Implementation of the MSFD to the
Deep Mediterranean Sea
IDEM

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Report 3.1. Report on gaps in data related to indicators, sub-basins, deep-sea ecosystems and human pressures/impacts

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ABBREVIATIONS TABLE

AIS	Automatic Identification System
CIM	Common Implementation Strategy (of the MSFD)
CFC	Chlorofluorocarbons
CFP	Common Fisheries Policy
COCONET	Towards COast to COastNETworks of marine protected areas
CWC	Cold-water corals
D1-D11	Descriptors 1 to 11
DSWC	Dense shelf water cascading
EBSA	Environmentally or Biologically Significant marine Areas
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EQS	Environmental Quality Standards
EUNIS	European Nature Information System
FRA	Fisheries Restricted Areas
GES	Good Environmental Status
GFCM	General Fisheries Commission for the Mediterranean
HELCOM	Convention for the Protection of the Marine Environment in the Baltic Sea Area
ICES	International Council for the Exploration of the Sea
IDEM	Implementation of the MSFD to the DEep Mediterranean Sea
IMP	Integrated Maritime Policy
ISA	International Seabed Authority
JRC	Joint Research Centre
MARPOL	Convention for the Protection of Marine Pollution from Ships
MEDITS	International bottom trawl survey in the Mediterranean
MPA	Marine Protected Area
MedPAN	Mediterranean Protected Areas Network
MS	Member States (of the EU)
MSFD	Marine Strategy Framework Directive
NIS	Non-indigenous species

OBM	Oil based muds (for drilling)
OECM	Other Effective area-based Conservation Measures
OMZ	Oxygen Minimum Zone
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polycyclic aromatic hydrocarbons
PERSEUS	Policy-oriented marine Environmental Research in the Southern EUropean Seas
PoMs	Programs of Measures
RSC	Regional Sea Conventions
SPAs	Special Protection Areas (SPAs), Birds Directive
UNEP-MAP	United Nations Environment Programme-Mediterranean Action - Plan Barcelona Convention
WBM	Water based muds (for drilling)
VME	Vulnerable Marine Ecosystems
VMS	Vessel Monitoring System
WFD	Water Framework Directive
WWF	World Wildlife Fund

The reader should note that the references in each section and subsection do not intend to be exhaustive, but rather to refer to key papers following the criteria of the authors of this document.

1 PART I: GENERAL GAPS

The following chapter provides an overview of the most prominent gaps common to all descriptors or to the majority of them. Detailed and definite explanations are encompassed within the gaps identified within each descriptor section.

1.1 *Knowledge and data*

Data availability and typology

Easily accessible areas like coastal regions and the sea surface are the most studied. The open sea and especially the deep sea, encompassing depths below 200m, generally suffer from scarcity of data, including in the Mediterranean Sea. As reported by Laroche et al. (2013) and Palialexis et al. (2014), the descriptors with less information are D2, D4, D10 and D11. Furthermore, the current formulation of descriptor D4, D5 and D7 does not conform to deep-sea environments. New frameworks taking into account the existing data should be devised. The review carried out for the deep Mediterranean Sea showed the lack of critical information on key parameters, and the need for openly shared quantitative records.

Consistency and comparability

Whereas European Seas are studied and addressed in international agreements, directives and programs, differences in national-based implementation hamper reaching comparable outcomes. According to Laroche et al. (2013) and Palialexis et al. (2014), the lack of implementation of standard monitoring programs using common methodologies prevent consistent assessments between different regions. The current scarcity of comparable data and long-time series for most descriptors and criteria impedes the identification of trends, thresholds and baselines. Consequently, the establishment of adequate monitoring programs and measures is mandatory.

Long time series and long-term monitoring programs

Long time series enable the understanding of ocean properties and ecological processes defining ocean dynamics and functioning (Ducklow et al., 2009). Long-term monitoring programs can also help to predict the occurrence of episodic events of ecological relevance like dense shelf water cascading (DSWC), harmful algal blooms or spreads of gelatinous organisms. Most research projects last 2-3 years, which impedes the description of longer term situations and effects. In addition, the diversity of methodologies and approaches applied hinders a continuous and consistent temporal tracking of the pressures and impacts. The 2017 EC evaluation of the monitoring programs under the MSFD reported that biodiversity (including descriptors D4 and D6) accumulates 41% of monitoring activities (European Commission, 2017b). On the opposite, monitoring is much more limited for descriptors D2, D7, D9, D10 and D11. The 2017 EC evaluation demonstrated that these programs were only partly appropriate for meeting MSFD requirements and assessing GES. One of the reasons of the low suitability reported is the application of already existing monitoring programs based on other directives. These directives contain important gaps with respect to

MSFD requirements, especially when considering the deep sea (Zampoukas et al., 2013). Monitoring targets are mostly on environmental states and impacts. Leaving human activities and pressures poorly supervised hinders the prevention of impact occurrence. The ActionMed project published a database of monitoring programs including a detailed analysis of contents and gaps (Alemany et al., 2017). Besides monitoring frequency, time-depending parameters should also consider the seasonal patterns of deep-sea dynamics. In short, baselines and trends cannot be defined without continuous monitoring.

Fragmented knowledge

Spatial and temporal gaps were clearly observed while reviewing datasets within IDEM tasks 2.1 and 2.2 (IDEM Project, 2018c, 2018b). Lack of data continuity is described in the previous paragraph concerning long time series. Spatially fragmented data encompassing water depth and geographical differences should also be recognized and described for each descriptor as geographical and bathymetric gaps. A knowledge gradient exists from the western to the eastern basins, but the clearest gradient occurs from north to south. Gradients reflect differences in economic resources between EU and non-EU countries that influence the number of national-based research programs. Differences of data and knowledge are also evidenced when comparing the number of Marine Protected Areas (MPA) designated in each sub-region (European Environment Agency, 2015; Abdulla et al., 2008).

1.2 *Regulations' integration*

Integration of the MSFD with EU legislation and RSC agreements

The MSFD includes several environmental topics already targeted by other EU legislation, including several European directives. Application of standardized guidelines for the initial assessment or for GES evaluation would increase the consistency of the MSFD reports generated by the different member states (MS). The adoption of assessment targets previously defined in other legal regulations could help establishing indicators for which data or thresholds have been established already. However, most MS reports evidenced limited integration with EU regulations and low coordination with Regional Sea Conventions (RSC) recommendations and action plans (Laroche et al., 2013; Palialexis et al., 2014). Otherwise, the programs of measures submitted by most MS chiefly contained action plans poorly implemented that were established for other directives, without appropriate adaptations (European Commission, 2015).

In order to improve consistency of future European environmental assessments, the revision of the following EU legislation is recommended:

a. *Water Framework Directive (WFD: 2000/60/EC).* The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater.

b. *Environmental Quality Standards Directive (EQS: 2008/105/EC).* This Directive lays down environmental quality standards (EQS) for priority substances and certain other pollutants, with the aim of achieving good surface water chemical status, focusing on territorial waters. The main goal of the directive is the statement of the concentrations permitted for different contaminants.

c. *Habitats Directive (HD: 92/43/EEC).* This Directive focuses on the conservation of natural habitats and of wild fauna and flora, and "aims to promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements". It forms the cornerstone of Europe's nature conservation policy with the Birds Directive (see below) and establishes the EU wide Natura 2000 ecological network of protected areas, safeguarded against potentially damaging developments[1]. It also ensures the conservation of a wide range of rare, threatened or endemic animal and plant species. Management plans, conservation measures, monitoring efforts and sustainable exploitations are keystones of the Habitats Directive.

d. *Birds Directive (BD: 79/409/EEC* and *2009/147/EC).* It is the oldest piece of EU legislation on the environment and one of its cornerstones. Amended in 2009, it became the Directive 2009/147/EC. Habitat loss and degradation being the most serious threats to the conservation of wild birds, the Directive "places great emphasis on the protection of habitats for endangered and migratory species. It establishes a network of Special Protection Areas (SPAs) including all the most suitable territories for these species. Since 1994, all SPAs are included in the Natura 2000 ecological network, set up under the Habitats Directive 92/43/EEC"[2]). With respect to marine environments, both the Habitats and the Birds directives encompass species and habitats from the coastal zones and from the shallow waters in open waters mostly.

e. Common Fisheries Policy (CFP: Council Regulation EC/199/2008; Commission Decision2010/93/EU; Regulation No 1967/2006). The principal aim is the sustainable development of fishing and aquaculture activities. Deep-sea resources are taken into account although the application of the regulations is restricted to regions were fish stocks occur and fishing activities take place. Regulation No 1967/2006 encourages a sustainable exploitation by defining protected species, habitats and areas, gear restrictions, minimum sizes and management and control plans.

f. Marine Spatial Planning Directive (2014/89/EU). This Directive establishes a framework for maritime spatial planning aimed at promoting the sustainable growth and development of maritime economies, marine areas and marine resources. The Directive defines the implementation requirements and contents of maritime plans.

g. *Integrated Maritime Policy (IMP).* Set of regulations concerning maritime issues and coordination between policy areas. The following topics are targeted in this policy: blue growth, marine data and knowledge, maritime spatial planning, integrated maritime surveillance and sea basin strategies. Multiple regulations and directives use this framework for their development.

