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A CEDA Information Paper

DREDGING AND SEAFLOOR INTEGRITY

Central Dredging Association

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DREDGING AND SEAFLOOR INTEGRITY

This paper has been prepared by a dedicated working group, part of the Environment Commission (CEC), the Central Dredging Association (CEDA).

Preamble

EU legislation requires that the potential impacts of marine dredging and disposal of dredged material are assessed in the context of the risk of not achieving or maintaining Good Environmental Status (GES) as defined for Descriptor 6 (D6) Seafloor Integrity, one of the eleven descriptors in the Marine Strategy Framework Directive (MSFD). The GES for D6 Seafloor Integrity is defined as Seafloor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded, and benthic ecosystems in particular are not adversely affected'.

This report describes the MSFD descriptor D6 Seafloor Integrity and its criteria and methodological standards in relation to dredging and disposal activities. Based on scientific studies, grey literature, and case studies, this report explains what Seafloor Integrity is and why it is important, how different types of dredging, disposal, and placement of dredged material or marine construction activities may affect Seafloor Integrity and discusses the relevant spatial and time scales in relation to assessing the possible impact of dredging projects under MSFD requirements. It also describes the cumulative effects of dredging projects on benthic ecosystems, as well as the benthic community's potential for recovery. Lastly, we give recommendations for CEDA and its members on how to act in relation to further developments regarding this topic.

Abbreviations

BHD	Birds and Habitats Directives
BHT(EUNIS)	Broad Habitat Types
CICES	Common International Classification of Ecosystem Services
D6	(MSFD) Descriptor 6 Seafloor Integrity
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
EUNIS	European Nature Information System
GES	Good Environmental Status
HD	Habitats Directive
HELCOM	Baltic Marine Environment Protection Commission (Helsinki Commission)
ICES tion	International Council for the Explora- of the Sea
MSFD	Marine Strategy Framework Directive
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo-Paris Convention)
WFD	Water Framework Directive

1. What is Seafloor Integrity?

This chapter gives a concise definition of the concept of Seafloor Integrity as defined under the MSFD, and its interpretation as given by the authors of the MSFD Task Group on D6 Seafloor Integrity.

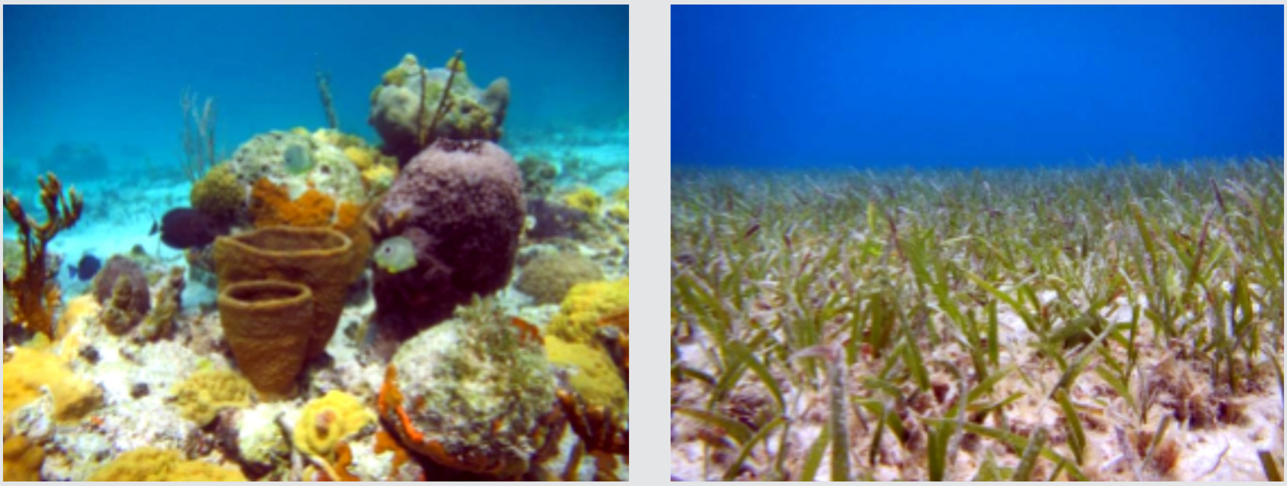

Figure 1.1: Examples of shallow benthic water hard substrate (left) and soft bottom (right) ecosystems. *Photos: Remment ter Hofstede.*

1.1 Seafloor Integrity under MSFD

According to the MSFD (Rice et al., 2012), the "Seafloor" is characterized by the physical and chemical characteristics of the seabed and the water column, such as water depth, salinity, light availability, substrate type, temperature, concentrations of oxygen, organic carbon, nutrients and pollutants, as well as their biological properties consisting of the composition, abundance, and production of organisms living in and on the seafloor. One of the most important physical characteristics is the seabed substrate, which can be broadly classified into soft substrates (e.g. sand, mud, gravel, and mixed sediments), hard substrates (e.g. bedrock or boulders), and biogenic substrate (e.g. maerl, shellfish beds, or coral). The seabed biology includes bacteria, flora, and fauna living either in or on the seafloor (see Figure 1.1 and Figure 1.2). The flora and fauna interact with the physical and chemical environment in the sediment and the water above the seafloor. Together, the physico-chemical and biological environments define the benthic ecosystems with types ranging from relatively species-poor communities in sandy or highly dynamic seafloors to very diverse communities at coral and stony reefs.

"Integrity" refers to the spatial connectedness within and between benthic ecosystems, allowing their natural processes to interact instead of being artificially isolated from each other (Rice et al., 2012). In other words, Seafloor Integrity reflects the level of structure and functioning of marine benthic ecosystems within the boundary conditions of the physical, chemical, and biological characteristics of the seafloor. Maintaining Seafloor Integrity is needed to preserve benthic resources and marine biodiversity. Furthermore, Rice et al. (2012) pointed out that "Good Environmental Status" cannot be defined exclusively as a "pristine" situation, i.e. without any human interference, and concluded that human activities can be considered sustainable if two conditions are met: (i) the pressures associated with those uses do not hinder the ecosystem components from retaining their natural diversity, productivity, and dynamic ecological processes and (ii) recovery from perturbations such that the attributes lie within their range of historical natural variation must be rapid and secure."

Figure 1.2: Conceptual drawing of typical benthic infauna. (*source: https://graysreef.noaa.gov/science/expeditions/2012_nancy_foster1/shell.html*)

To meet the aim of the MSFD, to achieve and maintain GES by 2020, each Member State is required to develop criteria, indicators, and targets for Seafloor Integrity. Although the criteria and targets are being developed at a national scale, the Regional Sea Conventions (e.g. OSPAR, HELCOM) are co-ordinating this process. This makes sense as the marine environment is not defined by country borders. The criteria, indicators and targets developed by Member States should, to be effective, be coherent within the different marine regions or sub-regions, especially with neighbouring countries that share similar waters.

