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Viewpoint

The Marine Strategy Framework Directive and the ecosystem-based approach – pitfalls and solutions

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ABSTRACT

The European Marine Strategy Framework Directive aims at good environmental status (GES) in marine waters, following an ecosystem-based approach, focused on 11 descriptors related to ecosystem features, human drivers and pressures. Furthermore, 29 subordinate criteria and 56 attributes are detailed in an EU Commission Decision. The analysis of the Decision and the associated operational indicators revealed ambiguity in the use of terms, such as indicator, impact and habitat and considerable overlap of indicators assigned to various descriptors and criteria. We suggest re-arrangement and elimination of redundant criteria and attributes avoiding double counting in the subsequent indicator synthesis, a clear distinction between pressure and state descriptors and addition of criteria on ecosystem services and functioning. Moreover, we suggest the precautionary principle should be followed for the management of pressures and an evidence-based approach for monitoring state as well as reaching and maintaining GES.

1. Introduction

The European Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC) has adopted ecosystem-based management (EBM) as a central part of its objectives (Article 1 of the MSFD). It wants to apply an ecosystem-based approach to the management of human activities in order to reach a good environmental status (GES) by 2020. Paragraph 44 of the MSFD preamble (EU, 2008) states that measures and subsequent actions should be based on EBM and also on the precautionary principle.

A cornerstone of the MSFD is the interpretation of the 11 descriptors (MSFD Annex I, see Table 1). Some of these descriptors can be said to represent the most important ecosystem features of concern (D1 – Biological diversity, D2 – Non-indigenous species (NIS), D3 – Commercial fish and shellfish, D4 – Food webs, D6 – Sea floor integrity, D7 – Hydrological conditions) either in terms of favourable or threatened features, forming different sectors of the ecosystem-based approach. Another part of the descriptors represents human drivers, pressures on the ecosystems and their resulting alterations (D3 – Fishery, D5 – Eutrophication, D8 – Contaminants, D10 – Litter, D11 – Energy and noise). The descriptors are further detailed in the EU Commission Decision 2010/477/EU (European Commission, 2010), subdividing them into overall 29 criteria and 56 associated 'indicators' which more specifically determine which attributes of the ecosystem features should be considered for the assessment of the environmental status. Table 2 lists the ones of the biodiversity-related descriptors D1 (Biological diversity), D2 (Non-indigenous species), D4 (Marine food webs) and D6 (Sea floor integrity) that we investigated. This approach of compiling long lists of 'indicators' is a recent trend in environmental policy that also can be observed in e.g. the European environmental assessment of the EEA (European Environmental Agency), the Aichi biodiversity targets (CBD-2012) or in indicators mapping human impacts on the oceans (Halpern et al., 2008).

This work highlights how the EU Commission Decision is interpreted among scientists, translated into operational indicators as the basis of the assessment of the environmental status and how well this is aligned with the ecosystem-based approach. With our findings we want to contribute to the revision of the EU Commission Decision (paragraph 4 of the preamble). The analysis and interpretation presented in this work is a result from the DEVOTES project reflecting the personal view of the authors and not the official position of the European Commission.

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Table 1
Qualitative descriptors for determining good environmental status in the MSFD (EU, 2008). The right column classifies the descriptors according to presence of corresponding pressure or state criteria/attributes within the descriptor (following the DPSIR framework).

MSFD descriptor	Short name	Classification
Biological diversity	D1	State
Non-indigenous species	D2	Pressure/state
Commercially exploited fish and shellfish	D3	Pressure/state
Marine food webs	D4	State
Human-induced eutrophication	D5	Pressure/state
Sea floor integrity	D6	Pressure/state
Hydrographical conditions	D7	Pressure/state
Concentrations of contaminants	D8	Pressure
Contaminants in fish and other seafood	D9	Pressure
Marine litter	D10	Pressure
Energy, including underwater noise	D11	Pressure

1.1. The conceptual basis of ecosystem-based management

EBM has been used as a way to account for the complex interactions of the biophysical and human components of an ecosystem rather than managing individual sectors of the ecosystem in isolation (Elliott, 2002; Kelble et al., 2013; Levin et al., 2009). It is an approach that includes humans and their sustainable use of the environment as a central part of the entire ecosystem (Atkins et al., 2011; Leslie and McLeod, 2007) and as such targets both ecosystem structure and processes and the ecosystem services delivered. To achieve this, EBM typically runs through specific phases, often in a kind of management cycle (but see also Tallis et al. (2010) for other approaches) in order to benefit from adaptive management.

The corresponding concept applied in this paper for such an adaptive management cycles is the DPSIR framework (Driver-Pressure-State-Impact-Response) which the European Environment Agency (EEA) has also adopted and used in e.g. their regular state assessments of the European environment (Atkins et al., 2011; European Environment Agency, 2010; Gabrielsen and Bosch, 2003; Kristensen, 2004) and which has been proposed for use in the MSFD (Borja et al., 2010) (Fig. 1). In short, it considers driving forces (D) in terms of human activities. These lead to pressures (P) on the natural system, which in turn change its state (S), i.e. the properties and processes of the ecosystem. The state changes in the natural system are finally resulting in impacts (I) to the human system and to the way we can use the natural resources (as ecosystem services). Society then finds a response (R) with e.g. implementing appropriate policy that is meant to change the nature and magnitude of the human activities associated to the drivers (Atkins et al., 2011; Elliott, 2011; Kristensen, 2004).

Any of these five stages in the DPSIR cycle can be observed, categorised and measured using their own set of indicators and thus inform management to find subsequent responses. The connection between response and driver, making the DPSIR a cycle, is the strongest response society can find. This is typically done in terms of different policies, for example in the agriculture, transport or energy sectors, MSFD being one of them.

Table 2
Criteria and attributes (‘indicators’ in original reference) for the biodiversity-related descriptors D1, D2, D4 and D6, as selected by the European Commission (2010). Criteria and attributes in italic are addressing the state/condition of habitats/communities/biotopes or functionally important groups/species. Names are partly shortened for easier readability.

