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Task Group 6 Report

Seafloor integrity

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PREFACE

The Marine Strategy Framework Directive (2008/56/EC) (MSFD) requires that the European Commission (by 15 July 2010) should lay down criteria and methodological standards to allow consistency in approach in evaluating the extent to which Good Environmental Status (GES) is being achieved. ICES and JRC were contracted to provide scientific support for the Commission in meeting this obligation.

A total of 10 reports have been prepared relating to the descriptors of GES listed in Annex I of the Directive. Eight reports have been prepared by groups of independent experts coordinated by JRC and ICES in response to this contract. In addition, reports for two descriptors (Contaminants in fish and other seafood and Marine Litter) were written by expert groups coordinated by DG SANCO and IFREMER respectively.

A Task Group was established for each of the qualitative Descriptors. Each Task Group consisted of selected experts providing experience related to the four marine regions (the Baltic Sea, the North-east Atlantic, the Mediterranean Sea and the Black Sea) and an appropriate scope of relevant scientific expertise. Observers from the Regional Seas Conventions were also invited to each Task Group to help ensure the inclusion of relevant work by those Conventions. A Management Group consisting of the Chairs of the Task Groups including those from DG SANCO and IFREMER and a Steering Group from JRC and ICES joined by those in the JRC responsible for the technical/scientific work for the Task Groups coordinated by JRC, coordinated the work. The conclusions in the reports of the Task Groups and Management Group are not necessarily those of the coordinating organisations.

This is the report of Task Group 6, responsible for the Descriptor referred to as Seafloor Integrity. Although individual subsections were drafted by subgroups of the Task Group, all text was reviewed through several drafts by all active Task Group members (two initial members were unable to complete the project due to competing priorities), and this report is a consensus document of all task group members. Inputs from the TG observers, particularly from OSPAR and HELCOM, was also taken into consideration and often led to improvements in clarity and linkages to work of existing agencies active in European seas.

Readers of this report are urged to also read the report of the above mentioned Management Group since it provides the proper context for the individual Task Group reports as well as a discussion of a number of important overarching issues.

Contents

EXECUTIVE SUMMARY

1. CONCEPTS

- "Sea-floor 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."

"Sea Floor" includes both the physical structure and biotic composition of the benthic community. "Integrity" includes the characteristic functioning of natural ecosystem processes and spatial connectedness. There are no points of significant disagreement among experts regarding key terms or what constitutes gradients of degradation in environmental status. However serious problems of sampling and measurement and high scientific uncertainty about aspects of benthic ecology and tolerances of benthic ecosystems to perturbations pose challenges to application of "good environmental status". Sound assessments of GES are possible, but they will have to integrate results from local scales where both natural benthic ecosystems and pressures may be very patchy, to much larger regional and subregional scales.

Many common uses of the sea necessarily impact the sea floor and benthic communities. "Good environmental status" of the seafloor requires that diversity and productivity are maintained and the uses do not cause serious adverse impacts to the natural ecosystem structure and functioning in both space and time. The pressures associated with those uses do not hinder the ecosystem components to retain their natural diversity, productivity and dynamic ecological processes. Perturbations due to use should be small enough that recovery is rapid and secure if a use ceases. Many benthic areas do not meet these standards and management must improve status.

Scale for assessing GES of the sea floor is particularly challenging for four reasons. First, benthic ecosystem features are patchy on many scales. Second, a wide range of human activities cause pressures on the sea floor, and they usually operate at patchy spatial scales. Third, although initial impacts of human activities are often local and patchy their direct and indirect ecological consequences may be transported widely by physical and biotic processes. Fourth, all monitoring of the seafloor is also patchy and often local. In all evaluations of impacts the scale of the impact relative to the availability of the ecosystem properties being impacted is an important consideration.

To deal with these challenges, the measurement of GES for seafloor integrity has three steps. First: identify the ecological structures and functions of particular importance. Second: identify the human pressures known or likely to reach levels that degrade environmental status. Third, for the ecosystem components and pressures identified as being of greatest importance, use a suite of appropriate Attributes and Indicators to assess status relative to pre-identified standards for GES, along gradients reflecting meaningful scales of the seafloor attributes and pressures. The standards for GES on various Indicators must reflect the different sensitivity and resilience of the Indicators and their functions in ecosystem processes. Risk-based approaches to monitoring and assessment are proposed to deal with the local-scale patchiness of seafloor Attributes, pressures, and impacts.

2. ATTRIBUTES

Substrate**:** The physical properties of the seabed such as grain size, porosity, rugosity, solidity, topography and geometric organization (e.g three-dimensional habitats). Substrate is a driver of patterns in diversity, function and integrity of benthic communities. Together with hydrodynamics, it is a main factor structuring benthic habitats. Four types of Substrate are considered separately, both because they contribute differently to ecosystem processes and they are affected differently by diverse pressures: soft sediments, gravels, hard substrates, and biogenic substrates. Indirect Indicators of functions are often more practical to use in assessing GES than Indicators of substrate itself.

Bioengineers: Organisms that change the structure of the seafloor environment in ways not done by geophysical processes alone, by reworking the substrate or by providing structures that are used by other species. Bioengineers may serve functions such as providing shelter from predation or substrate for other organisms, reworking of sediments, transporting interstitial porewater, and facilitating material exchange at the sediment-water interface. Bioengineers are sensitive to may pressures, but often prove difficult to monitor directly. Indirect indicators of the functions they serve or indicators from mapping the pressures on bioengineers are often practical alternatives for assessing GES.

Oxygen: Concentration of dissolved oxygen in the bottom water and/or in the upper sediment layer of the seafloor. Decreasing oxygen supply of bottom water and/or the upper sediment results in significant changes of the benthic communities and can lead to mass mortality. Oxygen depletion is particularly associated with excessive nutrient and organic enrichment of the seafloor. Important indicators for Oxygen concentration include abundance of organisms sensitive or tolerant to oxygen level and the spatial distribution of oxygen/hydrogen sulphide concentrations conducted in critical regions and in critical seasons.

Contaminants and Hazardous Substances**:** Guidance on including these substances in assessments of GES is presented in the Report of TG-8. Particular attention should be given to applying that guidance for seafloor communities and habitats. Sediments may be repositories for many of the more toxic chemicals that are introduced into water bodies. Contaminated sediments represent a hazard to aquatic life through direct toxicity as well as through bioaccumulation in the food web.

Species Composition: The list of species present in an area, their abundances, and/or their evolutionary and ecological relationships, including their pattern of occurrence in space and time. Species composition captures information on the biological diversity, structure, and dynamics of communities. It represents a fundamentally valued feature of ecosystem's potential to function well, to resist potential threats, and be resilient. Of the large number of indicators of species composition, those focusing on diversity among samples (space or time) and measures of species/area relationships may be most useful. These must be applied on local scales to account for natural scales of community structure and pressures on them.

Size Composition: Abundance or biomass of individuals of different sizes in the community, with "Size" either continuous or as categories. The size composition of a community integrates information of about productivity, mortality rate, and life histories of the full community. Indicators include the proportion of numbers (or biomass) above some specified length, parameters (slope and intercept) of the "size spectrum" of the aggregate size composition data, and shape of a cumulative abundance curve of numbers of individuals by size group.

Trophodynamics**:** A complex attribute with many subcomponents. Key ones include Primary and Secondary Production, Carrying Capacity, Energy Flows, and Food Web Relationships. TG 4, on Food webs deals thoroughly with primary production, energy, flow and food webs. When evaluating Seafloor Integrity it is important to follow the expert guidance from TG 4 in the specific context of the benthic community, its food web relations, and benthic-pelagic relationships. Secondary Production and Carrying Capacity are also important to Seafloor Integrity but at this time there are no practical indicators for their assessment.

Life History Traits: Life History Traits are the categorisation of characteristics of the life cycle that species can exhibit, i.e. growth rates, age or size or maturation, fecundity and the seasonality of life history features such as reproduction. Various combinations of these traits lead to species differing in their natural productivity, natural mortality, colonization rates, etc. They are important to GES as they reflect the status of ecosystem functioning. Their changes are direct measures of the condition of the biota, or may uncover problems not apparent with other Attributes, and provide measurements of the progress of restoration efforts. Many synthetic indices based on representation of species with different sensitivities and tolerances for general or species pressures have been used.

3. COMBINING INDICATORS

Because of the patchiness of seafloor attributes, pressures and impacts on many scales, the optimal suites of Indicators and their reference levels will differ on all but local scales. This means that monitoring must be adapted to local conditions, and expanded for the seafloor – both in terms of area covered and types of attributes measured. It also means that no single algorithm for combining Indicator values will be appropriate for evaluating GES or providing a meaningful "index" of GES for Seafloor Integrity. It may be possible to conduct such analytical syntheses of Indicators for individual Attributes on local scales. However across Attributes and on even moderate scales expert assessments rather than algorithmic formulae will be needed for evaluation of GES of Seafloor Integrity.

1. Definition of the Descriptor

According to the Marine Strategy Framework Directive, "descriptor 6" is:

- "Sea-floor 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."

"Sea Floor" is interpreted as including both the physical and chemical parameters of seabed - bathymetry, roughness (rugosity), substrate type, oxygen supply etc; and biotic composition of the benthic community. "Integrity" is interpreted as both covering spatial connectedness, so that the habitats are not unnaturally fragmented, and having the natural ecosystem processes functioning in characteristic ways. Areas of high integrity on both of these standards are resilient to perturbations, so human activities can cause some degree of perturbation without widespread and lasting harms to the ecosystems. "Structure and functions of ecosystems" is a commonly used concept in ecology, and the concept is used in its conventional sense. "Not adversely affected" is interpreted as meaning that impacts may be occurring, but all impacts are sustainable such that natural levels of diversity, productivity, and ecosystem processes are not degraded. Section 3 of this report elaborates further on what is meant by sustainability of impacts.

2. Scientific understanding of the key concepts associated with the Descriptor

There is no single scientific consensus statement on what constitutes "good environmental status" for sea floor integrity. However, there are also no points of significant disagreement among experts regarding the definitions of the key terms in the descriptor, or on what constitutes gradients of degradation in environmental status. Rather, there are serious problems of sampling and measurement of attributes of sea floor integrity, and high scientific uncertainty about major aspects of benthic ecology, benthic-pelagic coupling, and tolerances of many benthic ecosystem attributes to perturbations. All of these concerns are discussed in detail in sections 3, 4, and 5 of this report. The incomplete knowledge, high uncertainty, and challenges of monitoring provide scope for much debate among scientific experts on details of what constitutes sea floor integrity, what levels of impact are sustainable, and what constitutes appropriate application of precaution. However, the debate of characteristic of healthy scientific inquiry in areas where there is much still to learn. The scientific debate is not an impediment to use of the descriptor in assessing good environmental status.

3. Documenting what Is "Good Environmental Status"

3.1 What is "Good" Environmental Status

The standard for "Good Environmental Status should reflect the **goals for management** of the impacts of human activities on the sea floor, as defined above. It is explicit in the definition of the descriptor "Sea Floor Integrity" that human uses of the ocean, including uses that affect the sea floor, are consistent with the MSFD, as long as those uses are sustainable. To suggest that "good" environmental status should require that all attributes of seafloor habitats, communities and populations be in unimpacted condition would require prohibiting essentially all commercial and social uses of the sea that interact with the seafloor directly or indirectly. That is a standard clearly inconsistent with the many provisions in the MSFD related to advancing the role of ocean industries and recreation in the economic and social prosperity of the EU. Many common uses of the sea necessarily impact the sea floor and benthic communities, and the issue to be addressed is how large the impact can be and still be considered “sustainable”. Even those few uses of the sea that may be conducted without direct impacts on the sea floor still may have at least indirect impacts, for example shipping on the surface may still expose the sea floor to sound and emissions of hazardous substances, including oil.

Sustainability is achieved when the pressures associated with all those uses cumulatively do not hinder the ecosystem components to retain their natural diversity, productivity and dynamic ecological processes. Perturbations due to use must be small enough that recovery is rapid and secure if a use ceases. Many benthic areas do not meet these standards and management must improve status.

For the purposes of good environmental status of the seafloor, **uses can be considered sustainable** if the pressures associated with those uses do not hinder the ecosystem components to retain their natural diversity, productivity and dynamic ecological processes. If ecosystem components of the sea floor are perturbed, recover needs to be rapid and secure. “Recovery” does not require that the ecosystem attributes in Section 5 return to exactly their status before any human use began, because natural variation would have led to changes in them in any case. However “recovery” does mean that the attributes must show a clear trend towards their pre-perturbation conditions, and the trend is expected to continue (if pressures continue to be managed) until the attributes lie within their range of historical natural variation. “Rapid” must be interpreted in the context of the life histories of the species and natural rates of change in the community properties being perturbed. For some seafloor habitats and communities, recovery from perturbation would require multiple decades or more, and in such cases management should strive to prevent perturbations.

For uses to be considered sustainable it is also necessary that ecological functions are not impaired by the pressures associated with the uses. Impairment of a function or process is considered to occur if the ecological consequences of the direct perturbations spread widely through the ecosystem in space and/or persist particularly long in time, or if the normal ecological linkages among species act to extend and amplify the effects of a perturbation rather than to dampen the effects.

A number of different states of the seafloor could exist, each consistent with all historical information on the natural diversity, productivity, and ecosystem processes, implying that there is no single state of the seafloor that uniquely defines “good”. Rather there must exist a range of possible conditions supporting different mixes of human uses, and all are “good” as long as all the conditions set above are met,, and they are managed in away that their status only varying within the range of natural variation for the area Likewise there should be a range of areas considered to be “healthy” and in or approaching “GES” which receive adequate protection from perturbations, such that not all benthic communities and habitats are always in a state of recovery.

The sustainability of use of the ecosystem is an anthropocentric interpretation of the goals of the MSFD. It is acknowledged that ecosystems and their attributes also have intrinsic values, beyond the uses society may choose to make of an ecosystem. To the extent that such inherent values can be identified, good environmental status also requires that these values are preserved. This may mean that some areas of the sea floor receive a high degree of protection from any human induced perturbations.

The **measurement of environmental status** for the sea floor will not be easy. The recommended way forward has three steps.

First, experts in the appropriate scientific disciplines (including holders of traditional and experiential knowledge) use their knowledge and the best available information to identify the ecological structures and functions of particular importance to a given ecosystem, include the sea floor. Methodologies for integrated or aggregated ecosystem assessments that identify the key structural and functional components of an ecosystem are under rapid development, but several groups have identified credible methodologies. References to the work of these groups, including the Group of Experts for the Assessment of Assessments, ICES EU Habitats Directive Reports, Marine Stewardship Council Guidelines, etc are given with the individual Attributes where they are discussed in more detail.

Second, similarly appropriate experts also use their knowledge and the best available information on the human activities likely to occur in the area of concern, to identify the pressures most likely to occur at level that have a possibility of degrading environmental status, and their likely past and present levels. Again, expert guidance on what pressures are associated with various human activities, and the types of ecosystem attributes most likely to be impacted by each pressure already is available (WGECO, Helsinki Convention, OSPAR assessments of human activities and their accumulation for QSR 2010 (BA-6), Water Framework Directive, and several EU Research Projects such as InExFish, Poorfish, etc, and will be included in the references for the individual Attributes treated below.).

Third, for the ecosystem components and pressures identified as being of greatest importance for a particular area, candidate indicators are identified. These candidates are tested against established criteria for selecting sound and robust indicators discussed in section 5 and a suite of appropriate indicators for monitoring and assessment is selected. Sound guidance on indicator selection is also available from a variety of sources, and Section 5 builds on that guidance in the context of the attributes of particular relevance to sea floor integrity.

The final component of identifying “Good Environmental Status” for sea floor integrity is **setting the standards** that have to be met for the indicators (or integrated assessments) selected as described above. There are a few properties of the sea floor where only very small levels of impact would be considered sustainable, and the goal of management should always to prevent impacts on those properties. These properties are ones that are considered to serve important ecosystem functions, such as providing shelter or oxygenating sediments, are fragile and hence likely to be damaged by many pressures (particularly physical disturbance), and have either no capacity to recover or very long recovery times. Lophelia reefs and cold-water coral deposits are examples of such features, and Section 5 highlights other such features in its various subsections.

For all other ecosystem features, where some level of impact is sustainable, identifying the level of impact consistent with our standards for sustainability is a trade-off between scientific rigour and availability of information. In all cases experts assessing sustainability on the selected indicators should use all the information and knowledge that is available. In practice this principle implies three levels of assessment of sustainability. Where there is adequate scientific knowledge and relevant information the scientifically most desirable standard is to directly assess the degree of perturbation of the selected indicator beyond which recovery ceases to be secure or rapid. Fish population dynamics has well developed methodologies for identifying such reference points for animal populations, as long as historical data on how productivity varies with abundance or density is available. These methodologies can be applied to populations other than exploited fish stocks, and to ecosystem indicators where ability of the ecosystem property to recover from perturbations or continue to serve some important ecosystem function is reflected by something other than "productivity".

When information is not available on how productivity (or other traits, including those referring to physical or chemical properties of the seabed) varies with the amount (or other appropriate measure of quality – see section 5) of an ecosystem feature, less demanding methods must be used to identify the reference level associated with good environmental status of a selected indicator. If experts have access to at least information about how the indicator has varied over time, or varies naturally in space, then reference level can be a percent of the spatio-temporal variation recorded for the indicator. If experts have no reliable estimate of the natural variance of the indicator is available, the only option is to set a reference level at an percentage of the mean value of the indicator, over whatever space and time period it is available.