The European marine waters are diverse and range from large open oceanic systems such as the Atlantic Ocean to semi-enclosed systems like the Baltic and Black Seas. Obviously, these European waters host a broad range of benthic habitats (http://www.emodnet.eu/seabed-habitats) for which specific criteria, indicators, and targets are (to be) developed to assess environmental status and develop programmes consisting of measures that describe initiatives implemented to achieve the aforementioned goals (European Commission, 2008). Many benthic ecosystems are highly biodiverse, such as seagrass meadows and coral or stone reefs, and some are very sensitive to dredging and disposal activities. Other benthic ecosystems are considered less sensitive, such as for example the deep parts of the Baltic Sea, where nearly permanent anoxic bottom-water conditions occur due to a low frequency of inflow of high saline oxygenated Kattegat water and a stratified water column, or permanently morphologically changing bottoms of sandy channels in estuaries.

Along with Descriptor 6 Seafloor Integrity, Descriptor 1 "Biological Diversity" forms an inherent set to describe the seabed habitat. Indeed, seafloor integrity should be at a level that ensures that the structure and functions of the ecosystems are safeguarded, and benthic ecosystems in particular are not adversely affected. From there, the recent EU Biodiversity Strategy 2030 clearly formulates a strategy to aim for at least 30 % of the sea to be protected – with at least one third (i.e. 10 %) of that area being strictly protected. Within this framework, there should be specific focus on areas with high biological diversity value or potential.

The diversity of marine benthic habitats in Europe is illustrated in Figure 1.3. Note that the map is added as an illustration to show the large

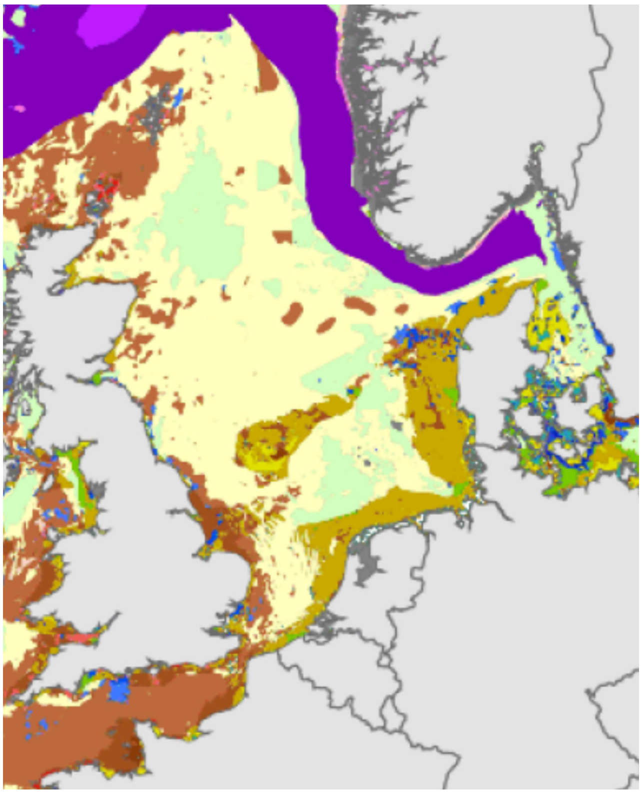

Figure 1.3: Broad-scale seabed habitat map for European waters (focusing on the North Sea), displaying the diversity in MSFD benthic broad habitat types. For further details and legends: http://www.emodnet.eu/seabed-habitats).

number of different benthic habitats. Each colour signifies one of the so-called benthic broad habitat types (BHT, European Commission, 2017). The legend is omitted, since this would render the figure unreadable; the map and its legend can be found in more detail on the indicated EMODnet website.The main BHT follow the revised EUNIS classification (Evans et al., 2017) and are delineated along defined depth and light gradients: littoral, infralittoral, circalittoral, bathyal, and abyssal. Another delineation is based on substrate type: rock and biogenic reef, and several types of sediment (mud, mixed, and coarse).

1.2 What is the value of the seafloor?

Seafloor ecosystems support valuable ecosystem services, which are defined as the contributions that ecosystems make to human well-being and are distinct from the goods and benefits that people subsequently derive from them (CICES[1]). These contributions are framed in terms of 'what ecosystems do' for people. In the latest version of CICES, the definition of each service identifies both the purposes or uses that people have for the different kinds of ecosystem service, and the ecosystem attributes or behaviours that support them. Ecosystem services comprise both biotic and abiotic outputs.

Examples of ecosystem services delivered by the seafloor ecosystems are the provisioning of fishery resources, sand for building, nutrient cycling, and coastal defence (Galparsoro et al., 2014). Coastal benthic ecosystems play a key role in supporting primary production and provide important spawning habitats and food resources for fish. Furthermore, benthic ecosystems with rich vegetation such as mangroves, seagrass meadows, maerl beds (a habitat of coralline red algae), and coral reefs are important carbon sinks, making them important contributors to the global atmospheric CO2 balance. Also, mangroves, seagrass meadows, and biogenic reefs serve as natural coastal defence systems as they create barriers that attenuate wave action and prevent erosion.

1. CICES - Common International Classification of Ecosystem Services version 5.1

2. How does dredging and disposal affect Seafloor Integrity?

This chapter describes the direct and indirect effects of dredging and disposal on seafloor integrity. It also briefly addresses the issues of scale, knowledge gaps, cumulative effects, and recovery when considering the assessment of the effects of dredging and disposal/placement of dredged material on the seafloor.

2.1 Effects of dredging and disposal on the seafloor

Dredging and disposal/placement will, by its very physical nature, change the seafloor[2]. An overview of the potential effects of dredging or disposal on the different components of seafloor integrity are shown in Table 2.1 (Hitchcock et al., 2002; Newell et al., 2004).

Table 2.1 Overview of the potential effects on seafloor integrity (habitats and species) resulting from the removal of sediment by extraction, dredging, or sediment disposal.

Direct effect	Indirect effect	Impact on seafloor integrity
1. Habitat loss		Death of organisms, reduced biodiversity
2. Increased suspended sediment concentration	Increased light attenuation	Reduced primary production and carbon flow to the seafloor, reduced benthic biomass
	Decreased filtering efficiency (filter feeders)	Reduced biomass of filter feeders
	Decreased predation efficiency for visual predators	Reduced biomass of predators
3. Sedimentation		Burial resulting in reduced biomass and density, as well as death of individuals
	Changed sediment composition	Changes in biodiversity and biomass
4. Release of organic matter and nutrients		Hypoxia, dominance of eutrophication related species
5. Introduction of contaminants	Changes in water quality	Bioaccumulation of toxins in marine food chain
		Changes in biodiversity and dominance of species tolerant to pollution
6. Changes in hydro-morphological regime	Hydrodynamic changes, altered grain size	Changes in biodiversity and biomass. Loss of habitats and species
	Changed light attenuation	Reduced primary production and carbon flow to the seafloor, reduced benthic biomass

2. Note that while dredging and disposal of dredged material are two separate activities, impacts are highly comparable. Therefore, and for the sake of readability, from here on we refer to 'dredging' alone. When specific, different disposal effects are referred to, this has been mentioned.