MSFD descriptor	Criterion	Attributes
D1 Biological diversity	1.1 Species distribution	1.1.1 Distributional range
		1.1.2 Distributional pattern within range
		1.1.3 Area covered by the species (for sessile/benthic species)
	1.2 Population size	1.2.1 Population abundance and/or biomass
	1.3 Population condition	1.3.1 Population demographic characteristics
		1.3.2 Population genetic structure
	1.4 Habitat distribution	1.4.1 Distributional range
		1.4.2 Distributional pattern
	1.5 Habitat extent	1.5.1 Habitat area
		1.5.2 Habitat volume
	1.6 Habitat condition	*1.6.1 Condition of the typical species and communities*
		1.6.2 Relative abundance and/or biomass
		1.6.3 Physical, hydrological and chemical conditions
	1.7 Ecosystem structure	1.7.1 Composition and relative proportions of ecosystem components
D2 Non-indigenous species	2.1 Abundance and state characterisation of non-indigenous species, in particular invasive species	2.1.1 Trends in abundance, temporal occurrence and spatial distribution
	2.2 Environmental impact of invasive non-indigenous species	2.2.1 Ratio between invasive non-indigenous species and native species
		2.2.2 Impacts of non-indigenous invasive species
D4 Marine food webs	4.1 Productivity of key species or trophic groups	4.1.1 Performance of key predator species using their production per unit biomass
	4.2 Proportion of selected species at the top of the food web	4.2.1 Large fish (by weight)
	4.3 Abundance/distribution of key trophic groups/species	*4.3.1 Abundance trends of functionally important selected groups/species*
D6 Sea floor integrity	*6.1 Physical damage, having regard to substrate characteristics*	*6.1.1 Type, abundance, biomass and areal extent of relevant biogenic substrate*
		6.1.2 Extent of the seabed significantly affected by human activities for the different substrate types
	6.2 Condition of benthic community	*6.2.1 Presence of particular sensitive and/or tolerant species*
		6.2.2 Multi-metric indexes assessing benthic community condition and functionality, such as species diversity and richness, proportion of opportunistic to sensitive species
		6.2.3 Proportion of biomass or number of individuals in the macrobenthos above some specified length/size
		6.2.4 Parameters describing the characteristics of the size spectrum of the benthic community

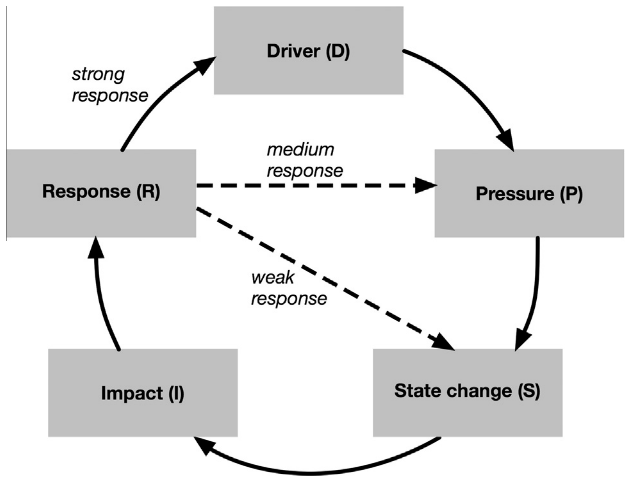

Fig. 1. Illustration of the DPSIR framework as a cycle with the various types of human response.

Table 3
7-Tenets of successful and sustainable environmental management measures (from Elliott, 2011).

Tenets	Explanation
1. Environmentally/ ecologically sustainable	Safeguard ecosystem features and functioning and the fundamental and final ecosystem services
2. Technologically feasible	Ensure availability of methods, techniques and equipment for ecosystem protection
3. Economically viable	Viable and sustainable cost-benefit relationship of the environmental management
4. Socially desirable/tolerable	Measures are required or at least understood and tolerated by society; social benefits are delivered
5. Legally permissible	Having regional, national or international agreements and/or statues which enable and/or force the management measures to be performed
6. Administratively achievable	Statutory bodies and conservational bodies are in place and functioning
7. Politically expedient	Approaches are consistent with prevailing political climate and have support of political leaders

Also other kinds of responses are seen in environmental management (dashed arrows in Fig. 1). A medium response is acting at the pressure (P) level, for example by setting legal limits to emissions, prescribing fishing gear or rigorous (maritime spatial) planning. This can be regarded as an implementation of the precautionary principle, not wanting to wait for state changes or impacts but instead trying to minimize or avoid pressures by timely management actions (Mace and Baillie, 2007). Applying the precautionary principle strictly, a human activity is only allowed when it can demonstrate that it does not have an impact on the natural system and thus does not change its environmental state (S) (Borja and Elliott, 2013). When this has been proved beforehand, there is no need for having state indicators to monitor potential state changes stemming from those activities and to causally link them to specific pressures.

A weak management response is one that acts at the state (S) level, for example by trying to preserve the ecosystem state in designated protected areas through isolation from manageable pressures or to take remediation measures (restoration from damage). This can be regarded as an implementation of evidence-based management, only acting when state changes already have taken place and can be measured.

The different stages of the DPSIR management cycle require their own set of indicators that quantify or describe the amount of drivers, pressures, state changes or impacts. Especially for the stages P and S these are often termed 'pressure indicators' and 'state indicators' and this is how we use these terms in this paper. This distinction is vital since these indicators should be useful to either support management decisions (pressure indicators) or validate them through monitoring (state indicators) (Failing and Gregory, 2003; Mace and Baillie, 2007). Besides being specific and derived from the results of the indicators, management responses should also follow the so-called 7-tenets (Table 3) of successful and sustainable environmental management (Elliott, 2011; Mee et al., 2008). These tenets ensure that all management decisions and measures taken on the basis of the indicators will support the EBM approach. Within the 11 descriptors of the MSFD (Table 1), the EU Commission Decision (European Commission, 2010) largely considers the pressure (P) and state (S) stages of the DPSIR framework. It is important to ensure that the resulting indicators used to implement the MSFD follow this underlying conceptual view that is the basis of the ecosystem-based approach utilized in the MSFD. Therefore, pressure indicators are assigned *target values* denoting the amount of pressure society is willing to still accept (tenet no. 4) while at the same time ensuring environmental sustainability (tenet no. 1). The resulting environmental status is monitored using state indicators that have associated *GES boundaries* denoting the state of an ecosystem feature above which a good environmental status is safeguarded.

