habitat type).

This distinction is necessary as data flows recording physical loss differ according to this dichotomy (see Figure 1, "Seafloor assessment process"). To distinguish unsealed physical loss from physical disturbance, unsealed loss requires validation, i.e. *in situ* observation of changes between EUNIS level 2 habitat types following the compilation of activity/pressure data to ascertain whether loss rather than disturbance has occurred.

Identification and prioritization of the main human activities resulting in loss

Human activities causing physical loss are identified, prioritized, and listed in Annex 1 (Tables A1.1 and A1.5) for five EU regions (Baltic Sea, Celtic Seas, Mediterranean Sea, Black Sea, and North Sea). Whether the human activities cause loss, physical disturbance, or both is indicated. All of the activities causing loss were present in each of the regions, with a few exceptions at present.

Steps for the collection and collation of physical loss data

1. *Identify the competent authorities*. ICES recognises that most sealed loss data will be held by the relevant licensing authorities within EU Member States. However, for some activities, regional or European-wide datasets from EU Member States exist and can be used. The identification of unsealed loss requires further ground-truthing at EU Member State level to assess if a change in habitat classification has occurred. Such information, if available, is likely to be held by relevant licensing authorities.
2. *Request spatial data*. The minimum data that should be collected for each activity is: type of activity (e.g. activity, structure type, licence information), geographic location (preferably in polygon format), and dates/timing/period of the operational phases (preferably in shapefile or CAD format, or as an attribute for the activity) (Annex 1, Tables A1.9 and A1.10).
3. *Produce total footprint of physical loss*. Assess the footprint either directly from the data at hand or, if the original data are points or polylines (and not a polygon), a loss footprint should be estimated. Unsealed and sealed loss are combined into a single loss layer.

4. *Assessment and documentation*. Assess and document the level of confidence on a categorical scale (Annex 1, Table A1.11) for each feature in the attribute table.
5. *Data management*. Manage data according to data management best practices, that follow the FAIR principles ("data management" section in Annex 1).
6. *Assessment of physical loss*.

The assessment of physical loss

The single physical loss layer can be used to assess contemporary total loss under D6C1, and per habitat type under D6C4. The assessment can be done in km^2 and as a proportion of the total spatial extent of the assessed area/habitat type.

Within steps 3 and 4 the precision of data may be variable, with data variously being stored as cartographic points, lines, polylines, and polygons. ICES advises that, when reporting, EU Member States should use polygons in the assessment of physical loss footprints. Where polylines or point data only are available, these should be converted to polygons using standardized buffers (to be agreed between countries) for each feature type.

The assessment process presented is applicable to all EU waters, including intertidal, and suitable for the assessment of loss in the 6-year MSFD reporting cycle. The methods are currently operational and demonstration products are presented in Annex 2 for the North Sea ecoregion (Annex 2, Table A2.1). These demonstration products include estimates of the total extent of physical loss pressure, both in km^2 and as a proportion of the total area of the assessed unit (%). To further demonstrate the applicability of the assessment process, the total extent of physical loss is estimated for the exclusive economic zones of the United Kingdom, Sweden, German, the Netherlands, Denmark, and Belgium (Annex 2, Tables A2.3–A2.8) and for the OSPAR Level 2 subdivisions (Annex 2, Tables A2.9–A2.12).

Selected issues on the assessment of physical loss

Hydrological change
Local scale sealed loss may also result in unsealed loss, caused by permanent changes in hydrographical conditions after structures have been put into the sea. Determining the extent of unsealed loss through changes in hydrographical conditions requires monitoring effort. Since loss patterns may be predictable, such monitoring may be guided or even partially replaced by hydrographical models. Modelling in this context is likely to be data hungry, i.e. reliant on data relating to the sealed loss involved, hydrographical conditions, and sediment type. It should be noted that hydrographical methods for assessing unsealed loss at this scale have been developed (O'Hara Murray and Gallego, 2014), but how such model results relate to loss as defined within the assessment process set out by ICES is, as yet, unclear.

Large-scale changes to hydrological conditions assessed under D7C1 (hydrogical changes to seabed and water column) may also cause physical loss if these changes result in a change from one EUNIS level 2 habitat type to another. Such losses, where verified by ground-truthing, can and should be incorporated into the assessment process as areal extents.

Loss of biogenic habitat
Biogenic habitats are habitats where animals, or more rarely plants, form a substrate upon which other organisms attach. Such physical habitats are distinct as they are characterized by living, habitat-forming species that are more easily impacted or disturbed by human activities than other physical substrates and may exhibit very slow recovery responses. These habitats often have limited spatial extents, compared with habitats formed of rock or sediment, and may be challenging to assess within broad-scale regional assessments.

Loss of biogenic habitat through abrasion, removal, deposition, or sealing may represent only a very small proportion at the national/EEZ level. Nevertheless, when reporting within individual MSFD broad habitat types the proportion of recorded loss in a subdivision could be high. The assessment process is suited for biogenic loss. Information is available to help quantify biogenic loss, as EU Member States do report on the current state of specific types of biogenic reef (e.g. for Habitats Directive Code 1170 Reefs, from various EUNIS level 4 or 5 habitats) and habitat suitability models do exist for some regions/subregions.

Historical loss of habitat

Estimates of current habitat loss are likely to grossly underestimate actual loss, as historical loss is likely to have been significant and unaccounted for. The assessment of the spatial distribution and extent of historical loss lies outside the currently proposed assessment, as it requires the setting of historical extent baselines and/or reference points/conditions. Estimating such loss relies on the availability of relevant historical records (including disentangling natural from anthropogenic causes) and the development of appropriate models of habitat suitability in order to estimate historical distribution and the extent of, for example, biogenic habitats. However, following the identification of such baselines, and corresponding loss estimates, historical loss can be incorporated into the assessment process.

D6C2 Physical disturbance

Physical disturbance under D6C2

Human activities, such as fishing and aggregate extraction, can result in disturbance of the seabed. A single activity can result in, and contribute to, many pressures and pressure subtypes. For example, fishing with bottom-contacting gears results in both abrasion of the seabed and deposition of sediments, while aggregate extraction results in both the removal of sediments and their deposition. The disturbance caused by different activities that result in impacts on the seabed acting through the same mechanism can be combined into a single pressure subtype. Abrasion of the seabed by different types of mobile bottom-contacting fishing gears have similar impacts on the seabed, and are routinely combined into a single measure of pressure; the swept-area ratio. Similarly, the impacts of sediment removal and those of abrasion on the seabed can be assessed within a single assessment process, provided that the footprint of substrate removal can be quantified and an estimate of the depletion of benthic biota within this footprint is made available.

Identification and prioritization of human activities resulting in disturbance

ICES identifed the main human activities that cause physical disturbance of the seabed within each marine region. Human activities causing physical disturbance are identified and listed in Annex 1 (Tables A1.1–A1.4) for five EU regions (Baltic Sea, Celtic Seas, Mediterranean Sea, Black Sea, and North Sea). With few exceptions, all of the activities causing physical disturbance were present in each of the regions. Three pressure subtypes were identified from the selection process as the main pathways from human activities to physical disturbance: abrasion, removal, and deposition (see "Elaboration on the advice").

Data requirements and estimation of disturbance layer

1. *Identify the competent authorities*. For aggregate extraction and other spatially localized activities, ICES recognises that most data will be held by the relevant licensing authorities within EU Member States. However, for some activities, e.g. fishing activity (vessel monitoring system [VMS] and logbooks), regional or European-wide datasets from EU Member States exist and can be used.
2. *Request data*. Spatial data on activities (preferably in shape file or CAD format) and attribute information (see Annex 1, Tables A1.6, A1.7, and A1.8) should be obtained for each activity. Presently, adequate spatial data is operational for mobile bottom-contacting fishing gears and aggregate extraction. Data on fishing activity in the ICES area (Northeast Atlantic and Baltic) are requested in a formal data call by ICES from its member countries, both EU and non-EU. Upon submission, and following a QC procedure by ICES experts and the ICES Data Centre, aggregated and anonymized data products can be produced by combining VMS and logbook information to produce pressure layers in the form of swept-area ratios (SAR) in grid cells of 0.05° × 0.05° by main gear groupings (see ICES, 2017 and ICES, 2019d). Data on aggregate extraction, dredging, and dredging disposal (removal and deposition disturbance) differs by country. In some countries vessels have an electronic monitoring system (EMS, a.k.a. black box) on board, while for other countries automatic identification system (AIS) data are available. For some regions a grid layer is produced by ICES on aggregate extraction in the form of extraction time (minutes) per year in a 50 × 50 m grid (ICES, 2018c).
3. *Produce total footprint of physical disturbance*. The pressure data are processed (e.g. translating grid cell intensity to spatial extent) to provide estimates of total spatial extent of abrasion (e.g. from mobile bottom-contacting fishing gears), removal (e.g. from aggregate extraction), and deposition (e.g. from dredging disposal). Subsequently, estimates for the three pressure subtypes are combined. All areas that are assigned

as loss are excluded (masked out) from the physical disturbance layer. The total footprint of physical disturbance is the sum of abrasion, removal, and deposition.

4. *Assessment and documentation*. Assess and document the level of confidence on a categorical scale (Annex 1, Table A1.12) for each feature in the attribute table.
5. *Data management*. Manage data according to data management best practices, that follow the FAIR principles ("data management" section in Annex 1).
6. *Assessment of physical disturbance*.

The assessment of physical disturbance (D6C2)

The physical disturbance layer can be used to assess total disturbance per habitat type, at regional and subregional scales, under D6C2. The assessment can be done either in km^2, or as a proportion of the total spatial extent of the assessed area/habitat type.

It is also possible to assess the disturbance by individual activities, such as abrasion by fishing activity at the métier level.

For activities resulting in removal, within steps 3 and 4 the precision of data may be variable; with data variously being stored as cartographic points, lines, polylines, and polygons. ICES advises that EU Member States reporting should use polygons in the assessment of physical disturbance footprints. Where polylines or point data only are available, these should be converted to polygons using standardized buffers (to be agreed between countries) for each feature type.

The assessment process of disturbance presented is applicable to all EU waters, including intertidal, and suitable for assessment of disturbance in the 6-year MSFD reporting cycle. The methods are currently operational and demonstration products are derived for the North Sea ecoregion for abrasion and removal (Annex 2, Table A2.2). These demonstration products include estimates of the total extent of physical disturbance pressure in km^2 and as a proportion of the total area of the assessed unit (%). To further demonstrate the applicability of the assessment process, the total physical disturbance footprint is also shown within the North Sea ecoregion for the exclusive economic zones of the United Kingdom, Sweden, German, the Netherlands, Denmark, and Belgium (Annex 2, Tables A2.3–A2.8) and subdivision (Annex 2, Tables A2.9–A2.12). In addition, the spatial extent of abrasion from mobile bottom-contacting fishing gears is shown for the Bay of Biscay and the Iberian Coast (Annex 2, Table A2.13), Celtic Seas (Annex 2, Table A2.14), and Baltic Sea (Annex 2, Table A2.15) ecoregions.