The impact on the seafloor and its biological components depends on the intensity of disturbance which can be related to the type, intensity and spatial extent of the equipment and the dredging method used. There are many more parameters that influence the impact of dredging and disposal/placement activities, for example if the disposed material is similar to the sediments at the disposal site or the natural morphodynamic activity at the dredging and disposal site, the amount of material per area, the frequency etc. Disposal can be long term/ permanent or temporary; it can affect just the dredging or disposal location, or also its wider surroundings. As per the MSFD, the definition of physical loss is a permanent change to the seabed which has lasted or is expected to last for a period of 2 reporting cycles (12 years) or more. A physical disturbance is defined as a change to the seabed from which it can recover if the activity causing the disturbance pressure ceases. In general, dredging activities are temporary disturbances. However, in some cases of deep aggregate extraction in areas dominated by communities with slow recovery rates, the effect is more likely to be considered a loss since recovery is assessed to exceed 12 years. Furthermore, the intensity of a physical disturbance may lead, in time, to a permanent change from one habitat type to another and hence to physical loss.

The temporal and spatial impacts are dependent on local hydrodynamics, sediment characteristics, morphology and ecology, and the natural variability in these. For instance, the dredging of muddy sediment will generate a higher turbidity and larger plume of fine particles and have a stronger impact on the filtering efficiency of shellfish than the dredging of sandy sediments. Or, as biological communities in high energy environments naturally consist of species that can cope with the high frequency of disturbance and are constantly recolonising the areas, frequent maintenance dredging may insignificantly impact the community. Some of these effects and impacts are described in more detail below.

1. Habitat loss (permanent)

Habitat loss is the result of removing or covering seafloor features, and (as a result) permanently (>12 years) reducing local physical seafloor diversity. Apart from removing the organisms during dredging leading to the direct death of individuals, habitat loss results in a permanent reduction of biodiversity and biomass/abundance of species. The severity depends on the importance of the habitat and species, the capacity for regeneration, and the extent of habitat loss.

2. Increased suspended sediment concentration

Dredging activities may result in a temporary increase in turbidity. Small particles may stay in suspension for some time and have a rather high specific light attenuation as this is related to the relative surface area of the particles. Naturally, the amount and characteristics of the sediment dredged, the natural level and variability of suspended matter in the system, and the timing in relation to growth seasons and hydrodynamic conditions are major factors determining the ecological effects of the increased concentrations of suspended sediment. Reduced light availability for primary producers such as sea grasses, macroalgae, phytoplankton, and microphytobenthos indirectly impacts the production in the food web as these primary producers form the fundament of food for fish and other organisms. Furthermore, visual predators such as crabs and flatfish will be directly affected by low visibility, and these species can potentially lose their competitiveness towards other species. The magnitude of the impact of suspended sediment in each case depends on the dynamics of the existing natural conditions.

The fitness of filter feeders such as bivalves, and some polychaetes depend on the nutritional content of the particles they filter out of the water. A high content of inorganic material or material having a higher grain size may lead to a lower efficiency of the process and less energy uptake which may influences the fitness and growth of the organisms (Perrino et al., 2019).

3. Sedimentation
The suspended sediments will settle on the seafloor in variable distances from the activity. Sedimentation has the highest effects on sessile invertebrates that are not able to move up or away or not used to sediment in their environment like many hard substrate fauna (e.g. on reefs). Species that naturally live in highly mobile sediments are usually less vulnerable. Since the species composition of benthic communities is highly related to sediment characteristics (Ysebaert & Herman, 2002), the similarity of the sediment characteristics compared to that of the original sediment will be key to the ability of the benthic communities and habitats to recover.

4. Release of organic matter and nutrients
The release of organic matter and nutrients through dredging may result in enhanced food availability for benthic organisms, but also lead to oxygen deficiency through stimulating primary production and enhanced carbon flow to the sediment. Changes in food availability may lead to changes in species compositions, from which species that are used to eutrophic circumstances may profit more than other species. Oxygen deficiency may lead to death or reduced fitness of sediment organisms.

5.Introduction/removal of contaminated sediment
Removal of contaminated sediments (and relocation to a landfill or otherwise isolated area) will result in a positive change to the state of the seafloor and reduce potentially occurring bioaccumulation in marine organisms. On the other hand, dredging contaminated sediment and the disposal thereof usually also release contaminants into the water, which may lead to toxic effects and accumulation in biota. The likelihood and extent of the effect depend on the degree of contamination of the sediment, the intensity of the dredging, volume of disposed sediment, and on local hydrodynamic circumstances.

6. Changes in hydromorphological regime as an indirect effect of dredging projects (permanent)
Especially in shallow coastal habitats such as inner estuaries and lagoons, changes in the depth, shape and sedimentation of the seafloor may affect the character and extent of intertidal habitats, flow velocities, slopes of banks and channels, and the dynamics of erosion and sedimentation. Changes in flow lead to changes in shear stress, bed load of suspended particles and food availability, and to changes in the grain size of the sediment. Such parameters determine the biodiversity, biomass, and abundance of species living in and on the seafloor. The benthic ecosystem could potentially also benefit from seabed modification. If, for example, the sediment characteristics are changed from coarse to fine sediment, the seafloor will provide habitats for other benthic organisms and may increase biodiversity with a similar functional role in the ecosystem to the marine life that has been lost (Cooper et al., 2008). An example is that fine sediments from the Euro Canal, Rotterdam are disposed north of the canal and cause an increase in species diversity in comparison with the surrounding sandy sediments (van Dijk et al., 2017). Also, landscaping of deep extraction pits may contribute to positive changes in benthic communities (De Jong et al. 2015).

2.2 Assessment issues

2.2.1 Scaling

The scale for assessing seabed integrity is challenging because the initial impacts of human activities, in this case dredging and disposal/placement, are often short-term, local, and patchy, but in case of permanently changed hydromorphological conditions like some capital dredging projects, their consequences may extend further and last for a long time due to the physical and biotic processes of the environment. Such long-term consequences should not be assigned to the dredging operation as such, but to the overall project for which the dredging activities are carried out. In many cases, local and short-term effects can be assessed with relative confidence since many studies have been conducted showing such effects. When conducting such an assessment, e.g. in the context of an Environmental Impact Assessment, various guidance documents exist to set up such an assessment and best practices[3].

2.2.2 Cumulative effects

The International Council for the Exploration of the Sea (ICES 2019a) found that the key human activities that resulted in physical disturbance on the seabed were similar for the 4 EU regional seas examined: fishing was found to be the most extensive cause of physical abrasion, aggregate extraction and dredging were also of relevance in most regions but much less extensive. Apart from these, there were other human activities that affected seabed integrity such as aquaculture, eutrophication from riverine input, the installation of offshore oil and gas platforms, cables, and pipelines, coastal defence works, and the construction of offshore windfarms. Furthermore, climate change will directly and indirectly affect species composition or the food-web via a temperature increase, i.e. invasive species adapted to higher temperatures will replace native ones (Quante & Colijn, 2016). Although it is currently not clear how these multiple pressures affect species and habitats, the relative importance of the pressures can be evaluated based, for example, on the area exposed and the intensity of the pressure.