Besides European legislation, RSC provide a framework to promote cooperation between MS and neighbouring countries sharing the same marine basin. The four relevant European Conventions are: 1) the Convention for the Protection of the Marine Environment in the North-East Atlantic (OSPAR); 2) the Convention for the Protection of the Marine Environment in the Baltic Sea Area (HELCOM); 3) the Convention for the Protection of Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention), and related protocols under the auspices of the United Nations Environment Programme - Mediterranean Action Plan (UNEP-MAP); and 4) the Convention for the Protection of the Black Sea (Bucharest Convention). The Barcelona Conventions system is the one that is directly relevant to the (deep) Mediterranean Sea.

The "Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean" and the "Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircrafts or Incineration at Sea" are the amended versions of the "Barcelona Convention" and the "Dumping Protocol" of 1976. Other relevant protocols in the same framework are described in the UNEP-MAP document published in 2005 (UNEP-MAP, 2005). Other relevant protocols in the same framework are: i) the Protocol for the Protection of the Mediterranean Sea against

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[1] http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm.

[2] http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm.

Pollution from Land-Based Sources and activities; ii) the Protocol Concerning SPA and Biological Diversity in the Mediterranean (adopted on 10 June 1995, in Barcelona, Spain, but still not ratified and entered into force by several countries[3]); iii) the Protocol for the Protection of the Mediterranean Sea against Pollution Resulting from the Exploration and Exploitation of the Continental Shelf and the Seabed and its Subsoil (adopted on 14 October 1994 by the Conference of Plenipotentiaries held in Madrid but not yet entered into force after 25 years); iv) the Protocol on the Prevention of Pollution of the Mediterranean Sea by Transboundary Movements of Hazardous Wastes and their Disposal; and v) the Protocol concerning cooperation in preventing Pollution from Ships and, in cases of Emergency, combating Pollution of the Mediterranean Sea.

In its Article 6, the MSFD includes specific instructions to MS for the usage of RSC structures to implement coordinated actions, measures and monitoring programs. Actually, the lack of connection between bodies in charge of RSCs and the MSFD constitutes an important gap in the implementation of the MSFD. This gap is in fact one of the main causes leading to the lack of coherence and consistency between MS measures and reports on the MSFD.

Comparative analyses of monitoring targets and requirements imposed by the EU legislation, RSCs, international agreements and the MSFD are available (e.g. Zampoukas et al., 2012).

Cooperation within the MSFD

The MSFD applies to all MS and also affects marine basins shared by multiple countries. Thus, cooperation is inherent to its implementation. In order to promote cooperation and consistency, it was decided to constitute the Common Implementation Strategy (CIM) encompassing multiple bodies and assignments. Within the CIM, descriptor specific task groups developed 29 criteria and 56 indicators that have been compiled within the 2010/477/EU Commission Decision. However, the lack of much needed technical details for practical implementation is a major weakness of this documents, and of the MSFD more generally (Bellas, 2014). As consequence, each MS generated its own definitions, acceptance levels and spatial and temporal scales for GES, thus leading to inconsistent assessments. Additionally, the lack of connection between RSC and MSFD actions and objectives represents a second weakness for the implementation of the Directive (Bellas, 2014).

1.3 *Approach and framework*

Interconnection between descriptors

Although interconnection between descriptors is recognized, it is not effectively considered for GES assessment. Descriptors can be grouped as indicators of state (D1, D4 and D6) and indicators of pressures (D2, D3, D5, D6, D7, D8, D9, D10 and D11). With regard to this grouping, two main relations are worth mentioning: (i) descriptors that complement and/or overlap to some extent, and (ii) pressure descriptors affecting state ones. A clear example involving both kinds of connections is D1(Cochrane et al., 2010). Assessment of biodiversity includes also seafloor ecosystems and trophic web structures, which are also included in D6 and D4, respectively. In addition, D1 as a state descriptor suffers from multiple pressures directly described in other descriptors such as D2, D5, D7, D8, D10 and D11. Descriptors could also be grouped according to data sources, differentiating between scientific research data (D1, D5, D7 and D8),

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[3] http://web.unep.org/unepmap/5-specially-protected-areas-protocol-spa-and-biodiversity-protocol

resource exploitation data (D3 and D11) and combined data (D2, D4, D6, D9 and D10). Finally, accurate evaluation of GES should consider cumulative and synergetic effects linked to different descriptors (Directive 2008/56/EC, Art 8.1b). However, no appropriate framework is provided to include such connections in GES assessments.

An appropriate indicator framework including policy-response indicators

An indicator framework is an organized system that provides a structure for categorizing relevant data and illustrating interconnections between indicators. The MSFD does not specify any indicator framework structure but implies the analysis of pressure-state relationships between descriptors, criteria and indicators. A comprehensive framework would target drivers, pressures, states, indicators and responses (DPSIR). It would also require extensive datasets and complex analyses for which long-term studies would be needed. Implementation of a Pressure-State-Response (PSR) framework is recommended for completing MSFD requirements in a reasonable time period (Probst et al., 2016). In consequence, policy-response indicators and linkages between pressures and impacts should be addressed. The monitoring of the ecosystem response and of the effectiveness of measures need to be included in future environmental assessments.

1.4 *Characterization and assessments*

MSFD assessments and implementation

Accurate assessments were only accomplished in a small percentage of the entire European marine area. Besides heterogeneous interpretations of the indicators defined, the majority of them are state indicators without a defined link to pressure and response parameters (Palialexis et al., 2014). Flexible interpretation and incomplete reports were fostered by lack of quantitative data, thresholds and reference conditions (European Commission, 2014). This is true both for coastal and deep-sea environments. Overall, GES assessment and definition were acceptable for some descriptors. However, the implementation at criteria or indicator levels for all marine regions was clearly incomplete (Palialexis et al., 2014). The definition of present criteria and indicators for some descriptors (i.e. D2, D4, D5) appear quite inadequate for the deep sea.

In-depth assessment of MPAs state, pressures and impacts

Gaps for a proper GES assessment also encompass areas designated Fisheries Restricted Areas (FRA) as hosting Sensitive Habitats (SH) or Vulnerable Marine Ecosystems (VME), defined by the General Fisheries Commission for the Mediterranean (GFCM) and Environmentally or Biologically Significant marine Areas (EBSA). The assessment should include a detailed analysis of the current state of these areas, including the characterization of the ecosystems functioning, future predictions and carrying capacity analyses. Inventories of natural capital with all-species assessments would enable socio-economic evaluations.

Areas designated as VME, EBSA, FRA or MPA, have been studied to some extent, whereas for vast areas of the Mediterranean we have only rude bathymetric data. Soft bottoms are almost universally neglected, though they are the biodiversity drivers of the deep-sea environment. Hence, approaches for the detection of non-MPA areas with high pressure or low pressure but high value should also be developed (Taranto et al., 2012). Baseline characterizations and maps would facilitate the identification of changes and impacts.

The detection of new potential MPAs should consider interdisciplinary approaches including historical, ecological and oceanographic features (Abdulla et al., 2008).