Adverse effects of physical disturbance on habitats (D6C3)

Key to the process of translating from pressure into adverse effects is to define and quantify pressures, in a way that allows their use in the assessment of impacts on seabed integrity. At the heart of this process is a benthic physical disturbance model, or a series of such models which translate various pressure subtypes into impact in a biologically meaningful way.

Assessing adverse effects from abrasion

Abrasion of the seabed results primarily from mobile bottom-contacting fishing gears, but other activities, such as aggregate extraction, can also result in abrasion. All activities that result in abrasion of the seabed can be combined into a single pressure through the mapping of the footprint of the activities on the seabed, and the intensity of the abrasion within this footprint can be quantified as the depletion of benthic fauna within this footprint (where depletion is defined as the fraction of benthic fauna killed or removed by a single pass within the footprint (Pitcher *et al*., 2017; Sciberras *et al*., 2018; Hiddink *et al*., 2019). These methods can be integrated in a benthic physical disturbance model (e.g. the Population Dynamic Model, see Annex 4 in ICES, 2018b) with subsequent indicators, that ICES has advised the EU could be used (ICES, 2017) to assess benthic impacts. Such a model can be extended to include abrasion by other activities where a footprint and depletion rate can be quantified.

To create a pressure layer that serves D6C3 (for impact indicators, e.g. ICES, 2017), ICES advises that the quantification of abrasion is mapped spatially, where both the intensity and depth of disturbance is represented. Table A1.6 in Annex 1 provides information on possible data flows that meet these requirements for fishing abrasion.

Assessing adverse effects from removal

Removal of the seabed can result from aggregate extraction, navigational dredging, scouring around structures, ship propellers, and other activities. The impacts of removal on the seabed can be assessed within the same benthic, physical disturbance model as the impacts of abrasion, provided that the footprint of substrate removal can be quantified and an estimate of the depletion of benthic biota within this footprint is available. The assessment process is suitable for the assessment of removal, and benthic physical disturbance models (e.g. the Population Dynamic Model, see Annex 4 in ICES, 2018b) are available that, in concept, can utilize the available pressure map. However, the mortality parameter describing removal within such models currently needs to be set at a precautionary high level due to a lack of parameter data. There are a large number of studies available that could be used in the estimation of the mortality parameter, but this analysis has not yet been carried out.

To create a pressure layer that serves D6C3, ICES advises that the quantification of removal is mapped spatially as the volume of substrate removed, per area, per time. Table A1.7 in Annex 1 provides information on possible data flows that meet these requirements for aggregate extraction removal.

Assessing adverse effects from deposition

Sediment deposition or the deposition of particulates on the seabed are the result of aggregate extraction, dredging of harbours and channels, scouring around structures, ship propellers, fishing with mobile bottom-contacting gears, and other activities which suspend sediments into the water. Dredge disposal will also result in the deposition of sediments, in addition to the potential sealing of the habitat. Quantification of the spatial extent of deposition requires modelling. However, parameterizing such models is computationally difficult and the approach is data hungry, i.e. relying on appropriate sediment data and hydrodynamic models. Nevertheless, the assessment process presented in this advice is capable of accommodating the output of such a model (volume of substrate deposited, per area, per time) should they become available.

To create a pressure layer that serves D6C3, ICES advises that the quantification of deposition is mapped spatially as the volume of sediments deposited, per area and per time.

Selected issues on the assessment of physical disturbance

Comparison between AIS and VMS

ICES identified AIS data sources (ICES 2019c, 2019d) and highlighted the difficulties and limitations of accessing such data, as the primary purpose of AIS is improving maritime safety. Since May 2014, AIS has been compulsory for all fishing vessels larger than 15 m overall length (class A); smaller vessels can have AIS (class B) installed voluntarily. Data challenges when working with the AIS data include lack of gear information, irregular coverage, lack of a unique vessel identifier for merging with logbook data (i.e. the AIS device is identified, but not necessarily the vessel), and time zone. It is noted that AIS could be used to supplement the VMS and logbook data, but AIS is not yet a standardized product in most ICES countries (Annex 1, Table A1.6).

An AIS North Sea case study is presented for 2017 data in ICES (2019c, Section 3.3), with maps showing differences between the spatial distributions based on AIS/fleet register data and based on ICES VMS/logbook data. It comes to the conclusion that, in general, AIS data underestimates fishing activity by showing lower maximum fishing hours. This underestimation is unrelated to issues associated with gridding, but relates to the omission of some trips that were recorded under the VMS system. Comparison shows that in the central North Sea away from the coastline, for example, registrations based on AIS data are missing. In some cases the maps show a misclassification of gears in the AIS/fleet register data. It is also concluded that for fisheries assessment on a regional scale, AIS data should be merged with logbook data at a national level in order to minimize errors. Issues relating to vessel ID and ensuring their correct merging with logbook data, however, remain a major restriction in their applicability. Clearly, in regions where VMS/logbook data are available, the VMS data gives a more reliable data product, even though the frequency position data is lower than in AIS.

Surface and subsurface abrasion

The seabed abrasion pressure and physical disturbance caused by mobile bottom-contacting fishing gears needs to take into account the penetration depth of the gears. For visualization on maps, separating abrasion into two classes (surface and subsurface) may be useful, but the assessment of the pressure will be more accurate if the actual penetration of each gear (or gear component) is used to quantify pressure, and when penetration depth dependent depletion (or

instantaneous mortality) is used in impact assessment (as in the Population Dynamic Model). An alternative way of presenting abrasion pressure that takes account of both the footprint (swept-area ratio, SAR) of the fisheries using different gear types and the depletion rates of the gear used, would be to sum the product of SAR and depletion for all different gear types used.

Six-year assessment period
Conducting the assessment of activity (relating to specific pressures) over 6-year cycles allows assessment to:

- Encapsulate trends in pressure;
- Identify increases or decreases of the pressure;
- Identify the existence of episodic pressures;
- Aggregate pressure over a 6-year period, resulting in more homogeneous spatial distribution; and
- Evaluate the effectiveness of management measures.

If there is potential for recovery, and the pressure is variable in space and time, taking account of variations in pressure between years will help to get the most accurate estimate of impact. If no recovery occurs, or the pressure is constant in space and time, taking account of temporal variation in pressure over time will not make a difference in assessing the impact. Therefore, impact assessments for all physical disturbance pressures would benefit from taking variations in the pressure into account.

An additional benefit of aggregating over longer periods is that the distribution of fishing and aggregate extraction effort becomes less patchy and more homogeneous over time scales longer than one year, within cells and between cells. Evaluating pressures over longer time scales will therefore result in a higher, and probably more realistic, estimate of the impact of these activities.

Gaps and key methodological improvements

Activity data

Fishing with mobile bottom-contacting gears. ICES sets out recommendations with regard to the inference of fishing activity, providing an evaluation of the data sources (VMS/AIS) that underpin this process (see section on "Selected issues on the assessment of physical disturbance"). However, gaps remain in data availability. The most significant activity within the abrasion subtype is fishing with mobile bottom-contacting gears (Annex 1, Table A1.2). ICES recognises the need for several key improvements in these fishing-activity data relating to the spatiotemporal scale of VMS, a further roll-out across regions where records are absent, and a wider coverage of the fleet to include small vessels. ICES notes that the provision of VMS data has only been mandatory for vessels larger than 12 m (overall length) since 2012 and that the interval between positions is recorded at a maximum of 2 hours (varying between 15 minutes and 2 hours). ICES recommends the adoption of an improved spatial resolution of aggregated VMS data from the current 0.05° c-squares to 0.01° c-squares. Data aggregation at a 0.01° resolution would require the ping rate to be increased accordingly, with a frequency that is five times higher. Combined with the current frequency of VMS polling, the latter restriction currently dictates the $0.05^{o} \times 0.05^{o}$ c-square resolution adopted, but the assessment process can be used at any spatial resolution.

In the EU proposal for amending the fisheries control regulation (COM/2018/368 final; EU, 2018) it is stated that "All vessels including those below 12 metres' length must have a tracking system". If this proposal is approved, it would greatly improve the ability to document fishing pressure from small-scale fisheries. The ICES VMS and logbook data call does not cover the Mediterranean Sea and Black Sea regions. In these regions, a large proportion of the fleet is below 12 m and therefore do not currently have VMS on board. ICES notes that it is necessary to solve the problems in accessing VMS data in some countries, and that confidentially issues directly related to spatiotemporal resolution of VMS data exist.

Aggregate extraction. Licensed areas of the extraction sites are available for all of the regions; however, more detailed data on the location of extraction (within a site) from electronic monitoring system (EMS) on board or AIS are currently only available for the Baltic Sea, North Sea, and Celtic Sea (Annex 1, Table A1.7). ICES advises adoption of the use of such high resolution systems and the recording of additional metrics such as volume, over and above the common metric of licence area (km^2) used within most regions.

The conversion of activity data to pressure

Deposition. Quantification of the spatial extent of deposition resulting from human activities requires hydrodynamic modelling for each region to take into account the dynamism in the spatial distribution of the pressure. This approach is less arbitrary than adopting a "buffer zone" approach, where the impact is assumed to occur in a fixed diameter buffer zone around the activity. However, parameterizing such models is computationally more difficult and the approach is data hungry as it relies on appropriate sediment data and hydrodynamic models. The production of such depositional pressure maps is not currently operational.

Unsealed loss. To distinguish unsealed physical loss from physical disturbance, unsealed loss requires further verification (i.e. ground-truthing of changes between EUNIS level 2 type habitats) following the compilation of activity/pressure data to ascertain whether loss rather than disturbance has occurred. Unsealed loss could, however, be incorporated in the overall assessments in a way similar to sealed loss using relevant activity data to assess contemporary total loss under D6C1 and D6C4. Such data is not yet available on a regional basis.

Abrasion. ICES recommends that an indicator equivalent of the swept-area ratio (SAR) for mobile bottom-contacting fishing gears is also developed for static fishing gear. It should reflect the intensity (i.e. pressure on the seabed) of the static gear activity, as disturbance levels from this activity are not estimated at present (only presence or absence of the activity).

Data precision and accuracy

ICES recommends the adoption of standardized methods used to convert point or polyline data (e.g. data that are sometimes provided as locations for pipelines and fixed structures) to polygons. Given the anticipated increase in hard structures (due to wind farm development), this should be an integral part of the MSFD reporting.