3.2 Dealing with scale

Scale for assessing environmental status of the sea floor is particularly challenging for three reasons. First, the **wide range of human activities causing pressures that may degrade the status of the sea floor operate at different but always patchy spatial scales**. For all pressures resulting from land based activities, there are two intrinsic gradients of their potential pressures. There is an inherent initial gradient from coastal areas to offshore regions. Initial concentrations or likelihoods of impact generally are highest closest to shore and diminish as transport processes (physical or biological) carry the pressures offshore. There is also an along-shore pattern of initial pressures that is patchy. Regardless of the activity causing the pressures, there are centres of introduction and gradients of decline from these centres. Inland activities such as agriculture and industries resulting in chemicals, nutrients or other pressures that are carried by river, have their initial inputs concentrated at river mouths and plume in the coastal waters. Activities occurring on the coast and inputting products or pressures directly into the sea are still clustered along the coastline as municipalities, industry sites, recreational centres, etc. Activities occurring in the sea are usually patchily distributed as well. Some marine activities are actually centred in nearshore or coastal areas, such as mariculture, recreation, mechanical energy, ports development, etc. All are also unevenly distributed along the coast on regional scales. Even activities that occur offshore are not evenly distributed in space; fishing, shipping, mining, hydrocarbon production etc are all concentrated in specific habitats, corridors, or sites. Consequently assessments of environmental status are almost always going to be done for areas that are a mosaic of different degrees and types of perturbations by human activities, making general statements of environmental quality difficult.

The patchiness of the human activities causing the pressures also means that the scales of **initial impacts of those activities are usually also local**. Initial impacts of fishing are where the gear is actually deployed; aquaculture where the facilities are sited; industries and municipalities where the facilities or town are located; river-based depositions start in the river plumes; shipping, cables and pipelines in corridors.

Of course assessments must address more than the *initial* impacts local of the patchy human activities, because effects can be transported more widely in the regional seas. However, both mechanisms by which impacts may spread still leave the impacts heterogeneously distributed in space. Impacts on the biotic components of sea floor integrity (increased mortality, contaminant loads, etc) are distributed by altering food-web relationships or changing pathways of energy flows. Impacts on structural features of seafloor integrity are distributed through the consequences of the changes to functions and ecosystem services provided by the physical features. These pathways make the impacts more than local, but still result in gradients and hotspots of impacts, and not homogeneous on the scales of assessments of environmental status.

Not only are the activities and their impacts patchy, but **all monitoring of the seafloor is also patchy**. Many monitoring programmes are designed to detect temporal trends rather than changes in geographic distribution. Most time series and established monitoring programmes of benthos are relatively nearshore, and many have quite restricted spatial coverage. The few efforts to develop monitoring programs with relatively wide coverage generally have sampling densities that are spotty relative to the scale of features being monitored. This is especially true for sampling of biotic features, which are patchy on scales much finer than any realistic benthic monitoring programme that could be designed and implemented for seas at regional scales. In the water column, oceanography processes and movements of mobile animals allow scientists to interpolate between sampling sites several tens of kilometres apart and have some confidence that they have representative estimates of the densities of organisms and values of physical ocean parameters between the sampling sites. Such situations are rare for benthic populations and physical features.

A third consideration is that there are many differences between coastal and deeper-water benthic communities. Some of these differences are simply consequences of history; because of proximity and greater ease of sampling much more is known of the coastal and nearshere seafloor habitats and communities than is known of offshore and deep-sea habitats and communities. Some are ecological; although knowledge is less complete offshore and in the deep-sea, many studies suggest that the dominant space and time scales are both greater in these ecosystems.

These realities about activities, impacts and sample sites have several inescapable **consequences for assessments of environmental status of sea floor integrity**. First, the existing nearshore monitoring programs rarely allow interpolation except along very strong gradients of specific pressures; down a specific river plume; along a gradient from a point source. Second, offshore the patchiness of benthic habitats is sufficiently fine-scale that only rarely can monitoring be on scales that allow interpolation into reliable quantitative maps on regional scales. Even where such maps can be produced, monitoring is not feasible on space and time scales fine enough that such maps could be powerful at detecting trends in environmental status on regional scales. Focused monitoring and assessment will remain importing at assessing environmental status on local scales and for some specific pressures, especially where monitoring can be required of an industry causing site-specific pressures. Some other strategy must be developed for general assessments of environmental status of sea floor integrity on regional and sea-wide scales, however.

The methodology for assessing environmental status at regional and subregional scales takes a risk-based approach, considering the threats posed by the human activities occurring in the region. It is considered feasible to map the spatial distribution of most human activities in the sea, particularly the ones most likely to cause the largest impacts on the sea floor. Such maps may not be possible on very fine spatial scales, but are likely possible on the scales characteristic of EUNIS Level 4 (or finer, for some sediment types) classifications of the benthos. It is also feasible to tabulate the major pressures caused by various human activities and the vulnerability of various properties of the sea floor to the various pressures. Such cross-tabulations have been developed already for many activities, pressures, and ecosystem features, in fact.

Together these feasible steps make it realistic that spatial qualitative "risk analysis" can be conducted at regional and sub-regional scales. Such risk assessments should take account of, inter alia:

i. the intensity or severity of the impact at the specific site being affected;

ii. the spatial extent of the impact relative to the availability of the habitat type

affected;

iii. the sensitivity/vulnerability vs the resilience of the area to the impact;

iv. the ability of the area to recover from harm, and the rate of such recovery;

v. the extent to which ecosystem functions may be altered by the impact; and

vi. where relevant, the timing and duration of the impact relative to the times when the area serves particular functions in the ecosystem (shelter, feeding, etc).

The information on how risk is distributed in space provides a basis for **assessing environmental status** from either of two directions. The assessment can start with specific **human activities** of particular concern. With such an approach monitoring and assessment should be based on the activity-pressure-impact tabulation. Monitoring should be stratified along the known gradients of occurrence of the main pressures, with pressures of different activities aggregated to allow cumulative effects to be considered. Assessments would start with the areas of highest risk, and if impacts of the highest risk areas do not exceed the threshold for good environmental status, then it can be assumed that the activities are overall sustainable. If the impacts in the highest risk areas do exceed the threshold for good environmental status, then assessments would be conducted for other risk strata, to determine how far along gradient impacts are considered not sustainable. Such an approach, with monitoring and assessment stratified by risk level, allows general statements to be made about environmental status at large scales while keeping monitoring requirements feasible. The approach also allows actions needed to improve environmental status to be identified, and is a particularly suitable basis for marine spatial planning.

Alternatively, assessments can start with specific **attributes** of the sea floor. Similar to the approach based on activities, the activity – pressure – impact cross-tabulation would be the basis to stratify monitoring by levels of threat to the key attributes being impacted by human activities. Assessment of environmental status would again start with the highest risk strata, and proceed to progressively low risk strata until areas were found to be in good environmental status. Good environmental status could be achieved if many occurrences of key benthic attributes were assessed as at low risk, or if impacts of activities in high risk areas could be managed or mitigated. This could be achieved either by management changing the pattern of human activities to make more ecologically important area exposed to low risk, or changing the mode of activities to make impacts in high risk areas less severe and more sustainable.

4. THE ATTRIBUTES OF SEAFLOOR INTEGRITY

4.1 Substrate

a) Description of the attribute: Seabed substrate

The attribute "seabed substrate" comprises a large variety of substrate types. The most obvious distinction in seabed types is between hard and soft substrata. Examples of soft substratum include sand and mud. Hard substratum can be abiotic (i.e. entirely of mineral origin, e.g. boulders or lava) or biogenic (i.e. structures created by living organisms, e.g. cold water corals). Although substrate type is a continuum from soft to hard, it is common practice to divide such continuum into substrate types, which are generally characterised by the proportion of silt, grain size and organic content (e.g. Eleftheriou and McIntyre 2005, http://www.searchmesh.net). Thus four substrate types are defined based upon their physical properties:

1) Soft substratum, e.g. fine sandy and muddy sediments (particle size < 2 mm)
2) Gravel substratum, e.g. cobble and pebbles (particle size from 2 to 256 mm).
3) Hard substratum: igneous or sedimentary (e.g. bedrocks, rocks boulders, lava etc., particle size > 256 mm).
4) Biogenic substratum/habitats (e.g. mussel beds, bioherms, maerl beds, cold water corals, sponge beds)

In addition, topography is considered to be an important feature common to all substrate types. Topography refers to structures occurring both naturally (e.g. seamounts, slopes, sand waves) and human induced (e.g. trawl marks, sediment extraction pits, artificial reefs). Topography does not occur independently of the presence of types of substrate, and all four substrate types above have some inherent topography. However, as explained below, topography does interact with substrate type in ways that are important for biotic communities and environmental status.

In addition, the ecosystem processes that are supported by the substrate features are also affected by depth. The functional significance of any substrate type is unlikely to be identical in coastal, shelf, slope, and basin locations. These functional differences are likely to be better monitored through the benthic communities associated with the substrate than though monitoring the substrate itself.

b) Why is the substrate important to seafloor integrity?

b1 - Soft substratum, e.g.: fine sandy and muddy sediments (particle < 2mm)

Given the large spatial extent of soft substratum in most areas (e.g. Breeze et al. 2002, Franca et al. 2009, Post 2008), this substrate type may be the most important, in terms of functions and services provided to the ecosystem. Areas with soft substratum can be highly productive, sustaining a rich assemblage of both invertebrates and fish (e.g. flatfishes, Florin et al. 2009). The properties (e.g. grain size, bacterial biomass, fauna) of soft substratum can be extremely variable. Extrinsic and intrinsic drivers determine the structural properties of soft sediments. Extrinsic drivers include geological properties, hydrodynamic regime (e.g. waves and currents), intensity of natural disturbances, depth, runoff from land, and bedload transport. As an example, mobile sands are often found in shallow waters where there is intensive hydrodynamic regime, while mud is found in sheltered and deeper waters. Degraer et al (2009) identified grain size and sediment mud content and bathymetry, slope and distance to the coast to represent the most important environmental variables determining the macrobenthic community distribution in the Belgian part of the North Sea. Other studies have similarly shown relationships between grain size and benthic community structure (e.g Blanchet 2005, Post 2008). As an example, areas dominated by sand may hold a lower biomass of infauna compared to mud while suspension feeders may be more common in sandy areas (e.g. Künitzer et al. 1992). Intrinsic drivers include the biological activity of organisms themselves, which can modify substrate properties (see the section on bio-engineers for more information).

In soft sediments, habitat forming organisms can modify sediment properties, e.g. tube-building polychaetes, seagrasses, cold–water corals and mussels (e.g. Callaway 2006). In many cases, the presence of these structures affects soft substratum environments in diverse ways. These include deposition of fine particulate matter (e.g. silt) and of larvae and meiofauna as a result of alterations in near-bed flow (e.g. Butman 1987). For example, sediment properties within dense aggregations of tube building polychaetes, such as *Lanice conchilega,* can differ from adjacent areas, which in turn influences the benthic community structure (e.g. Rabaut 2007).

b2. Gravels, e.g. cobble and pebbles (particles 2 to 256 mm)

The fauna on gravel substrate is often dominated by small epifaunal sessile organisms. Kostylev et al. (2001) demonstrated that species richness was considerably higher in areas of gravel substratum compared to other substrate types. Habitat forming organisms can also influence the structure of benthic communities in this substrate type.

b3. Hard substratum (igneous or sedimentary) e.g. bedrocks, rocks boulders, lava etc. (> 256 mm)

This substrate type is very important for a large number of organisms. The physical structure and complexity (rugosity) of hard substratum can be extremely variable and this will influence the structure of the associated fauna (e.g. Dunn and Halpin, 2009, Stoner 2009). As an example, hard substrates with high geometrical complexity (e.g. a rock with a large number of interstices or cracks with variable shape) create more microhabitats for organisms, including cryptic species, compared to a smoother substrate. Several studies have shown a strong correlation between habitat complexity and diversity of benthic and fish communities (e.g. Wilson 2007). The spatial distribution of sessile epifauna and habitat forming organisms can be highly influenced by availability of hard substratum (Diesing et al. 2009).

b4. Biogenic habitats

Biogenic habitats are very diverse in size and structure. These include coral reefs, polychaete worm reefs, seagrasses, kelp beds, marsh grasses, maerl beds, mussel and oyster beds. Similar to abiotic hard substrates, these biogenic substrates provide three-dimensional habitats for a large variety of species. Furthermore, the complexity and the properties of the physical structure have a large influence on the associated fauna (e.g. Lawrie and McQuaid 2001). Tropical coral reefs are the most species-rich marine ecosystems (Grassle 2001), making the protection of reef building species an essential aspect of the conservation of marine diversity. Similarly, the diversity in cold-water coral grounds (e.g. Mortensen et al. 2008) can be much larger compared to adjacent areas. Habitat complexity provided by reef-building species can influence predator-prey relationships in several ways, such as providing a refuge for a prey species (Grabowsky 2004). Differentiating between the effects caused by the biological activity of the animal inhabiting the habitat *per se* from its structural effects on sediment properties can be difficult. As an example, fine sediments can be deposited inside mussel bed matrix, both as a result of reduction in the current strength of the near-bed flow and due to production of material by the mussels themselves (e.g. Ragnarsson and Raffaelli 1999, Buschbaum et al. 2009). Further, biogenic habitats have been considered to be important for various fish species. As an example, some studies have found associations between some fish species such as redfish (*Sebastes* spp.) and tusk (*Brosme brosme*) and cold-water stony corals (e.g. Husebø et al. 2002, Costello et al. 2005). The role of three-dimensional habitats is so well recognised that artificial reefs have been installed in several areas to reduce detrimental impacts on existing habitats, through trawl exclusion, and to restore damaged habitats or to improve fish production by providing a habitat of greater complexity to species of commercial interest. Artificial reefs have also been used for other fisheries management purposes such as to improve cost-effectiveness of fishing practices (Claudet and Pelletier 2004), but they are particularly suitable as obstacles to mobile fishing gears (Iannibelli and Musmarra 2008; Baylesempere et al. 1994; Munoz-Perez et al. 2000, Relini et al. 2004, Sanchez-Jerez and Ramos-Espla 2000). Nevertheless, whether artificial reefs act more as fish aggregation devices or whether they actually contribute to increased fish abundance has not been demonstrated yet (Claudet and Pelletier 2004).

b5. Topography

Topography includes both naturally occurring (e.g. seamounts, slopes, sand waves) and human induced features (e.g. trawl marks, sediment extraction pits, artificial reefs, wrecks). Topography can have a large influence in structuring geological properties, ecological communities and habitats (e.g. Bourillot et al. 2009). Habitat suitability modelling has identified topography (e.g. the degree of slope) to be important in predicting distribution of substratum properties and the structure of associated fauna (Bryan and Metaxas 2007, Degraer et al. 2009, Tittensor et al. 2009).

c) Which subcomponents of the attribute reflect a gradient of degradation, and why

In most cases, and unlike for many of the other attributes of seafloor integrity, there is no single axis that defines a continuum from “good” status to a degraded status for the substratum. Rather, from whatever state is characteristic of a site, change in any direction may be considered as degradation. The best indicator of whether a particular change can be defined as degradation or not is the degree to which ecosystem functions associated with the soft substrate are degraded. That question can usually be better addressed with indicators of the function being fulfilled rather than with indicators of the substrate itself. Those indicators can be found in the attributes Species Composition, Oxygen, Bio-engineers, Trophodynamics, and possibly Life History Traits.

The magnitude of impacts of human activities differs greatly between substrate types. Meta-analyses have been useful to rank the severity of fishing gears across substrate types and faunal groups (Kaiser et al. 2006). In general, biogenic habitats tend to be most sensitive to physical disturbance as these consist of fragile structure, while fauna from mobile sands tends to be most resilient.

c1. Soft substratum, e.g.: fine sandy and muddy sediments (particle < 2mm)

The axis of degradation for soft substratum is usually difficult to define, and may be better reflected in the state of the benthic communities rather than the state of the soft substratum *per se*. The functioning of benthic communities on soft substratum may be altered when the magnitude of anthropogenic disturbance becomes greater than the level of natural disturbance, or when anthropogenic disturbances trigger long-term changes. For example, the mud content of sediments in the Bay of Biscay has decreased over a 30 years period (Dubrulle et al. 2007, Bourillet et al. 2004, Hily et al. 2008). The combined effects of storms and trawling activities during this period may have resulted in increased particle resuspension and export of the mud particles to other areas (Madron et al. 2005, Ferre et al. 2008, Hily et al. 2008) which in turn probably contributed to the changes in the composition of the dominant benthic species (Hily et al. 2008). Other studies have shown direct effects of trawling on surficial sediments (Schwinghamer et al. 1998). Other human impacts may originate from changes in terrestrial sediment input due to land activities and management. Human activities may reduce the sediment input from rivers because sediment may be trapped in dams (e.g. Morais 2008) or extracted. For example, the sand extraction from the Loire river from 1945 to 1980 was estimated to equal to 400 years of river bedload transport (Belleudy 2000).