Current status of MPAs

The latest report from the UNEP-MAP convention reported that only 5.31% of the area deeper than 200m is covered by MPAs and Other Effective area-based Conservation Measures (OECM). MPA distribution, understood as the cumulated percentage of all MPA in each basin, is defined below following MedPAN UNEP/MAP RAC/SPA (2016):

- Alboran Sea: 7.93%
- Algerian-Provencal Basin: 17.38%
- Tyrrhenian Sea: 13.34%
- Adriatic Sea: 5.17%
- Ionian Sea: 1.21%
- Levantine Sea: 5.13%
- Aegean Sea: 3.95%

Of these MPA, 186 sites have been designated at national level (correspondent to 1.60% of the Mediterranean Sea), of which 76 have at least one no-go, no-take or no-fishing zone (about 0.04% of the Mediterranean Sea). According to MedPAN UNEP/MAP RAC/SPA (2016), no-go, no-take or no-fishing zones are only found in nationally designated sites and at least 10 countries have designation(s) that allow the creation of such zones. Most no-go, no-take or no-fishing zones are smaller than 5 km², only 18 MPAs have such zones covering over 10 km^2 and only 2 cover more than 100 km^2. Little is known as to whether these no-go, no-take or no-fishing zones are implemented and effectively managed.

The 2015 report of the European Environment Agency (EEA) on MPAs in Europe's seas analysed the main gaps and deficiencies of this protection system (European Environment Agency, 2015). Shortly said, the report noted that MPAs in European seas require further improvement in several aspects. Large regional differences, especially between EU and non-EU countries, hinder the achievement of an overall GES of the Mediterranean Sea. Connected to this, the current MPAs network cannot be defined as representative or ecologically coherent. Apart from coverage deficiencies, efficient management and "no extraction" demands are only considered in a small number of MPAs. The evaluation of EU MPA networks itself needs harmonized and standardized information, based on scientific knowledge. The main gaps identified where legislation ambiguity, low governance implication, insufficient funding, fragile monitoring plans and too small numbers of staff members. Coherent and consistent assessments would allow the development of common monitoring actions and programs of measures. The first step to improve the current situation should be the designation of clear objectives and priorities, especially considering that none of the MPAs at depths over 200 has had an inventory of its biota and scheduled monitoring surveys. It would also be interesting to specify hard/soft bottoms % of the MPAs. Stakeholders support and involvement is also essential for the development of successful MPAs.

1.5 *Socio-economic implications*

Stakeholder's implication and engagement

Stakeholder's involvement in marine conservation is essential to achieve successful results. Recognizing the significance of current marine and maritime sectors, involving relevant stakeholders may anticipate the solution of future conflictive interests (Fritz and Hanus, 2015). The main gap regarding stakeholder's involvement is the absence of a clearly defined structure establishing when and how they should be engaged (Hendriksen et al., 2014). Unproductive regional cooperation, observed in the MSFD and RSCs, also leads to low stakeholder's collaboration. Additional gaps hindering cooperation and implication encompass the lack of economic resources and little influence of some stakeholders groups in decision-making procedures (Hendriksen et al., 2014). Within the IDEM project, engagement of 300 stakeholders was initiated by a letter disseminating the aims of the project and inviting them in future collaborations (IDEM Project, 2018). Within task 3.1 and in the following tasks, planned knowledge elicitation exercises aim at encompassing multiple points of view, including stakeholder's opinions and degree of awareness on sensitive matters (see Section 4).

Economic assessments

The MSFD includes explicit and implicit demands on economic and social assessments in Articles 8, 10 (in connection with Annex IV) and 13 (Directive 2008/56/EC). Socio-economic analyses should be included when considering GES evaluation and when selecting environmental targets, identifying the economic sectors using marine waters (Bertram and Rehdanz, 2013). Ecosystem functions produce directly and indirectly goods and services to the human population. These goods and services need to be evaluated and their cost of degradation included in the assessments. However, marine services are less tangible than terrestrial ones. Thus, their conversion into monetary or valuable terms is not straightforward. Additionally, the relation between ecosystem functioning and the production of goods and services that lead to human benefits is poorly understood. The ActionMed project included economic and socioeconomic impacts and gaps when analysing each descriptor (Antoniadis and Hema, 2016). Common socioeconomic gaps encompass the need for evaluation of the cost of action and no-action to identify cost-effective solutions. However, most of the MSFD outcomes report poorly on socioeconomic impacts. In order to fill in such gap, human activities and economic sectors could be evaluated as an extra criterion included in each descriptor.

2 PART II: DESCRIPTOR-SPECIFIC GAPS

2.1 *DESCRIPTOR 1: BIODIVERSITY*

Descriptor 1 for determining good environmental status requires that: "*Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.*" This descriptor is linked to the following ecosystem elements as listed in Annex III to Directive 2008/56/EC: species groups of birds, mammals, reptiles, fish and cephalopods; pelagic habitats; benthic habitats (in conjunction with Descriptor 6); ecosystems including food webs (in conjunction with Descriptor 4).

2.1.1 Major knowledge gaps concerning specific indicators and criteria

DATA AVAILABILITY

As part of the first MSFD cycle, completed in 2018, EU countries have undertaken initial assessments of environmental status and setting of environmental targets to achieve GES. However, the data used in these assessments for Descriptor 1 by Mediterranean countries are mostly restricted to shallower water, with minimal consideration of deep-sea environments, reflecting the paucity of data available for deeper waters (Coll et al., 2010; Danovaro et al., 2010). A review of datasets on indicators and human pressures/impacts for each MSFD descriptor, which were obtained from scientific literature, public datasets related to monitoring programs and open access (OA) repositories, is given in the IDEM Deliverable 2.1 (IDEM Project, 2018c). In summary, analysis of the Descriptor 1 datasets indicated that:

- Most OA repositories only contain occurrence data on distributions of individual taxa, although information on habitat types is found in some repositories and has been used to model the distribution of seabed habitats classified according to the EUNIS and MSFD typologies (IDEM Project, 2018a).
- The majority of the data available through scientific publications are either quantitative measures of abundance/diversity or non-quantitative data on the species present, and very limited data on other parameters such as population demographics are available. Cold-water corals and fishes are the two most studied species groups, while several publications include data for various macroinvertebrates (e.g. Scyphozoa, Mollusca, Polychaeta, Serpulida, Sipuncula and Crustacea); however, meiofaunal and microbial communities are underrepresented. In terms of the habitats studied, the majority of works focused on open slopes, canyons, or cold-water coral habitats, while data on pelagic habitats is generally lacking (IDEM Project, 2018c).

The following paragraphs review the existing gaps within the context of the criteria listed for Descriptor 1 in Commission Decision (EU) 2017/848 laying down criteria and methodological standards on GES of marine waters, as well as specifications and standardised methods for monitoring and assessment. As outlined in the Annex to this Decision, the Descriptor 1 criteria are grouped into four themes:

1. Species groups of birds, mammals, reptiles, fish and cephalopods (Criteria D1C1, D1C2, D1C3, D1C4, and D1C5; relating to Descriptor 1)
2. Pelagic habitats (Criterion D1C6; relating to Descriptor 1)
3. Benthic habitats (Criteria D6C4 and D6C5; relating to Descriptors 1 and 6)
4. Ecosystems, including food webs (Criteria D4C1, D4C2, D4C3, and D4C4; relating to Descriptors 1 and 4)

Theme 1: Species groups of birds, mammals, reptiles, fish and cephalopods

Within the context of the Mediterranean deep sea, the species groups relevant to the MSFD Descriptor 1 criteria D1C1 to D1C5 are marine mammals (i.e. deep-diving toothed cetaceans), deep-water fishes and deep-water cephalopods. While this excludes several relevant species groups (e.g. most benthic species), such species are indirectly considered within the context of the criteria relating to habitats and ecosystems (under Descriptors 1, 4 and 6).

In the case of deep-diving toothed cetaceans (relevant for D1C2 to D1C5), data from the deep sea is extremely scarce. While it is known which species of cetacean forage in the deep sea, the actual use of the deep sea by these species is very poorly known (e.g. Do all individuals forage in the deep sea? How often do they venture into the deep sea? To what depth do they dive? Do they forage on bathypelagic prey or on demersal species or both?). However, these cetaceans are not strictly deep-sea species given that each individual regularly rises to the surface, so their assessment cannot be done for the deep sea alone. Instead, a holistic approach should be taken by including the situation in shallower waters. Indeed, the most important anthropogenic pressures for these cetaceans occur in shallower waters (and surface waters), and monitoring of their populations is also much more feasible if done through surface and shallow-water (i.e. up to 200 m depth) surveys. The main potential source of impact on deep-diving toothed cetaceans in the deep sea is through the introduction of underwater noise, which is monitored under Descriptor 11. Similarly, marine litter, which may also represent a source of impact on these cetaceans, is monitored under Descriptor 10. Since assessment of these cetaceans under Descriptor 1 is more appropriately based on data from shallow waters, they will not be considered further here, even if the scarcity of cetacean data from the deep sea may be construed as a gap.