Consideration of geographical scale has significance for any assessment of cumulative effects. In relation to the geographical scale, the assessment must cover both the extent of the pressure factor and the extent of the potentially affected species and habitats (effects). The scale is not clear if one is to assess the effects of pressure factors operating on very different spatial and temporal scales. As the scale becomes larger, the importance of local pressure factors (e.g. local or site-specific pressure factors such as fishing, raw material extraction, and clotting) may become less important, and others (e.g. pressure factors such as eutrophication acting on the basin scale) more important (Therivel & Ross, 2007).

2.2.3 Recovery

In general, the assumption is that a benthic assemblage will recover to some state that occurred before the dredging or disposal/placement took place. However, the timescale over which the recovery occurs may be long. Recovery time for species is related to the regeneration time that, for pelagic organisms, can be

[3] E.g. https://www.bmapa.org/documents/BMAPA_TCE_Good_Practice_Guidance_04.2017.pdf, https://www.epa.wa.gov.au/sites/default/files/Policies_and_Guidance/Technical%20Guidance%20-%20EIA%20of%20Dredging%20Proposals-131216.pdf.

estimated to 0-2 years, and for benthic flora and fauna 1-10 years (maybe more for eelgrass for example). Studies reviewing reported benthic recovery following dredging and dredged material disposal (e.g. Wilber and Clark 2007, Foden et al 2009, Hill et al. 2011) conclude that impacts are difficult to predict but range from months to decades. However, there are some patterns: recovery was measured in months to a few years when activities were in shallow, naturally disturbed habitats, and if sediment was unconsolidated and fine, while recovery was measured in years for activities in deep, stable habitats, and if sediments were sand and gravel.

Examples of both fast and long-term recovery can be found in the literature. Investigations of recovery following aggregate extraction demonstrated that recovery is faster in high energy environments. Furrows rapidly disappear due to sediment transport and already 'disturbed' type communities rapidly recolonize and recover (Hill et al., 2011). A study by Froján et al. (2011) concluded that recovery of functional diversity to a level found in a neighbouring undredged habitat had not occurred at either high or low dredging activity sites five years after the cessation of dredging.

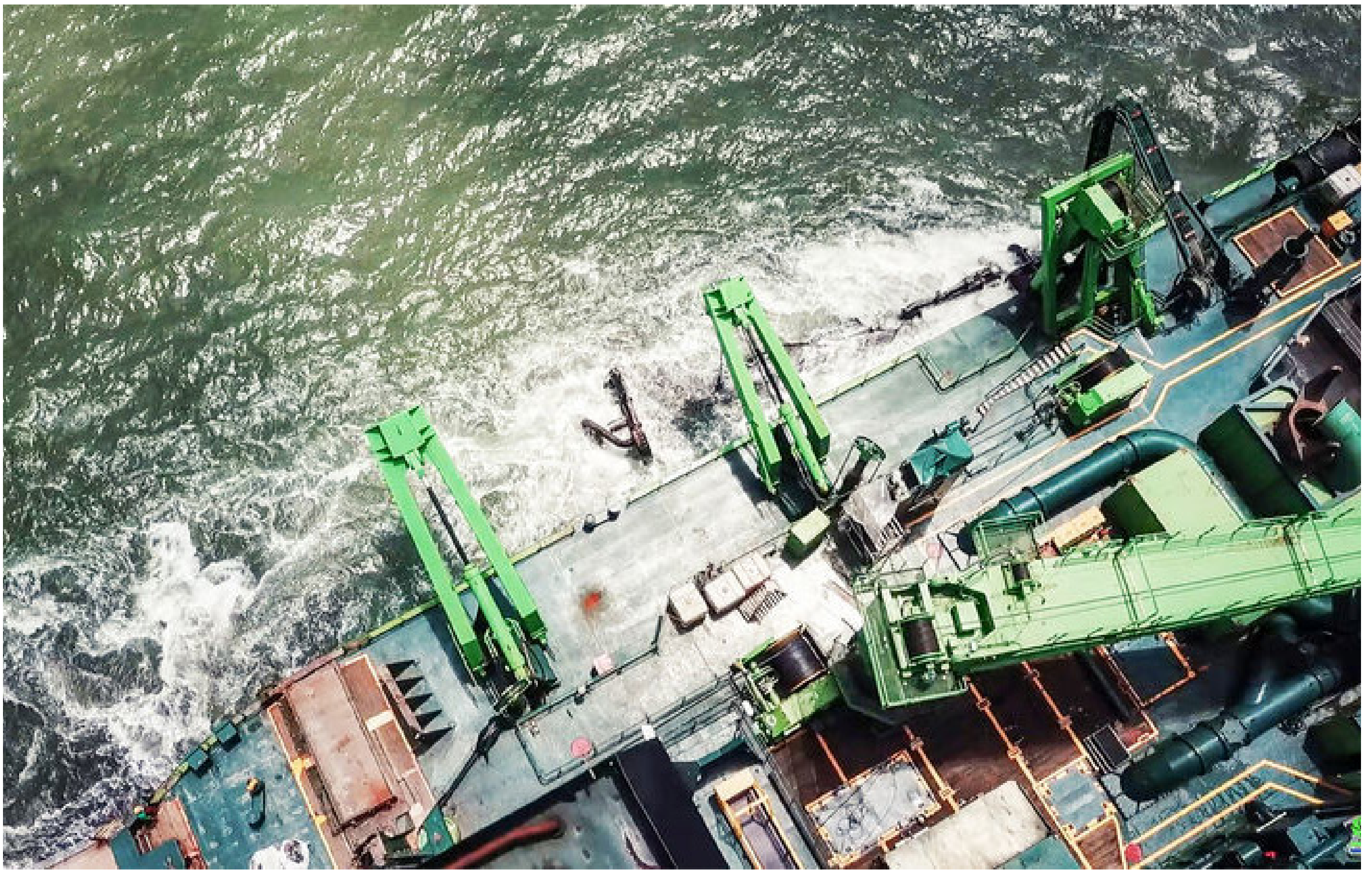

Figure 2.1: Dredged-induced turbidity dispersion

3. How is Seafloor Integrity assessed?

This chapter describes the EU MSFD status assessment required for Descriptor 6 Seafloor Integrity, to be carried out and reported by each EU member state every 6th year, and the use thereof in assessing the impact of dredging and disposal activities on the seafloor.

3.1 MSFD Seafloor Integrity assessment by member states: outline and embedding

The MSFD assessment area overlaps in parts with that of the Water Framework Directive (WFD), and with that of the Birds and Habitats Directives (BHD). Each directive's remit is such that they do not (or at least should not) conflict. This means that when overlapping, the MSFD assesses those indicators (criteria) that are not covered by the WFD. The same applies for the overlap between WFD and BHD and MSFD and BHD. For benthic environments, the BHD protection level mostly focuses on the habitat types and typical species present in the protected areas[4,5], as described in Annex I of the Habitats Directive (HD) (other annexes (II, IV and V) do not list any benthic species (Piha & Zampoukas, 2011)).