Several studies have shown that human impacts can alter properties of soft substratum in a variety of ways that will influence the benthic communities. In some cases, a clear decrease in sediment quality in response to anthropogenic stress is observed (e.g. Zhou et al. 2007). In other cases, the effects of changes in sediment properties on the community dynamics may not be easily interpretable, and in turn, detecting a gradient in degradation can be difficult. As an example, extraction of sediments can result in variety of changes in sediment properties depending on locations and substrate types, such as increase in gravel in some cases and dominance of sand in others (ICES 2009). As a result, small-scale impacts and degradation can only be assessed in reference to a documented initial or pristine state. It is not realistic to assess degradation at such small scales, as human impacts may induce changes in both directions (e.g. cause increase or decrease of a particular species).

c2. Gravels, e.g. cobble and pebbles (particles 2 to 256 mm)

The axis of degradation for gravel substrate is usually hard to define as a gradient of the gravel itself, as it is relatively robust to most human activities. In some cases, direct extraction of gravel (e.g. Boyd et al. 2005) or exposure to sediment load (e.g. sediment dumping) can result in overall decrease in the spatial extent of gravel. More importantly it is the frequency and magnitude of disturbances in gravel substrates that may degrade its environmental state. This degradation usually will be reflected in changes in the benthic community long before the properties of the gravel are changed. The fauna of gravel beds tends to be more sensitive to towed bottom fishing gears compared to soft substratum because it often includes fragile forms (e.g. Kaiser et al. 2006). Collie et al. (1997) showed that undisturbed seabeds with pebbles and cobbles were dominated by rich epifaunal assemblages, which were largely removed on such seabeds where scallop dredging takes place. Furthermore, several studies have shown that recovery rates following gravel extraction (Boyd et al. 2005) and bottom fishing (Collie et al. 1997) can be much slower in gravel than in soft substratum. Finally, Grizzle et al (2009) observed greater density of epifauna on gravel seabeds and boulders inside an area closed to fishing activities than in adjacent fishing ground.

c3. Hard substratum (igneous or sedimentary) e.g. bedrocks, rocks boulders, lava etc. (> 256 mm)

Similar to gravel, the axis degradation for hard substrate is usually hard to define as a gradient of the hard bottom itself. Considering the robustness of most hard structures of geological origin, it is difficult to imagine what physical impact can have direct influence upon this substrate type. As an example, boulders can be moved by fishing gears without any impacts on the substratum itself. The axis of degradation may be better reflected in the state of the fauna in areas of hard bottom areas (e.g. boulders) which often consists of fragile sessile epifaunal organisms such as sponges and corals that can be very sensitive to physical impacts (Freese et al. 1999).

c4. Biogenic habitats

Human activities, in particular fishing (Kaiser et al. 2006), can damage three-dimensional biogenic habitats, resulting in the reduction of the spatial extent of these habitats and causing changes in the physical (e.g. sediment properties) and the biological (e.g. species composition) environment. Many biogenic habitats can be very sensitive to fishing impacts. As an example, the loss of the bryozoan (*Cinctipora elegans*) biogenic reefs in New Zealand over the period 1960 to 1998 due to oyster dredging resulted in sediment transport and dune formation (Cranfield et al. 2003). Many other biogenic habitats are considered to be very sensitive to bottom fishing. For example, coldwater corals (e.g. Fosså et al. 2002) are easily broken down during fishing. Coral colonies generally consist of a live coral surrounded by a layer of coral rubble, i.e. coral that has died from natural causes. However, it is evident that in many areas where coral occurrence has been documented in the past, loss of corals due to bottom fishing has taken place. According to an estimate for Norwegian waters, between 30 and 50% of cold water coral reefs have been damaged as a result of bottom trawling activities (Fosså et al. 2002). Similarly, sponges (porifera) can be very sensitive to fishing impacts (e.g. Wassenberg et al. 2002).

There can be a gradation in the magnitude of impacts, as some biogenic habitats are more sensitive than others, and also in the spatial distribution of these effects (e.g. some areas are more fished than others). A reduction of the surface area covered by a biogenic habitat at regional scale can be clearly defined on an axis of degradation. In general, the magnitude of impacts on biogenic habitats depends on their structural properties and recovery rates. While cold water corals are extremely sensitive to physical impacts and recovery rates are extremely slow (Mortensen and Mortensen 2005), other habitat forming species are more robust to human impacts, e.g. polychaete reefs of *Sabellaria spinulosa* (Vorberg 2000). Full guidance on how to define and evaluate an axis of degradation for biogenic habitats is presented in the Attribute "Bio-engineers".

c5. Topography

It is difficult to define a single axis on a continuum where changes in topography range from "good" to "bad". Depending on the initial state, changes in any direction may be considered as degradation. Human activity may decrease or increase the complexity of bottom topography, either by flattening out sea floor (i.e. reducing seabed heterogeneity) or creating furrows and depressions in flat habitats. Sand and gravel extraction are carried out widely in the European waters. Such extraction can have considerable influence on the seabed topography, sediment properties and benthic communities, mainly at the scale at which the extraction takes place (Boyd et al. 2005, ICES 2009). Various fishing gears leave marks on the seabed that vary in shape and size depending on the type of gear used. The persistence of these fishing gear marks on the seabed over time is also variable, but trawl marks in the deep sea generally persist over longer time compared to shallow waters (e.g. Clark and Rowden 2009). On the other hand, various structures e.g. artificial reefs, oil platforms, wrecks etc., that are added to the seafloor increase its complexity (Baylesempere et al. 1994). In the case of biogenic habitats, changes in topography are evident in many locations, such as destruction of emerging biogenic habitats that reduces surface heterogeneity (e.g. Cranfield et al. 2003). The effects of coastal development, fishing and extraction can have a large influence on the seabed landscape both at small and large scales. However, the effects of altering seabed topography can be more indirect. Jones and Frid (2009) showed that the alteration in surface topography in sediments changed the species composition, which in turn affected porewater nutrient concentrations.

d) *Which human activities and pressures are closely linked to / reflected by the attribute or specific sub-components (or is it a general feature that may be affected by a variety of activities & pressures)*

Marine substrates can be affected by many human activities. Impacts on marine sediments tend to differ between inshore and offshore environments. In inshore environments, sediments can be influenced by eutrophication, dumping and extraction of sediments, port dredging, hydrocarbon exploration, land reclamation, pollution events and fishing.

In offshore environments, fishing is the principal human activity affecting marine substrates but other activities (e.g. hydrocarbon exploration and exploitation) are likely to have effects primarily on local scales. However, causing changes in the substrate properties can require considerably large impacts, although this may vary among substrate types. The spatial distribution of fishing is generally very patchy (e.g. Piet and Quirijns 2009), suggesting that some areas can be under high pressure from fishing while others are rarely fished.

e) Important classes of indicators

Indicators are here classified in terms of a DPSIR framework (Singh et al. 2009). The axis of degradation will be generally better represented by indicators of biotic attributes of the seafloor integrity. Therefore impact and state indicators should be found in the attributes Species Composition, Oxygen, Bio-engineers, Trophodynamics, and possibly Life History Traits. Nevertheless, pressures exerted by human activities and appropriateness of management need to be assessed from pressure and response indicators. Multibeam echosounder backscatter measurements with appropriate ground-truthing might have an increasing contribution to state indicators.

e1. Pressure indicators

Pressures are developed by driving forces, which are human activities, policies and environmental changes at regional scales (Rogers and Greenaway 2005). Although they may become the main pressures in the future, global warming and acidification will not be taken in account here as they are exerted at global scale and do only marginally depend upon regional marine policy.

Pressure indicators of the different human activities expected to impact the seafloor should be monitored. For fishing activities, several pressure indicators (or data to compute them) such as fleet capacity, fishing effort and fishing mortality of fish stocks (Piet at al. 2007) are already available and can be used to monitor the overall pressure generated from fishing on the seafloor at regional scale. In addition to being fully appropriate to the descriptor seafloor integrity, these indicators are also suitable as pressure indicators for other descriptors, such as biodiversity (descriptor 1), commercial species (descriptor 3) and foodweb (descriptor 4). These pressure indicators can be derived from fishery statistics based upon logbook data, the common fleet register of the European Union (http://ec.europa.eu/fisheries/fleet/index.cfm) and other database form national administration and stakeholders.

Indicators of the distribution and frequency of fishing activities using all gears likely to contact the seafloor during normal operations are also required, but particularly for mobile gears like trawls and dredges. These indicators may be maps or spatial indicators (e.g. proportion of area swept by towed gears, average frequency of trawling) aggregated at scales that are appropriate for management (Hiddink et al. 2006 a). These indicators might be sensitive to management and should reflect the effect of Marine Protected Areas ([MPAs] - as a result of reduction of fishing pressure to zero levels inside the MPAs, although possibly with an increase in pressure in areas outside the MPAs), the change in fishing effort and in the gears used (gear substitution may occur when fishing with trawls may become less profitable due to higher fuel costs). In this respect, VMS (Vessel Monitoring System) data provide high-resolution spatial distribution of effort (which is essential to assess the proportion of seabed impacted). The recent availability of VMS data to science allowed the development of suitable indicators. In developing these indicators special attention should be given to the effect of scale (e.g. Piet and Quirijns 2009). Based upon modelling, relationships between indicators of pressure from trawling and state indicators of benthic communities were estimates (Hiddink et al. 2006 b). Technological creeps is susceptible to undermine the meaning of fishing pressure indicators (e.g. Eigaard 2009), therefore technological improvement in all EU fleet require close monitoring.

Similarly to fishing activities, pressures from other human activities at sea including (i) the amount of marine sediments extracted, (ii) the size of the surface area licensed for extraction of sand, gravel and other material, (iii) the amount of material dredged in ports and estuaries and (iv) the amount of material dumped at sea. Pressure indicators should be estimated based upon national administrations/agencies, industry sectors and stakeholders. Data for these indicators are included in administrative registers of activities, sales registers and shipping registers but also in other sources such as satellite and aerial surveys. Lastly, where relevant in the context of MSFD, pressure indicators for land-based activities should also be considered. Land-based activities clearly impact estuarine and coastal areas and some impact may spread out over the shelf (e.g. Lorance et al. 2009). Where relevant, runoff of terrestrial origin and input of contaminants susceptible to accumulate into the substrate (e.g. Courrat et al. 2009) should be monitored.

Pressure indicators present the advantages of being easy to understand and quick to respond to changes in management action, easy to implement at a relevant scale for fisheries management and above all they are convenient for communication to policy makers and stakeholders (Hiddink et al. 2006).

e2. Impact indicators

Most impact indicators of human activities on the seafloor descriptors are expected to apply to biological attributes of the seafloor. Bio-engineers, life-history traits and size-composition attributes might be the most sensitive to human impacts. Overall functional indicators of benthic communities are suitable to reflect the impact of trawling (e.g. de Juan et al. 2009). Nevertheless, indicators of the impacts on the substrate attribute may be suitable. In general, imaging techniques are suitable to assess impacts on the seabed when they are not undermined by low spatial coverage; this may be especially the case with discrete and small 3-dimensional habitats. Experiments have shown that trawling may decrease the proportion of organic matter in the sediments in conditions where undisturbed sediment has a low organic content (Bhagirathan et al. 2010). In sedimentary environment, Sediment Profile Imagery may allow to assess trawling impacts (Smith et al. 2003). In the case of European waters, such tools would most likely prove more cost-effective when used for ground-truthing pressure indicators. Nevertheless, it is most likely that in European seas pressure indicators and biotic indicators from the other attributes of seafloor Integrity will be more suitable to assess the impact of fishing. Suitable impact indicators for extraction of marine aggregates are density/extant and depth of dredge tracks and scours detected by imaging techniques and sediment composition with respect to pre-dredge conditions or local reference sites (Boyd et al. 2005).

e3. State indicators

Depending on the region and habitat, useful state indicators can be the proportion of an area where benthic invertebrate biomass and/or production (P) are above a given percentage of pristine benthic biomass or production (Hiddink et al., 2006 a). Habitat suitability modelling is useful to predict distribution of species that are tightly correlated with environmental parameters (e.g. slope, substrate type, temperature etc). Examples include cold water corals (Guinan et al. 2009, Roberts et al. 2005) as well as shelf benthic communities (Degraer et al. 2008). Recent developments have been achieved in predictive models of seafloor habitats and benthic biotopes at the scale of large shelf areas (e.g. Buhl-Mortensen et al. 2009, Rattray et al. 2009). These habitats or biotope models seem highly suitable to monitor long-term variation in seafloor attributes, and make increasing use of multibeam echosounder (MBES) backscatter imagery (Brown and Blondel 2009). Together with recent development of backscatter classification techniques, MBES provides a cost-effective tool to image large areas of the seafloor allowing derivation of maps of the seabed environment and benthic habitat (Brown and Blondel 2009). Sufficient ground-truthing data, e.g. grab, boxcorer, sediment profile camera, underwater video, hyperbenthic sledge, beam trawl will be required to extrapolate the habitat classification from MBES backscatter imagery (Le bas and Huvenne 2009, Kenny et al. 2003, Buhl-Mortensen et al. 2009), and such information may be forthcoming for more areas in the near future. Nevertheless, in well-known areas, MBES backscatter data already showed very good agreement with available ground truth data (Simons and Snellen 2009). Indicators of benthic habitats are considered a promising way forward, and should be identified and used to monitor long-term changes in seafloor habitats

e4. Response indicator

The response indicators refer to policy and management actions to remediate human impacts on marine ecosystems (Rogers and Greenaway 2005). Response indicators relevant to the seafloor include fisheries management responses such as (i) measures to control fleet capacity and fishing effort, (ii) technical measures to reduce the impact for towed gears on the seabed, and (iii) any spatial measure to conserve or reduce the impact of fishing on Vulnerable Marine Ecosystems (VMEs). Examples of suitable response indicators include fleet capacity, fishing effort (total and by gear) and total number and total surface area of MPA´s.

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4.2 Bio-engineers

a) Description of the attribute

In this context bio-engineers are organisms that change the structure of the seafloor environment in ways not done by geophysical processes alone, either by reworking the substrate (bioturbation) e.g. by feeding, building burrows, locomotion and ventilation, or by providing structure by themselves that are used by other species, e.g. coral reefs or mussel beds. In this later respect this attribute overlaps with biogenic substrates section 4.1.

b) Why the attribute and subcomponents are important to seafloor integrity

Bioengineers may serve functions such as creating or by themselves providing shelter from predation or substrate and habitats for other organisms. Important functions are as well the displacement and mixing of sediments by burrowing and ingestion and defecation of sediment grains, and the transport of interstitial porewater by flushing voids and burrows (bioirrigation). The activities by bioengineers by bioturbation promotes several chemical processes e.g. the remineralization of organic matter and the oxidation-reduction reactions in sediments by increasing the total area of oxic—anoxic boundaries and thereby the surface available for microbial activity and diffusive exchange . The mediators of bioturbation are typically annelid worms, bivalves, gastropods, or any other infaunal or epifaunal organisms (Aller 1988, Aller 1994, Meysman et al. 2006). In the photic zone macroalgal communities also serve the ecosystem with energy input via photosynthesis.

c) Which subcomponents of the attribute reflect a gradient of degradation, and why

Good ecological status of bioengineers are judged in relation to the function of the feature being assessed, i.e. the ability to serve the ecosystem with shelter from predators or contribute to the material exchange at the sediment-water interface. Important subcomponents of the attribute are the type, abundance, biomass and areal extent of bio-engineers.

In terms of bio-engineers, an axis of degradation is the degree to which the functions served by the engineers characteristic of the ecosystem are lost as the bioengineers are killed or the structures they create are damaged. The nature of the damage may vary considerably from permanent ecological damage e.g. the physical destruction of biogenic deep-water coral reefs, to recovery within days e.g. the reconstruction of burrows by benthic annelids. Sensitivity of various types of bioengineers to human perturbations varies greatly and is defined in relation to the degree and duration of damage caused by a specified external factor. Gradients of degradation will thus vary depending on the frequency and severity of the specific disturbance i.e. if the pressure is permanent, re-occurring or sporadic and the resilience of the particular bio-engineer(s) to the pressure(s) on it.

Organisms creating the physical structure of the seafloor may either recover through passive or active migration of organisms or recruitment. In cases of migration recovery can be much faster. Processes of recovery are thus also scale dependent and the resilience of communities are strongly dependent the scale and the patchiness of disturbance (Kaiser et al. 2006).

Physical destruction, including direct harvesting of structuring organisms such as mussel beds and kelp forests, show gradients of degradation due to the intensity of the disturbance. As bio-engineers provide services to other organisms as habitats and shelter, gradients are likely to be reflected in metrics of biodiversity as well as in metrics of the structuring organisms themselves. Fishing activities for example results in changes in habitats, functioning and benthic production (Jennings et al., 2001; Kaiser et al. 2002; de Juan et al., 2007).

After an episodic disturbance e.g. if seafloor kills occur due to dredging of sediments, bioturbating communities generally recovers fully given enough time(Cooper et al. 2008).

d) Which human activities and pressures are closely linked to / reflected by the attribute

Bio-engineers are sensitive to direct physical disturbance causing removal or redistribution of substrate, and changes in mortality from pressures such as eutrophication.

Fishing with towed bottom gears are used globally to capture fish, molluscs and crustaceans. The fishing process causes varying levels of disturbance to the seabed that alters complexity by removing, damaging or killing biota which may lead to reduced benthic production and changes in community structure and habitat (Dayton et al. 1995; Kaiser et al. 2002, Tillin et al. 2006). The loss of bioturbating macrofauna from soft-sediment habitats also alters sediment nutrient fluxes

(Olsgard et al. 2008). The direct effects of different towed fishing gears are habitat specific and the most severe impacts on biogenic habitats with heavy bottom contacting gears i.e. dredges (Kaiser et al. 2006).

Causal links between pressures and the ecological consequences are summarised in table below:

Pressure	**Ecological consequence**
Direct physical disturbance and removal of substrate	Loss of structuring organisms/complexity Loss of habitat Loss of biodiversity Reduced production
Change in energy at the seafloor level	Turbidity increase/light penetration changed distribution of macroalgae Smothering of organisms and habitats (clogging gills and filter feeding organisms)
Discharge and spread of particulate matter	Turbidity increase/light penetration changed distribution of macroalgae Smothering of organisms and habitats (clogging gills and filter feeding organisms)
Mortality of organisms-food web interactions	Changes in community composition including cascading effects Change in sediment fluxes of nutrients
Changes in salinity/freshwater input	Changed distribution of organisms

e) *What are important classes of indicators to include, in order ensure that the key aspects of this attribute and its subcomponents, and its important linkages to pressures, are all covered?*

Important indicators for this attribute are metrics of abundance of organisms and extent of habitats. Guidance on how such indicators should be developed is presented in Section 4.5. It is only necessary to ensure that any bio-engineers important to a given area are identified during the evaluation process. Then the species-composition guidance on calculating indicators can be applied. In some cases it would also be possible to measure the function being served. However, this is more likely to be possible for functions like nutrient regeneration through reworking sediments (where nutrient levels can be measured directly) than for functions like provision of shelter for juvenile fish (where "use of shelter" can only be measured indirectly. Pressure indicator would be areas exposed or not exposed to activities which damage or destroy the bioengineers, such as the areas not fished.