Benthic habitat maps following common methodologies and with equal resolution (for instance, there is a lack of benthic community maps from the Mediterranean Sea) are not yet produced at the EU scale. Existing maps (e.g. EMODnet) should be refined, both in terms of resolution and habitat discrimination.

The assessment process advised here assigns categorical values associated with data confidence (1–4) to activity data. However, methods that produce confidence estimates pertinent to assessment outputs are yet to be developed.

Issues relating to scale

The assessment of pressure relates to scale. The Commission Decision (EU) 2017/848 (EU, 2017) requires assessments of MSFD habitats to be at bio-geographically relevant scales (subdivisions of a region or subregion). There may be other nationally assessed pressure–activity combinations that lie beyond regional assessment, but which are regarded as important when viewed at the smaller national or local scale. Whilst their omission is unlikely to affect the output of regional assessment, EU Member States have the option to record such disturbance or loss. ICES recognises that some specific habitats, in particular those in intertidal and coastal areas, may be strongly affected at a local scale by pressures that are not ranked as being important on a regional scale, e.g. seagrass beds that may be affected by anchoring (see section 2.4 in ICES, 2018a).

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Annex 1

Ranked human activities that affect the seabed

Table A1.1 Ranked marine activities (through expert opinion: see section on Established data flows under "Basis of the advice") in five EU exemplary (sub-)regional seas (Baltic Sea, North Sea, Celtic Seas, Mediterranean and Black Sea) causing habitat loss (L) and/or disturbance (D). Numbers denote the ranking of each activity in each region, with 1 denoting the activity that was deemed to cause the greatest amount of physical disturbance in that region. The equal = symbol shows activities that were assigned an equal ranking (were scored equally in the exercise) with another activity in the same region. The top five activities causing pressures are highlighted in green. Activities that were judged to cause solely loss (e.g. port infrastructures) are highlighted in grey and were discounted from further consideration. N.D.R: denotes activities that are considered by expert judgement to be not directly relevant to D6/physical pressures and were also excluded from the ranking exercise.

Theme	Activity	Physical loss/ Disturbance	Baltic	North	Celtic	Med	Black
Extraction of living resources	Fish and shellfish harvesting (professional, recreational)	D	1	1	1	1	1
Physical restructuring of rivers, coastline, or seabed (water management)	Restructuring of seabed morphology, including dredging and depositing of materials	D	2	3	3	3	2
Physical restructuring of rivers, coastline, or seabed (water management)	Coastal defence and flood protection	L	9=	2	4=	2	3=
Extraction of non-living resources	Extraction of minerals (rock, metal ores, gravel, sand, shell)	L/D	3	6=	2	6	8=
Transport	Transport — shipping (incl. anchoring)	D	4	5	11=	4	4
Transport	Transport infrastructure	L	5	4	17=	8	8=
Tourism and leisure	Tourism and leisure infrastructure	L	8=	11	12	7	6
Extraction of non-living resources	Extraction of oil and gas, including infrastructure	L/D	15	7	4=	15=	7
Cultivation of living resources	Aquaculture — marine, including infrastructure	L/D	6	16=	6=	10	11
Physical restructuring of rivers, coastline, or seabed (water management)	Canalization and other watercourse modifications	L	11=	13	17=	9	3=
Production of energy	Renewable energy generation (wind, wave, and tidal power), including infrastructure	Lo/Di	8=	6=	5	19=	15=
Tourism and leisure	Tourism and leisure activities	Di	10	16=	17=	5	5
Urban and industrial uses	Waste treatment and disposal	Di/ N.D.R	12	15=	7	11	9
Security/defence	Military operations (subject to Article 2(2))	Di	11=	9	9	15=	12
Physical restructuring of rivers, coastline, or seabed (water management)	Land claim	Lo	9=	12=	8	14	15=
Production of energy	Transmission of electricity and communications (cables)	Lo/Di	13	10	13	12	10
Education and research	Research, survey and educational activities	Di	7	8	14	16	13
Physical restructuring of rivers, coastline, or seabed (water management)	Offshore structures (other than for oil/gas/renewables)	Lo	16=	12=	6=	15=	15=
Extraction of living resources	Hunting and collecting for other purposes	Di	14=	14	16	13	14=
Extraction of living resources	Marine plant harvesting	Di	14=	17=	10	19=	15=
Production of energy	Non-renewable energy generation	N.D.R	16=	15=	11=	19=	15=
Extraction of non-living resources	Extraction of water	Di	16=	17=	17=	17	14=

Theme	Activity	Physical loss/ Disturbance	Baltic	North	Celtic	Med	Black
Extraction of living resources	Fish and shellfish processing	Di	16=	17=	15	19=	15=
Extraction of non-living resources	Extraction of salt	Di	16=	17=	17=	18	15=
Cultivation of living resources	Aquaculture — freshwater	N.D.R	16=	17=	17=	19=	15=
Cultivation of living resources	Agriculture	N.D.R	16=	17=	17=	19=	15=
Cultivation of living resources	Forestry	N.D.R	16=	17=	17=	19=	15=
Transport	Transport — air	N.D.R	16=	17=	17=	19=	15=
Transport	Transport — land	N.D.R	16=	17=	17=	19=	15=
Urban and industrial uses	Urban uses	N.D.R	16=	17=	17=	19=	15=
Urban and industrial uses	Industrial uses	N.D.R	16=	17=	17=	19=	15=

Abrasion activities with data type, footprint, and metric across five EU regions

Table A1.2 Abrasion activity–regional sea interactions with data type, footprint, and metric. Based on the MSFD list and ICES (2018a) Priority Activities. Green highlights are key activities causing the pressure. Yellow highlights denote important, but not key activities. EMS = electronic monitoring system.

ABRASION	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea	Notes
Extraction – Living resources (Fishing)	VMS + Log - SAR	VMS + Log - SAR	VMS + Log - SAR	VMS + Log - SAR	VMS + Log - SAR	Applies to mobile bottom-contacting gears, and VMS-only vessels. Logbooks not available for all fishing in all regions
Aggregate extraction	Licence (metric = surface area and/or volume) + AIS – Small footprint. No metric	Licence (metric = surface area and/or volume) + EMS/AIS – Small footprint. No metric	Licence (metric = surface area and/or volume) + EMS/AIS – Small footprint. No metric	Licence (metric = surface area and/or volume) + AIS – Small footprint. No metric	Licence (metric = surface area and/or volume) + AIS – Small footprint. No metric	Small footprint, no data on impact. No AIS available for all countries/regions
Structures (tourism, O&G, transport) – Construction	Plan/Licence - No metric	Plan/Licence - No metric	Plan/Licence - No metric	Plan/Licence - No metric	Plan/Licence - No metric	
Structures – Operation	NA	NA	NA	NA	NA	
Navigational?? dredge (all) – Dredging	Licence – Small footprint, no metric	Licence – Small footprint, no metric	Licence – Small footprint, no metric	Licence – Small footprint, no metric	Licence – Small footprint, no metric	
Dredging disposal	NA	NA	NA	NA	NA	
Transport – shallow routes, anchoring, and recreational	Permitted area, shallow routes, AIS, no metric	Permitted area, shallow routes, AIS, no metric	Permitted area, shallow routes, AIS, no metric	Permitted area, shallow routes, AIS, no metric	Permitted area, shallow routes, AIS, no metric	Abrasion from propeller turbulence in shallow waters and anchoring
Cultivation (aquaculture)	NA	NA	NA	NA	NA	Only anchor chain, small, no metric

Removal activities with data type, footprint, and metric across five EU regions

Table A1.3 Removal activity–regional sea interactions with data type, footprint, and metric. Based on the MSFD list and ICES (2018a) Priority Activities. Green highlights are key activities causing the pressure. Yellow highlights denote important, but not key activity.

REMOVAL	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea	Notes
Extraction – Living resources (Fishing)	Gear & métier specific, VMS + Log – SAR (small/part)	Gear & métier specific, VMS + Log – SAR (small/part)	Gear & métier specific, VMS + Log – SAR (small/part)	Gear & métier specific, VMS + Log – SAR (small/part)	Gear & métier specific, VMS + Log – SAR (small/part)	Taking out fine sediment. Not quantified. Could be modelled. Major disturbance covered elsewhere
Aggregate extraction	Licence, AIS, metric: minutes in grid. Some countries	Licence EMS/AIS, metric: minutes in grid	Licence, AIS, metric: minutes in grid. Some countries	Licence, no metric	Licence, no metric	AIS not available for all countries/regions. Aggregate extraction is removal of material for e.g. industrial or beach nourishment purposes.
Structures (tourism, O&G, transport) – Construction	Plan/licence – very small, no metric	Plan/licence – very small, no metric	Plan/licence – very small, no metric	Plan/licence – very small, no metric	Plan/licence – very small, no metric	
Structures – Operation	NA	NA	NA	NA	NA	Structures may cause scouring – but not parameterized
Navigational?? dredge – Dredging	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Dredging defined as sediment removal to clear an area.
Dredging disposal	NA	NA	NA	NA	NA	Dumping of dredged material
Transport – shallow routes, anchoring, and recreational	Permitted area, tiny footprint, shallow routes, AIS, no metric	Permitted area, tiny footprint, shallow routes, AIS, no metric	Permitted area, tiny footprint, shallow routes, AIS, no metric	Permitted area, tiny footprint, shallow routes, AIS, no metric	Permitted area, tiny footprint, shallow routes, AIS, no metric	Insignificant
Cultivation (Aquaculture)	NA	NA	NA	NA	NA	

Deposition activities with data type, footprint, and metric across five EU regions

Table A1.4 Deposition activity–regional sea interactions with data type, footprint, and metric. Based on the MSFD list and ICES (2018a) Priority Activities. Green highlights are key activities causing the pressure. Yellow highlights denote important, but not key activity.