It should be noted that the effects of dredging and disposal of sediments affect ecosystem components that extend beyond the criteria of MSFD descriptor D6 and may be assessed under other MSFD descriptors. Resuspension of sediment particles affects water clarity and may impact primary production, which is assessed under descriptor D5 "Eutrophication". It may also affect the structure and functioning of the water column habitats and species, which fall under descriptor D1 "Biodiversity". The release of contaminants in the water and sediment falls under the assessment of D8 "Contaminants", and when these components are taken up by consumption species, this is assessed under descriptor D9 "Contaminants" in fish and other seafood.

This document does not address the descriptors other than D6 in specific. However, it should be noted that any consenting procedures may demand that assessments are carried out using criteria and thresholds from the other descriptors (in particular, the D1 "Biological Diversity" descriptor which is explicitly linked). Likewise, other indicators from WFD and BHD may also need to be included in the consenting procedures.

3.2 MSFD D6 Criteria & Indicators

Criteria are the characteristics of the descriptor that make the descriptor more concrete and quantifiable. Indicators are the quantified metrices that fill in the criteria; they are derived from the parameters that are measured in the

4. Sites of Community Importance (SCIs) are the pre-requisite step for establishing Special Areas of Conservation (SACs). Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) form the Natura 2000 network. In turn, the Natura 2000 network forms part of the Emerald Network of Areas of Special Conservation Interest (ASCIs) and is considered the EU's contribution to the Emerald Network.

5. The Birds Directive specifies so-called Special Protection Areas, whereas the Habitats Directive specifies Special Areas of Conservation or Sites of Community Interest.

field (or remotely, e.g. from satellites) and the threshold values of these indicators define the Good Environmental Status for the descriptor.

Each member state sets the criteria (indicators) and threshold values for Good Environmental Status (GES) which are set at the regional or sub-regional scale[6]. Regional Sea Conventions such as HELCOM and OSPAR develop indicators and thresholds that cover the cross-border indicators and fill in the gaps that have not been covered by the member states.

For the benthic seabed habitats (relating to the combined descriptors D1 "Biological Diversity" and D6 Seafloor Integrity), the following criteria are to be used to assess the extent to which GES is achieved:

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

The high-level assessment criteria for D6 Seafloor Integrity are further described in Table 3.1. The assessment is carried out for each broad habitat type (BHT, see Figure 1.3). The benthic broad habitat types are defined by depth (intertidal, subtidal etc.), light availability (relating to macrophytes), and substrate type (mud, sand, rocks). Details can be found in EC (2017)[7].

Indicators for the physical impact of human activities such as dredging are quantitatively described with the criteria D6C1 and especially D6C2 (which focus on the pressures) in Table 3.1. These criteria are relatively straightforward and comprise the quantitative description of the extent and spatial distribution of the seafloor surface lost or affected by a specific pressure.

However, relevant indicators and thresholds are needed to make the criteria workable in operational context. For example, the term 'distribution' in the first two criteria ("spatial extent and distribution") is operationally confusing: what would be its parameter, how would it be measured[8]? Also, criteria describing the "loss of habitat types" by the changes in a habitat's species structure and function need further specifications.

Regional Sea Conventions such as HELCOM for the Baltic Sea and OSPAR for the Northeast Atlantic Ocean have been working to develop cross-boundary indicators and thresholds for seabed habitats[9]. The OSPAR Ecological Quality Objectives for threatened and/or declining habitats (EcoQOs) identify 16 seabed habitats and associated communities which are threatened and/or declining and can contribute to the implementation of D6 of the MSFD (OSPAR 2011). Six indicators pertaining to D6 are included in the developing of common biodiversity

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6. http://mcc.jrc.ec.europa.eu/dev.py?N=24&O=135&titre_chap=D6%20Sea-floor%20integrity

7. EC (2017) COMMISSION DECISION (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU

8. From CEDA NAVIs comments to the MSFD May 2017

9. The Bucharest Convention and the Barcelona Convention are the regional sea conventions for respectively the Black Sea and the Mediterranean Sea. They have not yet developed comparable sets of seabed habitat indicators.

<table>
<tr><th>Criteria elements</th><th>Criteria</th><th>Methodological standards</th></tr>
<tr><td>Physical loss of the seabed (including intertidal areas).</td><td>D6C1 — Primary: Spatial extent and distribution of physical loss (permanent change) of the natural seabed.</td><td rowspan="2">Extent of loss

Extent of disturbance pressures

Scale of assessment:

Subdivision of region or subregion.</td></tr>
<tr><td>Physical disturbance to the seabed (including intertidal areas).</td><td>D6C2 — Primary: Spatial extent and distribution of physical disturbance pressures on the seabed.</td></tr>
<tr><td rowspan="3">Benthic broad habitat types if present in the region or subregion, and other habitat types as defined in the second paragraph.</td><td>D6C3 — Primary: Spatial extent of each habitat type which is adversely affected through change in its biotic and abiotic structure and its functions (e.g. through changes in species composition and their relative abundance, absence of particularly sensitive or fragile species, or species providing a key function, size structure of species), by physical disturbance.</td><td>Extent of adverse effects</td></tr>
<tr><td>D6C4 — Primary: The extent of loss of the habitat type, resulting from anthropogenic pressures, does not exceed a specified proportion of the natural extent of the habitat type in the assessment area.</td><td rowspan="2">Scale of assessment:

Subdivision of region or subregion, reflecting biogeographic differences in species composition of the broad habitat type.

Extent of loss – for each benthic broad habitat type in each assessment area

Extent of quality – at a single location as deviation from reference state quality</td></tr>
<tr><td>D6C5 — Primary: The extent of adverse effects from anthropogenic pressures on the condition of the habitat type, including alteration to its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species, or species providing a key function, size structure of species), does not exceed a specified proportion of the natural extent of the habitat type in the assessment area.</td></tr>
</table>

Table 3.1 The 5 primary criteria for assessing the environmental status of D6 Seafloor Integrity, including criteria elements and methodological standards

indicators under the OSPAR list that relate either to the seabed habitat quality or to the spatial extent of the pressure from human activities. Not all these indicators are operational yet. HELCOM, through the CORESET project, has developed a suite of indicators that are relevant for D6[10]. Five of the indicators are addressed at benthic habitats and communities. However, none of these indicators are sufficiently developed to be applied at the regional level of the Baltic Sea (HELCOM, 2013).

3.3 Assessment scales

Europe includes four marine regions, defined on the basis of geography and environment: the Baltic Sea – a large brackish-water basin, the North-East Atlantic Ocean – a highly diverse oceanic system with extensive continental shelf areas, the Mediterranean Sea - a large and deep oligotrophic sea, and the Black Sea – an almost enclosed basin with low salinity and high H2S levels below 150 m depth.