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4.3 Oxygen Concentration

a) Description of the attribute

Oxygen means the concentration of dissolved oxygen in the bottom water and/or in the upper sediment layer of the seafloor. Episodic oxygen depletions are a signal that a marine system has reached a critical point of eutrophication, which, in combination with physical processes that stratify the water column, tips the system into hypoxia. It is caused by the consumption of oxygen by the microbial processes responsible for the degradation of organic matter accumulating at the sea floor. Oxygen depletion may result in hypoxia (low oxygen concentrations) or even anoxia (absence of oxygen). These events may be episodic, seasonally occurring in summer or autumn (most common), or persistent. Decreasing oxygen supply of bottom water and/or the upper sediment results in significant changes of the benthic communities and can lead to mass mortality of macroscopic organisms.

b) Why the attribute and subcomponents are important to seafloor integrity

Decreasing oxygen concentration leading first to behavioural effects, e.g. benthic fauna shows aberrant behaviour (Riedel et al. 2008), culminating in mass mortality of macroscopic species when hypoxia approximates anoxic conditions (Dıaz, R. J. & R. Rosenberg 1995; Gray et al. 2002). In principle, a sea region is in GES when oxygen concentrations are within their natural range and at least above 3,5 to 4.5 ml/l (Gray et al. 2002, HELCOM 2009). In regions where hydromorphological conditions should provide high oxygen concentrations benthic fauna show no aberrant behaviour associated with oxygen levels. In sea regions where oxygen depleted subareas are normal the spatial extents of these areas are not exceeding pre-eutrophication ranges.

c) Which subcomponents of the attribute reflect a gradient of degradation, and why

The critical point to be assessed is a situation where the demand for oxygen has exceeded its supply, which can lead to oxygen deficiencies. This process is accelerated by nutrient enrichment and therefore oxygen concentrations are widely used as indicator for eutrophication. In sea regions like the Baltic Sea, concentrations below 4.5 ml O_2/litre are defined as oxygen depletion and concentrations below 2 ml O_2/litre are defined as severe, acute oxygen deficiency and can end up in anoxic conditions (Gray et al. 2002). When oxygen concentrations fall below about 1 ml/l, bacteria start to use anaerobic processes, producing hydrogen sulphide. Hydrogen sulphide is toxic for most of marine macro-organisms, and its concentration is described in terms of negative oxygen. Also in some regions, i. e. in the deep basins of the Baltic Sea, where oxygen depletion is due to limited water exchange to some extend a natural phenomena (HELCOM 2003), eutrophication induced by excessive nutrient input has considerably worsened this oxygen depletion and further threatened marine ecosystems, biodiversity and fish stocks (Thurston 2001). Oxygen depletion has a clear impact on biogeochemical cycles, respectively (Middelburg & Levin 2009, Conley et al. 2002). Anoxic periods cause the release of phosphorus from sediments. Ammonium is also enriched under hypoxic conditions. The dissolved inorganic phosphorus and ammonium from the bottom waters can be mixed into the upper water column and enhance eutrophication effects. Part of the phosphate released from sediments will attach to the newly formed iron oxides, another part may sustain or enhance algal blooms. The enhanced efficiency of NH_4 and PO_4 release from O_2-stressed sediments represents an important biogeochemical feedback mechanism that reinforces the eutrophication process (Kemp et al. 2005).

d) What are the pressures that act upon the attribute

The worldwide distribution of coastal oxygen depletion is associated with major population centers and watersheds that deliver large quantities of nutrients into the sea. Additionally, local changes of the hydro-morphological regime, i.e. by the digging of holes due to sediment extraction, or high concentrations of local fertilizer inputs, i.e. by aquaculture, can lead to the same effect on a smaller scale (Dıaz & Rosenberg 2008).

e) What are the indicators or classes of indicators that cover the properties of the attribute and linkages to the pressures?

Assessments of the spatial distribution of oxygen/hydrogen sulphide concentrations in the bottom water should be conducted in critical regions and in critical seasons, e. g. during late summer and autumn, and should be conducted on a scale which enables the detection and description of the local oxygen depletion phenomena. Even short term and very local events can be early warning signals that a region has reached critical levels of nutrient loads. Oxygen/Sulphide concentrations can be measured directly by oxygen/sulphide sensors and/or together with a visual image of the gradients by a profile imagery camera (Nilsson & Rosenberg 1997). Assessed have to be numbers of years with or without summer hypoxia per reporting period and the areal extend of the depletion zones for a susceptible region or habitat type. Additionally in those zones, states of the benthic communities, e. g. species compositions, structured by occasional or regular occurrence of hypoxia events have to be assessed. Ecological effects, i.e. decreasing natural biodiversity are depending on a combination of sensitivity to oxygen levels by the organism and the duration and intensity of hypoxia that governs the survival and functioning of organisms under conditions of hypoxia (Middelburg & Levin 2009).

Indicators are the periods, the frequencies, the extent and distribution of areas with hypoxia and/or the local reduction of dissolved oxygen together with the distribution and abundance of benthic communities which species compositions are altered and structured by occasional or regular occurrence of hypoxia events (see Life History Traits). A good example of an existing monitoring which combines these parameters is the Baltic Sea Monitoring explained by the "Manual for Marine Monitoring in the COMBINE Programme of HELCOM" (http://www.helcom.fi/groups/monas/CombineManual/en_GB/main/).

f) How are the indicators aggregated to assess GES for the descriptor?

For sea floor integrity normal oxygen supply is an essential criterion. Therefore, normal oxygen concentrations in all regions which are naturally oxygen saturated are a minimum requirement which cannot be compensated by others attributes in a good status.

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4.4 Contaminants and hazardous Substances

a) Description of Attribute

In the *Definition of terms in descriptor and understanding of the key concepts*, section 1of TG 8 Report, for "Sea floor Integrity" it is particularly important to take account of "*direct and/or indirect adverse impacts of contaminants on the marine environment such as harm to living resources and marine ecosystems"*.

b) Why is important to Good Environmental Status?

There is a tight link between chemical and ecological status. Sediments where benthic communities live are the repositories for many of the more toxic chemicals that are introduced into water bodies. Contaminated sediments represent a hazard to aquatic life through direct toxicity as well as through bioaccumulation in the food web.

There are indications for effects due to chemicals on benthic community structure in European marine waters, but the links are not clear. It can be expected, however, that in most cases, where and if contaminants do contribute to population or higher levels effects, the quantitative contribution of contaminants to the observed population effect will remain unknown.

Assessment of contaminant levels and toxins as part of Monitoring marine environmental quality Programs all around Europe does not generally encompass bioaccumulation analyses in benthic communities. As benthic communities, in fact, structural and functional analyses of the benthic assemblages are performed, but contaminant levels and toxins are not analysed into as a whole, though benthic sediments and communities represent repositories for toxic chemicals.

The WFD 2000/60/EC uses *Macroinvertebrates* community structure as a descriptor (biological quality element) for assessing the good environmental status. Some monitoring programs and studies include biomonitoring (bioassays and biomarkers) on some invertebrate target species (see *Table 1. Summary of field effects attributed to chemical contaminants* of the *Annex 2*; *Annex 8*; *Annex 13* of the TG8 Report; Italian National Monitoring Plans, 1999-2009, www.minambiente.it; Water Framework Directive Chemical Monitoring Activity "*Guidance on chemical monitoring of sediment and biota*" (http://www.circa.europa.eu).

Contaminants may affect levels of ecosystem organisation from individual to community level. Although there are obvious issues with representativeness and specificity, such information is clearly the ultimate goal in an assessment of contaminant effects on marine ecosystems. The ability of biological effects methods to identify and quantify effects of contaminants is regularly reviewed by the ICES Working Group on the Biological Effects of Contaminants. Briefly, with few exceptions, it is not really feasible at this time to link community or population effects to contaminants in field studies. The main reason is the large natural variability and the influence of other factors, such as organic enrichment or physical disturbance. An added complication for population assessment is the difficulty in observing dead or moribund individuals in marine ecosystems. Methods by which to quantify more or less contaminant specific effects at the individual level have increasingly been developed over the past decades and have been used in national and international monitoring programmes since the 1980s. An integration of such methods and the quantification of chemical determinants in assessments of adverse effects on the individual health of marine organisms lies at the core of a recently developed OSPAR monitoring framework (for this part see section *2.1.3.* and *Annex 4* of TG 8 Report).

c) What constitutes the "axis of degradation" of the attribute? What characterizes a "good" position on this attribute?

See section 4.2 of the TG 8 report.

d) What are the pressures that act upon the attribute?

The pressures considered under Descriptor 8 are inputs of contaminants into the marine environment. These derive mainly from land-based sources via rivers and coastal run-off and/or from atmospheric sources (see *Section 4.1* in TG8 Report).

In particular, for the seafloor habitats and communities, we have to consider industrial activities, maritime traffic, offshore oil and gas activities, wastewater discharge, etc., which directly introduce contaminants and hazardous substances into the environment, and dredging activities, positioning of cables and sea-lines, offshore oil and gas activities that disturb sediments and make contaminants and hazardous substances recycling. All these human activities represent pressures which can cause the input of contaminants in the marine ecosystem and then potential effects on the sea-floor integrity.

e) What are the appropriate indicators or classes of indicators?

Indicators that use biomarkers and bioassays (BIOMONITORING) and can be linked to other aspects of Benthic Integrity are necessary to evaluate GES for benthic integrity, as well as direct indicators of concentrations (eg. EQS in the Water Framework Directive and EACs in OSPAR). TG 8 report should be consulted for more specifics on both classes of indicators, and how they should be integrated in assessments.

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4.5 Species composition (diversity, distinctness, complementarity/(dis)similarity, species-area relationships)

a) Description of the attribute

Species composition (SC) refers to the species pool that comprise a community or any other ecological unit, including their abundance (both absolute and relative; expressed as density, frequency or other units), phylogenetic/taxonomic relationships, and spatial pattern of occurrence as mosaics on many scales]. SC, therefore, is a highly complex attribute that includes: (a) the identity of the community units; (b) their historical relationships; (c) their ecological responses; (e) their relative and absolute patterns of abundances in space and time, and (d) the interactions among them. The attribute is also indicative of the functioning of the species in the community since their morphological and anatomical characters constrain the role they may play in the community. The latter is particularly important for their involvement in the biogeochemical cycles and energy flow, and, therefore, for the ecosystem functioning (Bremner, 2008). SC of macrobenthos has been traditionally used as an estimator of the marine environmental health (Pearson and Rosenberg, 1978) as well as of the biodiversity (e.g. Warwick and Clarke, 2001).

The term "integrity" calls for estimators of two-dimensional (spatial) attributes of the sea bottom and not to those referring to spot (e.g. single station) observations. Therefore, the suggested approach to check the integrity is to look for biotic (dis)similarities between ecological units. This corresponds to the measurement of the β (beta) diversity according to Magurran (2004) or to the turnover diversity according to Gray (2000). In severely impacted communities the β (beta) diversity changes as a result of the dominance of the r-strategists (see section 4.8) and tolerant species. The most suitable component of the marine ecosystem to use for seabed integrity is benthic fauna. Benthic fauna plays vital roles in detrital decomposition, nutrient cycling, and energy flow to higher trophic levels. In addition, these species live in close association with bottom substrata, where major pressures such as organic pollutants and chemical contaminants tend to accumulate and where low-oxygen conditions are typically the most severe. Because of their relatively sedentary lifestyles, it is difficult for these organisms to avoid exposure to pollutants and other adverse conditions in their immediate surroundings (Hyland et al., 2005).

b) Why is species composition important to Good Environmental Status (GES)?

A "good environmental status" (GES) for SC of a benthic macro-invertebrate community depends primarily on the habitat. SC fluctuates over time and space due to environmental and anthropogenic stresses (Gray, 1997; Warwick and Clarke, 2001). As a general pattern, communities with good environmental status are assumed to be those with a few abundant species and many rare ones. SC of such a community tends to be random sample of the species pool of the wider area or biogeographic sector or province and the roles that the species play in the ecosystem are very often complementary rather than competitive. . The latter is the result of the process of the niche saturation with species: as competitive species, using the same kind of resources, accumulate the niche is saturated and the free space left in the ecosystem is that offered by other niches. Such a community has high resilience potential to change. The resilience arises because biodiversity buffers ecosystem processes, and through them the ecosystem services that ca be used sustainably, against environmental variation. Different species or phenotypes (or genotypes) respond differently to specific environmental changes, and lead to functional compensation among the species and phenotypes / genotypes. This can result in a smaller variation in aggregate community properties in systems with higher diversity; the "insurance policy" of Loreau et al., (2001 and references therein). In extreme ecosystems (e.g. hydrothermal vents, sandy beaches, estuaries, lagoons) the absolute numbers of the abundant and rare species may be lower but the relative pattern remains as described above).

c) *Criteria for evaluation of this attribute of the Descriptor:*

What constitutes the "axis of degradation" of the attribute? The axis of degradation follows the model of Pearson and Rosenberg (1978) (P-R model) which describes and classifies the changes generally occurring in a community along an organic enrichment gradient: from a natural (undisturbed) zone in which no anthropogenic stress is observed and in which all niches are saturated with species or genotypes, up to an azoic zone (grossly polluted of severely disturbed). According to their model four stages of benthic communities can be identified along the axis of degradation: natural, under natural, polluted, grossly polluted. The four sequential stages represent categories assigned for heuristic reasons along the continuum of change shown by the macrobenthic community. The community itself does not proceed from stage to stage in discontinuous steps. Although this trend has originally been described for the organic enrichment gradient, the trend is probably general for any source of environmental degradation. If one takes into account Odum's (1997) principle that any disturbance sets the community back to an earlier successional stage, a progression similar to the stages described by the P-R would be expected. According to the hierarchical-to-stress hypothesis of Olsgrard et al. (1997) as pollution increases the gradients are reflected by higher taxonomic categories and not by species. However, there is no evidence to restrict this hypothesis to pollution only: other sources of disturbance may well have the same results in SC. Although the P-R model had originally been applied to soft-bottom communities of the coastal benthic environments it has been proved to be also valid in the Mediterranean coastal lagoons (Magni et al., 2009). Additionally, the model has recently been modified by Rosenberg et al. (2004) to meet the requirements of the WFD.

What characterises a "good" position on this attribute? A "*good*" species composition for a benthic unit comprises a number of species which, as a whole, take advantage of all the three dimensions of the seabed, penetrating deeply in the sediments. Only few of the species may be dominant while the majority of them are rare species represented in the samples by only a few individuals. Such a species composition exists in "*natural*" environments and is capable of performing or of contributing to a high number of ecosystem functions.

How can reference levels for "good" species composition be established? A few publications exist which have brought evidence that benchmarks can be established (e.g. Hyland et al., 2005; Magni et al., 2009; Rosenberg et al., 2004) along environmental degradation gradients. These papers all call attention to the need to interpret these benchmarks because the marine environment may be highly variable and because multiple stressors affect the species compositions. A well established approach to deal with the issue of the benchmarking is the BACI (Before-After, Control-Impact) one. A BACI approach requires habitat specific data before and after the stress or between controlled ("*natural*") and impacted sites. Therefore, if appropriately selected and managed, Marine Protected Areas (MPAs) may serve for the production of the standards of a "*good*" species composition in cases when habitat types are well matched between areas inside the MPAs and other sites exposed to human pressures. This can only be done for sites within shared biogeographical zones. MPAs also may not be protected from some types of pressures, for example harmful chemicals or nutrients that may be transported large distances by natural oceanographic processes. In those cases they may provide benchmarks relative to activities excluded from the MPA, but not relative to wholly unimpacted conditions.

The multiple stressors which act simultaneously as well as the inherent seasonal and inter-annual variability are additional sources of uncertainty in the establishment of the benchmarks (see next paragraph). Therefore, stratified sampling which encounters all stages of the environmental gradient on multiple sites (locations) with each of the biogeographic provinces and for each habitat type is regarded as instrumental in our attempt to establish benchmarks in general, and specifically reference levels that identify the boundary of "*good*" Environmental Status, and evaluate how severely sites are impacted by pressures. Finally, only measures which can be used comparatively within and between spatial scales can be informative for the seabed integrity. When matched for major natural habitat features (depth, substrate, temperature, energy regime etc) similarities among areas with good status of their SC are supposed to be high whereas they are anticipated to be low between sites of good and not good status in SC.

d) What are the pressures that act upon the attribute?

Any pressure that can change abundance of species or increase mortality can affect SC in communities. A large body of scientific literature documents that SC may respond to multiple pressures which can act alone or in concert: organic pollution including urban wastes, pollutants including toxic effluents, eutrophication, hypoxia, mechanical removal through operations of sand removal, waste disposal, fishing gears contacting the sea bottom, maritime operations, and building of new infrastructure on the sea bottom, are just a few of many that could be be mentioned (Clark, 1997). For managerial purposes, however, it is important to differentiate between the relative contributions of the various pressures (e.g. organic enrichment) and the natural environmental variation (e.g. percentage of fine grains in the sediments. The problem of the multi-stressors acting on the species composition is more complex than it appears and, in addition to the sampling approach proposed in the previous paragraph, requires thorough experimentation to remove the effects of all stressors but one at the time. The issue of scale adds additional effort on the afore-mentioned efforts.

e) What are the indicators or classes of indicators that cover the properties of the attribute and linkages to pressures?