DEPOSITION	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea	Notes
Extraction – Living resources (Fishing)	Gear & métier specific, VMS + Log, no metric.	Gear & métier specific, VMS + Log, no metric.	Gear & métier specific, VMS + Log, no metric.	Gear & métier specific, VMS + Log, no metric.	Gear & métier specific, VMS + Log, no metric.	Not modelled, can extend beyond trawling footprint. Important as the extent of trawling is very large. Sediment- and current-specific
Aggregate extraction	Licence, AIS – No metric	Licence EMS/AIS – No metric	Licence, AIS – No metric	Licence, AIS – No metric	Licence, AIS – No metric	AIS no available in all countries and regions. Not modelled, can extend beyond extraction footprint. Sediment- and current-specific
Structures (tourism, O&G, transport) – Construction	Plan/licence – very small, no metric	Plan/licence – very small, no metric	Plan/licence – very small, no metric	Plan/licence – very small, no metric	Plan/licence – very small, no metric	
Structures - Operation	Plan/licence – tiny, no metric	Plan/licence – tiny, no metric	Plan/licence – tiny, no metric	Plan/licence – tiny, no metric	Plan/licence – tiny, no metric	Potential deposition of scoured material
Dredge – Dredging	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Sometimes amount and area is specified within the licensed area. Pressure is beyond the activity footprint
Dredge disposal	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Plan/licence – no metric	Sometimes amount and area is specified. Some modelling. Pressure is beyond the activity footprint
Transport – shallow routes, anchoring, and recreational	Permitted area, very small, shallow routes, AIS, no metric	Permitted area, very small, shallow routes, AIS, no metric	Permitted area, very small, shallow routes, AIS, no metric	Permitted area, very small, shallow routes, AIS, no metric	Permitted area, very small, shallow routes, AIS, no metric	Insignificant

DEPOSITION	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea	Notes
Cultivation (Aquaculture)	Plan/licence – no metric	Plan/licence – no metric	Plan/licence - no metric	Plan/licence – no metric	Plan/licence – no metric	Some modelling. Very small areas

Sealing activities with data type, footprint, and metric across five EU regions

Table A1.5 Sealing activity–regional sea interactions with data type, footprint, and metric. Based on the MSFD list and ICES (2018a) Priority Activities. Green highlights are key activities causing the pressure.

SEALING	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea	Notes
Extraction – Living resources (Fishing)	NA	NA	NA	NA	NA	
Aggregate extraction	NA	NA	NA	NA	NA	
Structures (tourism, O&G, transport) – Construction	NA	NA	NA	NA	NA	
Structures – Operation	Permit/Licence /Geolocation/ Map/Different databases, Metric Polygon/ Polyline/Line	Permit/Licence /Geolocation/ Map/Different databases, Metric Polygon/ Polyline/Line	Permit/Licence /Geolocation/ Map/Different databases, Metric Polygon/ Polyline/Line	Permit/Licence /Geolocation/ Map/Different databases, Metric Polygon/ Polyline/Line	Permit/Licence /Geolocation/ Map/Different databases, Metric Polygon/ Polyline/Line	Different structures, different data formats: points, polygons, lines, polylines
Dredge – Dredging	NA	NA	NA	NA	NA	
Dredging disposal	NA	NA	NA	NA	NA	
Transport – shallow routes, anchoring, and recreational	Permit area. Fixed anchors. No metric	Permit area. Fixed anchors. No metric	Permit area. Fixed anchors. No metric	Permit area. Fixed anchors. No metric	Permit area. Fixed anchors. No metric	Insignificant footprint from concrete block anchors
Cultivation (Aquaculture)	Plan/licence – no metric. Very small area.	Plan/licence – no metric. Very small area.	Plan/licence – no metric. Very small area.	Plan/licence – no metric. Very small area.	Plan/licence – no metric. Very small area.	Insignificant footprint from concrete block, mooring foundations, anchors

Data overview of dominant activity causing abrasion: fishing with mobile bottom-contacting gears

Table A1.6 Regional/sub-regional assessment of data type, metric, data flow, method, and gaps/impediments to operation for abrasion caused by mobile bottom-contacting fishing gears.

ABRASION	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea
Data	VMS + logbook data	VMS + logbook data	VMS + logbook data	VMS + logbook data (for large trawlers, and for some areas); non-EU and smaller vessels maybe possible from AIS data	VMS + some logbook data / or AIS data
Metrics	Swept-area ratio (km^2) per year on C-square grid (0.05° × 0.05°)	Swept-area ratio (km^2) per year on C-square grid (0.05° × 0.05°)	Swept-area ratio (km^2) per year on C-square grid (0.05° × 0.05°)	Swept-area ratio (km^2)	Presence of fishing vessels
Data flow	ICES data call	ICES data call	ICES data call		National agency of fisheries and aquaculture
Method	Methods to calculate the pressure regionally are coherent, established and published. Vessel speeds representing fishing activity are assigned to a 0.05° × 0.05° grid (the c-square approach), each covering about 15 km^2 at 61°N latitude, which is the spatial resolution adopted by ICES. Estimates on total SAR within each grid cell are calculated by métier and habitat.			No common regional method developed to use VMS/AIS (except Italy and Greece have a common method to calculate the SAR)	Common method to calculate the presence of fishing vessels

ABRASION	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea
Gaps or impediments to operation	Vessels < 12 m length don't have VMS (vessel monitoring data by satellite). AIS (automatic identification system) data from some vessels are available, but not used at present. Benthic impact assessment methodologies are well established, but the interaction with oxygen depletion has to be considered. Russia does not supply VMS but might be derived from AIS.	Vessels < 12 m length do not have VMS. Benthic impact assessment methodologies are well established.	Vessels < 12 m length don't have VMS. AIS data from some vessels are available, but not used at present. Benthic impact assessment methodologies are well established.	The majority of coastal fishing vessels (< 12 m and in some cases < 15 m) are not equipped with VMS. Could use AIS (the ping frequency is acceptable but it does not cover a large number of vessels). Benthic impact assessment methodologies are very well established; however, there is a lack of benthic community maps (and in general spatially-explicit data). Regular monitoring is conducted by many EU countries but data (including VMS) are not open-access. Lack of applicability of SAR to static gears where the disturbance levels are unknown (but potential to do this: several project proposals).	Black Sea EU Member States (Bulgaria & Romania) are submitting some aggregated effort data to JRC. Logbook data exists only partly. There were no Black Sea partners involved with VMS work under the BENTHIS project. Existence/ availability of logbook data is unknown..

Data overview of dominant activity causing removal: aggregate extraction

Table A1.7 Regional/sub-regional assessment of data type, metric, data flow, method and gaps/ impediments to operation for removal caused by aggregate extraction.

REMOVAL	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea
Data	Licence areas, AIS from some countries	Licence areas, EMS/AIS	Licence areas, EMS/AIS	Licence areas	Licence areas (points of the polygon corners)
Data flow	ICES WGEXT Data call, HELCOM regional data	ICES WGEXT Data call	ICES WGEXT Data call	National fragmented databases	In reports
Metrics	Area in km^2, minutes extracted in 50 m grid in DK	Area in km^2, minutes extracted in 50 m grid for some countries	Area in km^2, minutes extracted in 50 m grid for some countries	Area in km^2	Area km^2, volume m^3 / licence
Method	Method to produce minutes extracted in 50 m grid only for DK	Method to produce minutes extracted in 50 m grid		No common method	No method
Gaps or impediments to operation	AIS not available for all countries/regions. Minutes extracted in 50 m grid only for the one year the exercise was done. Volume reported not per site but total for the country. If volume would be included in the pressure, the information is confidential. A synthesis of rates of depth and recovery rate of fauna for aggregate extraction activities has not been carried out, although lots of individual studies may exist (but may be company owned).			Data are diverse through the region if available, limited regional coordination, no common method, very small-scale activity	Very small-scale activity

Data overview of dominant activity causing deposition: disposal of (dredged) material

Table A1.8 Regional/sub-regional assessment of data type, metric, data flow, method, and gaps/ impediments to operation for deposition caused by disposal of (dredged) material.

DEPOSITION	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea
Data	Licensed areas, deposition areas or points	Licenced areas	Licenced areas	Licence areas	Licensed areas
Data flow	HELCOM Annual data call, national databases	OSPAR Annual data call, national plans	OSPAR Annual data call, national plans	National fragmented databases	In reports
Metrics	Area in km^2, amount of deposited material	Area in km^2, amount of deposited material (for some countries)	Area in km^2, amount of deposited material (for some countries)		
Method	Regional level perspectives may be possible.			No common method	No method
Gaps or impediments to operation	Data are reported as points or polygons, amount and the material of the deposit reported for some sites. The scale of reported activities differs between the different coastal states. Sometimes amount and area is specified. Some modelling of the pressure foot print, e.g. in Danish waters. Pressure is beyond the activity footprint.	At the moment no model or parameter estimates are available to convert deposition into an estimate of the state of the seabed.	At the moment no model or parameter estimates are available to convert deposition into an estimate of the state of the seabed.	Data are diverse through the region if available, limited regional coordination, no common method, very small-scale activity	Very small-scale activity

Data overview of dominant activity causing sealing: physical structures

Table A1.9 Regional/sub-regional assessment of data type, metric, data flow, method, and gaps/stumbling blocks for sealing caused by physical structures.

SEALING	Baltic Sea	North Sea	Celtic Sea	Mediterranean Sea	Black Sea
Data	Permit/licence/ geolocation/map	Permit/licence/ geolocation/map	Permit/licence/ geolocation/map	Permit/licence/ geolocation/map	Permit/licence/ geolocation/map
Data flow	National databases, existing regional databases	National databases, existing regional databases	National databases, existing regional databases	National databases, existing regional databases	National databases, existing regional databases
Metrics	Area in km^2	Area in km^2	Area in km^2	Area in km^2	Area in km^2
Method	Assess footprint of the structure either directly from the polygon data at hand or, if original data are points or lines, a footprint should be estimated.				
Gaps or impediments to operation	A lot of different structures, different data formats for structures: points, polygons, lines, polylines. Fragmented datasets, but improved with new sectors (e.g. renewables, oil & gas)				

Human activities, advised data sources, and specificities with regard to the data call for physical loss reporting

Table A1.10 Human activities, advised data sources, and specificities with regard to the data call for physical loss reporting.

Activity	Data sources (including some known regional sources)	Specific definitions for details in the data call/ data flow, e.g. buffers to derive the footprint
Restructuring of seabed morphology, including depositing of materials	National data call or, if not possible, national reporting through OSPAR and HELCOM	- Information by type on area should be provided from licensing. - information on deposition method and hydrodynamic condition (local or dispersive). - Type of deposited sediment and natural substrate in the deposition area.
Transport infrastructure	National data call	Information by type on area should be provided from licensing or by national port administration.
Aquaculture — marine, including infrastructure	National data call	- Footprint depends on the aquaculture method and species. - Information on area should be estimated based on the installation type and moorings.
Renewable energy generation, including infrastructure	National data call (for wind farms, only licensed areas as large polygons are available through EMODnet Human activities)	Information on area should be estimated based on the installation type and moorings from licensing or environmental impact assessments (EIAs).
Tourism and leisure infrastructure	National data call	Information on area should be provided from licensing or by administration.
Coastal defence and flood protection	National data call	Information on area should be provided from licensing or by administration.
Land claim	National data call	- Information on area should be provided from licensing or by administration. Note: For land claim the initial coastline should be identified, if possible.
Canalization and other watercourse modifications	National data call	Information on area should be provided from licensing, EIAs, or by administration.
Military operations (e.g. munition dump sites)	National data call, existing data sources on munition dump sites (OSPAR, HELCOM, EMODnet)	Information on area of historical munition deposition sites should be provided.
Transmission of electricity and communications (cables)	National data call	- Cables: information on whether cables (or parts of cables) are buried inside the seabed (depth) or protected/covered with gravel or laid straight on the surface of the seabed. - Diameter of the cable (including shielding structure) to be used to estimate needed buffer, if possible.
Extraction of oil and gas, including infrastructure (oil rigs, pipelines)	National data call or, if not possible, EMODnet / Human activities /Hydrocarbon extraction / Offshore installations, including status of operational and decommissioned rigs	- Oil and gas platforms/ drilling pits: information on footprint should be provided from licensing. - Pipelines: information on whether they are buried inside the seabed or protected/covered with gravel or laid straight on the surface of the seabed.
Offshore structures (other than for oil/gas/renewables)	National data call	- Information on footprint should be provided depending on the structure (artificial reefs/wrecks) and mooring, if available.