2. Definitions and terms

2.1. Indicator

Within the framework of the MSFD the term 'indicator' is used in two different ways. Firstly, the directive itself uses the term for the methods needed to monitor if environmental targets have been met (MSFD article 10). This is equivalent to what is commonly called an index or assessment system, i.e. a statistic (Claussen et al., 2011) reflecting some ecosystem feature and corresponds to how we use the term in this paper. Member States are thus developing indicator sets in order to do the assessment of the environmental status and the RSCs also have sets of so-called common (OSPAR) or core (HELCOM) indicators representing operational assessment methods.

The other usage occurs in the EU Commission Decision 2010/477/EU (European Commission, 2010) and refers to the subordinate classification category of the GES criteria within each descriptor. These indicators can be referred to as attributes of the GES criteria. Consequently, these different meanings of the term 'indicator' easily confused or misunderstood. In order to avoid this, we therefore use the term 'attribute' instead to describe the subordinate category of the GES criteria in the EU Commission Decision and we suggest eliminating the term 'indicator' from the Commission Decision when it will be revised.

2.2. Impact

The term 'impact' is commonly used to describe the effect of some pressure on the ecosystem, either the abiotic (habitats) or the biotic ones (organisms). Impacts are thus the consequences for the ecosystem in terms of changes to some ecosystem features. This is how the MSFD and especially the EU Commission Decision (European Commission, 2010) use the term. The DPSIR framework, however, strictly only uses 'impacts' as describing the changes to the human system resulting from state changes in the natural system (Elliott, 2011). As such, 'impact' as used in the MSFD is equivalent to 'state change' within the DPSIR framework. Since our study focuses on the EU Commission Decision and its implementation, we use the term impact in the MSFD sense of "impact on the natural/environmental system".

3. Overview of Europe's biodiversity indicators

An inventory of existing indicators including 557 entries for marine biodiversity-related ecosystem features covering biological diversity, non-indigenous species, food webs, and sea floor integrity (MSFD descriptors D1, D2, D4, D6) was established through a consultation mainly of scientists involved in the implementation of the MSFD or with knowledge to the indicators applied or being developed in their respective area. The inventory is available as a database and analysis software from http://www.devotes-project.eu/devotool (currently database version 6). It contains metadata ranging from indicator descriptions, data requirements and especially the assignment of the indicators to GES descriptors/criteria/attributes as well as developmental status, geographical coverage, applicable habitats, targeted biodiversity components and related pressures. Further details on the survey can be found in Teixeira et al. (2014).

The following sections describe and analyse the contents of the inventory and the metadata specifically related to MSFD requirements which have been assigned to the indicators by the different experts.

3.1. Indicators for biodiversity-related descriptors

80% of the indicators in the inventory have been associated to D1, 4% to D2, 30% to D4 and 15% to D6. The sum of these numbers is larger than 100% indicating that there is overlap in the assignment to descriptors. A substantial amount of indicators has been assigned to more than one of these descriptors at the same time (Fig. 2).

57% of the 557 indicators were assigned to a single biodiversity-related descriptor while 32% were assigned to two descriptors, most of them being either D1 + D4 or D1 + D6 indicators. 9% of the indicators cover three descriptors, most of these cases being of the type D1 + D4 + D6. There were also a few indicators targeting four or five descriptors, and then mostly including D5 (Human-induced eutrophication) or D7 (Hydrological conditions), which are not detailed in this inventory. In general, about half of the descriptors were considered operational, i.e. tested and validated, ideally with associated target values or GES boundaries.

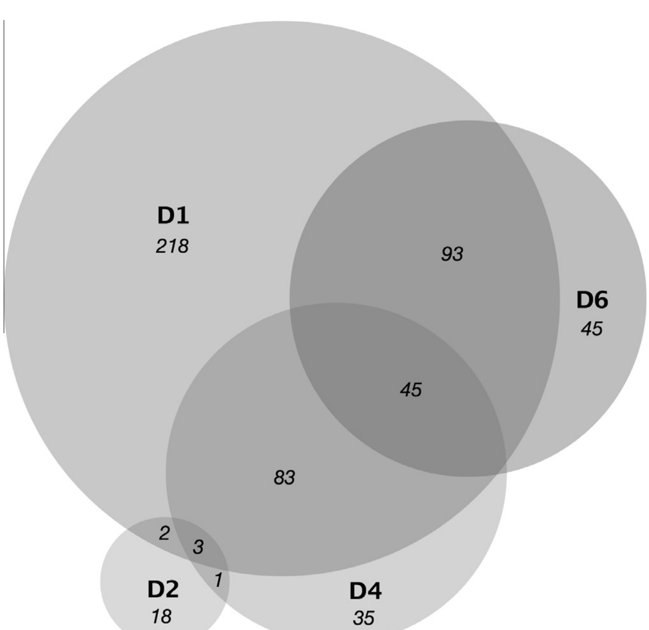

Fig. 2. Number of indicators assigned to descriptors D1, D2, D4 and D6 only (218, 18, 35 and 45, respectively), and the number of indicators assigned to multiple descriptors (e.g. 3 indicators assigned to D1, D2 and D4 at the same time).

3.2. Indicators on GES criteria and attributes

3.2.1. Biological diversity (D1)

42% of the D1 indicators (185 of 444) have been assigned to *Habitat condition* (criterion 1.6) and within this criterion most (110) are connected to *Condition of the typical species and communities* and *Relative abundance and/or biomass* (attributes 1.6.1 and 1.6.2, respectively), while only few cover *Physical, hydrological and chemical conditions* (attribute 1.6.3). 40% of the indicators on *Habitat condition* were at the same time assigned to the *Condition of benthic community* of D6 (criterion 6.2), 31% to *Physical damage* (criterion 6.1). The same pattern was observed with D4, where 39% of the indicators on D1 *Habitat condition* were also assigned to D4 *Abundance/distribution of key trophic groups/species* (criterion 4.3).

125 indicators are addressing *Ecosystem structure* (criterion 1.7). Only a few of them (15) have been assigned solely to this criterion while most were assigned to other criteria within descriptor D1, but also in descriptors D4 and D6. In sum, within the different biodiversity components specified in D1 (species–habitats–ecosystems), most indicators target the species level (criteria 1.1–1.3), followed by the habitat level (criteria 1.4–1.6) and finally the ecosystem level (criterion 1.7).