There exists a variety of methods for measuring β diversity These can be classified into three broad categories according to Magurran (2004): (a) Measures which examine the difference between two or more areas of α (alpha) relative to γ (gamma) diversity such as Whittaker's β_w measure. These measures are termed measures of turnover diversity by Gray (2000). Wilson and Shmida's index β_T is the second best tested measure of this category; (b) In the recent years, another such measure has been launched which is based not only on the species numbers but also on their phylogenetics/taxonomic classification in higher levels: Average Taxonomic Distinctness (Δ^+) and Variation in Taxonomic Distinctness (Λ^+) which are measure of species relatedness of different sites in relation to the species pool of the broader (bio)geographic area (Warwick and Clarke, 2001); (c) Measures of complementarity and similarity (dissimilarity): The Jaccard and Bray-Curtis coefficients are among the best measures of this category. This category does not include only measures based on the species identity (e.g. Jaccard) but also on the species relative abundances (Bray-Curtis) and also those who can incorporate the phylogenetic/taxonomic relations of the species (Izsak and Price, 2001).

Measures which explore the species-area relationship and measure the turnover related to species accumulation with area (Harte et al., 1999; Lennon et al., 2001; Ricotta et al., 2002). The slope z in the relationship between log(S) and log(A) or the slope m in the relation between S and log (A) can be considered as measures of turnover if areas are nested subsets.

Most of the above measures assume homogeneity in the sampling gear and sampling design and for most of them there is no *a priori* "*correct*" reference value which may differentiate the "*good*" or other levels of the environmental status. They need comparative studies, as explained in the previous paragraphs, and often require randomization tests because the sampling distribution of the "expected value" of many indicators will be unknown. In the case of the measures of Taxonomic Distinctness, there is an additional challenge to produce the expected distribution of the "*good*" (expected) values through a randomization process. Because the full pool of *possible* species that could have been represented in the sample must be specified. Complementarity/similarity coefficients do not always require sample homogeneity especially if the "*good*" sites are *a priori* defined from the impacted ones and thus they can compared through non-parametric tests such as the ANOSIM.

f) How are the indicators aggregated to assess GES for the descriptor?

Two ways of aggregating the indicators may be used in ecology: (a) multimetric methods, which combine or aggregate the indicators using a formula; (b) multivariate methods, such as the Discriminant Analysis in which areas are classified into groups of GES and non-GES according to the scores derived from the indicators. Discriminant Analyses require reference samples from the desired groups, and the analysis can test the validity of this a priori classification and estimate the likelihood that "unknown" samples are members of each group, Other multivariate ordination methods do not require pre-identification of reference samples from pre-determined groups, but can identify systematic patterns of difference in SC for sets of sites. From these patterns and knowledge of the species present at the ends of the continua, it is often possible to infer which axes correspond to the axes of degradation, and where samples are located on the axis.

g) References for Species Composition

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4.6 Attribute - Size Composition of the Biotic Community

a) Description of Attribute

This could be reported as either the numbers or biomass of individuals of different sizes in the community. For clarity to non-specialists this text generally talks about numbers and abundance, but most of the statements are also valid if biomass is used instead of numbers. Dealing with biomass is particularly useful for communities with many colonial marine benthic species, where counting abundance of "individuals" can be problematic. Although "size is inherently a continuous attribute, when recording measurements "size" can be either continuous or binned (assigned to categories of size). For many typical analyses and presentations, categories (size classes) are used; usually ranked from smallest to largest. Particularly for species with stable food supplies and indeterminant growth, size and age covary to some (often large) extent, and many of the arguments in the section could be presented for age composition instead of size composition. However, for many benthic species, size is much easier and cheaper to determine than age.

b) Why is size composition important to Good Environmental Status?

Ecologically the size composition of a community integrates a great deal of information of about the processes underlying community dynamics; including the productivity, mortality rate, and life history strategies of the benthic species in the area, viewed in aggregate.

Information about *productivity* is reflected in that the growth achieved by individuals in a community varies with changing productivity of a system (Jennings and Mackison 2003, Brown et al. 2004, Law et al. 2008, Blanchard et al. 2009). Highly productive systems are capable of producing more large individuals, and individuals are capable of achieving larger sizes. In highly productive systems individuals that can grow large spend less time in smaller size classes. All these factors mean that more productive systems have a higher proportion of large individuals than less productive systems. However this reflects the increasing presence of large organisms; small organisms, some quite long-lived and slow-growing, are still well represented in these communities.

Size composition also reflects information about *mortality rates* in that in order to grow large, individuals have to live long enough to achieve their full growth potential. When mortality rates are elevated, increasing numbers of individuals die before reaching their full potential size, and large individuals come to comprise a smaller proportion of a community (Bianchi et al. 2002, Duplisea et al. 2002, Hall et al. 2006, Pope et al. 2006, Law et al. 2008).

Information about *life history strategies* is reflected in that maximum potential size (often called $L_{\text{-infinity}}$ or L_{inf}) and growth rates (often referred to as "k"; both symbols from the classic von Bertallanffy growth equation [see, e.g. Charnov 2008]) are central components of species' life history strategies. A large body of ecological literature has accumulated showing that a number of life history traits vary with growth rate and maximum potential size; including traits associated with fecundity, age and size of maturation, and natural mortality (Charnov and Gilhooly 2004, deRoos et al. 2006, Gislason et al. 2008, in press, Anderson et al. 2009). As communities are placed under increasing stress, species with faster initial growth rates but smaller maximum sizes and earlier ages of maturation tend to increase in dominance. As a result, communities under stress tend to have a higher proportion of small individuals than communities in comparable settings but under less stress. Much of this research is not specifically on marine benthic communities and exceptions to all of the generalizations above are known to occur. Nonetheless, the general patterns seem quite robust for marine species and ecosystems in general and benthic species and communities in particular (Hall 1994, Jennings et al. 2002, Borja et al. 2003, Dauvan et al. 2007).

As an attribute that integrates the productivity, mortality rates, and life histories of the benthic community, size composition reflects both the trade-offs made in coexistence of marine communities and the contributions of anthropogenic activities to both system productivity and mortality (Beverton and Holt 1959, Charnov 1993, West and Brown 2005, Gislason et al 2009, in press). By reflecting the consequences of both ecological processes of predation, primary productivity, and environmental influences such as temperature and natural disturbances and human stressors size composition contains a great deal of information about both the evolutionary and recent history of a community. It also contains information about the potential development of the community, at least in the near future, in response to changes in stressors, particularly those affecting mortality rates of various sizes of individuals in the community (Duplisea et al 2002, Hiddink et al. 2006, Pope et al. 2006) or system productivity (Maury et al 2007).

c) *Criteria For Evaluation of this Attribute of the Descriptor:*

What constitutes the "axis of degradation" of the attribute: For a benthic community, an axis of degradation would be a pattern of increasing proportion of the community comprised of small individuals, and correspondingly less of the community comprised of large individuals. The pattern of change in size composition of individuals in a community could be noted from monitoring of a single area over time or from sampling along a spatial gradient – either nearshore to offshore or along-shore following a gradient in any pressure considered to possibly be impacting the community.

What characteristics a "good" position on this attribute?

A "good" size composition for a benthic community is one where individuals of species capable of growing to "large" sizes (i.e. have relatively high L_{inf}) and whose ranges and habitats include the particular area are represented in appropriate samples, *and* for all species present a range of sizes is observed, including some individuals that have reached nearly their full growth potential (their respective L_{inf}). For size-based properties to be monitored and assessed, the full species composition of the area does not need to be determined. However, there has to be some knowledge of what L_{inf} classes are expected to occur in the community when it is healthy, in order to know what a "good" size composition would be. Such knowledge usually can be inferred from basic information on species' ranges, their general habitat preferences (see below), and the maximum sizes they have been known to reach.

d) Factors to consider in setting a "good" reference level for the attribute.

Because size composition of a community is affected by the basic productivity of the area (Pearson and Rosenberg 1978, Kerr and Dickie 2001, Jennings and Mackinson 2003, Maury et al, 2007), a "good" position has to be identified based on the natural productivity of the specific area of interest (Jennings and Dulvy 2005). Factors that affect the natural productivity of benthic communities are discussed in section 4.7 as part of the Trophodynamics subsection. Communities that differ substantially any of the features discussed in that subsection would be expected to have different size compositions, notwithstanding the additional effects of any human pressures on those communities. Likewise communities with different natural disturbance regimes (for example wave and tidal actions, ice scouring), causing different intrinsic natural mortality rates (Hall 1994, Diaz et al. 2004, Dauvin 2007) , would also be expected to have different size compositions, even before human pressures are considered. As a consequence, selecting a reference level for a "good" size composition will have to be done specific to each benthic community.

Although reference levels for "good" size composition are community specific, general information is often enough to start the process of determining appropriate reference levels. If there are historical data on the frequency of "large" individuals in benthic samples from a time when human impacts were considered sustainable, those data can provide guidance on how large the larger individuals in a community should be, if the community as a whole is being impacted sustainably. If there are data from other benthic systems thought to be similar in productivity and general species composition (at least similarity of the dominant species in the major L_{inf} classes), those data can provide a general frame of reference for what the size composition (especially the proportion of the community that is "large") of a healthy community should be. Even an inventory of species known to occur in the general area can be a starting point for setting reference levels of size composition, particularly if accompanied by some information on the maximum sizes attained and general habitat preferences of the species (substrate types, and ranges of depth, temperature and salinity known to be occupied).

It is conceptually possible that life history theory and principles of community ecology could be used to reconstruct the size composition of a community with a sustainable level of impact, using general knowledge of the likely species composition and productivity of a marine system. However such approaches are in early stages of development (Brown et al. 2004, Gislason et al. 2008, Anderson et al. 2009) and not expected to be suitable as support for decision-making for some time to come. The increasing use of representative Marine Protected Areas (IUCN 2004, UNEP-WCMC 2009) can provide reference size compositions from comparable benthic systems, depending on how human activities in the MPA are managed (Dinmore et al. 2003, Blythe et al

2004, Hall-Spencer et al. 2009). It is important to note, though, that "Good Environmental Status" does not require pristine and totally unimpacted conditions; only that impacts are sustainable. Consequently, if size compositions of the benthic communities in "no-take / no impact" MPAs are to be used as reference sources for "good" size compositions, care should be taken in selecting the right timeframe for the reference state of "good". The size composition of the community at the time when populations of all the major L_{inf} classes have become securely re-established in the community should provide the guidance, and not the size composition at some later time when the larger L_{inf} classes have achieved whatever greater level of dominance they might reach a fully protected benthic community.

Most benthic communities experience seasonality in reproduction, growth, and recruitment of new individuals, and recruits are generally small relative to the maximum size that they could reach if they survive to "full" growth. Therefore any attempt to characterize the "good" range on any size-based metric should include the seasonality factor and either estimate the indicator(s) for a specific season, or deal with seasonal variation directly in computation of the indicator value(s).

Substrate, productivity and natural disturbance regimes can be patchy on very fine spatial scales (Dauvin and Ruellet 2009, Hiddink et al. 2006, Quintino et al. 2006, Blanchett et al. 2008). If Good Environmental Status is going to be evaluated on the basis of long-term monitoring of specific sites, then that fine-scale variation can be included in the standard for "good". The best information possible for the inherent productivity and L_{inf} classes of the specific sites should be used, and care should be taken that the sites are unbiased samples of the total area for which conclusions about GES are to be drawn. If sampling precision cannot ensure matching of features on such local scales, then the average productivity and L_{inf} groups characteristic of areas on intermediate scales (hundreds of km^2 or more) are appropriate for setting standards for "good" on indicators of size composition. Sampling designs should then ensure samples are representative of the general characteristics of the intermediate scale, using appropriate stratification and randomization of site selection. Even when sampling can be spatially quite precise, it is more important to ensure that the selection of sites for evaluating environmental status be representative of the scale at which decisions about GES are to be made than that the fine-scale patchiness of the total area is captured fully.

e) What are the pressures that act upon the attribute?

It is both a strength and a weakness of size composition that it integrates many types of human pressures. All pressures that affect productivity (e.g. nutrient enrichment, light attenuation, thermal regimes) also affect the rate at which individuals grow and move through their possible size classes (Brown et al 2004, Jennings and Blanchard 2004, Pope et al. 2006). Changes in growth rate of individuals changes the time they spend passing through intermediate size classes before reaching their species' L_{inf} (or dying). Depending on whether growth rates decrease or increase, the community size composition becomes skewed towards respectively smaller or larger size compositions. All pressures that increase mortality rate (e.g. direct harvesting; impacts of fishing gears, pollutants and contaminants; winter die-offs, summer lethal temperatures, increases in predator abundance, decrease in prey abundance) mean fewer individuals survive to the larger sizes classes attainable by the species. As a result the size composition of the community become increasing skewed towards a greater abundance of smaller individuals.

Pressures that decrease productivity or increase mortality, if sufficiently intense or maintained for a long time, can prevent species with older ages or larger sizes at maturity from reaching the ages or sizes at which they reproduce. These species are likely to be among the larger species in the community (Lorenzen 1996, Charnov and Gilhooly 2004, deRoos et al. 2006, Anderson et al.

2009). As a consequence, pressures that affect species composition through differential mortality rates or reduced productivity will also be captured by size composition, without having to taxonomically identify all samples to species. Communities with higher mortalities – i.e. more stressed communities - will have fewer species with large L_{inf}, and greater dominance of species with relatively smaller L_{inf}. Thus the more stressed communities will have size compositions increasingly skewed towards high abundance of small individuals.

This generality of size composition to reflect the impacts of diverse pressures is a strength for two reasons. First, when there are many activities causing pressures in an area, tracking size composition will provide information about the aggregate effects of the pressures on the benthic community. This is important because decisions about GES are based on the aggregate impacts of all human-induced pressures on a system, and inferring overall status from independent results on a number of different pressure-specific indicators is not straightforward (see the final Report of the project Management Committee). Second, size composition allows impacts of human-induced pressures on benthic communities to be tracked when information on the specific human activities in a particular area is not available, so pressure-specific indicators cannot be selected.

The generality and integrative nature of size composition is also a drawback, however. Specificity and responsiveness are important properties of indicators; specificity because it allows policy-makers and managers to focus interventions on the pressures causing the environmental problem(s), and responsiveness because it provides rapid feedback on the effectiveness of the interventions (Rice and Rochet 2005). When a strong signal in size composition is observed, there is no specificity about the cause of the change. Other information is necessary to know what management actions are needed to address the unsustainable impacts. There is also likely to be a lag in measures of size composition when a management measure is implemented, because even if the measure is effective, some time will be required for the increases survivorship or productivity to show up as larger numbers of large individuals (Greenstreet et al. in press). This means size composition is unlikely to give immediate feedback on the effectiveness of management measures that are implemented.

f) *What are the indicators or classes of indicators that cover the properties of the attribute and linkages to the pressures?*

Two major classes of indicators have been explored for size composition of marine biotic communities; proportion of numbers (or biomass) above some specified length and parameters (slope and intercept) of the "size spectrum" of the aggregate size composition data.

The proportion of the community larger than some specified value is a direct indicator of how much of a community finds adequate resources and survives long enough to grow above the criterion size. It is considered to be readily communicated to diverse non-specialists and policy-makers, with the intuitive interpretation of "percent big" coinciding with the technical information the indicator class is supposed to reflect. Indicators in this class are easy to calculate if the sizes of individuals taken in samples are measured. However, because most benthic sampling gears are size selective (Proudfoot et al. 1997, ICES 2009b) it requires that a consistent sampling gear and methodology be used for the entire period when trends in the indicator are being estimated.

It is also almost always necessary to specify some size range over which the indicator will be calculated, because even if a gear is considered fully selective for some range of sizes benthos, there will be some size below which sampling efficiency is likely to decrease substantially (Proudfoot 1997, ICES 2009b). If the indicator is being calculated for samples taken over an area large enough to have diverse substrates, the size selectivity of the sampling gear has to be either equal or known for each substrate type. Remote monitoring of benthic community composition by visual means can avoid some of the problems with selectivity of many benthic sampling gears, but requires some way to calibrate the size of the organisms being observed with the camera or other instrumentation. These are well known problems for sampling benthos, however, and sampling guidelines are widely available (OSPAR nd, ICES 2009b).

Selection of the critical size for this class of indicator also requires care. As a ratio indicator, sensitivity is lost if either the numerator or denominator is expected to be small (Rice 2000, 2003, Rice and Rochet 2005). This consideration would make it desirable to choose approximately the median size of individuals in a community vulnerable to the sampling gear. However, studies exploring this indicator for fish communities (ICES 2008, 2009a, Greenstreet et al. in press) have documented that recruitment variation shows up first and to the greatest extent in the numbers of small individuals in a community. Over time, as animals grow, mortality buffers some of that initial variation. As a consequence, if recruitment variation is moderate or large (which is typically found in multi-year studies [Frid et al 2009, Estes and Peterson 2000, Watson and Barnes 2004]) the ratio of "number of individuals above X" divided by "number of individuals below X" (where "X" is the criterion length) or by "total number of individuals" will have much more variable denominator than numerator when X is near the median size. This would make year-to-year changes in value of the indicator large, and the indicator would largely reflect variation in recruitment processes rather than variation in pressures on community size composition. This is not desirable. Statistical analyses and simulations with size composition data from fish communities have suggested a criterion value of "X" chosen such that only about 10% of all measured individuals are above the criterion is necessary for the effects of recruitment variation to be substantially smaller than the impacts of pressures on the proportion of the community that is "large" (ICES 2009a, Greenstreet at al, in press). Whether this result applies to benthic communities has not been established. However, the possibility that recruitment variation in the small sizes can make the indicator noisy and insensitive unless the criterion size for the ratio is set appropriately needs consideration for each application of this class of indicator.