Data management

The quality of guidance relating to physical disturbance and physical loss pressures depend on the quality of data provided and how it is collated, as well as the routines to process and analyse them. Due to the complexity of the data, the different setups between individual countries, and differences between the data aggregating units used for holding and extracting the data, trying to standardize workflows and/or final products can be a challenging task. One way to address this issue could be the development of "best practices guides" and the preparation of predefined workflows and routines.

ICES recommends that these best practices follow the ICES manual for data management (ICES, 2019a). This centres on the FAIR principles, ensuring that all data are:

- Findable (through documentation and metadata).
- Accessible (through clarity on licensing, formats, and the data policy).
- Interoperable (through extended use of shared reference systems and services).
- Reusable (by having known data quality and good documentation).

With regard to data compilation, useful overarching principles are:

- Use existing standards and formats to describe data wherever possible, making adaptations only where necessary (i.e. avoid making new standards/formats).
- Create documentation (ideally ISO meta-data) on the origin of the data you are using in the process, including digital identifiers (i.e. DOIs) where possible.
- Ensure data are delivered to an agreed data policy (ideally an open one, such as the ICES Data Policy).
- Have a clear understanding of the level of temporal/spatial resolution at which data are delivered/used in a data product (they do not need to be the same).
- If data are aggregated, where possible provide guidance on how this aggregation should be done – and document that this has happened.
- Where possible, use QC scripts/programmes to check data are following expected formats/value ranges, etc. This process will have an iterative feedback for improvement over a number of reporting cycles (of data).

Verification/double checking by a second expert should be carried out where possible, the "*four-eyes principle*". The four eyes principle – meaning verification by a second individual – is a cornerstone of any quality system (e.g. good manufacturing practice [GMP], good laboratory practice [GLP], or International Organization for Standardization [ISO] 17025).

It is recommended to report on data confidence for physical loss and physical disturbance. For physical loss, it is important to identify a level of confidence in the positional accuracy of the data. Recommendations for assigning confidence to data contributing to assessing physical loss are shown in Table A1.11. Recommendations for assigning confidence to data contributing to assessing physical habitat disturbance are shown in Table A1.12.

Table A1.11 Recommendations for assigning confidence to data contributing to assessing physical habitat loss; 1 = high, 4 = low.

Confidence level	Description	Examples
1	Data on actual positions of a human activity, originating from official documents or portals.	Wind turbines and their cable routings
2	Data on planned, instead of coordinates on actual positions, as originating from official documents or portals.	Pipelines
3	Data on the licensed areas of the human activities, typically available from marine spatial plans or only gridded data.	Wind farm spatial extent, munition dump site
4	Roughly estimated or modelled extension of physical habitat loss.	Loss of biogenic reefs, Unsealed loss

Table A1.12 Recommendations for assigning confidence to data contributing to assessing physical habitat disturbance; 1 = high, 4 = low.

Confidence level	Description	Examples
1	High-frequency polling systems.	Electronic monitoring system (EMS) for, e.g. dredging,
2	Interpolation of data from low-frequency polling systems.	Vessel monitoring systems (VMS) for, e.g. fishing.
3	Data on the licensed areas of the human activities, typically available from marine spatial plans. Coarse gridding of low-frequency polling systems.	Dredging sites, WGSFD fishing abrasion data product.
4	Roughly estimated or modelled extension of physical habitat disturbance.	Deposition models.

Annex 2 Demonstration product for assessing physical loss (D6C1, D6C4) and physical disturbance (D6C2) on benthic habitats

Note: The outputs presented in the following demonstration product are intended as proof of concept of the assessment process and not a status assessment. It is a demonstration product developed in response to requests from a client to highlight the operational aspect of the seafloor assessment process as presented in this advice for physical loss (D6C1 and D6C4) and physical disturbance (D6C2) acting on benthic habitats.

Contents

1 Physical loss and physical disturbance in the Greater North Sea ecoregion

This demonstration illustrates the application of the assessment process for three of the four principal pressure subtypes: abrasion, removal, and sealing, which give rise to seabed loss (D6C1/D6C4) and physical disturbance (D6C2). The assessment is done for the North Sea ecoregion and for different exclusive economic zones (EEZ) and subdivisions within the North Sea ecoregion. For the sake of brevity, we have not included estimates of abrasion by fishing métier. Estimates for some of these métiers are provided in ICES (2017, 2018b).

1.1 Abrasion

For abrasion, the most significant activity is fishing with mobile bottom-contacting gears. For the North Sea region, VMS and logbook data are collected and stored by the national fishery agencies. Data that ICES receive are processed using regionally coherent, established, and published methods (see Annex 1, Table A1.6). Vessel speeds representing fishing activity are assigned to a 0.05° × 0.05° grid (the c-square approach), each covering about 15 km² at 61°N latitude, which is the spatial resolution adopted by ICES. The swept-area ratio (SAR, also defined as fishing intensity) is the swept area divided by the surface area of the grid cell. Data on fishing abrasion in the North Sea is taken from the latest ICES VMS and logbook data call. A map of surface abrasion (SAR) is shown in Figure A2.1.

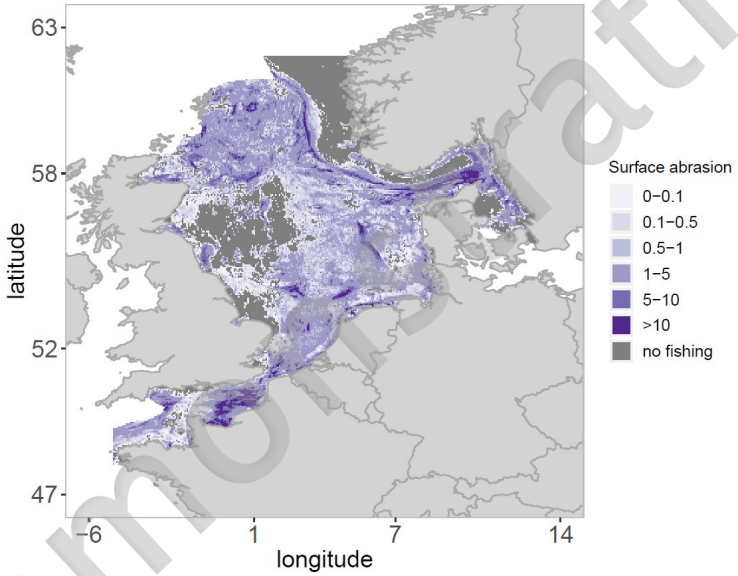

Figure A2.1 Geographic distribution of surface abrasion (swept-area ratio per year) from mobile bottom-contacting fishing gears in the North Sea ecoregion in 2016.

1.2 Removal

For removal, the most significant activity is aggregate extraction. Data on aggregate extraction differs per country in the North Sea (Annex 1, Table A1.7). In UK, Belgium, and the Netherlands ships have an electronic monitoring system (EMS, aka black box) on board, while for other countries, AIS data are collected from dredging vessels (e.g. Denmark). EMS data show where and when the extraction has taken place. AIS data from extraction vessels can also be used to visualize extraction footprints when filtering for speed and doing some further processing. Both AIS and EMS data can be processed via GIS spatial analysis. A grid layer produced by ICES working group on aggregate extraction (ICES, 2019e) on a 50 × 50 m grid with time (min) extracted in each grid cell during one year (2017) is used in the demonstration product. A map of removal by aggregate extraction is shown in Figure A2.2.

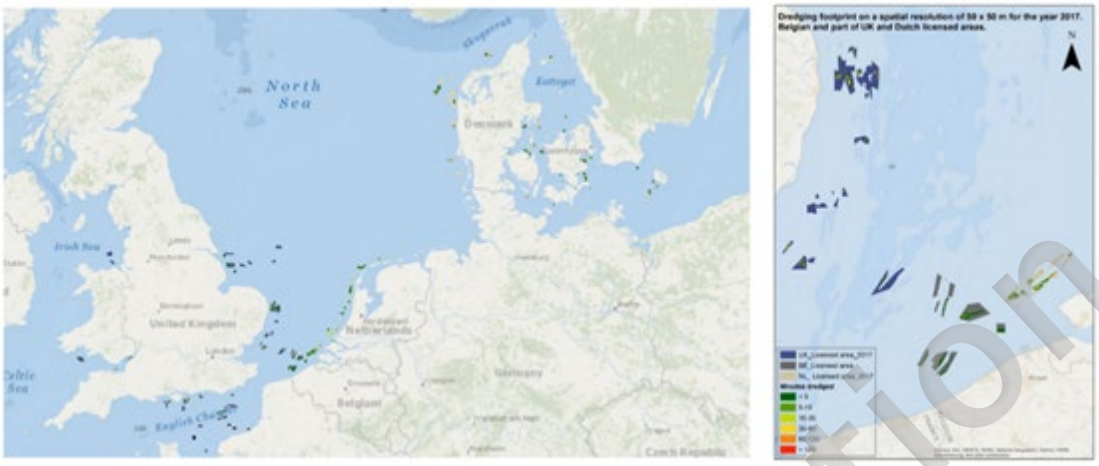

Figure A2.2 Aggregate extraction footprint (in minutes dredged) on a spatial resolution of 50 × 50 meter for the year 2017. Data are available for the Swedish, Dutch, UK, Belgian, and Danish EEZs.

1.3 Sealing

For sealing, the most significant activity is the placement of physical structures (Annex 1, Table A1.9). A common metric – the area sealed in km^2 – exists for this pressure. To assess the footprint (in km^2) of the structure, either polygon data can be used directly or, in the case where the original data is provided as points or lines, a footprint can be estimated by applying a buffer. The data used in the demonstration product is restricted to sealing by hard structures from offshore wind farms, wave and tidal energy, and oil and gas in the North Sea region (Figure A2.3). The data on sealing used in the demonstration product is collated by Kenny *et al.* (2017).