Descriptor 1, Criterion 1 (D1C1): The mortality rate per species from incidental by-catch is below levels which threaten the species, such that its long-term viability is ensured.

Commission Decision (EU) 2017/848 specifies that: *Member States shall establish the threshold values for the mortality rate from incidental by-catch per species, through regional or subregional cooperation. Data shall be provided per species per fishing metier for each ICES area or GFCM Geographical Sub-Area or FAO fishing areas for the Macaronesian biogeographic region, to enable its aggregation to the relevant scale for the species concerned, and to identify the particular fisheries and fishing gear most contributing to incidental catches for each species.*

Following Commission Decision (EU) 2017/848, the criteria elements for D1C1 are "*Species of birds, mammals, reptiles and non-commercially-exploited species of fish and cephalopods, which are at risk from incidental by-catch in the region or subregion*", whereas the criteria elements for Descriptor 3 include "*Commercially-exploited fish and shellfish*", with a note that "*Extraction of, or mortality/injury to, non-commercially-exploited species (incidental by-catches) as a result of fishing activities, is addressed under criterion D1C1*." According to the GFCM Data Collection Framework, the term 'bycatch' includes "*The part of the catch that is unintentionally captured during a fishing operation in addition to target species. It may refer to the catch of other commercial species that are landed, commercial species that cannot be landed (e.g. undersized,*
damage individuals), non-commercial species, as well as to incidental catch of endangered, vulnerable or rare species (e.g. turtles, sharks and marine mammals)" (GFCM, 2018).

It is here understood that Descriptor 3 criteria should be applied to species that are commercially exploited, whether they are target species or bycatch of other (non-target) commercial species. Member States should establish the list of commercially-exploited species according to the Descriptor 3 'specifications and standardised methods for monitoring and assessment', whereas criterion D1C1 applies to non-commercial species that may be caught as part of the bycatch. Such non-commercial species are usually returned to sea.

D1C1.G1 Limited data on fishing mortality for non-commercial species

Fishing mortality is the loss to the population of a species resulting from fishing and corresponds to the proportion of individuals captured by the fisheries. As such, fishing mortality can be estimated based on catch data, thus requiring data on both landings and discards, as well as on fishing effort and on the population size from which the catches are derived. The EU/GFCM data collection obligations do not cover all species, but only commercial species (not relevant to D1C1) and selected other species (e.g. species to be monitored under protection programmes listed in Table 1D of the Annex to Commission Implementing Decision (EU) 2016/1251; or vulnerable species listed in Appendix E to the GFCM Data Collection Reference Framework, of which only some cetaceans, sharks, rays and chimaeras are really relevant to the deep sea). Consequently, no data exists for several non-commercial species that are present in the bycatch. In addition, even for those non-commercial species that are actually monitored, the available data is generally insufficient to reliably estimate fishing mortality rates.

D1C1.G2 Inconsistencies in fishing metiers that are monitored in different GSAs

The scale of assessment for deep-diving toothed cetaceans and deep-sea fish under criteria D1C1 to D1C5 is regional (i.e. the entire Mediterranean), while sub-regional assessment is indicated for cephalopods. As indicated above, Mediterranean Member States need to provide data per species per fishing metier for each GFCM Geographical Sub-Area (GSA), to enable aggregation to the relevant scale for the species concerned. Several Member States have developed at-sea observer programs to get information on discards onboard fishing vessels. However, this often represents only a very small proportion of fishing trips. In addition, for commercial species, discard data is not collected for all fleet segments (a group of fishing vessels of the same size and using the same gear for more than 50 percent of the time at sea during a year), but only when it exceeds 10 percent of the total volume of catch for a given fleet segment in a given GSA (GFCM, 2018). Since different fleet segments use different gears, data is therefore only available for a subset of fishing metiers in each area, which differ across the different GSAs. When the same onboard observers programme is used for monitoring discards of both commercial and non-commercial species, the same issue is also applicable to the non-commercial species. Since these discard data account for 100% of the fishing mortality of non-commercial species, the fact that discard data is only available for a subset of gears per GSA results in unreliable estimates of total fishing mortality. In addition, the inconsistencies in fishing metiers that are monitored in different GSAs make it impossible to aggregate data from different GSAs for assessment at sub-regional or regional scales.

D1C1.G3 Lack of information on natural mortality rates

Although the mortality rate from incidental by-catch equates to the fishing mortality, in reality in order to ensure long-term viability of a population it is the total mortality that needs to be considered. Total mortality includes fishing mortality and natural mortality (the loss to the population from natural sources such as predation, disease and old age). Thus, the natural mortality rates must be known in order to control fishing mortality rates ensuring that the total mortality rates do not exceed levels that adversely affect the long-term viability of the species. There are several approaches that can be used to estimate natural and/or total mortality rates (see for example reviews by Vetter, 1988 and Simpfendorfer et al., 2005). However, these approaches all require data on biological parameters (such as von Bertalanffy growth parameters, female gonadosomatic index, age at maturity and reproduction rates, etc.), which are generally not known or not assessed for most non-commercial species.

D1C1.G4 Knowledge gap regarding differences in mortality rates between age/size cohorts

Although it is possible to calculate an overall fishing/natural/total mortality rate for a given population, such a gross figure may be insufficient to establish appropriate extraction thresholds. This is because mortality rates are unlikely to be constant throughout the lifespan of most species. The pattern of natural mortality will depend on the species' survivorship curve, for instance juvenile/small-sized individuals may be more susceptible to predation from larger predators, whereas as individuals reach their maximum age, they are more likely to die of old age; this would result in higher mortality rates for younger and older individuals compared to intermediate age classes. Similarly, fishing mortality can vary with age due to the size-selectivity of fishing gear or differences in the spatial distribution and habitat-utilization patterns between juvenile and adult individuals. Therefore, population demographic data (i.e. life history tables with abundance, fecundity and survivorship values per age class) are needed in order to determine the natural mortality rates per age cohort. These data, together with knowledge on the susceptibility of different age/size classes to fishing, would enable establishing thresholds of fishing mortality that, when added to the natural mortality, result in a total mortality that does not adversely affect the long-term viability of the species. However, population parameters such as length-frequency distributions by sex and maturity stages are only collected for commercially important target species (see also gap D1C3.G1).

Descriptor 1, Criteria 2, 3 and 4 (D1C2-4).

Criteria D1C2, D1C3, and D1C4 are related because they are all based on aspects of population ecology (abundance, demographic characteristics, distribution) of species. A number of gaps is equally applicable to D1C2, D1C3, and D1C4, and hence these criteria will be treated together. In contrast to D1C1, the criteria elements for D1C2-4 (and indeed D1C5) include any species within the relevant species groups, i.e. also including species that are commercially exploited or that are not caught (as target or bycatch) by the fishery industry.

For commercially-exploited fish and cephalopods, assessments under Descriptor 3 are used for Descriptor 1 purposes, using criterion D3C2 for D1C2 and criterion D3C3 for D1C3. Therefore, in the case of commercially-exploited species, the gaps identified under Criteria D3C2 and D3C3 apply and will not be repeated here; this section will instead focus on gaps regarding non-commercial species which are only relevant to Descriptor 1.

Descriptor 1, Criterion 2 (D1C2): The population abundance of the species is not adversely affected due to anthropogenic pressures, such that its long-term viability is ensured

Commission Decision (EU) 2017/848 specifies that: "*Member States shall establish threshold values for each species through regional or subregional cooperation, taking account of natural variation in population size and the mortality rates derived from D1C1, D8C4 and D10C4 and other relevant pressures. For species covered by Directive 92/43/EEC, these values shall be consistent with the Favourable Reference Population values established by the relevant Member States under Directive 92/43/EEC*" and that the unit of abundance measurement shall be the "*number of individuals or biomass in tonnes (t) per species*".