The biomass size spectrum refers to the observation that over a wide range of sizes, the ln(numbers) of individuals per size group decreases approximately linearly with increasing size. The plot of ln(N) by size class has been referred to as the community "size spectrum". This was first observed for pelagic communities (Sheldon et al 1972) and had been explored primarily for fish communities (Pope et al. 1987, Murawski and Idoine 1992, Rice and Gislason 1996, Gislason and Rice 1998, Bianchi et al. 2001, Benoit and Rochet 2004, Shin et al. 2005). However, there have been some applications to benthic communities as well (Schwinghamer 1988, Duplisea 1998, Duplisea et al 2002, Dinmore and Jennings 2004). This work has found that although the slopes of benthic communities are typically not as steep as the slopes of pelagic communities, size-based approaches are as applicable in benthic systems as they are in pelagic ones (Blanchard et al 2009, Maxwell and Jennings 2006). The less steep slopes reflects the much greater representation of detritivores and grazers on macroalgae in the benthic systems, and these feeding strategies have much weaker size constraints than do predator-prey relationships.

The intercept of the size spectrum is considered to reflect the productivity of the ecosystem, with more productive systems having higher intercepts (i.e. supporting larger numbers of individuals). The slope of the size spectrum reflects the rate at which numbers of individuals decrease with size. The slope is considered to reflect primarily community-level mortality rate and the size ratio preferences of predators relative to their prey. It has been noted that differences in growth rates among communities can affect the slope, as individuals move through the size classes at different rates (Jennings et al. 2002, Jennings and Blanchard 2004, Blanchard et al. 2009). However when communities differ in the slopes of their size spectra, the contribution of different growth rates has been found to usually be small compared to the contribution due differences in their mortality rates (Blanchard et al 2009, Hiddink et al. 2008), taking account of the relative proportion of the community comprised of detritivores and grazers. Consequently the slope is interpreted as primarily a measure of mortality with steeper slope reflecting higher mortality rates.

More recent research, largely through simulation modelling, has suggested that across a large enough range of sizes the size spectrum is not linear. Rather the plot of ln(N) by size contains small waves corresponding to major trophic steps and "trophic cascade" relationships (Benoit and Rochet 2004, Shurin and Seabloom 2005, Andersen and Pedersen 2009). However such complications are unlikely to be a major factor in application of this class of indicator to sampled benthic communities. A size spectrum can only be quantified across a range of sizes that can be sampled consistently and with comparable selectivity by a single gear, or using multiple gears only if their size selectivity can be calibrated with high precision. That means usually a size spectrum can only be calculate across one order of magnitude of sizes or less (say 1 to 10 cm or 3 to 30 cm). Across such a restricted range of sizes the curvilinearity in a size spectrum due to "trophic cascade" relationships is rarely a consideration (Shurin and Seabloom 2005, Andersen and Pedersen 2009), and the linear slope and intercept can be used as indicators of mortality and productivity, respectively. Slopes and intercepts are likely to be statistically correlated when an intercept at the origin is estimated and the smallest observations in the data set are not at or near zero. However this statistical artefact can be overcome easily by a direct rescaling to an "origin" within the range of observations (Daan et al. 2005).

As long as only relative changes to the slope and intercept are considered when interpreting these indicators, the rescaling to overcome a potential statistical artefact does not compromise interpretability or sensitivity of this class of indicators. As with the other class of size-based indicators, there is no *a priori* "right" slope or intercept for a benthic size spectrum. Rather, trends over time or space in either or both slope and intercept are changing provide information on whether mortality or productivity, respectively, are showing the same changes. In at least fisheries applications, the size spectrum parameters were found to be quite responsive to changes in mortality rate, with only short lags.

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4.7 Trophodynamics and energy flow

Trophodynamics is a complex attribute with many subcomponents. Key ones include Primary and Secondary Production, Carrying Capacity, Energy Flows, and Food Web Relationships. TG 4, on Food webs deals thoroughly with primary production, energy, flow and food webs. When evaluating Seafloor Integrity it is important to follow the expert guidance from TG 4 in the specific context of the benthic community, its food web relations, and benthic-pelagic relationships. Likewise, when evaluating Food Web relations within the TG 4 framework, it is important to ensure that role of seafloor nutrients and the benthic community is considered explicitly. However this TG only provides developed guidance for Secondary Production and Carrying Capacity. Otherwise the guidance provided by TG 4 is considered fully sufficient to address trophodynamic aspects of Seafloor Integrity, as long as that guidance is followed for the benthos and benthic nutrients.

Sub-Attribute: Secondary production

a) Description of the attribute

Secondary production is the production of biomass by heterotrophic organisms and is measured as the increase in biomass over time. In food webs, secondary production can be defined as the total amount of biomass that becomes available to be consumed by the next trophic level (Brey 2008).

b) Why the attribute and subcomponents are important to seafloor integrity

The amount of secondary production in an ecosystem therefore defines how much of the primary production is converted into heterotrophic biomass. The amount of secondary production by a particular trophic level also determines how much food is available for higher trophic levels. Secondary production on the seafloor by benthic invertebrates determines how much energy is transferred from lower trophic levels (phytoplankton and detritus) to the seabed, and it also defines the amount of energy that is available as food to benthivorous fish species. Fish species that eat benthos during at least one of their life stages include many species of commercial fish species such as cod, haddock and plaice. Benthic invertebrates are also eaten by diving ducks. Therefore, quantification of secondary production is important for understanding the energy flow in food webs and carrying capacity of ecosystems. Secondary production has also been used as an indicator of ecosystem health (Murawski 2000, Rochet & Trenkel 2003).

c) Which subcomponents of the attribute reflect a gradient of degradation, and why

There exist spatial gradients in the natural levels of secondary production in ecosystems, but human activities generally result in a reduction and occasionally an increase in secondary production. A reduced secondary production means that the natural flow of energy through the ecosystem is impeded. Hence an axis of degradation is a gradient of declining secondary production *relative to the level of secondary production previously observed for the site, or typical of sites with similar natural levels of nutrients, depth, substrate, and the other typical determinants of primary production.*

d) Which human activities and pressures are closely linked to / reflected by the attribute or specific subcomponents (or is it a general feature that may be affected by a variety of activities & pressures)

The seafloor is a habitat for exploited species of fish and invertebrates, such as flatfish, crabs and lobsters. Exploitation will decrease the standing stock biomass of an exploited population, and will also lead to a reduction in the average body size when the largest individuals of a species are preferentially caught, as is usual in most fisheries. Smaller organisms have a higher P to B ratio, and therefore the P/B of exploited populations will be higher than that of pristine populations. By reducing the population size, the fishery will also reduce competition over resources, again leading to a higher P/B. This means that the reduction in secondary production due to exploitation will usually be less severe than the reduction in biomass. Similarly, in communities with many species that all differ in their life history parameters such as growth and natural mortality rates, the most productive species tend to be least affected by exploitation. Species with low natural mortality rates will be more strongly affected by additional fisheries mortality than species with high natural mortality rates, because the fisheries mortality is larger relative to their natural mortality. Life history correlates strongly to body size, with smaller organisms having higher growth and mortality rates. This means that in exploited communities, a shift in dominance to smaller species can be expected (Brey 2008; see 4.8). Hence in exploited communities secondary production may be maintained, and occasionally even increased, even though the species composition (see 4.5) and distribution of life history traits (see 4.8) may be changing.

Bottom trawling causes widespread disturbance of sediments in shelf seas and can have a negative impact on benthic fauna. Bottom trawling reduces the production of benthic invertebrate communities by killing benthos. For the North Sea, a model showed that the bottom trawl fleet reduced benthic biomass and production by 56% and 21%, respectively, compared with an unfished situation (Hiddink et al. 2006). On Georges Bank production at a shallow trawled site was markedly lower than production at the nearby recovering site (Hermsen et al. 2003).

Eutrophication can have positive effects on secondary production through an increase in primary production. In some areas of the Baltic sea, macrobenthic production seems to have doubled as a response to eutrophication (Diaz & Rosenberg 2008). The recent reduction in flux of nitrate and phosphates to some coastal seas seems to have had a negative impact on the productivity of coastal shrimp and flatfish fisheries (Rijnsdorp & van Leeuwen 1996). However, when large phytoplankton blooms die off and sink to the bottom, dissolved oxygen levels in bottom waters drop due to microbial breakdown of these algae. When dissolved oxygen levels fall below 2 ml $O_2\ l^{-1}$ benthic fauna start to show unusual behaviour such as abandoning their burrows, probably because oxygen levels in their burrow drop faster than those in the water column. When these animals leave their burrows, they become available to epibenthic predators that cannot normally extract deep burrowing shrimp, clams and worms from the sediment. Mild hypoxia can therefore temporarily increase the energy flow to the mobile predators in the ecosystem by generating a pulse of energy when the animals in lower trophic levels become stressed due to hypoxia. This does not always happen and it is only within a narrow range of conditions that hypoxia facilitates secondary production of mobile predators. Severe hypoxia culminates in mass mortality of fish and benthic invertebrates when dissolved oxygen levels falls below 0.5 ml $O_2\ l^{-1}$ (hypoxia, Diaz & Rosenberg 2008). Areas that are exposed to long periods of hypoxia have a low secondary production and no benthic macrofauna. Benthic secondary production in Chesapeake Bay is estimated to have been reduced by 5%, while secondary production in the Baltic Sea has been reduced by 30% due to hypoxic events.

Climate change has an effect on the magnitude, timing and distribution of primary production, the temperature regime and hydrodynamic regime of the world's oceans. This in turn is likely to affect secondary production. However, currently we are lacking the science that is necessary to understand and predict the impact of climate change on secondary production at the seabed.

e) What are important classes of indicators to include, in order ensure that the key aspects of this attribute and its subcomponents, and its important linkages to pressures, are all covered?

Secondary production is a common measure that can be used as an indicator over large spatial scales and in different ecosystems (Rochet & Trenkel 2003). The reference level has to be local, however, as this depends on the local input of energy into the system and the hydrodynamic regime at a location. In addition to overall production, the production to biomass ratio may be a more sensitive indicator of changes in the pressures on the seafloor. Some routine monitoring of biomass of benthic communities exists in the EU, and for some of these schemes the production and production/biomass ratio can be estimated from these programmes. However, the spatial coverage of such monitoring schemes is very limited. As there exists no way of measuring secondary production directly in a single measurement, any estimated value is highly dependent on the estimation model for deriving it, or it requires regular repeated sampling of the same stations. Validated models that predict benthic secondary production over relevant spatial scales only exist for the southern North Sea (Hiddink et al. 2006). Therefore, secondary production does not currently seem a practical operational construct to assess GES for the whole EU seabed.

Sub-Attribute: Carrying capacity

a) Description of the attribute and its relevant subcomponents

Carrying capacity can be defined as the capacity of the ecosystem to support biomass of the organisms that live on the seabed. Generally, carrying capacity of the seafloor is defined by the amount of basic resources, which are food input and space that is available to the organisms that live there. For example, for populations of filter feeding bivalves, carrying capacity is determined by the amount of phytoplankton in the water and the rate of advection of that water over the bivalves.

It can be viewed as the maximum biomass that the ecosystem can support in the absence of factors that limit the abundance of organisms. In addition to the availability of resources, temperature can also have an effect on the carrying capacity by modifying the energy requirements of organisms (Myers et al. 2001).

b) Why the attribute and subcomponents are important to seafloor integrity

The carrying capacity of the seafloor determines how many organisms can live in this habitat and the organisms in an ecosystem perform many important ecosystem functions, such as the production of food for higher trophic levels, the transfer of pelagic food to the benthic ecosystems, nutrient recycling and sediment mixing. A reduction in carrying capacity can therefore reduce the amount of these functions that can be performed and therefore degrade the functioning of the ecosystem as a whole. In theory, ecosystems with a higher carrying capacity will recover faster in absolute terms when their biomass is reduced by a disturbance (May & McLean 2007). Systems with higher carrying capacities are logically expected to be able to provide higher levels of ecosystem services, where these are dependent on the amount of biomass or production available, such as fishery yields for commercially exploited species such as clams and Norway lobster.

A reduction in ability of ecosystem to support organisms (= carrying capacity) can be considered much more serious than a reduction in actual numbers of organisms, as the reduction in carrying capacity has a long-term impact on the number of organisms in the ecosystem, while a reduction in the actual number of organisms is usually temporary, with recovery towards the carrying capacity likely if the pressure(s) causing the impact is relaxed.

c) Which subcomponents of the attribute reflect a gradient of degradation, and why

Carrying capacity is likely to be affected in two ways. Firstly, the amount of energy that reaches the seafloor may be modified, generally by changes in the amount of primary production at the surface, or by changes in the amount of this primary production that reaches the seabed. In coastal ecosystems that are fuelled by terrestrial detritus, similarly the input or the amount reaching the seafloor of detritus may be modified. The amount of energy that is transferred to the seabed may be affected by changes in the stratification of the water column, and by a change in the number of filter-feeding organisms in an ecosystem. Secondly, the amount of space available to seafloor organisms may be reduced by human activities, and this will directly reduce the number of organisms that live on the seafloor in this particular habitat. Any reduction in carrying capacity relative to the carrying capacity expected given the local environmental conditions (e.g. energy reaching the seafloor, space available) is an axis of degradation.

d) *Which human activities and pressures are closely linked to / reflected by the attribute or specific subcomponents (or is it a general feature that may be affected by a variety of activities & pressures)*

Activities such as aggregate dredging removed parts of the seafloor (Seiderer & Newell 1999), and scallop dredgers may slowly degrade hard substrates on reefs. Bottom trawling reduces the carrying capacity of the seabed to support fish populations (Fogarty 2005). Land reclamation and the development of offshore structures on the seabed also reduce the amount of available seafloor and therefore carrying capacity for space-limited organisms.

Increases in seabed temperature due to climate change will increase the energy requirements of ectothermic organisms, and therefore increase the amount of food individual organisms will use (Myers et al. 2001). This means that the carrying capacity of ecosystems will go down with increasing temperatures.

Changes in the species composition away from sessile filter-feeders due to bottom trawling may reduce the flux of organic material from the pelagic to the benthic environment and therefore reduce the carrying capacity of the seafloor (Tillin et al. 2006).

Changes in the hydrodynamic regime due to engineering projects such as barrages, harbours and piers are likely to change to transport of food to filter feeding organisms, and as such change the spatial distribution of carrying capacity for such organisms (Smaal et al. 2001).

e) *What are important classes of indicators to include, in order ensure that the key aspects of this attribute and its subcomponents, and its important linkages to pressures, are all covered?*

Carrying capacity is impossible to measure directly as it represents the potential biomass in the absence of other limiting factors rather than the actually realized biomass. As such, carrying capacity is an interesting ecological concept but has little practical operational value. Assessment carrying capacity based on availability of food requires a very detailed understanding of the functioning of the ecosystem including the hydrodynamic regimes and is currently only feasible for specific areas.

Closing comment on trophodynamics and energy flow as Attributes of Seafloor Integrity. This review has concluded that although secondary production and carrying capacity are important components of Seafloor Integrity, there are no practical direct indicators of these ecosystem properties. There are many indirect indicators, but the most promising ones are already covered in the guidance provided for the Attributes of Species and Size Compositions, Life History Traits, Oxygen etc. The food web relationships and nutrients associated with the benthos are also important to Seafloor Integrity, but the guidance provided by TG 4 on the Descriptor Food Webs is considered appropriate for including those factors in evaluation GES. In all cases what matters is that in the selection, monitoring and calculation of indicators in those frameworks, care be taken to include appropriate benthic components and benthic-pelagic coupling. Even more, when interpreting the information in those indicators relative to GES and pressures on marine systems, the interpretations should take due account of the benthic components of the trophodynamic relationships.

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4.8 Attribute – Life History Traits

a) Description of attribute

Life History Traits (LHT) are the categorisation of characteristics of the life cycle that species can exhibit, i.e. growth rates, age or size or maturation, fecundity and the seasonality of life history features such as reproduction. Various combinations of these traits lead to species differing in their natural productivity, natural mortality, colonization rates. Strictly LHT do not include behavioural traits such as mobility, or morphological traits such as growth form although different authors may confound them in a variety of ways. From the point of view of assessing the ecological functioning of assemblages it is the wider concept of the Biological Traits (BT) present that is important. Species deliver ecological functions as a result of the traits they possess

– a worm irrigating its burrow (trait – burrower) promotes nutrient recycling (a function). As different species possess different combinations of traits, so changes in the species composition of an assemblage of species on the seabed can result in altered delivery of key ecological functions such as nutrient recycling, sediment stabilisation, biogenic habitat provision or food provision for fish (Bremner et al., 2006a, Bremner et al., 2006b).