3.2.2. Non-indigenous species (D2)

The 24 indicators targeting D2 are the most specific ones in the inventory since nearly all cover D2 criteria only. There is little overlap to D1 with only five indicators also covering D1, mainly *Population size* (criterion 1.2) and D4 (four indicators). This is due to the specific nature of the descriptor and its subsequent criteria and attributes. Only in cases where non-indigenous taxa are simultaneously key trophic groups/species, the indicators have also been assigned to D1 or D4. Within D2, most indicators (15) were assigned to *Abundance and state characterisation of non-indigenous species, in particular invasive species* (criterion 2.1). Most of them directly address *Trends in abundance, temporal occurrence and spatial distribution* (attribute 2.1.1). *Environmental impact of invasive non-indigenous species* (criterion 2.2) is only covered by six indicators, none of them being operational. They typically use a ratio of non-indigenous to indigenous species. Only the indicator "Biopollution level index" targets the *Impacts of non-indigenous invasive species* (attribute 2.2.2) using the habitat level.

3.2.3. Marine food webs (D4)

The majority of D4 indicators (143 of 167) were assigned to *Abundance and distribution of key trophic groups/species* (criterion 4.3) and most of these were at the same time assigned to D1 and D6 criteria for assessment of habitats and biogenic substrates. The focus of most of the available indicators is on top predators while other trophic groups were less well covered.

3.2.4. Sea floor integrity (D6)

183 indicators have been assigned to D6. They exhibit a large overlap between the two criteria of D6, since 103 indicators are addressing *Physical damage* (criterion 6.1) while 102 indicators are addressing *Condition of benthic community* (criterion 6.2). Over 60% of the indicators on *Physical damage* are covering *Biogenic substrates* (attribute 6.1.1) and many of these indicators where simultaneously assigned to D1 as well as D4. Most of the

indicators addressing *Condition of benthic community* (criterion 6.2) are targeting *Presence of particularly sensitive and/or tolerant species* (attribute 6.2.1) and for habitat-defining species these indicators have often also been assigned to *Type, abundance, biomass and areal extent of relevant biogenic substrate* (attribute 6.1.1). At the same time, 23 of these indicators have further been assigned to *Multi-metric indexes assessing benthic community condition and functionality* (attribute 6.2.2) and are largely assessment systems from the European Water Framework Directive (WFD; Directive 2000/60/EC) combining the assessment criteria from the normative definitions of the WFD.

4. Pitfalls for the ecosystem approach (and solutions)

4.1. Double counting

The results of the inventory analysis show that the assignment of indicators to multiple criteria and attributes within and across descriptors is predominant in descriptors 1, 4 and 6. Only descriptor 2, which focuses on the narrow and specifically defined area of non-indigenous species, has nearly as many indicators specific to a single attribute than indicators assigned to multiple ones.

The reasons why we see multiple assignments in the inventory are twofold:

(i) The definitions of the criteria and associated attributes in the EU Commission Decision are vague and consequently are interpreted differently. We acknowledge that some of the attributes are very specific, for example *Habitat area* (attribute 1.5.1). However, others can be attributed to various indicators. For example, *Population genetic structure* (attribute 1.3.2) can be described both at the genotype and the phenotype level (Zampoukas et al., 2012). *Condition of the typical species and communities* (attribute 1.6.1) may be interpreted as the ratio between weight and size or as abundance of a species and as such is similar to attributes 1.2.1 or 1.6.2. Even if criteria or attributes are described differently under the various descriptors/criteria, in practice there are overlapping data requirements, indicating that the same ecosystem feature is considered important in multiple descriptors. Therefore, coordination between the scientific working groups defining the criteria/attributes for their respective descriptor is important in order to avoid overlap and eliminate the risk of using the same assessment results under more than one descriptor/criterion.

(ii) The assignment of indicators to multiple attributes was done by design in Member States and is a specific feature of the indicators and the associated assessment framework. This implies that the same indicator is able to capture different features of the ecosystem at the same time or various attributes are regarded to be essentially equal. This could be a way to save monitoring effort. Of course, the same monitoring data can be used to calculate different indicators and thus inform on various ecosystem features. However, using the same indicator for several different attributes bears the risk of overemphasizing certain features of the ecosystem (like species abundance) and missing out other important ones.

Nonetheless, both usages may lead to the violation of principles important within the framework of ecosystem-based management. Double counting, in terms of accounting the same ecosystem feature in different contexts for the purpose of doing an assessment, needs to be avoided (Nardo et al., 2008). This is especially important when subsequently using the indicators to construct an aggregated summary indicator representing overall environmental status. Some examples from the inventory illustrate this and give recommendations for solutions.

4.1.1. Double counting within a descriptor

For descriptor D1 (Biological biodiversity) there is a high risk of double counting concerning benthic habitat-forming species. In the inventory, the indicator "Areal extent of eelgrass" has been related to *Area covered by the species* (attribute 1.1.3) within the *Species distribution* criterion 1.1. At the same time, eelgrass is also regarded a benthic biotope and the same indicator has consequently also been assigned *Area* (attribute 1.5.2) within the *Habitat extent* criterion 1.5. If used without distinction, this implies that the same indicator may be accounted both on species level and on habitat level. A subsequent integration process of indicators towards environmental status will accordingly count this indicator twice. It is furthermore confusing that attribute 1.1.3 which is dealing with area is subordinate to *Species distribution* (criterion 1.1) while attribute 1.5.2, also dealing with area, is subordinate to *Habitat extent* (criterion 1.5) although the criterion 1.4 exists concerning habitat distribution. The same term 'area' is here put under different thematic headings suggesting they mean something different, but without being followed by specific definitions. This results in a high amount of individual expert views and use cases which barley lead to coherent results and assessments on the scale of regional seas and across Member States.