The MSFD assessments are carried out at a regional or sub-regional (sea) scale. This means that the GES is determined at the level of a specific Broad Habitat Type, its occurrence on the whole regional sea, or its sub-region (often covering several Member States), and its quality assessed over its complete regional sea occurrence. The application of the MSFD assessment at a (sub)regional scale, it seems, cannot be used at a relatively small scale over a short period. However, results from (sub)regional assessments specific for BHT can act as a baseline for smaller scale changes related to activities such as dredging and disposal/placement. Issues with aggregations derived from monitoring results at different temporal and spatial scales have been discussed in the context of MSFD assessments (e.g. Prins et al., 2014).

3.4 How to assess status and impact?

By now we understand that the seafloor is a heterogenic mosaic of species and habitats with variable levels of sensitivity and thus is affected to different degrees by dredging and disposal and other human activities. Therefore, a variety of indicators and methods are necessary to understand the status of the benthic ecosystem and the changes that can be imposed by human activities in a cumulative and biologically relevant manner.

3.4.1 Environmental Impact Assessment (EIA)

EIAs are about assessing the environmental impacts of projects on the environment. Although EIAs differ from country to country, various components of an EIA across countries are strongly consistent. In EIAs it is also required to determine the compliance of a project with relevant EU directives and programs and show that the project will not prevent the achievement of long-term goals or be contrary to the objectives and initiatives set out in, for example, the WFD or MSFD. Thus, it is required to make an assessment in relation to MSFD and GES. This assessment is typically done as a qualitative compliance assessment including considerations on the magnitude and temporal and spatial extent of a project's activities in relation to the relevant regional sea. To our knowledge, no dredging projects have yet assessed the potential impacts on GES in a quantitative manner.

10. http://www.helcom.fi/helcom-at-work/projects/completed-projects/coreset

3.4.2 MSFD assessment methodologies

In general, there are two types of methods being used for assessing habitat sensitivity: a categorical approach, using expert judgement (e.g. Halpern et al., 2008) and a quantitative approach, based on a mechanistic understanding of how human activities affect the benthic ecosystem (i.e. ICES 2019c). The categorical approach simply adds up different activities, without considering what pressures these activities are causing, or the biological mechanisms through which the activities may be affecting marine ecosystems. The quantitative approach is recommended as it estimates the impact of the activity as a function of the mortality imposed and the recovery rate of the benthic community and therefore can be used by managers and industry for the most precise management of activities, allowing optimal room for activities while at the same time protecting sensitive species and habitats.

An example of a quantitative approach is developed by ICES, which investigated the main physical disturbance pressures causing benthic impacts on habitats per EU region (ICES 2019a, 2019b, and 2019c) and produced some advice[11]. ICES advises the use of a single assessment process to assess physical loss (D6C1 and D6C4) and physical disturbance (D6C2) on the seafloor. The suggested assessment process expresses the spatial extent and distribution of pressures, both separately and in combination per subdivision and (where possible) per MSFD broad habitat type. The ICES work is summarised below with focus on the assessment of dredging and disposal/placement of dredged material.

Defining activities and their pressure.

Three subtypes of physical disturbance/loss were identified as being caused by dredging activities: 1) Abrasion. The dominant activity is fishery, aggregated extraction considered to have a small footprint. 2) Removal, e.g. aggregated extraction and dredging. 3) Deposition, e.g. dredging disposal. The fourth, not relevant for dredging activities, was Sealing, e.g. placement of permanent structures. The three first subtypes can result in either disturbance or loss depending on the extent and severity.

Area and intensity of the pressures.

Availability of data on aggregate extraction, dredging, and dredging disposal (removal and deposition disturbance) differs by country. Extraction activities need authorisations and therefore the spatial extent of the licensed areas is known, but they are much larger than the actual footprint of the dredging activity, so the area of actual extraction is needed to have a good estimate of the pressure. The choice of grid size to calculate actual footprint should be driven by the time interval between the registered signals. In some EU countries vessels have an electronic vessel monitoring system (VMS) on board, while for other countries automatic identification system (AIS) data are available. For some regions, a grid layer on aggregate extraction in the form of extraction time (minutes) per year in a 50 × 50 m grid have been produced by ICES (ICES, 2019c). Licensed areas of the disposal sites (km2) are available for all of the EU. More detailed data on the exact location of the disposal within a licensed area and the amount (in volume, tonnes dry weight) of deposited material are available through HELCOM and OSPAR

11. http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2019/Special_Requests/eu.2019.25.pdf

for some countries (ICES 2019c).

Quantification of the spatial extent and intensity of dredging pressures, like drift of suspended sediment, needs hydrodynamic modelling that takes account of the dynamics in the dredging area in relation to the situation without dredging (e. g. existing natural variability of suspended matter). Another approach is adopting a 'buffer zone' approach, where the impact is assumed to occur in a fixed diameter buffer zone around the activity.

From pressure to impact.

While methods for converting pressure to benthic impacts for abrasion by e.g. mobile fishing gears are very well established (Pitcher et al., 2017; Sciberras et al., 2018; Hiddink et al., 2019), quantitative assessments of benthic impacts caused by dredging or disposal are less well developed. The ICES work links the pressure analysis to a Population Dynamics (PD) model that relates pressure to the fraction of fauna removed (d) and recovery rate (r). This is the same model used for assessing trawling impacts. The model is not parameterised for dredging activities, hence a conservative approach was used. A synthesis and analysis of existing studies to estimate essential relationships, pressure, and impact, as well as recovery rates, are needed to improve the assessment.

The severity of disposal/placement of dredged material on benthic communities depends on the amount of sediment released in relation to the area, the frequency and duration of the activity, the grain size, the hydrodynamics as a driver of sedimentation, as well as biological factors like habitat conditions and species population structure and dynamics. Models exist for assessing impacts on benthic vegetation and fauna groups such as mussels. However, no model exists today that includes a community of fauna species or groups. The development of such models and their efficient combination with monitoring results are needed to be able to assess the impact of sediment deposition on seabed ecosystems.

Assessing good environmental status.

Evaluating whether a MSFD habitat type in a regional sea is currently qualified to hold good environmental status (GES) will require defining a quality threshold beyond which its quality is considered to be in a good status. It also requires a surface threshold, the proportion of the habitat (in the assessment area) that needs to be beyond the quality threshold for the habitat type to be considered in a good status. Thresholds for defining GES for D6 have not yet been established.

Result for the North Sea case.

The North Sea was used as an example using the modelled impacts described above. The results showed that fishing abrasion, which is considered the dominating activity, had by far the highest impact (54%), while removal from aggregated dredging, which is considered to be the second most important activity, had an impact that was magnitudes lower (0.1%).

4. How to work towards GES?

The experience with the assessment of GES described in Chapter 3 shows that there is a number of methodological challenges related to assessing status and managing pressures. However, the generic goal of working towards GES is usually reducing the pressure from human activities. This chapter discusses how planning and management can improve sustainable dredging and disposal/placement activities and support the process towards GES for the benthic ecosystem under the MSFD.