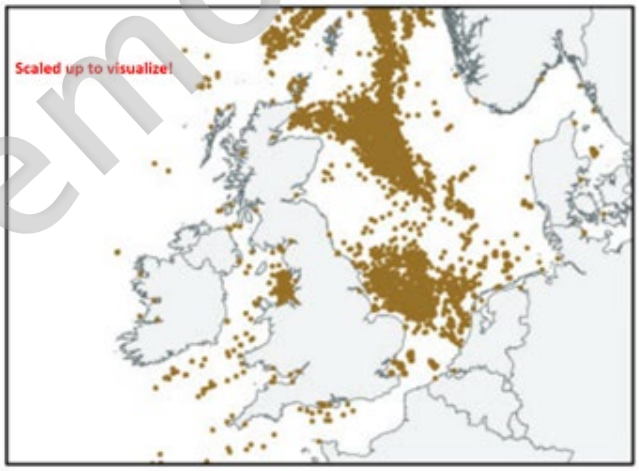

Figure A2.3 The locations of sealed loss by hard structures as collated by Kenny *et al.* (2017). Polypoints are not drawn on the correct scale.

1.4 Physical loss of seabed habitats (D6C1/D6C4)

The spatial extent of sealed physical loss by hard structures for the North Sea ecoregion and by MSFD broad habitat type is shown in Table A2.1. Each hard structure is linked to a MSFD broad habitat type assigned at a c-square resolution of 0.05° × 0.05° using the midpoint of the c-square. A map with the MSFD broad habitat types was downloaded from EMODnet in September 2019.

Table A2.1 The spatial extent of physical loss for the North Sea ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km²)	Loss (%)	Total area (km²)
Total region	161.7	0.0	652799.9
Offshore circalittoral sand	85.8	0.0	242124.6
Offshore circalittoral mud	46.3	0.0	108043.5
Offshore circalittoral coarse sediment	9.9	0.0	76719.5
Circalittoral sand	11.7	0.0	68621.7
Upper bathyal sediment	0.0	0.0	61407.2
Circalittoral coarse sediment	5.0	0.0	30287.7
Infralittoral sand	1.6	0.0	14835.8
Unknown (Na)	0.1	0.0	9676.5
Offshore circalittoral mixed sediment	0.4	0.0	7701.7
Circalittoral mud	0.4	0.0	6900.5
Circalittoral mixed sediment	0.3	0.0	4822.7
Offshore circalittoral rock and biogenic reef	0	0	4734.6
Infralittoral coarse sediment	0.1	0.0	3299.0
Circalittoral rock and biogenic reef	0	0	3058.6
Upper bathyal sediment or Upper bathyal rock and biogenic reef	0	0	2552.9
Upper bathyal rock and biogenic reef	0	0	2406.2
Infralittoral mud	0	0	2372.8
Infralittoral rock and biogenic reef	0	0	1901.4
Infralittoral mixed sediment	0	0	1333.0

1.5 Spatial extent of physical disturbance (D6C2)

The spatial extent of abrasion from fishing with mobile bottom-contacting gears and removal from aggregate extraction is estimated for the North Sea ecoregion in Table A2.2. All areas that are assigned as loss are excluded from the physical disturbance assessment and, hence, the physical disturbance model is refined in its geographical extent to the region without physical loss. The spatial extent of abrasion is calculated by multiplying the swept-area ratio of each 0.05° × 0.05° c-square cell with the surface area of the cell, where abrasion in a specific grid cell cannot be greater than the area of that grid cell (minus the area that is assigned as lost). The spatial extent of removal is calculated as the sum of all 50 × 50 meter areas with aggregate extraction. To assess the total disturbance footprint, it is assumed that abrasion and removal do not overlap spatially; hence in a grid cell with abrasion and removal, total disturbance cannot be greater than the total area of the cell. Abrasion and removal are linked to a MSFD broad habitat type assigned at a c-square resolution of 0.05° × 0.05° using the midpoint of the c-square. A map with the MSFD broad habitat types was downloaded from EMODnet in September 2019.

Table A2.2 The spatial extent of physical disturbance from abrasion and removal for the North Sea ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	355947.2	54.5	441.9	0.1	356109.6	54.6	652799.9
Offshore circalittoral sand	129647.4	53.5	62.4	0.0	129653.7	53.5	242124.6
Offshore circalittoral mud	89148.8	82.5	10.0	0.0	89148.8	82.5	108043.5
Offshore circalittoral coarse sediment	43926.2	57.3	38.2	0.0	43949.4	57.3	76719.5
Circalittoral sand	44582.2	65.0	157.5	0.2	44624.5	65.0	68621.7
Upper bathyal sediment	14423.2	23.5	0	0	14423.2	23.5	61407.2
Circalittoral coarse sediment	11507.3	38.0	49.4	0.2	11548.0	38.1	30287.7
Infralittoral sand	6604.5	44.5	6.6	0.0	6607.5	44.5	14835.8
Unknown (Na)	1751.3	18.1	0	0	1751.3	18.1	9676.5
Offshore circalittoral mixed sediment	4636.4	60.2	1.0	0.0	4637.4	60.2	7701.7
Circalittoral mud	3878.7	56.2	71.4	1.0	3906.0	56.6	6900.5
Circalittoral mixed sediment	1965.7	40.8	27.0	0.6	1971.4	40.9	4822.7
Offshore circalittoral rock and biogenic reef	723.9	15.3	0	0	723.9	15.3	4734.6
Infralittoral coarse sediment	1638.2	49.7	0	0	1638.2	49.7	3299.0
Circalittoral rock and biogenic reef	393.5	12.9	0.7	0.0	394.2	12.9	3058.6
Upper bathyal sediment or Upper bathyal rock and biogenic reef	104.5	4.1	0	0	104.5	4.1	2552.9
Upper bathyal rock and biogenic reef	189.0	7.9	0	0	189.0	7.9	2406.2
Infralittoral mud	529.2	22.3	0.5	0.0	529.7	22.3	2372.8
Infralittoral rock and biogenic reef	248.5	13.1	0	0	248.5	13.1	1901.4
Infralittoral mixed sediment	48.8	3.7	17.1	1.3	60.5	4.5	1333.0

1.6 Physical loss (D6C1/C4) and physical disturbance (D6C2) per EEZ

The spatial extent of physical loss and physical disturbance is shown for United Kingdom (Table A2.3), Swedish (Table A2.4), German (Table A2.5), Dutch (Table A2.6), Danish (Table A2.7), and Belgian (Table A2.8) exclusive economic zones. The methodology used to estimate physical loss and physical disturbance is similar to the estimation of physical loss and physical disturbance for the entire North Sea ecoregion. Shapefiles of the various exclusive economic zones are downloaded from marineregions.org.

Table A2.3 Overview of physical loss and physical disturbance for the United Kingdom EEZ within the North Sea ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	134.3	0.1	120396.9	46.1	82.9	0.0	120458.2	46.1	261189.9
Offshore circalittoral sand	72.7	0.1	49919.6	37.5	6.0	0.0	49923.0	37.5	132984.8
Offshore circalittoral mud	40.3	0.1	38996.4	85.7	0.3	0.0	38996.4	85.7	45524.0
Offshore circalittoral coarse sediment	7.6	0.0	16624.7	43.8	38.1	0.1	16647.9	43.8	37979.4
Circalittoral coarse sediment	4.8	0.0	2798.2	20.5	30.8	0.2	2825.2	20.7	13657.3
Circalittoral sand	6.7	0.1	4578.8	34.6	2.8	0.0	4581.6	34.6	13229.1
Infralittoral sand	1.6	0.0	2744.8	59.6	0	0	2744.8	59.6	4602.6
Offshore circalittoral mixed sediment	0.3	0.0	2274.0	62.4	1.0	0.0	2275.0	62.4	3644.3
Unknown (Na)	0.1	0.0	198.4	9.5	0	0	198.4	9.5	2093.4
Circalittoral mud	0.0	0.0	644.8	36.3	0	0	644.8	36.3	1774.6
Circalittoral mixed sediment	0.1	0.0	344.6	20.3	2.7	0.2	347.3	20.4	1700.3
Circalittoral rock and biogenic reef	0	0	221.1	15.2	0.7	0.0	221.8	15.2	1458.2
Infralittoral coarse sediment	0.1	0.0	874.6	61.3	0	0	874.6	61.3	1427.1
Offshore circalittoral rock and biogenic reef	0	0	149.7	30.7	0	0	149.7	30.7	488.4
Infralittoral rock and biogenic reef	0	0	12.9	4.4	0	0	12.9	4.4	293.9
Infralittoral mud	0	0	13.9	5.8	0.5	0.2	14.4	6.0	241.8
Infralittoral mixed sediment	0	0	0.2	0.3	0	0	0.2	0.3	90.6

Table A2.4 Overview of physical loss and physical disturbance for the Swedish EEZ within the North Sea ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	0.0	0.0	8233.2	58.6	0	0	8233.2	58.6	14044.3
Offshore circalittoral mud	0.0	0.0	5265.8	69.6	0	0	5265.8	69.6	7562.1
Upper bathyal sediment	0	0	1492.7	80.3	0	0	1492.7	80.3	1858.9
Offshore circalittoral mixed sediment	0	0	683.1	53.6	0	0	683.1	53.6	1274.4
Offshore circalittoral sand	0	0	278.5	49.9	0	0	278.5	49.9	558.3
Circalittoral mud	0	0	16.2	3.1	0	0	16.2	3.1	528.4
Circalittoral mixed sediment	0	0	0.4	0.1	0	0	0.4	0.1	404.1
Offshore circalittoral rock and biogenic reef	0	0	130.6	36.5	0	0	130.6	36.5	358.1
Offshore circalittoral coarse sediment	0	0	241.4	79.5	0	0	241.4	79.5	303.6
Circalittoral rock and biogenic reef	0	0	74.7	30.6	0	0	74.7	30.6	243.7
Infralittoral rock and biogenic reef	0	0	24.4	10.6	0	0	24.4	10.6	229.2
Circalittoral sand	0	0	0	0	0	0	0	0	203.8
Infralittoral mud	0	0	5.9	3.3	0	0	5.9	3.3	181.6
Circalittoral coarse sediment	0	0	0.9	0.6	0	0	0.9	0.6	152.4
Infralittoral sand	0	0	16.8	16.7	0	0	16.8	16.7	100.9
Infralittoral coarse sediment	0	0	0.7	1.3	0	0	0.7	1.3	51.0
Infralittoral mixed sediment	0	0	1.0	3.1	0	0	1.0	3.1	33.9