Besides using terms unambiguously and consistently, such duplication can be eliminated if the criteria of descriptor D1 are specified and interpreted specifically with avoiding overlap in mind. This can be done using the species level only on mobile species that are wide-ranging and typically not associated to a single habitat, as also suggested by Cochrane et al. (2010). The species level criteria (1.1–1.3) would accordingly only apply to highly mobile biodiversity components (marine mammals, birds, reptiles and fish) and the habitat level criteria (1.4–1.6) would be used for the (often immobile) components tightly associated to a single or a few related habitats. Since the term 'habitat' is used in the sense of 'biotope' (Olenin and Ducrotoy, 2006) for descriptor D1 in the EU Commission Decision, criteria 1.4–1.6 would assess the combination of the physical habitat and its associated communities. As such, the habitat level criteria (1.4–1.6) should not focus on individual species, even if habitat-forming, and 'Habitat extent' always involves the whole community. Also, this would result in removing attribute 1.1.3 completely since this attribute is meaningless for mobile species. Area is only meaningful for immobile components and then always associated to the habitat level and as such is already covered with attribute *Habitat area* (1.5.1). Finally, this would remove the ambiguous use of the term 'distribution' between species and habitat level.

This strict distinction of the species and biotope level of biodiversity helps integrating existing indicators from e.g. the EU Habitats Directive (HD; Directive 92/43/EEC) into the MSFD in a consistent way. Indicators on special habitats as defined in the HD (habitat types of community interest) thus fall under criteria 1.4–1.6 when assessing their status as a whole, including both their physical and biological components. However, if individual species from the Annexes of the HD would be investigated not focusing on their relationship to the associated special habitat, the corresponding indicators would fall under criteria 1.1–1.3.

A related ambiguity is present in descriptor D6 (Sea floor integrity), illustrated using the same indicator from the inventory as above. The indicator "Areal extent of eelgrass" has been related to *Biogenic substrates* (attribute 6.1.1), subordinate to *Physical damage* (criterion 6.1). At the same time eelgrass was regarded a particularly sensitive species in benthic biotopes and thus related to *Presence of particularly sensitive and/or tolerant species* (attribute

6.2.1) within the *Condition of benthic community* criterion 6.2. Again, in one instance the eelgrass was considered a biogenic substrate (for other species) and in another instance it was considered a species within a biotope itself. If the abundance of eelgrass is part of the indicator, it would be accounted twice when aggregated to a higher level for overall environmental assessment. In addition, from the naming of criterion 6.1 that is "having regard to substrate characteristics" it was not clear for experts why only the status of biogenic substrates is assessed within criterion 6.1. This led to the situation that some experts also assigned indicators to this criterion which concern geogenic substrates alone (Teixeira et al., 2014).

4.1.2. Double counting between different descriptors

Habitat-forming species have a special relevance for the ecosystem status. They support biodiversity, host and shape a complex benthic food web and are also indicators for sea floor integrity. However, most indicators on D4 (Marine food webs) in the inventory are related to the assessment of A*bundance/distribution of key trophic groups/species* (criterion 4.3). This criterion does not have a high indicator value for the energy flow in food webs. Habitat-forming species are mostly important for providing shelter and substrate to the other species and the corresponding abundance/area indicator do not target the processes and linkages within and between the food webs but are restricted to the state of a particular node of that web, much like the indicators already in place for descriptor D1. Consequently, the assessment of abundance, distribution and/or extent of habitat-forming species should be restricted to D1, assessing them together with their communities on biotope level (criteria 1.4–1.6).

Within descriptor D6 (Sea floor integrity) 74% of the indicators in the inventory addressing *Condition of benthic community* (criterion 6.2) have also been assigned to *Habitat condition* (criterion 1.6) of descriptor D1. Obviously, the benthic communities are also regarded as being the biotic components of the benthic biotopes (termed 'habitat' within descriptor D1) so the condition of benthic communities also reflects the condition of biotopes. This leads to double counting and is specifically the case for *Multi-metric indexes assessing benthic community condition and functionality* (attribute 6.2.2). This attribute is largely covered by WFD assessment systems in the inventory. As these also assess the proportion of sensitive and tolerant species (included as criterion in the normative definitions of the WFD for different ecological status classes) there is an additional overlap between attribute 6.2.2 and the *Presence of particular sensitive and/or tolerant species* (attribute 6.2.1). Thus, sea floor integrity is currently assessed largely by investigating the state of biotopes (in terms of the condition of benthic communities) and using the same ecosystem features and measures as in descriptor D1. Only the attributes addressing length and size (6.2.3 and 6.2.4) do not overlap with D1 in the inventory and thus reflect a distinct feature of sea floor integrity, complementing the attributes assessed within criterion 6.1. In addition to this, the *Abundance trends of functionally important selected groups/species* (attribute 4.3.1) within descriptor D4 aims at the same ecosystem feature as attribute 6.2.2 as it also targets functionality and uses abundance trends.

On the basis of these observations, it is recommended to integrate all criteria and attributes relating to condition or state of the benthic communities and to functionally important groups into the habitat level of descriptor D1 (italic criteria and attributes in Table 2). Especially, the discrimination of functionally important groups/species (attribute 4.3.1) as key trophic elements, thus implying there are also "other species", is not well-defined and dangerous to use since it implies to have species of different importance levels and even non-important or redundant species (Gitay et al., 1996; Naeem, 1998).

Instead of using the state of specific species or the structure of groups of species for the description of the food web as in criterion 4.3, descriptor D4 should focus on the interactions between these trophic groups such as bottom-up and top-down effects and trophic pyramids. Accordingly, *Productivity (production per unit biomass) of key species or trophic groups* (criterion 4.1) should be more broadly defined to also include production of primary and secondary producers since the criterion is currently restricted to key predator species. If the same species are also handled within criterion 4.3, a clear differentiation is needed on which aspects are assessed within descriptors D1, D4 and D6 respectively in order to avoid double counting. Hence, D1 should report on the state and structure of species, biotopes and ecosystems and D4 on the entities relevant to the trophic structure and the interactions between them. For example, a strong decline of an important species or trophic group would then be reflected in both descriptors, just with two different aspects (on structure and on function) of the affected ecosystem. Finally, D6 would provide the necessary complementarity to the ecosystem-based approach if its criteria and attributes would focus on functionality and ecological processes essential for sea floor integrity (as implicit in D6 definition). Functional aspects are rather poorly covered in the current proposal of the Commission Decision, except for the trophic interactions dealt with in D4. On the other hand, the structure of benthic ecosystem components, reflected in most of D6 current requirements, is demonstrated to be covered by D1 and to fit well within its scope. Alternatively, D6 could only report on the pressures on the sea floor while the state/condition of the benthic communities are reported in D1; assuming clearly that a more functional approach to GES assessment is to be disregarded for the MSFD, except for the trophic aspects.