As stated above, for commercially-exploited fish and cephalopods, D1C2 assessments follow criterion D3C2, and are therefore based on Spawning Stock Biomass estimates where these are available. For non-commercially-exploited species, indices of abundance or biomass need to be computed to inform the D1C2 criterion. To assess long-term viability, assessment under D1C2 requires standardized time series of abundance and/or biomass for the monitored species. Such data is available from MEDITS, but this trawl survey only covers soft bottom habitats in European Member States, i.e. in the northern Mediterranean Sea.

Gaps identified for criterion D1C2 are also applicable for criteria D1C3 and D1C4 (see gaps D1C2-4.G1, D1C2-4.G2, D1C2-4.G3, D1C2-4.G4 below).

Descriptor 1, Criterion 3 (D1C3). The population demographic characteristics (e.g. body size or age class structure, sex ratio, fecundity, and survival rates) of the species are indicative of a healthy population which is not adversely affected due to anthropogenic pressures.

Commission Decision (EU) 2017/848 specifies that: “*Member States shall establish threshold values for specified characteristics of each species through regional or subregional cooperation, taking account of adverse effects on their health derived from D8C2, D8C4 and other relevant pressures*”.

Although D1C3 is a primary criterion for commercially-exploited fish and cephalopods (assessed under D3C3), it is a secondary criterion for non-commercially-exploited species.

In contrast with D1C2, there is no specified distinction in terms of the type of assessment for commercial (under D3C3) and non-commercial (under D1C3) species. The actual demographic parameters to be used are not specified, and can vary according to the species. However, these must be consistent across Member States given that threshold values for the specified characteristics of each species need to be established through regional or subregional cooperation, in order to allow assessment at regional/subregional scales. Time-series data of population demographic characteristics is required for monitoring the status of a population and ensuring it is not adversely affected by anthropogenic pressures.

The following gaps are applicable to D1C3. Other gaps identified for this criterion are also applicable for criteria D1C2 and D1C4 (see gaps D1C2-4.G1, D1C2-4.G2, D1C2-4.G3, D1C2-4.G4 below).

D1C3.G1 Knowledge gap regarding population demographics of non-commercial species

The only extensive source of time-series data on populations of deep-water fishes and cephalopods is the MEDITS survey programme; fishery catch statistics do not provide data for non-commercial species. Data derived from MEDITS includes indices of abundance and biomass for all benthic / demersal fish and cephalopods collected, whereas population parameters such as length frequency distributions by sex and maturity stages are only collected for a limited number of commercially important target species and some species of conservation concern (MEDITS Handbook, 2017). Thus, in practice, population demographic characteristics (e.g. population age/size structures, sex ratios, fecundity and mortality rates per age/size cohort) are not available for most non-commercial species.

D1C3.G2 Limited research on parameter selection for assessing the status of populations subjected to non-fishery anthropogenic pressures

For commercially-exploited species, the distribution by age and size of individuals provides information on the health of a given stock; healthy stocks are characterized by a high proportion of old / large individuals and limited adverse effects of exploitation on genetic diversity (ICES, 2015a). According to Tsagarakis et al. (2013), size-based indicators such as maximum length of deep-water fish species is one of the most informative metrics related to fishing impact, and several size-based indicators already exist in the literature (see review by Shin, 2005). On the other hand, size-based indicators are not necessarily the best approach to assess the population status of non-commercially-exploited species that may be subjected to non-fishery anthropogenic pressures such as exposure to contaminants; indeed, the most appropriate parameters to use may vary depending on the type of pressure affecting a population.

<u>Descriptor 1, Criterion 4 (D1C4). The species distributional range and, where relevant, pattern is in line with prevailing physiographic, geographic and climatic conditions.</u>

Commission Decision (EU) 2017/848 specifies that: "*Member States shall establish threshold values for each species through regional or subregional cooperation. For species covered by Directive 92/43/EEC, these shall be consistent with the Favourable Reference Range values established by the relevant Member States under Directive 92/43/EEC*".

D1C4 is a primary criterion for species covered by Annexes II, IV or V to Directive 92/43/EEC (the 'Habitats Directive'), very few of which occur in the deep Mediterranean Sea; it is a secondary criterion for other species.

The species distributional range is defined as the spatial limits in which a species is naturally present (excluding erratic occurrences). In the marine environment, it can be described by the geographic and bathymetric limits where a species occurs. The distributional range of deep-sea species can be highly variable in space and time, as it is often driven by biological and environmental variables, interactions among life history traits and anthropogenic pressures, and climate forcing. Changes in the distributional range of species can be grouped into three categories: (i) Parallel shifts: the distribution stays the same (values and shape), but it is shifted in a specific direction; (ii) Contraction; (iii) Expansion. The species distributional pattern is the way concentrations of individuals of the species are distributed within the distribution range. Various patterns of occupation can be described; at regional and subregional scales distribution patterns tend to be clumped since individuals are aggregated in habitat patches that meet their resource utilization needs. Changes in the distribution pattern of a species can occur due to fragmentation or fusion, which alter the extent of discontinuity between occupied patches, or due to colonization and local extinction in the case of meta-populations. As for D1C2 and D1C3, to monitor changes in distributional range or pattern of a species under D1C4, distributions must be assessed over time.

The following gap is applicable to D1C4. Other gaps identified for this criterion are also applicable for criteria D1C2 and D1C3 (see gaps D1C2-4.G1, D1C2-4.G2, D1C2-4.G3, D1C2-4.G4 below).

D1C4.G1 Spatial mismatch between surveyed areas and species distribution ranges/patterns

Assessment under D1C4 requires time-series distributional data on selected species, but the spatial scale and resolution of the data must also match the distributional ranges and aggregation patterns in order to be able to detect range shifts, contraction or expansion, or changes in patch occupation patterns. Thus, besides general limitations in terms of data availability, an additional gap within the context of D1C4 is the possibility of a spatial mismatch between the areas covered by scientific surveys and the natural range of a species. It should be noted that for the deep sea, which has been little explored, the distribution range as understood from the literature/past work may not reflect the actual distributional range of a species, since it may be conditioned by where studies of the deep sea have been made. Thus, the absence of a species from a particular area may reflect the lack (or paucity) of studies on that area. In addition, in the case of species occurring at low population density and where individuals are dispersed, an apparent 'contraction' (that is, the species is not found in an area where it was previously found) may be an artefact due to chance.

Descriptor 1, Criteria 2, 3 and 4 – Common Gaps

D1C2-4.G1 Inadequate data for species associated with hard substrata

Trawl surveys such as MEDITS preferentially target soft bottoms, and thus the available time-series data is limited to species occurring on sedimentary bottoms on bathyal plains. Although there have been several studies on bathyal hard bottoms such as cold-water coral habitats and rocky canyons (summarized in IDEM Project, 2017) which also provide useful data, these are limited to one-time surveys, often using different methodologies (e.g. baited lander experiments, fishing with longlines, grab sampling, dredging or remotely operated vehicle surveys). Consequently, no time-series data on species from hard bottom habitats is available, while aggregation of the data from one-time surveys for regional and sub-regional assessment is also not possible due to the different sampling methodologies employed. In addition, species that bore in deep-water hard substrata are not collected by most gear used to sample these habitats, and are also not possible to see in video surveys; thus, data on these species are practically absent.

D1C2-4.G2 Limited data for species in environments deeper than 1,000 m

A number of studies have collected data on deep-sea fishes (and crustaceans) in bathyal environments deeper than 1,000 m. The available information has been reviewed by Sarda et al. (2009). Most of the work relates to exploratory surveys, listing species, abundance levels, and geographic and depth distributions, with some studies also reporting population parameters such as age at maturity and fecundity of selected species. As there is no regular sampling programme that covers these depths (MEDITS only covers up to 800 m), no time-series data are available and the data from one-off surveys are not always comparable due to the use of different sampling methodologies. This also has implications for monitoring and assessment of species with wide bathymetric ranges that extend from less than 800 m into deeper waters. Even if time-series data from MEDITS surveys are available for these species, these data only cover part of the species' bathymetric range, and therefore provide an incomplete picture on their population status and trends.