Many studies (Pearson and Rosenberg, 1978; Dauer, 1993), have demonstrated that assemblages of macrobenthos respond relatively rapidly to anthropogenic and natural stress, through a combination of differential mortality, variations in recruitment and immigration; such that the suites of life-history traits and other biological traits in the assemblage are altered in response to the stressors. Gray (1979) attempted to simplify the many combinations of life history strategies into one of three ecological groups: r (r-selected: species with short life-span, fast growth, early sexual maturation and larvae throughout the year); k (k-selected: species with relatively long life, slow growth and high biomass); and T (stress tolerant: species not affected by alterations). More recent studies have used the greater availability of multivariate statistical approaches to consider changes in the entire suite of biological traits, so called Biological Traits Analysis, to reflect changes in system functioning or health (Bremner et al., 2003a, Bremner et al., 2003b, Charvet et al., 1998, Charvet et al., 2000).

b) Why the attribute and subcomponents are important to seafloor integrity

The distribution of Biological Traits including LHT are important to GES as they reflect the status of ecosystem functioning (Bremner et al., 2006b). LHT are considered (Dauer, 1993) important components of ecosystem status and there is a growing literature on the use of multivariate analyses of Biological traits as indicators of ecosystem health (Tillin et al., 2006, Tillin et al., 2008). Changes in traits are useful because: (i) they are direct measures of the condition of the biota, (ii) they may uncover problems undetected or underestimated by other methods; and (iii) such criteria provide measurements of the progress of restoration efforts. Benthic invertebrates are used frequently as bio-indicators of marine monitoring.

c) Which subcomponents of the attribute reflect a gradient of degradation, and why

A “good environmental status” (GES) of LHT or BT for a benthic community is habitat specific (Borja *et al.,* 2004; Rosenberg *et al.,* 2004; Muxika *et al.,* 2007). Relative to a given habitat, in a community with “good” status there is a diversity of traits, and sensitive (or structuring) species are common. Because GES of LHT is habitat-specific, methods developed for the Water Framework Directive require that monitoring data be compared to ‘reference conditions’, specific for each type (habitat) (Borja *et al.,* 2007, 2009a). GES is then inferred when the deviation from reference conditions are slight, showing low proportion of opportunistic/sensitive species, natural levels of richness and diversity, presence of structural species, etc. (of course, all of them related to the habitat studied). Tillin (2008) provides a review of alternative approaches and concludes that reference site comparisons remain the most robust.

Benthic communities respond to improvements in habitat quality in a number of ways and over a variety of timeframes. Different authors have proposed various specific sequences for these gradients of response to reduction of pressures, focusing on increases of numbers of individuals, species richness and diversity, and ratios of sensitive to tolerant species (i.e. Pearson and Rosenberg 1978, Bremner et al. 2006b). The proposed sequences are specific to particular pressures, but some general patterns of response can be identified. For assemblages including slow growing structural species (e.g. *Lophelia*) recovery may not occur at all. In systems with a ready supply of larvae recovery can be rapid and follows a predictable trajectory (i.e. Pearson &

Rosenberg (1978) describe initial colonisation by small, tolerant species with large numbers of dispersive larvae, as conditions further improve species with larger body size, slower growth and poorer dispersal accumulate, out-competing the initial colonists leading to a ‘normal’ recovered assemblage).

Four progressive steps relating to organic enrichment stressed environments have been proposed (Salen-Picard, 1983): (i) initial state (in an unpolluted situation, there is a rich biocenosis in individuals and species, with exclusive structural species, high diversity, high natural productivity); (ii) slight unbalance (regression of exclusive species, proliferation of tolerant species, the appearance of pioneering species, decrease of diversity, increase of mortality); (iii) pronounced unbalance (population dominated by pollution indicators, very low diversity); and (iv) azoic substrata. Some authors (e.g. Grall and Glémarec (1997), Borja *et al.* (2000)) have summarized these steps by means of biotic indices, showing the proportion of sensitive/opportunistic species, or by means of multimetric and multivariate methods (Borja *et al.,* 2004, 2007, 2009a; Rosenberg *et al.,* 2004; Muxika *et al.,* 2007), which include also other attributes, such as richness, diversity, abundance, etc., for the benthic quality assessment. This implies a shift in life history traits between the stages and also in associated biological traits, for example a decrease in large-bodied species between stages 1 and 3, loss of structural species, decrease in deep burrowing species etc.

Anthropogenic physical impacts, for example from aggregate dredging, towed fishing gears, also alter the traits composition of the assemblage, for example through the loss of erect structural species (Kaiser et al., 1999).

d) What are the pressures that act upon the attribute

Any pressure that alters species composition has the potential to alter the distribution of biological and LH traits and so alter ecological functioning. This is both a logical consequence of species substitutions/changes but has been demonstrated for fisheries impacts, altered sediment characteristics and changes in water quality (Bremner et al., 2003a, Tillin et al., 2006). , Some of the methods widely tested and adopted in for assessments with the WFD (e.g. AMBI, M-AMBI, BQI, IQI, DKI, etc., see a review in Borja *et al.,* 2007, 2009a) have been shown to respond to a variety of pressures often associated with an changing ocean chemistry, such as: hypoxia and eutrophication processes; urban and industrial discharges; oil platform discharges; engineering works (marina and dyke construction); dredging; fish and shellfish aquaculture; mine tailings; hydromorphological pressures (dredging, sediment discharges). However these WFD methods have not yet been thoroughly explored for physical disturbances such as fishing with mobile, bottom-contacting gears, where biological Traits Analysis is being explored (Bremner et al. 2006b, Tillen et al. 2006, 2008).

e) What are the indicators or classes of indicators that cover the properties of the attribute and linkages to the pressures?

Marine benthic monitoring programmes tend to collect basic data of the form of species abundance/biomass patterns in space/time. These data are then subject to processing to emphasise highlight deviations from GES. A number of indicators exist based on ratios of species’ abundances such as diversity and richness indices, opportunistic/sensitive species proportion (e.g. AMBI), methods integrating several of these indicators (e.g. most of those used in the WFD). For certain pressures a signal in LHT of a species may be observed before the abundance changes. In the case of the methods used in the WFD, there is an extensive literature in the interpretation of the good status (Rosenberg *et al.,* 2004; Muxika *et al.,* 2007; Borja and Dauer, 2008; Borja *et al.*, 2009b). In coastal waters most of them have been intercalibrated (Borja *et al.,* 2007, 2009a, Pinto et al. 2009), providing an opportunity for consistent similar interpretations across different geographies. Some of the indicators (AMBI, M-AMBI) have been also tested in other geographic regions in North and South America, Greenland, North Africa, Southeast Asia or Southwest Indian Ocean (e.g. Cai *et al.,* 2003; Muniz *et al.,* 2005; Afli *et al.,* 2008; Bigot *et al.,* 2008; Borja *et al.,* 2008; Callier *et al.,* 2008; Josefson *et al.,* 2008; Bakalem *et al.,* 2009).The indicators in which these methods are based are regularly monitored across Europe, and include abundance, richness, diversity, proportion of opportunistic/sensitive species, biomass (in some cases), etc. Multivariate statistical packages have been used on species/traits data sets and in the context of measuring deviations between a reference site and the monitoring site under the Biological Traits Approach and this has been used both to assess ecological health (Bremner et al., 2003a) and to set boundaries for MPAs (Frid et al., 2008).

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5. On combining Indicators within Attributes and Attributes within the Descriptor

This section should be read in the context of the section of the Management Committee Report (referenced in the Preamble) that discusses methods for aggregating indicators. This section develops the proposals in that report with a specific focus on Seafloor Integrity.

5.1 Experience with Benthic Indicators within the Water Framework Directive

Science support for the Water Framework Directive (WFD) has prompted substantial research on the comparative performance of various indicators in estuarine and near-coastal waters, and how to combine benthic indicators to assess environmental quality in those systems (Patricio et al. 2009, Aubry and Eliot 2006, Bald et al 2005, Blanchett et al. 2008, Borja and Dauer 2008, Borja et al. 2004, Dauvin et al. 2007, Labrun et al. 2005, Muxika et al. 2007, Pinto et al. 2009, Quintino et al. 2006, Teixeira et al. 2008, in press). Performance was evaluated by degree to which indicators can arrange sites in an orderly pattern across a spatial or temporal gradient ("discriminatory power") and ease to be calculated for a wide range of ecological conditions ("robustness").

Without summarizing all the results, several conclusions can be drawn from the body of comparative research:

- No single class of indicators consistently outperforms all other classes of indicators.
- Performance of various classes of indicators varies across areas with different habitats and disturbance regimes.

   - Classes of indicators that consistently had higher discriminatory power in areas that were rich in species and biomass often were insensitive in species-poor, low productivity areas.
   - Classes of indicators that performed better in inherently species-poor, low productivity areas often had weak discriminatory power in more productive areas.
   - Reference levels for even subsets of indicators considered appropriate by experts will be different depending on the specific range of habitats and disturbance regimes in the range of areas being evaluated.
- Classes of indicators that are effective at reflecting pollution-related pressures are not necessarily effective at reflecting pressures due to physical disturbances from fishing, dredging etc.
- Classes of indicators that have the highest discriminatory power, particularly in higher productivity areas, often lack robustness. They rely on identifying suites of species that are members of different functional groups and/or life history trait groups. These species can differ among areas, and require substantial knowledge about the benthic ecosystem dynamics in each area where they are applied.

Experts generally agreed in their classification of sites into at least four categories of environmental quality, but behind this general comparability of results, experts differed substantially in the weightings they apply to different types of indicators in conducting their individual evaluations, and even in the types of data that they considered most relevant to calculating indicators to use in their assessments.

From these results four overall conclusions about combining indicators and attributes for assessing "benthic integrity" emerge.

1) Many algorithms for setting reference levels and integrating indicators and classes of indicators have been tried and found satisfactory by different sets of experts.
2) No single algorithm has been demonstrated as being consistently superior to alternatives, at least to the point that a single approach is being adopted by experts globally.
3) Given the differences in performance of various sets of indicators under different circumstances, no single algorithm may exist that has superior performance in all potential applications.
4) Notwithstanding 3), some integrative property of "benthic integrity" does exist, and experts are able to at least rank-order samples to reflect it with moderate to high consistency.

5.2 What needs to be assessed with the indicators

Conclusions about GES will have to be drawn at the regional or subregional scale, using scientifically sound and consistent methodologies. These scales almost always include a diversity of habitat types (defined by substrate and depth, temperature and salinity ranges), natural disturbance regimes, and types and intensities of human pressures. A useful indicator-based evaluation of "good" environmental status will provide information on the direction and magnitude of change in status relative to prior assessments, and on the nature and extent of shortcomings relative to achieving GES, such that effective programs can be strengthened and appropriate mitigative or remedial measures can be taken to address outstanding shortcomings.

It will be hard to meet the needs of the decision-makers. For regions and subregionsl of even moderate diversity, optimal suite of indicators or classes or indicators will be different for different sites, and sampling of all sites is unlikely to be balanced and repsentative included in the sampling design. Moreover, no single reference level for any indicator will be universally appropriate within a region or sub-region with even a moderate diversity of habitats and natural disturbance regimes. As a consequence the evaluation of GES for seafloor integrity will have to balance two undesirable but inescapable compromises; having an evaluation methodology that is scientifically sound and makes best use of available information, and having an evaluation methodology that is consistent in all applications – consistent with regard to the types of information used and the methods applied in their use. Increasing consistency in methods on regional and large sub-regional scales will come at a cost of requiring use of suboptimal and sometimes inappropriate indicators, reference levels, and analytical algorithms. Increasing the matching of methods to specific conditions within each region or subregion will come at a cost of less consistency in practice within the larger scales.

5.3 The way forward

Taking account of experience with simpler problems of assessing individual fish stocks, and more complex problems of conducting integrated assessments that jointly address environmental, social and economic considerations, a way forward emerges. For each region (or subregion) for which GES of the Seafloor must be assessed, section 4 provides sufficient guidance for experts to select an appropriate suite of classes of indicators, and more local scales, specific indicators within the classes. In parallel, Section 3 (and the references therein) sketches the framework for risk-based design of monitoring and sampling regimes, reflecting both the spatial distribution of human pressures in the region, and the diversity of habitat types and disturbance regimes present.

At local scales GES can be evaluated with consistent sets of indicators, indicator weightings, and reference levels. Scales at which such uniform approaches are meaningful can only be chosen on a case-by-case basis, using expert knowledge *and* input from decision-makers and informed stakeholders. For some types of pressures, particularly related to pollution, there is a large body of experience on how to proceed at this scale. However, even at this scale the evaluation should not focus on providing a single number for the local area, particularly if the area is chosen to reflect a known pressure gradient. Rather it should integrate the information in the suite of indicators and reference levels into a clear, concise, and usually multi-factorial reflection of the status of the seafloor community within the locale or along the pressure gradient. However, it might achieve this through a relatively fully specified algorithm for using the set of indicators and reference levels, with the individual parameters developed on an application-specific basis.

It is neither feasible nor ecologically appropriate to specify equally prescriptive algorithms for evaluating GES of seafloor integrity at regional and large sub-regional scales. Specific indicators, reference levels, and weightings are not robust enough to make full use of available and relevant information. Choosing compromise indicators, weightings and reference levels would produce approaches that are likely to be suboptimal in each contributing area. More importantly, there would be a merging and likely obscuring of much information important for understanding where the successes and failures in progressing towards GES were occurring, and in informing decision-makers about where policies and management were working well and where adaptation or innovation in policy and manager were needed.

What is needed for combining the information available on the diverse attributes of seafloor integrity is a fully specified and well-structured *process* for conducting assessments of GES.

Elements of such a process are provided by the Assessment of Assessments Report (UNEP and IOC-UNESCO 2009). The key design features of reliable, consistent assessments are summarized in the Management Committee Report section on Combining Indicators.

That report elaborates how those design features can be ensured in an assessment process. Designing a sound assessment process, incorporating those design features in the process and products produced, will provide the only realistic avenue for having regular evaluations of GES of benthic integrity on regional and large sub-regional scales. The periodic (possibly but not necessarily annual) assessments may adapt practice from assessment to assessment with regard to indicators selected, weightings and reference levels applied, and approaches to integrating local scale evaluations into regional conclusions. However full information will be provided to allow meaningful comparison of assessments over time or between areas, and for decision-makers to understand where progress is being made and where greater efforts are needed.

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6. MONITORING AND RESEARCH REQUIREMENTS

6.1 Monitoring needs

Some of the Attributes of GES for Seafloor Integrity have been subject of targeted monitoring for years or decades, with a focus in recent years on implementation of the Water Framework Directive (WFD). Some aspects of Species Composition, Life History Traits, and Oxygen are examples of Attributes where the WFD has prompted systematic monitoring to support some classes of indicators. For other Attributes, a similar theme to focus monitoring efforts has been absent. However in those cases, for example Size Composition and aspects of Life History Traits related to Biological Traits Analysis, these features represent new potential uses for data from existing monitoring programs. The main monitoring challenge for Seafloor Integrity is not the complete absence of monitoring of ecosystem components that would be of value to assessing GES of the benthos. Rather it is the impracticality of monitoring the European seas comprehensively on scales where the quality of Seafloor Integrity and pressures on the seafloor are highly patchy. The material in section 3, on risk-based monitoring and evaluation of GES is the only practical approach to addressing the serious problems of spatial scale and monitoring of Seafloor Integrity. All the Attribute-specific treatments of monitoring repeat that theme in one form or another.

6.1.1 Substrate

Analysis of existing and new bathymetry data is required for initial assessment and further monitoring of seafloor environment status (Wilson et al., 2007). Similarly it is important to map the distribution of substrates/habitats, especially those that are considered sensitive to human impacts. Monitoring may be based upon pressure indicators, state indicators or a combination of both. The scale aspect is essential here as distribution of human activities and substrate types is generally very patchy (see section 4 dealing with scale). Monitoring should consider all substrate types in a given area but the monitoring effort per type should be proportional to a sensitivity or risk criteria rather than to the surface of each substrate type. Biogenic substrates have smaller spatial extent compared to most other substratum types, and, considering their vulnerability to physical impacts, may require more intensive monitoring efforts and at higher spatial resolution compared to other substrate types.

6.1.2 Bioengineers

There is a need for compilation of high resolution habitat maps for European seas and increased knowledge about the ecological function for different components of benthic habitats. The information also need to be analysed in relation to what could be expected under unperturbed situations i.e. what are the reference level for seabed integrity.

6.1.3 Oxygen

For the Baltic Sea Region the “Manual for Marine Monitoring in the COMBINE Programme” of Helsinki convention describes in detail the monitoring requirement for the Baltic Sea. Results are regularly published in regional and thematic assessments reports for the specific regions or the Baltic Sea in total.

6.1.4 Contaminants

See the requirements in the report of TG 8.

6.1.5 Species Composition

Many standardized programs for monitoring of benthic communities have been implemented in support of the WFD (see overall review of “Combining Indicators for references and details). These monitoring programs do provide the data needed for calculating many indicators under Species Composition. However the spatial scales of those programs are almost always much finer than the scales at which GES will be assessed, and the patchiness of seafloor substrates and biota mean that simple interpolation of monitoring results from monitored sites to other sites cannot be assumed to be valid. Here particularly the risk-based designs discussed in section 3 will be highly relevant to seafloor monitoring. In addition the time scales at which managers and policy makers must respond differ from those of greatest interest to the scientists conducting the monitoring (Borja and Dauer, 2008; Borja et al., 2003, 2007). Consequently, the development and implementation of a full “case study” supported by focused monitoring, each time a management problem appears is not viable. Strategies such as rapid assessment techniques (RATs) are being explored, to get wider use of the monitoring programs that are feasible. In turn, the interest in RATs has facilitated the design and experimentation of many indicators, including some of those cited in section 6.4.

6.1.6 Size Composition

All sampling that can support indicators of Species Composition can also support indicators of Size Composition, as long as sizes of organisms sampled are recorded as well as species identities. Because size is particularly inexpensive and easy to measure, compared to conducting taxonomic identifications of all individuals in a sample, the logistic monitoring requirements of Size Composition are in fact much lower than the requirements of Species Composition. However, all the problems of tractable spatial and temporal scales for benthic monitoring of organisms remain with Size Composition. Likewise the need for known and highly standardized selectivity of sampling gears used in monitoring all remain with Size Composition, just as they do for size composition.

6.1.7 Trophodynamics – Secondary Production & Carrying Capacity

Current levels of monitoring do not have the resolution that allows mapping of secondary production over relevant scales, but we do also not have models that allow consistent prediction of benthic productivity over large scales. This hampers our ability to use secondary production as an indicator of GES. We do know what the impact of climate change on secondary production is likely to be, and this hampers our ability to recognize such impacts

We do not currently have to ability to measure carrying capacity of an ecosystem, and therefore there is no way of monitoring changes in carrying capacity. It is quite poorly understood how hydrodynamics and primary production affect the carrying capacity of seafloor ecosystems, with the exception of bivalve aquaculture systems.