4.2. Pressure and state indicators

The terms pressure, state and impact are not defined in the EU Commission Decision or in the Directive itself. Regional sea conventions, Member States and scientific experts working on the implementation of the MSFD have various ways of interpreting those terms reflected in the different ways of assigning indicators to descriptors, criteria and attributes in the inventory. As an example, some indicators in the inventory have been assigned to both attribute 6.1.1 and 6.1.2. While both attributes belong to the same criterion, attribute 6.1.1 is aiming at the *state* of biogenic substrates while attribute 6.1.2 reflects the *pressure* level or subsequent *state change* on the seabed as a consequence of human activities. The same pattern is observed in the inventory between pressure attribute 6.1.2 and state attributes 6.2.2, 1.4.1, 1.5.1 or 1.6.1 respectively. Another example is the fact that some indicators on abundance or biomass of biodiversity components were assigned to nearly all pressures given in the MSFD (Annex III – Table 2) while other comparable indicators where not assigned to any pressure at all (Teixeira et al., 2014). This might indicate that some experts regard their indicators as useful for reflecting some pressure level while others use them as sole state indicators and refrain to establish a direct causal effect. These examples symptomatically illustrate the various ways of understanding the intended differentiation within and between descriptors with respect to pressure and state.

Applying the DPSIR framework, all MSFD descriptors and their subordinate criteria and attributes in the Commission Decision can be assigned to pressure and state in different ways (see right column in Table 1). For example, Borja et al. (2013) regard D3 and D6 as state descriptors at the descriptor level. The definition of D3 describes state in terms of "populations [...] within safe biological limits" (European Commission, 2010). The definition of D6 describes the integrity of the sea floor in terms of state, ensuring "that the structure and functions of the ecosystems are safeguarded" (European Commission, 2010). A classification also including the criteria and attribute level is presented in (Claussen et al., 2011): Besides categorising D1 and D4 as sole state descriptors, these authors describe D3 and D6 as mixed descriptors and the remaining ones as pressure descriptors.

Looking at the criteria within D3 (Commercially exploited fish and shellfish), the logic of the classification of Claussen et al. (2011) can be followed. Criterion 3.1 is directly specifying the pressure *Level of pressure of the fishing activity*. The remaining criteria within this descriptor are then interpreted as state criteria: *Reproductive capacity of the stock* (3.2) and *Population age and size distribution* (3.3). Within descriptor D6 (Sea floor integrity), *Physical damage, having regard to substrate characteristics* (criterion 6.1) can be regarded a pressure criterion reflecting the magnitude of human activities while the *Condition of the community* (criterion 6.2) clearly reflects state properties of benthic communities. Taking the subordinate attributes into account, however, this view no longer seems consistent. Attribute 6.1.1 is about *Type, abundance, biomass and areal extent of relevant biogenic substrate* and the description of the attribute does not indicate any connection to a certain physical pressure. It is, in fact, a pure state attribute that should be handled within D1 and at the habitat level. Attribute 6.1.2 refers to the *Extent of the seabed significantly affected by human activities* and as such targets the level of human pressure resulting in physical damage. However, this attribute can also be interpreted as a state attribute, where the "*physical damage*" refers to the actual impact and thus the state change. Similarly, the *Presence of particularly sensitive and/or tolerant species* (attribute 6.2.1) can be interpreted as a state attribute investigating the presence or absence of sensitive or tolerant species within a specific spatial region. Often, the presence of a certain proportion of tolerant species (in terms of their abundance) is however not used as a distinct feature of biological diversity as such but rather as a measure of the level of pressure on a benthic community. Actually, this is what descriptor D6 tries to capture: sea floor integrity as a measure of the magnitude of pressure.

In D2 (Non-indigenous species), *Abundance and state characterisation of non-indigenous species* (criterion 2.1) represents the state of NIS and the subordinate attribute 2.1.1 is investigating *Trends in abundance, temporal occurrence and spatial distribution* of NIS. However, the corresponding indicators in the inventory suggest that this is interpreted as reflecting the pressure level from mostly invasive species and not their state, despite the term 'state characterisation' in the criterion definition. On the other hand, *Environmental impact of invasive non-indigenous species* (criterion 2.2) is aiming at the consequences of pressures arising from NIS and is not explicitly referring to pressures but rather to impacts on the natural system, implicitly using NIS as the actual pressure. In fact, attribute 2.2.1 uses the ratio of invasive NIS (not all NIS) and native species and this attribute does not reflect environmental impacts at all, but is a measure of potential pressure. Furthermore, the focus on *invasive* NIS is important (Olenin et al., 2010). The inventory data show that most indicators assigned to attribute 2.2.1 use NIS including the non-invasive ones. The resulting ratio to native species has no relevance for the pressure. Thus, while criterion 2.1 defines a state criterion, it is used as a pressure criterion in practice and while criterion 2.2 is titled as an impact criterion, it is defined as a pressure criterion. It is not entirely clear whether this confusion is just the consequence of using the term 'state' in criterion 2.1 and 'impact' in criterion 2.2. When the state of NIS as such has any importance for the assessment of biological diversity, then we propose to treat this aspect within D1 and clearly define it as a state criterion. Otherwise, D2 should be treated a pure pressure descriptor addressing the magnitude of pressure from invasive NIS and terms should be used accordingly avoiding targeting state change in favour of pressures.

The above examples show that different interpretations of the MSFD descriptors and their content are possible, leading to potentially differently designed assessment systems between EU Member States when operationalizing indicators and synthesizing them into an overall assessment. A common synthesis method is the (numerical) combination of attributes to criteria, to descriptors, to final assessment value (Cardoso et al., 2010). Having descriptors containing both pressure and state criteria will then lead to (numerically) merging pressure and state indicators at criteria level although, from a general perspective, the descriptor level suggests that only environmental states (for D3 and D6) are aggregated. The outcome may then become difficult to interpret and a subsequent society response might end up being inappropriate or even failing to meet the original aim. It is therefore generally not recommended to mix pressure and state indicators in ecosystem-based management (Gabrielsen and Bosch, 2003) and consequently in the assessment. This is in contrast to the layout of the Commission Decision where pressure and state indicators are located within the same descriptor by design (European Commission, 2011).