D1C2-4.G3 Poor knowledge on meso- and bathy-pelagic species

There are no regular surveys targeting pelagic species occurring deeper than 200 m since the maximum echo-sounding depth of the annual MEDIAS surveys, which is used to monitor sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) populations, is 200 m (MEDIAS Handbook, 2017). In addition, most of the one-time studies undertaken in deeper waters targeted demersal or benthic species and habitats. In general, data on meso- and bathy-pelagic species is thus lacking, and this should be considered as a major gap.

D1C2-4.G4 Insufficient information for establishment of threshold values
Data availability has been highlighted as a major limitation for assessment of populations of species that are not commercially exploited under D1C2, D1C3 and D1C4. The only aspect for which data availability is not a major issue is abundance/biomass indices for benthic and demersal deep-water fishes and cephalopods occurring on sedimentary bottoms down to 800 m, where data is available through MEDITS surveys. The scarcity of data on every other relevant aspect (parameters besides abundance/biomass, other habitats, deeper bathymetries, etc.) not only renders assessment of population abundance, demographic characteristics and distribution ranges/patterns difficult, if not impossible, at present, but also hampers the establishment of scientifically meaningful threshold values for these parameters.

Descriptor 1, Criterion 5 (D1C5). The habitat for the species has the necessary extent and condition to support the different stages in the life history of the species.

D1C5 is a primary criterion for species covered by Annexes II, IV or V to Directive 92/43/EEC (the 'Habitats Directive'), very few of which occur in the deep Mediterranean Sea; it is a secondary criterion for all other species. As in the case for criteria D1C2-4, the criteria elements for D1C5 include any species within the relevant species groups, i.e. also including species that are commercially exploited or that are not caught (as target or bycatch) by the fishery industry. However, D1C5 differs from D1C2-4 because the latter focus on population parameters of the species, whereas D1C5 relates to its habitat.

Habitat can be defined as the physical location where a given species occurs, and must provide the physical, chemical and biological conditions and resources required (or tolerated) by the species for growth, reproduction, survival and for completing its life cycle. It can be described in terms of both qualitative and quantitative measures. In either case, a significant amount of information is needed to understand, identify, and predict the habitat of a species. In practice, this could be done by developing suitable habitat models (Lauria et al., 2017) provided that sufficient data are available.

D1C5.G1 Lack of knowledge on habitat conditions required by deep-sea species to complete their life cycle
D1C5.G2 Absence of minimum thresholds for habitat extent required to support deep-sea species
Understanding the habitat conditions required for survival and reproduction of a given species requires detailed knowledge on its physiological tolerances and ecological requirements at each part of its life cycle; these conditions are likely to differ between larvae, juveniles, and adults and may also vary between adults depending on their sex and reproductive status. Such knowledge would allow identification and/or prediction of areas where habitat conditions are suitable for the species. For most species, knowledge on habitat requirements is limited both in terms of the range of parameters that have been measured, and in terms of knowledge on the conditions needed by different life stages. Even if such information were available, assessing the habitat extent that is necessary to support the different stages in the life history of a species is not straightforward. Therefore, there are no minimum thresholds for habitat extent required by different life stages of deep-sea species, and there is insufficient knowledge and data needed to establish these.

Theme 2: Pelagic habitats

Descriptor 1, Criterion 6 (D1C6). The condition of the habitat type, including its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of

particularly sensitive or fragile species or species providing a key function, size structure of species), is not adversely affected due to anthropogenic pressures.

No detailed list of pelagic habitat types is identified in Commission Decision (EU) 2017/848, which refers only to the pelagic broad habitat types: variable salinity, coastal, shelf and oceanic/beyond shelf. This decision specifies that: “*Member States shall establish threshold values for the condition of each habitat type, ensuring compatibility with related values set under Descriptors 2, 5 and 8, through regional or subregional cooperation*” and that “*The extent to which good environmental status has been achieved shall be expressed for each area assessed as: (a) an estimate of the proportion and extent of each habitat type assessed that has achieved the threshold value set; (b) a list of broad habitat types in the assessment area that were not assessed.*” The unit of measurement for D1C6 is given as: “*The extent of habitat adversely affected in square kilometres (km^2) and as a proportion (percentage) of the total extent of the habitat type.*”

D1C6.G1 Inefficient sampling of functionally important deep-water pelagic species

The diversity of life is difficult to describe for the entire deep-water pelagic province, both in qualitative and quantitative terms. This is partly due to the variability of the environment, but is also hampered by the limited capacity to perform efficient sampling of several species groups. For instance, accurate assessment of deep-sea plankton abundance or diversity is challenging given that plankton are patchily distributed in space and time and sampled volumes (e.g. via Niskin bottles) represent a minute fraction of the pelagic habitat. On the other hand, fast-swimming animals are difficult to assess because they are behaviourally adapted to evade capture, and are therefore hard to sample. Yet these species groups are important components of pelagic systems.

D1C6.G2 Utility of upper-trophic level predators as indicators not fully known

Studying the feeding ecology of pelagic predators can provide information on the abundance of a set of species, from macroplankton to fast-swimming nekton (Würtz, 2010). It is thought that the feeding and breeding grounds of upper-trophic level predators represent biodiversity hotspots, associated with topographic and oceanographic features that promote pelagic productivity. Therefore, top predators could be used as indicators of ecosystem status and performance, with their distribution and aggregation patterns serving as proxies for pelagic habitat mapping (Boyd et al., 2006). While this approach may be useful from the point of view of cost-benefit ratio, its scientific appropriateness needs to be fully demonstrated through a thorough characterization of the deep-sea pelagic habitats occurring in top predator aggregation areas and elsewhere.

D1C6.G3 Poor knowledge of biological component of deep-sea pelagic habitats

The Mediterranean Sea circulation pattern is complex and its interaction with biological processes may define a variety of marine pelagic habitats, from the surface to the deeper waters. Important components that can serve as pelagic hotspots of productivity include persistent hydrographic systems (currents, gyres and thermal fronts) and static systems (e.g. seamounts, canyons and continental slope features), but also ephemeral habitats such as transient upwellings and deep convections which can create small-scale fronts and convergence zones (Hyrenbach et al., 2000). These hydrographic features can be used to define pelagic habitats based on physical considerations. However, knowledge about the biological component of the deep-sea pelagic system is still poor, both for establishing habitat boundaries and for implementing species-environment interaction models. Without such biological knowledge, detailed habitat mapping within the pelagic realm is not possible (let alone setting thresholds for the maximum proportion of each habitat that may be adversely affected without altering the overall habitat condition).

See also: D1C2-4.G3

Themes 3 and 4: Benthic habitats and Ecosystems including food webs

The MSFD benthic habitat categories relevant to the deep sea listed in Commission Decision (EU) 2017/848 are: "*Upper bathyal rocks and biogenic reefs; Upper bathyal sediment; Lower bathyal rock and biogenic reef; Lower bathyal sediment; Abyssal.*" Several habitat types can be included within these broad categories, for instance: canyons (rocky or sedimentary), rocky bottoms with large cnidarians (including cold-water coral (CWC) frameworks) or bivalves, different types of sedimentary bottoms in bathyal or abyssal plains (muds, sands or coarse sediment), chemosynthetic habitats (hydrothermal vents and mud volcanoes), and seamounts. In terms of ecosystems including food webs, Commission Decision (EU) 2017/848 refers to "*Trophic guilds of an ecosystem*" with specifications on selection criteria to be used for establishing the list of trophic guilds that will be monitored. An overview of the state of the art in terms of scientific knowledge on deep-sea habitats and food webs is given in IDEM Deliverable 1.1 (IDEM Project, 2017).

The criteria used for assessment of benthic habitats (Criteria D6C4 and D6C5) relate to Descriptors 1 and 6. Gap assessment under these criteria is described under Descriptor 6 (see gaps D6C3-5.G1, D6C3-5.G2, D6C3-5.G3, D6C3-5.G4, D6C3-5.G5). Some of the gaps identified above (especially D1C2-4.G1, D1C2-4.G2 and D1C2-4.G4) are also relevant here.

The criteria used for assessment of ecosystems including food webs (Criteria D4C1, D4C2, D4C3, and D4C4) relate to Descriptors 1 and 4. Gap assessment under these criteria is described under Descriptor 4 (see gaps D4C1.G1-G3, D4C2.G1-G3, D4C3.G1-G3, and D4C4.G1-G3). Some of the gaps identified above (especially D1C2-4.G1, D1C2-4.G2, D1C2-4.G3 and D1C2-4.G4) are also relevant here.