6.1.8 Life History Traits

All the comments on monitoring for Species Composition and Size Composition also apply to monitoring to calculate the indicators associated with Life History Traits. There is one additional and serious problem, however. Not only are indicators of Life History Traits more complex than indicators of Species Composition and Size Composition because all the monitoring information must be augmented by knowledge of the species' and sizes' biological traits, but unbiased and consistent sampling across trait classes may more particularly hard to achieve. When individuals or species with one set of traits is increasing as individuals or species with a different set of traits is decreasing, the traits themselves may affect the catchability of the individuals or species in any standardized sampling gear. For example the change in biological traits may skew the size composition of the community such that a standardized gear samples a lower (or higher) proportion of the community present over time, or perhaps more sedentary species are replaced by more active ones making sampling gears that attract organisms (e.g. baited pots) more effective and possibly make mobile sampling gears (dredges etc) less effective. Consequently consistent monitoring programs would document changes in abundance and community composition that mis-represented the changes in the actual benthic community, even though the gears and methods had not changed. There is no easy fix for this problem. However, if the distribution of life history traits of the community change in ways that affect the relative catchability of all the components of the community, the biases will be present whether one calculates indicators of Life History Traits, or just calculated indicators of Species and Size Composition.

6.1.9 Tabulation

Late in the preparation of this section, a template was developed for codifying existing information on monitoring programs relative to GES for Seafloor integrity.

This template could only be partially completed in the time available. It is included for illustrative purposes. If it is found useful, it could be completed over the coming months, drawing from national expertise in every EU country.

Attribute	**Indicator** (or Ind. Class)	**Monitoring needs**			**Existing Programs**		
		Ecosystem feature(s) (e.g. abundance of specific species, all species in the community, concentration of specified nutrients, etc	**Frequency:** *Several/year* *Seasonal* *Annual* *Every few yrs*	**Spatial extent** Local 10's of km^2 100's of km^2 1000's of km^2 (can propose multiple, or stress one is essential)	**Scale** (small, partial, adequate, full)	**Gear**	**Reference /name**
Size Composition	Size spectrum	All individuals or biomass in specified size range, regardless of species	Any, depending on pressure, but annual is common	Any, depending on pressure, but must be consistent. Large (100s or 1000s of km^2) is common			
Size Composition	Percent larger than criterion	All individuals or biomass in specified size range, regardless of species	Any, depending on pressure, but annual is common	Any, depending on pressure, but must be consistent. Large (100s or 1000s of km^2) is common			
Substrate	Fishing Pressure	All regional seabed	Quarterly	10mins x 10 mins	EU waters covered	Vessel Monitoring System (VMS)	Piet and Quirins, 2009

Attribute	Indicator (or Ind. Class)	Monitoring needs			Existing Programs		
		Ecosystem feature(s) (e.g. abundance of specific species, all species in the community, concentration of specified nutrients, etc	**Frequency:** *Several/year* *Seasonal* *Annual* *Every few yrs*	**Spatial extent** Local 10's of km^2 100's of km^2 1000's of km^2 (can propose multiple, or stress one is essential)	**Scale** (small, partial, adequate, full)	**Gear**	**Reference /name**
Substrate	Other pressures (oil and gas; dumping, sand and gravel extraction)		Quarterly/annual activity	Area where pressures area exerted		Data from administrations and stakeholders	
	State indicator	Topography and rugosity	Several years	Box sampling (e.g. a 1 x 1 km square per 50 x 50 km sampling area)	None	MBES	
	State indicator	Topography and rugosity	Several years	One sampling every n km	None	Ground-truthing (e.g. grab, boxcorer, underwater video, beam trawl	
Bio-engineers	Presence of attribute	Abundance of bio-engineering fauna and flora, and structures	Every few years	Any depending on spatial distribution and patchiness of indicator species and structures	Partial: National benthic monitoring programmes.	Benthic grab/core sampling	

Piet G. J., Quirijns F. J., 2009. The importance of scale for fishing impact estimations. *Can. J. Fish. Aquat. Sci.*, 66 (5), 829-835

6.2 Research needs

General

Many factors identified as monitoring needs fit equally well as research needs, and some are even repeated here. Overall, although there is a sound understanding of ecological processes in the seafloor, and of the first order, direct impacts of most human pressures on seafloor ecosystem attributes, much remains to be learned about the dynamics of how those processes interact, the natural factors that influence these dynamics, and how the ecosystem interactions convey the direct impacts of human pressures into indirect impacts on system components and their interaction. In this way the seafloor is little different from the water column. The added complexity on the seafloor however, arises from the often small spatial scales at which these dynamics and interactions are played out. Mixing processes that strongly influence ecosystem dynamics and interactions in he water column are often of lessor importance when key parts of the benthic community are connected to the seafloor. Moreover, the sediments provide reservoirs for nutrients, contaminants and many other chemicals that can affect the system dynamics, Giving time scales to the dynamics of seafloor communities that can also be more complex than those in the water column.

Specific

6.2.1 Substrates

Relationships between habitat properties, ecosystem functioning and diversity have been research topics over the past decades. Further research should focus on examining the relationship between habitat complexity and benthic community metrics (e.g. abundance, diversity, productivity). Habitat mapping is a prerequisite for marine spatial plans (e.g. Day et al., 2008). In recent years, advances in acoustic techniques (e.g. multibeam and side-scan sonar) and interpretation of backscatter information showed that different types of substrates can be delineated using this approach. However, groundtruthing is most often required (e.g collection of sediment samples), (e.g. Brown and Blundel 2009). Acoustic methods allow surveying larger areas in shorter time and at lesser expense than conventional methods (e.g. dredge, grabs) and they are non-destructive. Therefore, the best strategy might be to use acoustics data for mapping and monitoring and conventional methods for groundtruthing. More work is required to understand and evaluate seabed backscatter data (see Brown and Blondel, 2009 and literature therein). Further, it is important to investigate associations between substrate types and benthic communities. Some organisms are inherently more sensitive to human impacts than others and it is important to identify these (Kaiser et al. 2006). A logical following step would be to examine the impacts of human activities on the various substrate types in a spatial context (Hiddink et al., 2007, Stelzenmuller et al. 2008) and such approach would allow identification of habitat at risk. With respect to the attribute substrate, the most important task should be to map marine habitats/substrates and to identify habitats at risk or that are of significant value.

Day V, Paxinos_R, Emmett J, Wright A, Goecker M. 2008. The Marine Planning Framework for South Australia:A new ecosystem-based zoning policy for marine management. Marine Policy 32:535–543

Hidding J.G. Jenning S. and Kaiser M. J. 2007. Assessing and predicting the relative ecological impacts of disturbance on habitats with different sensitivities. Journal of Applied Ecology 44: 405–413

Stelzenmüller, V., Rogers, S. I., and Mills, C. M. 2008. Spatio-temporal patterns of fishing pressure on UK marine landscapes, and their implications for spatial planning and management. – ICES Journal of Marine Science, 65: 1081–1091.

6.2.2 Bio-engineers

There is a need for compilation of high resolution habitat maps for European seas and increased knowledge about the ecological function for different components of benthic habitats. The information also need to be analysed in relation to what could be expected under unperturbed situations i.e. what are the reference level for seabed integrity.

6.2.3 Oxygen

Better knowledge of strategies to mitigate low oxygen areas would be valuable, as would better ability to attribute causation to areas of low oxygen.

6.2.4 Contaminants

See the requirements in TG 8.

6.2.5 Species Composition

The recent scientific arena has demonstrated that the time scales at which managers work differ from those of the scientists (Borja and Dauer, 2008; Borja et al., 2003, 2007). Consequently, the former aspects of the development and implementation of a full "case study", each time a problem appear is no longer applicable. Logistics is another option of the problem and for this reason the concept of the rapid assessment techniques (RATs) which, in turn, has facilitated the design and experimentation of many indicators, including those cited above. The other problem in the implementation of the indicators was their capacity to distinguish natural variability in community structure (disturbance) and function from that caused by the anthropogenic activities (stress). A few non-metric multivariate techniques have already been developed (Anderson, 2001) and they will play an important role in the further development of the concept of RATs and indicators.

6.2.6 Size Composition

All the ecological research requirements in the opening part of this section are relevant to Size Composition. It is also important that the size selectivity of sampling gears be better documented, as well as the degree to which sampling selectivities are general across habitat types. If these basis selectivities remain undocumented, then no sound inferences can be drawn about the ecological meaning of observed changes in size (or species) composition from monitoring.

6.2.7 Trophodynamics

We do not have models that allow consistent prediction of benthic productivity over large scales. This hampers our ability to use secondary production as an indicator of GES. We do not know what the impact of climate change on secondary production is likely to be, and this hampers our ability to recognize such impacts.

We do not currently have to ability to measure carrying capacity of an ecosystem, and therefore there is no way of monitoring changes in carrying capacity. It is quite poorly understood how hydrodynamics and primary production affect the carrying capacity of seafloor ecosystems, with the exception of bivalve aquaculture systems.

6.2.8 Life History Traits

Major research issues, regarding the application of LHT requires (Borja and Dauer, 2008; Borja *et al.,* 2009c): (i) assessing ecological integrity, (ii) evaluating if significant ecological degradation has occurred, (iii) identifying the spatial extent and location of ecological degradation, and (iv) determining causes of unacceptable degradation in order to guide management actions. Some research of the different processes used for developing, calibrating and validating indices in different regions is needed, e.g.: (i) reduction of the present bewildering array of available indices by identifying the index approaches, components and formulations that are most widely successful (Index Format); (ii) establish minimum criteria for index validation processes that demonstrate index accuracy and reliability (Index Validation); (iii) compare and intercalibrate methods to achieve uniform assessment scales across sites and habitats (Index Intercalibration); and (iv) integrate indices across media and ecosystem elements (Index Integration).

7. SUMMARY TABLE: SEAFLOOR INTEGRITY

The Management Committee for the joint ICES-JRC project developed a tabular summation of the main results of the Task Groups working towards the science basis for implementation of the MSFD. That Summary Table is presented below. Ecological details providing the basis for all cell entries can be found in the preceding sections of this Report.

TG 6 Seafloor integrity			
ATTRIBUTE	**Criteria** to assess the descriptor	**Classes of Indicators**	**Considerations in Use of Indicator Classes**
1- Substrate	Change in natural 3-dimensional structure Degree of alteration of original substrate composition/types Size of area exposed to pressures known to alter substrate Changes in ecological functions provided by substrate features	Spatial extent of benthic habitats % area with benthic invertebrates known to be associated with particular substrates biomass/production above a given % of undisturbed areas 1-% of area exposed to pressure X above level Y, where X and Y are location specific an take account of different backgrounds	ON SELECTION AND USE OF INDICATORS Spatial extend of habitats is valuable to inventory but costly to monitor change directly, and often insensitive to pressures impacting functions served by the habitats. Impacts of pressures on substrates likely to be more sensitively assessed through Species Composition, Size Composition, and Life History Traits Attributes. Pressure indicators are likely to be more cost effective and sensitive than many direct indicators of substrate features. Where there are multiple human-induced pressures on substrate, cumulative effects should be evaluated. ON REFERENCE LEVELS Reference levels for extent of substrate types and abundance of species associated with specific substrates need to be judged relative to local historical baselines, which are often not quantified

TG 6 Seafloor integrity			
ATTRIBUTE	**Criteria** to assess the descriptor	**Classes of Indicators**	**Considerations in Use of Indicator Classes**
2- Bio-engineers	Change in number and/or spatial extent of bio-engineers Change in availability of functions served by bioengineers Size of area exposed to pressures known to alter substrate or harm bio-engineers directly	Abundance of bio-engineer species Extent of habitats used by or provided by bio-engineers 1-% of area exposed to pressure X above level Y, where X and Y are location specific an take account of different backgrounds	ON SELECTION AND USE OF INDICATORS Some types of bio-engineers are hard to monitor directly, and monitoring the functions they serve through species-, size-, and life history indicators may be more cost-effective and sensitive to impacts on bio-engineers Assessments of bio-engineers must be local. Intervals between assessments depend on the type of bio-engineer Where there are multiple human-induced pressures on bio-engineers, cumulative effects should be evaluated. ON REFERENCE LEVELS Reference levels for abundance of bioengineers and extent of habitats associated with bioengineers need to be judged relative to local historical baselines, which are often not quantified
3-Oxygen	Changing oxygen concentration of bottom water and/or upper sediment layer	Extent of area with spatial and temporal hypoxia Ratios of oxygen / hydrogen sulphide concentrations Presence of benthic communities associated with low oxygen conditions	ON SELECTION AND USE OF INDICATORS Instruments make direct measurements of oxygen and hydrogen sulphide feasible, but seasonal monitoring may be challenging. Then benthic community data may give time-integrated picture of past hypoxia. Assessments should done in critical areas, and annually at critical times of year (often late summer and autumn) Guidance on Eutrophication (TG 5) relevant here as well ON REFERENCE LEVELS Standards for setting reference levels are in TG 5

TG 6 Seafloor integrity			
ATTRIBUTE	**Criteria** to assess the descriptor	**Classes of Indicators**	**Considerations in Use of Indicator Classes**
4-Contaminants	See TG 8 Accumulation of contaminants in sediment and biota	See TG 8	ON SELECTION AND USE OF INDICATORS Evaluations of Contaminants in marine ecosystem should always consider benthos Substrates might be reservoirs for contaminants and should be part of assessments of contaminants in marine systems. ON REFERENCE LEVELS See TG 8
5 -Species composition of benthos	The number of species in the benthic community The relative abundances of species in the benthic community The presence of species know to be particularly sensitive or particularly tolerant to various pressures or to general disturbance regimes	Diversity and richness indices taking in account also species/area relationships Shape of cumulative abundance curves of numbers of individuals by species Position of samples in multivariate representations community composition Presence of diagnostic species	ON SELECTION AND USE OF INDICATORS Selection of diagnostic species requires good knowledge of communities in area being assessed, but can be effective when a specific pressure is a major concern. Many indices of richness and diversity, and methods of community ordination have been advocated for use. Expert guidance on choice is needed – see TG 1 – Biodiversity Assessment of this attribute should occur at regular intervals, and be standardized for seasonality ON REFERENCE LEVELS Reference levels for all species composition indicators need to be judged relative to local historical baselines, which are often not quantified. Knowledge from benthic habitats of similar depth, latitude, substrate type etc, can provide starting points for setting reference levels.

TG 6 Seafloor integrity			
ATTRIBUTE	**Criteria** to assess the descriptor	**Classes of Indicators**	**Considerations in Use of Indicator Classes**
6 - Size-composition of benthos	Changing proportion of the community comprised of small and large individuals	Proportion of number or biomass above some specified length Biomass size spectrum Shape of cumulative abundance curves of numbers of individuals by size group	ON SELECTION AND USE OF INDICATORS This Attribute often uses same information as for species composition, but required less sample processing. Assessment of this attribute should occur at regular intervals, and be standardized for seasonality\ ON REFERENCE LEVELS Reference levels for all size composition indicators need to be judged relative to local historical baselines, which are often not quantified. Knowledge from benthic habitats of similar depth, latitude, substrate type etc, can provide starting points for setting reference levels.
7 Tropho- dynamics	Rates of Nutrient supply, mobilisation, regeneration in the benthos and sediments Levels of secondary production in the benthos Changes in carrying capacity	See TG4	ON SELECTION AND USE OF INDICATORS TG 4 does not address indicators for secondary production and carrying capacity. However sensitive and cost effective direct indicators of these properties of tropho-dynamics are not available at this time. Indirect indicators of secondary production and carrying capacity are already covered under Species Composition; Size Composition, and Life History traits. ON REFERENCE LEVELS No guidance because there are presently no suitable indicators
8 Life-history traits	Changes in functional diversity	Opportunistic-sensitive species proportion	ON SELECTION OF INDICATORS All Indicators for this Attribute use same information as for

TG 6 Seafloor integrity			
ATTRIBUTE	**Criteria** to assess the descriptor	**Classes of Indicators**	**Considerations in Use of Indicator Classes**
	Changes in relative abundance of traits associated with opportunistic and sensitive species	(e.g.AMBI) Biological traits analysis Conceptually possible to apply for changing life history traits within a species / population over time.	species composition, but require more knowledge of life history traits of the species. Many proposed Indicators use discrete community stages, but continuous Indicators (e.g ordinations) also possible Assessment of this attribute should occur at regular intervals, and be standardized for seasonality ON REFERENCE LEVELS Reference levels for all life history trait indicators need to be judged relative to local historical baselines, which are often not quantified. Knowledge from benthic habitats of similar depth, latitude, substrate type etc, can provide starting points for setting reference levels

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Abstract

The Marine Strategy Framework Directive (2008/56/EC) (MSFD) requires that the European Commission (by 15 July 2010) should lay down criteria and methodological standards to allow consistency in approach in evaluating the extent to which Good Environmental Status (GES) is being achieved. ICES and JRC were contracted to provide scientific support for the Commission in meeting this obligation.

A total of 10 reports have been prepared relating to the descriptors of GES listed in Annex I of the Directive. Eight reports have been prepared by groups of independent experts coordinated by JRC and ICES in response to this contract. In addition, reports for two descriptors (Contaminants in fish and other seafood and Marine Litter) were written by expert groups coordinated by DG SANCO and IFREMER respectively.

A Task Group was established for each of the qualitative Descriptors. Each Task Group consisted of selected experts providing experience related to the four marine regions (the Baltic Sea, the North-east Atlantic, the Mediterranean Sea and the Black Sea) and an appropriate scope of relevant scientific expertise. Observers from the Regional Seas Conventions were also invited to each Task Group to help ensure the inclusion of relevant work by those Conventions. This is the report of Task Group 6 Seafloor Integrity.

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