In order to reinforce the distinction between pressure and state in the assessment, one option would be to define descriptor D6 as pressure descriptor only, incorporating all state-related aspects of sea floor integrity into descriptor D1 since all state attributes are also possible attributes for describing biological diversity of benthic habitats and biotopes. This would give due emphasis to the pressures as descriptors of their own.

4.3. The ecosystem level

The links between the natural and the human system are at the core of the ecosystem approach to management (Leslie and McLeod, 2007) as defined by the UN Convention on Biological Diversity (CBD) and consequently supporting sustainable marine management (Elliott, 2013, 2011). Accordingly, ecosystem services linking the marine ecosystems to society that depends on delivery of those services are of particular importance. Ecosystem service indicators can thus inform on overall ecosystem health (Samhouri et al., 2012).

Although the MSFD includes sustainable use of the marine environment as part of the definition of good environmental status (Borja et al., 2013; EU, 2008), the EU Commission Decision does not include criteria targeting ecosystem services that can be used to inform on the aspect of sustainable use. Within the existing descriptors, ecosystem services are only indirectly included. For example, descriptor D3 (Commercially exploited fish and shellfish) defines criteria on fish demographics aiming to ensure fish populations able to be caught (ecosystem service: food provision) and still be viable and productive. On the other hand, the biodiversity descriptor completely lacks ecosystem service criteria/attributes despite the fact that the CBD is explicitly referred to in the preamble of the MSFD and biodiversity is one of the most important ecosystem services of the oceans (Atkins et al., 2011; Costanza et al., 2014; Hooper et al., 2005; May, 2011). As a consequence, indicators targeting ecosystem services are currently not part of the inventory studied in this paper. There are, nonetheless, indicators available. In a case study, some ecosystem services indicators have been tested against a set of criteria to ensure their relevance and applicability to environmental management (Hattam et al., 2015) and it is recommended to include such ecosystem services as criteria within the appropriate descriptors in a revised Commission Decision, since ecosystem services are tightly linked to biodiversity and should only be evaluated together (Loreau, 2010; Mace et al., 2012). For example, a provisioning service like food provision is related to D3 and D4, a regulating service like biological control is related to D1 and D4 and a habitat service like gene pool protection is related to D1 and D6.

In contrast to the Habitats Directive that targets the conservation, or the Water Framework Directive that targets the ecological status, the assessment within the MSFD should reflect the environmental status as a whole (Borja et al., 2013). There is an inherent link between biodiversity and ecosystem functioning (Cardinale et al., 2011; Covich et al., 2004; Gamfeldt et al., 2014; Heip et al., 2009; Hooper et al., 2005; Loreau et al., 2001). This calls for criteria and attributes specifically addressing ecosystem functioning (Borja and Elliott, 2013). Currently, the focus is still largely on the structural elements of the ecosystem while the functional relationships between them are under-represented. Even within descriptor D4 (Marine food webs), attributes focus on structural features (abundance, production) of key groups and species rather than functional aspects between them such as bottom-up and top-down effects, trophic pyramids and competition avoidance. Hence, it is recommended to add criteria on ecosystem functioning to the EU Commission Decision. This can for example be done by extending the scope of D1 with ecosystem functions related to species and habitats in general and extending D4 with functions related to food webs. D6 should only target ecosystem functions important for maintaining sea floor integrity. This will result a more comprehensive ecosystem-based approach, especially when also integrating ecosystem services into the set of criteria (Atkins et al., 2011; Kelble et al., 2013).

The inventory reveals that several indicators on ecosystem functioning already exist and are considered for their use in the MSFD. This includes indicators based on biological traits analysis (BTA) (Bremner, 2008), energy flows and transfer efficiencies among trophic levels or functional groups (Pauly, 1996), distribution of species richness over body sizes (Cohen, 1991; Rossberg, 2013), bottom-up effects in marine size spectra (Quinones et al., 2003; Rossberg, 2012), demographic skewness of herbivorous populations (Brand, 2009), herbivory pressure and symbiosis (epiphytes) (Fernández-Torquemada et al., 2008) and indicators using the relationship between macrobenthic biomass and system productivity (Van Hoey et al., 2007). Also, the scientific literature shows an increasing trend in the development of measures of functional integrity of the marine environment. As an example, the metrics recently proposed by de Juan et al. (in press) aim at informing on several functional aspects such as recovery, resilience, vulnerability or fluxes. Their "Functional Integrity" measure is based on functional composition and diversity building on biological traits and functional redundancy, also including spatial heterogeneity and habitat complexity.

5. General conclusions

It can be said that the 11 descriptors of the MSFD form the different sectors of the ecosystem approach as seen by the EU. They constitute the conceptual basis on which to specify real objectives and identify the associated indicators to measure the end points of the objectives. Within this conceptual view, the EU Commission Decision (European Commission, 2010) is the specific set of criteria and attributes that are needed to bring the conceptual MSFD descriptors to the level of measurable objectives able to inform management whether environmental targets are met and GES is achieved.

The analysis in this study shows how the scientific community currently perceives this concept and where the difficulties in the implementation process and in the understanding of the concept are most likely to occur. To conclude, we draw the following general recommendations from our analysis:

5.1. Define and use terms consistently

Terms need to be clearly and unambiguously defined and subsequently used consistently throughout the EU Commission Decision. This is true for all terms used in connection with ecosystem health and management (Tett et al., 2013) and especially the case for key terms like habitat, biotope (Costello, 2009; Olenin and Ducrotoy, 2006) or pressure, state and impact (Atkins et al., 2011; Gabrielsen and Bosch, 2003). As demonstrated in the inventory, the use of tentatively identical terms like benthic habitat/community and sessile benthic species in D1, habitat-forming species in D4 and biogenic substrate in D6 is not contributing to a coherent understanding of the of the EU Commission Decision and its subsequent use.