2.1.2 Additional gaps concerning relevant topics poorly or not addressed within the existing MSFD-defined criteria.

D1AG[4].G1 Need for deeper understanding of deep-sea ecological functioning

Understanding the processes regulating the functioning of deep-sea ecosystems is a prerequisite for developing appropriate indices for and assessing environmental status in terms of different components of biodiversity. The MSFD Descriptor 1 criteria break down assessment into four themes (i.e. selected species, pelagic habitats, benthic habitats, ecosystems) with each criterion focusing on a specific aspect. While this may be the most pragmatic approach for monitoring, it is imperative that the interdependencies between the different ecological components are not ignored. For instance, changes in the abundance of particular species may be both a consequence of, and a driver for, changes in ecosystem functioning. Several aspects of Mediterranean deep-sea ecology are not well known. For example, how do these oligotrophic ecosystems have the capability to sustain large populations of benthic suspension-feeders? How do benthic-pelagic coupling mechanisms influence deep-sea assemblages? What is the role of microbes in structuring deep-sea assemblages? Which kind of connectivity exists among the deep benthic populations in different Mediterranean sub-regions, and between Mediterranean Sea and Atlantic Ocean assemblages? How do atmosphere-driven high-energy processes occurring in the Mediterranean Sea, and mesoscale circulation and turbulences, determine the distribution and composition of seamount assemblages? How are benthic communities structured over steep bathymetric gradients? The development of robust indicators in relation to anthropogenic pressures of biodiversity in the deep sea, and their appropriate

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[4] AG meaning "additional gap"

interpretation within the context of good environmental status, necessitates answering such questions to obtain a more integrative understanding of deep-sea ecosystem functioning.

See also: D6AG.G1 and D6AG.G2

2.1.3 Geographical gaps

This section refers to the main geographical gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of geographical gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, meta-analysis and data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018b, 2018a).

D1GG[5].G1. Heterogeneous geographical data coverage

The two main sources of data relevant to Descriptor 1 are the MEDITS trawl surveys, and one-time studies whose results are published in the scientific literature. The review of scientific publications presented in IDEM Deliverable 2.1 (IDEM Project, 2018c), which includes studies based on both MEDITS data and one-time surveys, showed that about twice as many publications consider each of the Western and Central-Ionian sub-basins, compared to the Aegean-Levantine basin. Data availability is also lower for the southern Mediterranean region; for instance, MEDITS is only carried out by European Member States and no similar data source exists for deep-sea regions falling under non-European jurisdictions.

2.1.4 Bathymetric gaps

This section refers to the main bathymetric gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of bathymetric gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, meta-analysis and data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018b, 2018a).

D1BG[6].G1. Uneven coverage of different depth ranges

Most of the studies conducted on the deep Mediterranean Sea cover a range from 200 meters down to more than 1,000 meters depth, but the number of publications with data limited to less than 1,000 m depth is substantially higher than those considering deeper waters (which may be partly explained by the fact that MEDITS surveys only go down to 800 m depth; thus all publications based on MEDITS data have 800 m as their deeper limit). In addition, the deepest parts of the Mediterranean Sea (>2,000 m depth) are practically neglected in the current literature. Interestingly, there is also a paucity of studies with data for the 200-500 m depth range for the Aegean-Levantine sub-region.

See also: D1C2-4.G2

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[5] GG meaning "geographical gap".

[6] BG meaning "bathymetric gap".

2.1.5 Habitats and species gaps

Theme 1: Species groups of birds, mammals, reptiles, fish and cephalopods

With regards to the criteria within the Descriptor 1 Theme "Species groups", which for the deep-sea refers mostly to fishes and cephalopods, the main gaps have already been highlighted above, but can be summarized as:

D1HS[7].G1 Inadequate data for soft bottom non-commercial species sampled through MEDITS
While abundance/biomass data for such species are available through MEDITS, parameters such as population size structures and other demographic characteristics are not collected. [See: D1C1.G1, D1C1.G3, D1C1.G4, D1C3.G1]

D1HS.G2 Scarce data for non-commercial species that are not sampled through MEDITS
Data for species occurring in habitats other than the sedimentary bottoms that are surveyed via MEDITS are either generally absent or based on only one-time surveys such that no time-series is available. Such species include those associated with hard substrata, those occurring in waters deeper than 800 m, and meso- and bathy-pelagic species. [See: D1C2-4.G1, D1C2-4.G2, D1C2-4.G3]

Themes 2-4: Pelagic habitats, Benthic habitats, and Ecosystems including food webs

D1HS.G3 Species data gaps for assessment of habitat condition and trophic guild diversity
Criteria D1C6, D6C5 and D4C1 all refer to species composition and their relative abundance in habitats/ecosystems. The review presented in IDEM Deliverable 2.1 (IDEM Project, 2018c) indicated that data coverage for different species groups is heterogeneous. Cold-water corals and demersal fishes are the two most studied species groups, while several publications include data for various macro-invertebrates (e.g. Scyphozoa, Mollusca, Polychaeta, Serpulida, Sipuncula and Crustacea). A few publications focus only on selected taxa or subsets of taxa (e.g. commercial decapods or cephalopods), while meiofaunal and microbial communities are generally under-represented.

D1HS.G4 Uneven data availability across deep-sea habitats
Distributional information is available for several benthic habitats, including canyons, cold-water coral habitats, seamounts, chemosynthetic habitats and open slopes (see review in IDEM Project, 2017; and maps in IDEM Project, 2018a). In contrast, detailed information on the species composition, abundance and/or biomass is mostly restricted to sedimentary bottoms, canyons and cold-water coral habitats, with some characterization of chemosynthetic habitats in the Aegean-Levantine basin. Meso- and bathy-pelagic habitats and abyssal benthic habitats are poorly known.

See also: D1C6.G1, D1C6.G3, D6HS.G1, D6HS.G2, D6HS.G3

2.1.6 Methods and technologies gaps

D1MT[8].G1 Lack of a standardized, Mediterranean-wide monitoring strategy that caters for pelagic, benthic hard-bottom, and deeper (>800 m depth) environments that are not surveyed via MEDITS
The identification of gaps for the Descriptor 1 criteria above creates a distinction between species and habitats that are adequately sampled through MEDITS surveys, and those that are not. For the latter, there

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[7] HS meaning "habitats and species".

[8] MT meaning "methods and technologies".

is a general lack of time-series data, and a problem of non-comparability of data derived from independent one-time surveys that very often use different approaches and sampling gear. The utility of the MEDITS surveys is that they are held annually and use a standardized methodology across all European Member States implementing the programme, ensuring comparability of data which can be easily aggregated for assessment at subregional/regional scales. No regular monitoring programme exists for deep-water pelagic habitats, hard substrata, or any bottoms deeper than 800 m.

D1MT.G2 Limitations of sampling techniques in deep-sea environments
By its very nature, the deep-sea environment is only accessible through remote sampling gear, which has its limitations for obtaining data relevant to biodiversity assessment. Trawl surveys such as MEDITS are useful for sampling demersal and surface-dwelling megabenthic species on sedimentary bottoms in open slopes and bathyal plains, but unsuitable for hard substrata. In addition, trawling does not quantitatively sample some functionally important benthic species occurring on soft bottoms, such as habitat-forming cnidarians, while it may also be argued that areas with high densities of these habitat-formers should not be sampled using destructive gear. Use of remotely-operated vehicles (ROVs) can be seen as an alternative non-destructive approach for obtaining data in such areas, while ROVs also allow surveying of hard-bottom environments. Permanent observatory stations equipped with video cameras would also allow monitoring of Descriptor 1 variables; although limited in spatial coverage, fixed observatories allow continuous acquisition of parameters over months (or more), thus providing a very high temporal resolution that cannot be attained with other sampling methods. However, video surveying through ROVs or fixed observatories is generally unsuitable for data acquisition on fast-moving mobile organisms, or on species whose identification is based on characters that are not visible in videos, and therefore cannot replace trawling (or other fishing-gear based techniques) on soft bottoms. In addition, neither trawl nor video surveys provide adequate data on pelagic species, or on macro-, meio- or micro-biota. These components of biodiversity are consequently very poorly known in the deep sea. For soft bottoms, this gap could be addressed through the use of grab or box core samplers, but the use of epibenthic dredges for sampling macrofauna on hard bottoms seems hardly appropriate for routine monitoring. Commission Decision (EU) 2017/848 lists the "*specifications for the selection of species and habitats under Themes 'Species groups of marine birds, mammals, reptiles, fish and cephalopods', 'Pelagic habitats' and 'Benthic habitats'*", which include scientific criteria (ecological relevance) and practical criteria such as monitoring feasibility. While the legislation specifies that the practical criteria shall not override the scientific criteria, a pragmatic approach that gives due consideration to the monitoring/technical feasibility of sampling is warranted for the deep sea.