Table A2.5 Overview of physical loss and physical disturbance for the German EEZ and by MSFD broad habitat type. No data are available on removal by aggregate extraction. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	0.8	0.0	26066.0	68.2	-	-	26066.0	68.2	38195.0
Circalittoral sand	0.2	0.0	8901.5	60.6	-	-	8901.5	60.6	14698.5
Offshore circalittoral sand	0.3	0.0	9000.7	71.7	-	-	9000.7	71.7	12554.8
Offshore circalittoral mud	0.2	0.0	5204.3	82.8	-	-	5204.3	82.8	6288.9
Infralittoral sand	0.0	0.0	1057.8	71.1	-	-	1057.8	71.1	1487.6
Circalittoral coarse sediment	0.0	0.0	479.9	47.8	-	-	479.9	47.8	1003.0
Circalittoral mud	0.0	0.0	630.7	68.0	-	-	630.7	68.0	927.8
Unknown (Na)	0	0	537.2	77.4	-	-	537.2	77.4	694.1
Offshore circalittoral coarse sediment	0	0	71.4	30.7	-	-	71.4	30.7	232.5
Offshore circalittoral mixed sediment	0	0	78.2	54.5	-	-	78.2	54.5	143.6
Infralittoral mud	0	0	82.5	75.2	-	-	82.5	75.2	109.8
Circalittoral mixed sediment	0	0	22.0	40.3	-	-	22.0	40.3	54.4

Table A2.6 Overview of physical loss and physical disturbance for the Dutch EEZ and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	11.8	0.0	48992.2	79.2	163.2	0.3	49047.0	79.3	61830.0
Offshore circalittoral sand	3.4	0.0	18210.0	76.1	13.7	0.1	18212.6	76.1	23919.0
Circalittoral sand	4.2	0.0	13679.0	77.0	81.7	0.5	13702.4	77.1	17767.9
Offshore circalittoral mud	3.2	0.0	12086.2	87.1	9.6	0.1	12086.2	87.1	13871.9
Circalittoral coarse sediment	0.1	0.0	1302.5	67.5	0.7	0.0	1303.2	67.6	1929.1
Unknown (Na)	0	0	837.3	68.9	0	0	837.3	68.9	1215.9
Circalittoral mud	0.4	0.0	972.8	92.2	56.2	5.3	1000.1	94.8	1055.3
Offshore circalittoral coarse sediment	0.1	0.0	927.5	91.9	0	0	927.5	91.9	1009.7
Infralittoral sand	0	0	726.7	93.6	1.2	0.2	727.6	93.7	776.5
Infralittoral mud	0	0	145.3	94.2	0.0	0.0	145.3	94.2	154.3
Infralittoral coarse sediment	0	0	62.0	84.0	0	0	62.0	84.0	73.8
Circalittoral mixed sediment	0.2	0.6	23.9	63.6	0	0	23.9	63.6	37.5
Offshore circalittoral mixed sediment	0	0	19.0	100.0	0	0	19.0	100.0	19.0

Table A2.7 Overview of physical loss and physical disturbance for the Danish EEZ within the North Sea ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	2.5	0.0	49812.4	66.5	86.4	0.1	49858.8	66.6	74891.7
Circalittoral sand	0.4	0.0	13829.4	73.9	21.3	0.1	13845.6	74.0	18703.2
Offshore circalittoral mud	1.3	0.0	14946.8	84.2	0	0	14946.8	84.2	17744.9
Offshore circalittoral sand	0.5	0.0	11818.0	77.3	0.4	0.0	11818.4	77.3	15281.6
Infralittoral sand	0.0	0.0	907.8	14.9	5.4	0.1	909.9	15.0	6076.2
Circalittoral coarse sediment	0.0	0.0	2359.8	53.4	17.9	0.4	2372.8	53.7	4422.3
Circalittoral mixed sediment	0.0	0.0	1574.8	60.0	24.3	0.9	1577.8	60.1	2626.4
Offshore circalittoral mixed sediment	0.0	0.0	1441.9	60.5	0	0	1441.9	60.5	2382.2
Offshore circalittoral coarse sediment	0.0	0.0	1018.1	47.0	0.0	0.0	1018.1	47.0	2167.7
Circalittoral mud	0	0	953.8	51.0	0	0	953.8	51.0	1869.0
Infralittoral mud	0	0	0.2	0.0	0	0	0.2	0.0	1303.1
Infralittoral mixed sediment	0	0	47.5	3.9	17.1	1.4	59.2	4.9	1208.5
Upper bathyal sediment	0	0	861.2	87.4	0	0	861.2	87.4	985.7
Infralittoral coarse sediment	0.0	0.0	53.0	43.8	0	0	53.0	43.8	120.9

Table A2.8 Overview of physical loss and physical disturbance for the Belgian EEZ and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	0.2	0.0	3980.5	99.5	109.4	2.7	3980.5	99.5	3999.9
Offshore circalittoral sand	0.1	0.0	1666.0	99.3	42.3	2.5	1666.0	99.3	1677.3
Circalittoral sand	0.1	0.0	925.5	99.5	51.8	5.6	925.5	99.5	930.0
Offshore circalittoral coarse sediment	0.0	0.0	520.9	100.0	0.1	0.0	520.9	100.0	520.9
Circalittoral mud	0	0	480.8	99.3	15.2	3.1	480.8	99.3	484.3
Infralittoral sand	0	0	116.6	100.0	0	0	116.6	100.0	116.6
Offshore circalittoral mud	0.0	0.0	96.4	100.0	0	0	96.4	100.0	96.4
Circalittoral coarse sediment	0	0	77.4	100.0	0	0	77.4	100.0	77.4
Infralittoral mud	0	0	38.7	100.0	0	0	38.7	100.0	38.7
Infralittoral coarse sediment	0	0	19.5	100.0	0	0	19.5	100.0	19.5
Unknown (Na)	0	0	19.4	100.0	0	0	19.4	100.0	19.4
Offshore circalittoral mixed sediment	0	0	19.3	100.0	0	0	19.3	100.0	19.3

1.7 Physical loss (D6C1/C4) and physical disturbance (D6C2) per subdivision

The spatial extent of physical loss and disturbance is shown for Kattegat (Table A2.9), English Channel (Table A2.10), Southern North Sea (Table A2.11), and Northern North Sea (Table A2.12), based on management units defined by OSPAR as subregion classifications (OSPAR subregions L.2.2.1, L.2.2.2, L.2.2.5, and L.2.2.7). The methodology used to estimate physical loss and physical disturbance is similar to the estimation of physical loss and physical disturbance for the entire North Sea ecoregion. Shapefiles of the different subdivisions are downloaded from odims.ospar.org.

Table A2.9 Overview of physical loss and physical disturbance for Kattegat and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	0.1	0.0	8698.4	37.4	18.3	0.1	8713.5	37.4	23273.1
Offshore circalittoral mud	0.0	0.0	5766.5	71.2	0	0	5766.5	71.2	8097.1
Infralittoral sand	0.0	0.0	313.4	6.1	5.4	0.1	315.5	6.1	5138.2
Offshore circalittoral sand	0.0	0.0	1003.4	33.9	0.4	0.0	1003.7	33.9	2963.0
Offshore circalittoral mixed sediment	0.0	0.0	600.5	41.9	0	0	600.5	41.9	1431.7
Infralittoral mixed sediment	0	0	35.9	3.0	7.3	0.6	43.2	3.6	1208.7
Circalittoral mud	0	0	434.2	36.8	0	0	434.2	36.8	1179.8
Infralittoral mud	0	0	0.2	0.0	0	0	0.2	0.0	1159.5
Offshore circalittoral coarse sediment	0.0	0.0	383.2	49.8	0.0	0.0	383.2	49.8	768.7
Circalittoral mixed sediment	0	0	18.3	4.1	0	0	18.3	4.1	442.9
Circalittoral sand	0	0	65.2	15.3	0	0	65.2	15.3	426.1
Circalittoral coarse sediment	0	0	1.7	1.0	5.3	3.1	7.0	4.1	170.4
Infralittoral coarse sediment	0	0	49.4	36.1	0	0	49.4	36.1	136.8
Infralittoral rock and biogenic reef	0	0	1.2	1.7	0	0	1.2	1.7	67.1
Offshore circalittoral rock and biogenic reef	0	0	25.6	38.5	0	0	25.6	38.5	66.5
Circalittoral rock and biogenic reef	0	0	0	0	0	0	0	0	16.6

Table A2.10 Overview of physical loss and physical disturbance for the English Channel and by MSFD broad habitat type. No data are included on removal by aggregate extraction from the French EEZ. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	0.4	0.0	35716.7	65.9	28.0	0.1	35731.7	65.9	54229.6
Offshore circalittoral coarse sediment	0	0	21325.0	76.8	11.1	0.0	21325.1	76.8	27775.5
Circalittoral coarse sediment	0.1	0.0	5049.5	46.5	14.6	0.1	5062.0	46.6	10863.5
Circalittoral sand	0.2	0.0	3252.0	70.0	1.1	0.0	3253.1	70.1	4643.1
Offshore circalittoral sand	0	0	1915.9	93.0	0	0	1915.9	93.0	2060.6
Offshore circalittoral mixed sediment	0.1	0.0	1394.4	76.5	0	0	1394.4	76.5	1823.9
Infralittoral sand	0.0	0.0	758.0	53.4	0	0	758.0	53.4	1420.2
Infralittoral coarse sediment	0	0	585.6	41.4	0	0	585.6	41.4	1416.0
Circalittoral rock and biogenic reef	0	0	106.3	11.7	0.7	0.1	106.9	11.8	909.1
Circalittoral mud	0	0	389.4	61.4	0	0	389.4	61.4	634.1
Offshore circalittoral rock and biogenic reef	0	0	173.8	28.2	0	0	173.8	28.2	616.8
Circalittoral mixed sediment	0	0	132.0	21.6	0	0	132.0	21.6	610.7
Infralittoral rock and biogenic reef	0	0	144.4	27.6	0	0	144.4	27.6	523.4
Unknown (Na)	0	0	60.2	16.2	0	0	60.2	16.2	373.0
Infralittoral mud	0	0	231.5	64.1	0.5	0.1	232.0	64.2	361.0
Offshore circalittoral mud	0	0	198.8	100.0	0	0	198.8	100.0	198.8