Especially the term 'habitat' is used differently between the descriptors. Within D1, habitat is explicitly defined as being used in the sense of biotopes (sensu Olenin and Ducrotoy, 2006). In D6, the term is not explicitly defined but used in a context where it easily can be interpreted as physical habitat without biotic features. In addition, the MSFD itself defines habitat types in Annex III – Table 1 as including "characteristic physical and chemical features, such as depth, water temperature regime, currents and other water movements, salinity, structure and substrata composition of the seabed" (EU, 2008) and goes on to say that special habitat types also are the ones under the Habitats Directive. However, the Habitats Directive defines habitats as including abiotic and biotic features, i.e. in the sense of biotopes. This inconsistent use needs to be harmonized in order to prevent the observed heterogeneous application in the environmental assessment.

5.2. Be specific when defining criteria and associated indicators

Depending on the stage in the EBM cycle, specific types of indicators are applied. For example, pressure indicators are related to what policy-makers can influence (i.e. the level of managed pressures), state indicators are used to monitor the (possibly long-term) progress of the effects on e.g. biodiversity as a consequence of the measures taken on pressure level. This is only effective with indicators that are specific to the respective EBM stage and not overcharged with various metrics, trying to inform about a broad range of ecosystem features at the same time. This would lead to indicators drowning in information or in double counting. Instead, we advocate restricting indicators to what they specifically are supposed to inform about. If an indicator summarizes many state attributes, even conflicting ones, it becomes impossible to relate progress in state to previous measures taken at pressure level. Also, the (biodiversity) state described by the corresponding state indicators, can be the result of various causal factors. Thus, in order to actually manage the various manageable components of an ecosystem (including humans) there is a need to target these specifically (Elliott, 2011).

In practice, we recommend to use pressure indicators to define threshold for pressures that society will accept and can achieve, then monitoring the subsequent effects using state indicators. A high-frequency monitoring of pressures then allows for quick action on individual managed pressures while a lesser frequent monitoring of state records the long-term progress (de Jonge et al., 2006; Mee et al., 2008).

An example of this is *Multi-metric indexes assessing benthic community condition and functionality* (attribute 6.2.2). While typically abundance, biomass and richness are treated separately in the GES criteria, in attribute 6.2.2 they are supposed to be specifically combined into a multi-metric index. However, it is better to deconstruct a multi-metric index into its components when the aim not is to communicate some higher level aspects (like ecological status) since this is the objective of the overall aggregation of indicators, not the individual ones.

5.3. Do not solely rely on pressure-state change relationships

Ideally, all state indicators are directly related to pressures and preferably respond to only one or a manageable number of pressures. However, having a statistically solid link between pressures and state change is a rare case in practice. This is because the state indicators are typically only indirectly related to pressures and respond to multiple pressures simultaneously (Smith et al., 2014). Linking individual pressures tightly to a specific state change thus ignores the complex interactions within the ecosystem (Mace and Baillie, 2007) that led to the development of the ecosystem-based approach. Even when it is possible to show a good relationship between increasing pressure and ecosystem response, this does not mean that the recovery cycle under decreasing pressure shows the same pattern (Tett et al., 2013).

Hence, pressure-state change relationships are crucial when it is important to know which specific pressures cause a certain response in the ecosystem, i.e., following the P–S DPSIR stages. On the other hand, if we are interested in reaching or maintaining a specified environmental status, it is not relevant to know which pressures caused a certain state change as long as we follow the precautionary principle for pressures. When the desired state is achieved as proved by an evidence-based monitoring strategy (Mee et al., 2008), then we must assume that the pressure level is sufficiently low.

5.4. Keep indicator synthesis in mind

Having mixed descriptors, i.e. descriptors containing both pressure and state criteria/attributes, has consequences for the subsequent step of synthesizing indicators into an overall assessment, as discussed above. The solution, however, is not to refrain from synthesizing indicators at all. While a single number surely cannot capture the complexity involved in environmental state (Borja et al., 2014; Derous et al., 2007; Purvis and Hector, 2000) it is still a useful means of communication, especially to the public (Gabrielsen and Bosch, 2003). Further, the ecosystem-based approach implies that overall environmental status can only be appropriately described by combining the different aspects of the environment into a holistic view, considering their functional linkages.

There are two ways to accommodate this: (1) Re-design the layout and definition of the criteria and attributes in all 11 descriptors such that no mixed descriptors remain; (2) prescribe a way of synthesizing indicators to the overall assessment value assuring no mixing of pressure and state indicators occurs. Both solutions attempt to ensure that the two DPSIR stages P and S are not mixed in a single assessment step. Keeping them apart and using the results of pressure and state indicators in different steps of the assessment procedure will thus ensure successful management. The authors suggest the first solution of re-designing the criteria/attributes as it leads to a clearer understanding of the descriptors and their meaning within the assessment. The subsequent overall assessment can then be done using integration rules as suggested by Borja et al. (2013). One such rule could be that for having a good environmental state, all pressure indicators must meet their target values. If the environmental targets are not met then by definition also the good environmental status is not achieved, regardless of the values of the state indicators.

6. Summary of recommendations for the revision of the Commission Decision

To avoid overlap, ensure that all relevant aspects are taken into account, we propose to take into consideration the following suggestions when re-organizing the criteria within MSFD descriptors:

- Restrict the use of the species level criteria within D1 (1.1–1.3) to mobile biodiversity components (marine mammals, birds, reptiles and fish).
- Restrict the use of the habitat level criteria within D1 (1.4–1.6) to the (often immobile) components tightly associated to a single or a few related habitats, as a combination of the physical habitat and its associated communities, not focusing on individual species, even if habitat-forming. Involve the whole community when evaluating "habitat extent".
- Remove attribute 1.1.3 as it is meaningless for mobile species, and attribute *Habitat area* (1.5.1) already covers it for immobile components.
- Expand D4 with the functional interactions between trophic entities.
- Define criterion 4.1 to also include production of primary and secondary producers.
- Re-define descriptor D6 either as pressure descriptor only, incorporating all state-related aspects of sea floor integrity into descriptor D1, or as state descriptor also including functional aspects.
- Include indicators related to ecosystem functioning (e.g. in D1, D4 and D6).
- Consider the inclusion of ecosystem services indicators across descriptors (e.g. D3 and D4 – food provision, D1 and D4 – biological control, D1 and D6 – gene pool protextion).

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