Throughout the different project phases, risks and opportunities in relation to the environment need to be managed. Management measures should be taken upfront (proactive) and during the course of the project (adaptive management approach). For unacceptable risks, relevant and sustainable compensation measures need to be found.

In general, the timely involvement of stakeholders with a variety of competencies reduces the risk of unintended environmental impacts and can uncover opportunities for improving procedure and methods. Ideally, a proactive assessment is carried out on different dredging and disposal activities, and details of the equipment used. E.g., the use of a backhoe dredger will have a different impact than the use of a cutter suction dredger. This will identify the design or methodology that has the least impact on the seafloor. In order to do this, contractors need to be involved early in the project. Modelling tools predicting the suspended sediment plume and degree of sedimentation can be used as a decision support tool and manage the expected impacts through adaptation of the project design (e.g. location of disposal site) and dedicated measures (e.g. dredging technique, change in timing). In longer-term projects (e.g. maintenance dredging), monitoring and hindcast modelling can be used to optimise the design or methodology and reduce the impact on the seafloor.

Adaptive management is a continuous planning process which takes into account the present and ongoing environmental conditions. This is a decision framework for dredging and disposal activities in a project, for example regarding the use of environmental windows and a monitoring scheme with an early warning system. Early warning systems may use threshold levels to detect possible effects on the ecosystem at an early stage. Threshold levels should be lower than the compliance levels, to ensure that effective adaptive management can be carried out.

Case study: Environmental window

The use of environmental windows can minimize environmental impacts, i.e. by executing an activity during a time/season where and when certain organisms are not present or are less sensitive; or biological (e.g. spawning) and chemical processes (e.g. O_2 consumption) are absent or less important. An example of using environmental windows is given by the Hamburg Port Authority (HPA) which has the responsibility to safeguard the accessibility of the port. The Elbe estuary is not only an important artery for marine traffic, but also a valuable habitat protected by the EU and German legislation. Part of HPA´s sediment management strategy is to use different locations for the disposal of dredged material, depending on seasons and the quality of the sediments. This ensures compliance with environmental regulations. For example, the disposal site ´Neßsand´, located 15 km downstream of the port, is limited for use from November to the end of March. Thus, migrating fish species entering the estuary and especially the nearby located shallow water areas which function as important spawning and nursery grounds are well protected from the disposal activities. Furthermore, due to higher water temperatures in summer, oxygen deficiency situations may occur. The environmental window prevents unwanted additional effects from the relocation activities (e.g. oxygen-consuming degradation processes within the dredged material). Instead, during the critical summer months, HPA relocates dredged material to a site in the North Sea. Disposal activities at ´Neßsand´ are then resumed in late autumn, when oxygen conditions have improved, and the reproduction cycles of fish and other organisms are finished.

The example from the Hamburg Port Authority is a good example that it is possible to ensure the protection of species and habitats using detailed knowledge about the local environment and proactive planning, while at the same time managing access to Germany's biggest seaport.

Case study: Seabed landscaping

Dredging activities may alter environmental conditions significantly. A new type of habitat may be created, which is not necessarily a bad thing. On the contrary, in recent years it has become increasingly clear that seabed heterogeneity (i.e. bed forms) constitutes habitats allowing for higher biodiversity and biomass. Flat seabeds tend to be ecologically less valuable than seabeds with meso-scale bedforms such as tidal ridges, shoreface-connected ridges, and sand waves.