Table A2.11 Overview of physical loss and physical disturbance for the Southern North Sea and by MSFD broad habitat type. No data are included on removal by aggregate extraction from the German EEZ. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	49.5	0.0	135994.0	65.4	391.2	0.2	136126.4	65.4	208063.9
Offshore circalittoral sand	20.5	0.0	46877.1	68.2	62.1	0.1	46883.1	68.2	68748.2
Circalittoral sand	11.3	0.0	37657.4	64.5	152.1	0.3	37698.6	64.6	58341.5
Offshore circalittoral mud	5.0	0.0	26003.1	87.6	10.0	0.0	26003.1	87.6	29681.9
Circalittoral coarse sediment	4.8	0.0	5467.4	33.7	29.5	0.2	5490.2	33.8	16247.7
Offshore circalittoral coarse sediment	5.3	0.0	7085.8	49.4	27.1	0.2	7108.9	49.6	14335.0
Infralittoral sand	1.6	0.0	4917.1	68.2	1.2	0.0	4917.9	68.3	7205.6
Circalittoral mud	0.4	0.0	2799.8	71.7	71.4	1.8	2827.1	72.4	3903.7
Circalittoral mixed sediment	0.3	0.0	1373.4	47.0	27.0	0.9	1379.1	47.2	2920.9
Unknown (Na)	0	0	1465.9	51.8	0	0	1465.9	51.8	2829.5
Offshore circalittoral mixed sediment	0.2	0.0	1208.8	60.7	1.0	0.1	1209.9	60.8	1990.6
Infralittoral coarse sediment	0.1	0.0	845.8	67.7	0	0	845.8	67.7	1248.9
Infralittoral mud	0	0	279.7	50.4	0.0	0.0	279.7	50.4	554.9
Infralittoral mixed sediment	0	0	12.6	22.7	9.8	17.7	17.0	30.6	55.6

Table A2.12 Overview of physical loss and disturbance for the Northern North Sea and by MSFD broad habitat type. No data are included on removal by aggregate extraction from the Norwegian EEZ. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Loss (km^2)	Loss (%)	Abrasion (km^2)	Abrasion (%)	Removal (km^2)	Removal (%)	Total disturbance footprint (km^2)	Total disturbance footprint (%)	Total area (km^2)
Total region	111.7	0.0	166131.2	47.4	4.3	0.0	166131.2	47.4	350345.7
Offshore circalittoral sand	65.2	0.0	78698.2	47.1	0	0	78698.2	47.1	166927.6
Offshore circalittoral mud	41.3	0.1	57165.1	81.8	0	0	57165.1	81.8	69919.0
Upper bathyal sediment	0.0	0.0	14423.2	23.8	0	0	14423.2	23.8	60633.5
Offshore circalittoral coarse sediment	4.5	0.0	8416.9	35.2	0	0	8416.9	35.2	23917.5
Unknown (Na)	0.1	0.0	224.7	3.6	0	0	224.7	3.6	6280.3
Circalittoral sand	0.2	0.0	3562.0	70.1	4.3	0.1	3562.0	70.1	5083.3
Offshore circalittoral rock and biogenic reef	0	0	475.9	12.2	0	0	475.9	12.2	3910.7
Upper bathyal sediment or Upper bathyal rock and biogenic reef	0	0	104.5	4.1	0	0	104.5	4.1	2552.9
Upper bathyal rock and biogenic reef	0	0	189.0	7.9	0	0	189.0	7.9	2391.6
Offshore circalittoral mixed sediment	0.1	0.0	1158.0	53.5	0	0	1158.0	53.5	2165.7
Circalittoral rock and biogenic reef	0	0	170.8	10.7	0	0	170.8	10.7	1601.0
Circalittoral mud	0	0	255.3	21.6	0	0	255.3	21.6	1182.9
Circalittoral coarse sediment	0.1	0.0	383.6	41.5	0	0	383.6	41.5	923.5
Infralittoral rock and biogenic reef	0	0	56.0	6.3	0	0	56.0	6.3	891.5
Circalittoral mixed sediment	0	0	442.1	52.1	0	0	442.1	52.1	848.2
Infralittoral sand	0	0	337.7	56.2	0	0	337.7	56.2	600.9
Infralittoral mud	0	0	17.7	6.0	0	0	17.7	6.0	297.4
Infralittoral coarse sediment	0	0	50.1	33.5	0	0	50.1	33.5	149.6
Infralittoral mixed sediment	0	0	0.2	0.4	0	0	0.2	0.4	68.8

2 Spatial extent of abrasion by bottom-contacting fishing gears in the Bay of Biscay and the Iberian Coast, Celtic Seas, and Baltic Sea ecoregions

This demonstration illustrates the application of the assessment process for abrasion from fishing with mobile bottom-contacting gears, which gives rise to physical disturbance (D6C2) of the seabed. The assessment is done for the Bay of Biscay and the Iberian Coast (Table A2.13), Celtic Seas (Table A2.14), and Baltic Sea (Table A2.15) ecoregions for the year 2016.

For all regions, VMS and logbook data are collected and stored by the national fishery agencies. Data that ICES receive are processed using regionally coherent, established, and published methods (see Annex 1, Table A1.6). Vessel speeds representing fishing activity are assigned to a 0.05° × 0.05° grid (the c-square approach), each covering about 15 km² at 61°N latitude, which is the spatial resolution adopted by ICES (ICES, 2017). The swept-area ratio (SAR, also defined as fishing intensity) is the swept area divided by the surface area of the grid cell. Data on fishing abrasion in these regions are taken from the latest ICES VMS and logbook data call.

The spatial extent of abrasion is calculated by multiplying the swept-area ratio of each 0.05° × 0.05° c-square cell with the surface area of the cell, where abrasion in a specific grid cell cannot be greater than the area of that grid cell. Abrasion is linked to a MSFD broad habitat type assigned at a c-square resolution of 0.05° × 0.05° using the midpoint of the c-square. A map of the MSFD broad habitat types was downloaded from EMODnet in September 2019.

Table A2.13 Overview of physical disturbance by abrasion for the Bay of Biscay and the Iberian Coast ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Abrasion (km²)	Abrasion (%)	Total area (km²)
Total region	116588.5	15.3	763905.7
Abyssal	109.6	0.0	515431.3
Upper bathyal sediment	15134.7	40.9	36983.3
Lower bathyal sediment or Lower bathyal rock and biogenic reef	205.2	0.6	35901.8
Offshore circalittoral sand	29074.1	82.7	35146.5
Offshore circalittoral mud	26893.1	85	31640.7
Upper bathyal sediment or Upper bathyal rock and biogenic reef	3470.5	15.8	21954.3
Circalittoral sand	8917.4	54.2	16444.5
Offshore circalittoral coarse sediment	11049.7	87.7	12599.8
Lower bathyal sediment	38.7	0.3	12077.6
Circalittoral coarse sediment	6866.6	78.7	8721.7
Circalittoral rock and biogenic reef	1983.3	26.6	7442.1
Offshore circalittoral rock and biogenic reef	4934.7	68.1	7247.8
Circalittoral mud	1736	27.3	6363.2
Offshore circalittoral mixed sediment	3351.7	95	3529.5
Circalittoral mixed sediment	1509.8	47.9	3150.4
Infralittoral sand	245.2	10	2442.2
Infralittoral rock and biogenic reef	86.9	4	2177.3
Upper bathyal rock and biogenic reef	769.4	38.7	1990.5
Unknown (Na)	146.2	23.3	626.2
Lower bathyal rock and biogenic reef	2	0.3	581.8
Infralittoral mud	39.3	6.9	569.5
Infralittoral coarse sediment	19.5	3.7	523.1
Infralittoral mixed sediment	5	1.4	360.5

Table A2.14 Overview of physical disturbance by abrasion for the Celtic Seas ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Abrasion (km²)	Abrasion (%)	Total area (km²)
Total region	293692.5	32	917024.8
Upper bathyal sediment	56854.1	36.4	156298.6
Abyssal	209.4	0.2	138244.4
Offshore circalittoral coarse sediment	65934.9	50.6	130307.1
Offshore circalittoral sand	84479.9	66.2	127617
Lower bathyal sediment	219.7	0.2	114013.4
Offshore circalittoral mud	53818.6	82.9	64923.7
Upper bathyal sediment or Upper bathyal rock and biogenic reef	9213.9	21.3	43203.1
Unknown (Na)	9803	22.8	43041.9
Lower bathyal sediment or Lower bathyal rock and biogenic reef	76.6	0.2	33772.5
Circalittoral coarse sediment	2439.4	13.9	17537.4
Circalittoral sand	2192	19.8	11063.6
Offshore circalittoral mixed sediment	2877.8	31.1	9260.5
Circalittoral rock and biogenic reef	1283.1	14.4	8883.6
Offshore circalittoral rock and biogenic reef	1989.1	28.6	6961.5
Circalittoral mud	1653.6	33.5	4932.9
Infralittoral rock and biogenic reef	153.6	8.8	1741.2
Infralittoral sand	62.2	4.2	1469.8
Circalittoral mixed sediment	275.7	26.5	1040.6
Upper bathyal rock and biogenic reef	59.6	7.1	834.9
Infralittoral coarse sediment	54.4	7.2	751.3
Infralittoral mud	37.3	7.8	476.9
Lower bathyal rock and biogenic reef	0	0	419.3
Infralittoral mixed sediment	4.4	1.9	229.6

Table A2.15 Overview of physical disturbance by abrasion for the Baltic Sea ecoregion and by MSFD broad habitat type. A value of 0.0 means larger than zero and smaller than 0.05.

Habitat	Abrasion (km²)	Abrasion (%)	Total area (km²)
Total region	39479.4	10.5	377727.5
Circalittoral mixed sediment	2846.2	2.6	108284.1
Circalittoral mud or Circalittoral sand	3126.8	6	52514.4
Offshore circalittoral mud or Offshore circalittoral sand	1224.9	3.6	33869.1
Circalittoral sand	6339.5	19.2	32933.3
Infralittoral sand	4250.2	16.4	25853.6
Circalittoral mud	3951	17.3	22803.2
Infralittoral mixed sediment	456.1	2.1	21369.4
Offshore circalittoral mud	10169.4	48.2	21091.8
Offshore circalittoral mixed sediment	4959.4	25.1	19757.1
Circalittoral coarse sediment	225.3	2	11098.4
Infralittoral coarse sediment	245.3	3.3	7501.1
Circalittoral rock and biogenic reef	38.6	0.6	6405.7
Infralittoral rock and biogenic reef	44.8	1.1	4109.7
Infralittoral mud or Infralittoral sand	21.8	0.6	3940.6
Offshore circalittoral sand	1183	44.3	2671.8
Infralittoral mud	361.3	15.4	2353.8
Offshore circalittoral coarse sediment	35.5	4.4	807.5
Offshore circalittoral rock and biogenic reef	0	0	287.1
Unknown (Na)	0	0	75.8