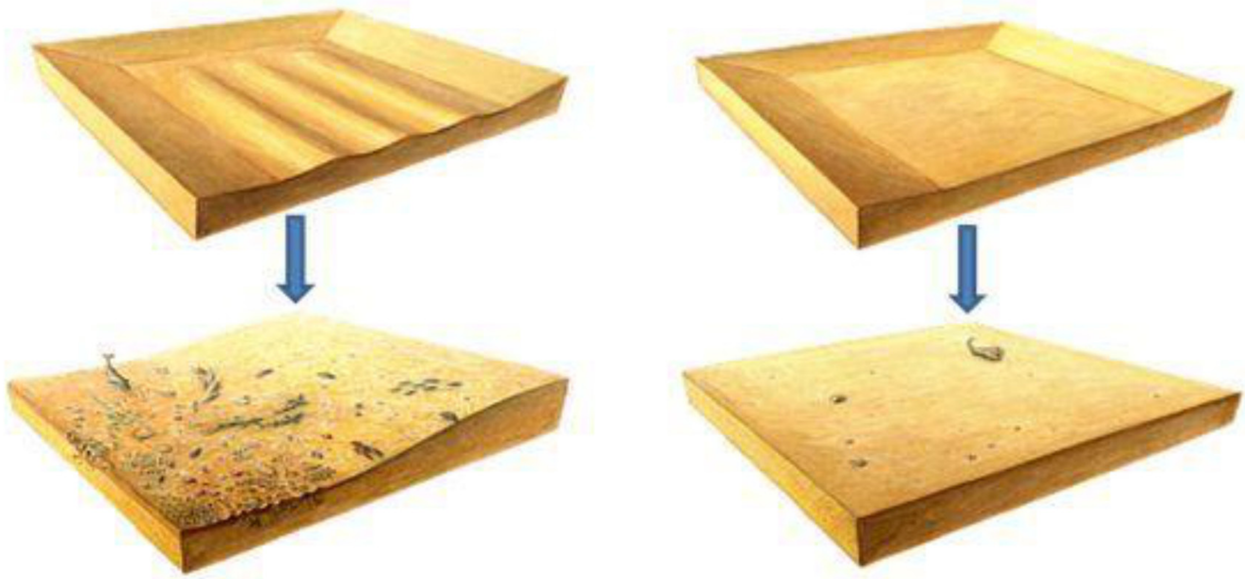


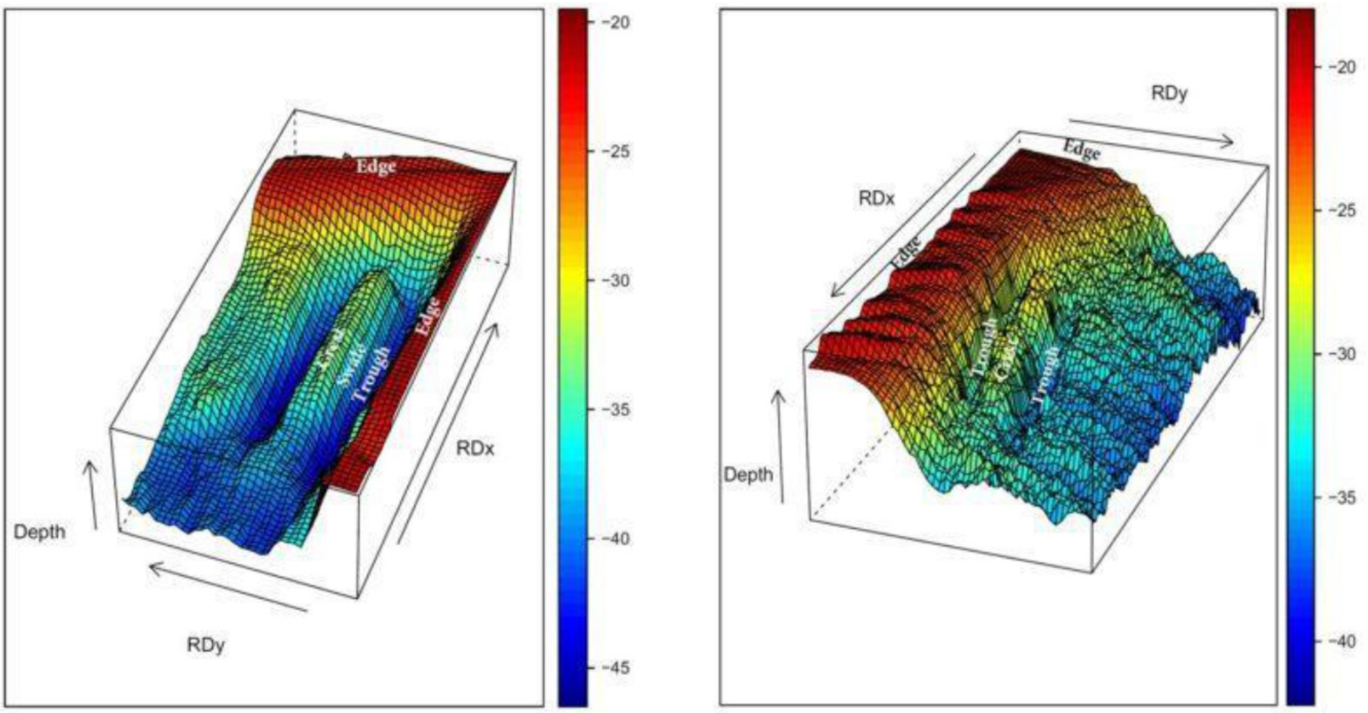
Figure 4.1 Seabed landscaping (left) versus traditional approach(right) (source: www.ecoshape.nl)

Such bedforms provide habitat to a larger range of species assemblages. Dredging activities could be designed and executed to leave behind the dredged areas, e.g. borrow pits, in such a heterogeneous state to improve seafloor integrity.

A 4-year pilot project to study the recolonization speed of borrow areas after marine sand extraction was executed in the Dutch North Sea (de Jong, 2016[12]). Two large-scale bedforms were left behind with steep sand ridges and deep pits after extraction, to test whether such landscaped bedforms would accelerate ecological recovery compared to a flat seabed and enhance biodiversity and biomass in the dredged area. These artificially landscaped sand ridges are about 700 metres long and 100 metres wide with crests of 10 metres high (see Figure 4.1).

Extensive monitoring showed that the distribution of organisms living in and on the seabed was strongly correlated with sediment characteristics and bed shear stress. Bed shear stress is the force per seabed surface area exerted by flowing water and it determines sediment erosion/sedimentation patterns and sediment composition. There it also defines the species composition and biomass of organisms living on the seabed. Due to the decrease in bed shear stress and sand extraction activities, fine sediment and organic matter settled on the seabed. One to two years after the cessation of sand extraction, the biomass of organisms living in and on the seabed and bottom-dwelling fish increased 10- to 20-fold compared to a reference area. Also, the species composition of the new benthic community (including fish) changed significantly.

Figure 4.2 A pilot experiment with 2 ecosystem-based sand ridges in the North Sea (Netherlands).



12. de Jong MF (2016) The ecological effects of deep sand extraction on the Dutch continental shelf. Implications for future sand extractions. PhD thesis

5. Conclusions and recommendations for CEDA Positions

The Marine Strategy Framework Directive (MSFD) requires that potential impacts of marine dredging and disposal/placement of dredged material are assessed in the context of the risk of not achieving or maintaining Good Environmental Status (GES) as defined for descriptor D6 Seafloor Integrity. As it is clearly indicated in the MSFD, descriptor D1 "Biological Diversity" forms an inherent set with D6 Seafloor Integrity to assess the overall GES of the benthic seabed habitats. From that, overall assessment and current practices – as described in the foregoing chapters - some guiding recommendations are formulated to the CEDA community in order to align dredging and disposal works with these environmental requirements..

Dredging and disposal/placement, as well as other human activities, affect the seafloor which consists of a heterogenic mosaic of species and habitats with varying degrees of sensitivity. Therefore, a variety of indicators and methods are necessary to understand and assess its status and the changes that can be imposed by planned human activity. The potential impacts of dredging and disposal/placement of dredged material must be assessed relative to the natural variability of suspended sediment and sedimentation in the specific sites. This understanding is key in the context of achieving or maintaining Good Environmental Status for MSFD Descriptor 6 (D6 Seafloor Integrity). Different approaches are available which vary in terms of applicability. Furthermore, not only the effect of dredging and disposal, but also cumulative effects must be assessed, i.e. the sum of effects of several different activities on species and habitats. However, there are many methodological challenges, e.g. the fact that objective and universal criteria do not exist. Additionally, there is still discussion on the geographical and temporal scales of such an assessment.

- *CEDA and its members should follow the further development of indicators and methods and proactively contribute to the discussion.*

Concerning the potential effects of an activity, the MSFD differentiates between physical disturbance and loss – which is very important in the assessment and outcome of a licencing procedure. The border between these two states can be regarded as a continuum.

- *Applicants for dredging and disposal activities should be aware that this may lead to the necessity of verification to what state the activity will finally lead - and thus will require specific and long-lasting monitoring (e.g. > 20 years).*

Operationally, the assessments require data on the occurrence of species and habitats, their actual status, the existence of pressures and their magnitude, as well as the sensitivity of species and habitats to the activities, plus recovery rates. However, there is a lack of (high-resolution) data not only for dredging and disposal activities, as well as relationships between the activity (amount, rate) and magnitude of pressure, but in general, broad knowledge gaps are sometimes a reality. Although the authorities of the EU member states are responsible for describing the status of the objectives of the EU directives and related basic monitoring, often the necessary data is not available.

- *Applicants for dredging and disposal activities should be prepared for a discussion on who is responsible for filling in these knowledge gaps and carrying out extensive monitoring.*

A promising step for mitigating the impact of dredging and disposal activities is the further understanding of the functioning of environmental windows and the application of adaptive approaches for sediment management. Today's digital platforms provide a great opportunity for the development of cost-effective management tools that can integrate new measurement technologies and quantify potential impacts as a basis for healthy management decisions.

- *CEDA and its members should evaluate the use of these tools at an early stage of their planned activity.*

In the context of licensing procedures, co-operation with the responsible authorities and stakeholders is recommended.

- *CEDA and its members should seek for early involvement of relevant parties and think of win-win solutions and any potential added value of their projects.*

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We are grateful to our members who make a major contribution to our activities. In doing so they can be proud of the fact that they are also supporting the entire dredging community, and helping to bring together the many different parties involved, regardless of membership status. Without our members we would not be able to do such excellent work. We hope others will be encouraged to follow their example and join us in fulfilling our mission to spread knowledge, enhance mutual understanding and encourage best practice in the dredging profession.

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