D1MT.G3 Prohibitive costs associated with deep-sea sampling
Deep-sea surveys require dedicated research cruises using vessels equipped with appropriate sampling gear. The costs of such surveys can be prohibitively expensive, while not all Member States have access to the necessary vessels and equipment to undertake such monitoring. A holistic approach at developing a monitoring programme for the Mediterranean deep-sea environment, possibly with collaborative joint surveys by 'adjacent' Member States, supported through EU funding, may be necessary to increase the cost-effectiveness of data acquisition in the deep sea.

2.1.7 Connections between descriptors

This section focuses in illustrating D1 related gaps that are also relevant for other descriptors. Identification of the connections between descriptors' gaps will endorse the establishment of an integrative approach regarding all project tasks. Therefore, when describing new indicators within task 3.2, these connections need to be considered since indicators filling a D1 gap could also be applied to other descriptors. The concept of displaying relationships between descriptors is based on the approach presented in Cochrane et al. (2010).

Relationships between gaps and descriptors are illustrated as dark grey coloured cells in Table 2.1. The interconnections are identified when a gap described for D1 is also relevant for other descriptors, affecting other ecosystem components represented by state descriptors (i.e. D4 and D6) or complementing pressures defined by pressure-based descriptors (i.e. D2, D3, D5, D7, D8, D9, D10 and D11). The gaps defined under sections 2.1.3, 2.1.4 and 2.1.5 are not added to the table since all identified deficiencies are already considered relevant for all descriptors.

	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**	**D11**
D1C1.G1	■										
D1C1.G2	■		■								
D1C1.G3	■		■								
D1C1.G4	■		■								
D1C2-4.G1	■	■	■	■	■	■	■	■		■	
D1C2-4.G2	■	■	■	■	■	■	■	■		■	
D1C2-4.G3	■	■	■	■							
D1C2-4.G4	■	■	■	■	■	■	■	■		■	
D1C3.G1	■	■		■	■	■	■	■		■	■
D1C3.G2	■	■		■	■	■	■	■		■	■
D1C4.G1	■				■	■	■				
D1C5.G1	■			■		■	■				
D1C5.G2	■			■		■	■				
D1C6.G1	■	■		■							■
D1C6.G2	■			■							
D1C6.G3	■	■		■							■
D1AG.G1	■		■	■		■	■	■			
D1MT.G1	■	■	■	■	■	■	■	■	■	■	■
D1MT.G2	■	■	■	■	■	■	■	■	■	■	■
D1MT.G3	■	■	■	■	■	■	■	■	■	■	■

Table 2.1. Representation of the connections between D1-identifed gaps and the rest of MSFD descriptors. Dark grey cells represent interconnections between the D1-gaps and the rest of descriptors. Format based on Cochrane et al. (2010). The left panels contain the gaps identified and described for Descriptor 1: ***D1C1.G1*** *Limited data on fishing mortality for non-commercial species.* ***D1C1.G2*** *Inconsistencies in fishing metiers that are monitored in different GSAs.* ***D1C1.G3*** *Lack of information on natural mortality rates.* ***D1C1.G4*** *Knowledge gap regarding differences in mortality rates between age/size cohorts.* ***D1C2-4.G1*** *Inadequate data for species associated with hard substrata.* ***D1C2-4.G2*** *Limited data for species in environments deeper than 1,000 m.* ***D1C2-4.G3*** *Poor knowledge on meso- and bathy-pelagic species.* ***D1C2-4.G4*** *Insufficient information for establishment of threshold values.* ***D1C3.G1*** *Knowledge gap regarding population demographics of non-commercial species.* ***D1C3.G2*** *Limited research on parameter selection for assessing the status of populations subjected to non-fishery anthropogenic pressures.* ***D1C4.G1*** *Spatial mismatch between surveyed areas and species distribution ranges/patterns.* ***D1C5.G1*** *Lack of knowledge on habitat conditions required by deep-sea species to complete their life cycle.* ***D1C5.G2*** *Absence of minimum thresholds for habitat extent required to support deep-sea species.* ***D1C6.G1*** *Inefficient sampling of functionally important deep-water pelagic species.* ***D1C6.G2*** *Utility of upper-trophic level predators as indicators not fully known.* ***D1C6.G3*** *Poor knowledge of biological component of deep-sea pelagic habitats.* ***D1AG.G1*** *Need for deeper understanding of deep-sea ecological functioning.* ***D1MT.G1*** *Lack of a standardized, Mediterranean-wide monitoring strategy that caters for pelagic, benthic hard-bottom, and deeper (>800 m depth) environments that are not surveyed via MEDITS.* ***D1MT.G2*** *Limitations of sampling techniques in deep-sea environments.* ***D1MT.G3*** *Prohibitive costs associated with deep-sea sampling.*

2.2 *DESCRIPTOR 2: NON-INDIGENOUS SPECIES*

The MSFD adopted an integrated ecosystem-based management approach to achieve/ maintain GES for the marine environment, including the goal that “non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem”. Descriptor 2 is closely related to several other GES descriptors in MSFD (e.g. descriptors 1, 3, 4, 5, 6).

The Commission Decision 2017/848 identified the following criteria and associated four indicators for Descriptor 2.

Three criteria have been defined for the D2 Non-Indigenous Species (NIS):

- D2C1 (primary): Newly introduced NIS - The number of NIS which are newly introduced via human activity into the wild, per assessment period (6 years), measured from the reference year as reported for the initial assessment under Article 8(1) of Directive 2008/56/EC, is minimised and where possible reduced to zero.
- D2C2 (secondary): Abundance and spatial distribution of established NIS, particularly of invasive species, contributing significantly to adverse effects on particular species groups or broad habitat types.
- D2C3 (secondary): Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to NIS, particularly invasive NIS

2.2.1 *Major knowledge gaps concerning specific indicators and criteria*

Examination of the latest assessment of the Member States’ monitoring programmes under the MSFD reveals that only 5% are related to NIS, and these “will require a clear acceleration to ensure proper coverage given the MSFD Deadlines for the update of marine strategies by 2018, and achieving Good Environmental Status by 2020” (EC 2017).

D2C1-3.G1 Lack of data concerning NIS at depths greater than 200m

Significantly, **none of the NIS monitoring programmes even targeted lower shelf and upper slope habitats**. The currently available data stems mostly from fortuitous finds (Galil et al. 2019, Goren et al. in prep.) and is limited to the Levantine basin (Israel, Lebanon, Mediterranean coast of Turkey and the SE Aegean Sea, mostly at 100 to 250 m depth. Records deeper than 200 m are rare. One can confidently state that the lower shelf and upper slope in the **Levant Sea** are *tabula rasa* as concerns habitats and biodiversity. Already shelf-inhabiting thermophilic NIS have spread from the Levant westwards (Galil et al. 2018), and it is likely that the same trend will manifest in the upper slope. It is likely that with **increasing seawater temperature**, thermophilic NIS will establish populations in deeper habitats **across the Mediterranean Sea**. It is recommended to establish operational NIS monitoring programs (inclusive of mega, macro, meio and microbiota), focusing on lower shelf and upper slope in the Levant Sea, aiming to identify the subset of deep-water thermophilic NIS likely to spread, and the habitats sensitive to their establishment.

2.3 *DESCRIPTOR 3: POPULATIONS OF ALL COMMERCIALLY EXPLOITED FISH AND SHELLFISH*

This descriptor concerns all commercially *exploited fish and shellfish populations and* stipulates that they "*should be within safe biological limits, exhibiting a population age and size distribution that is indicative of healthy stocks*". The MSFD builds on existing EU legislation including the Common Fisheries Policy (CFP) and the criteria describe stocks status based on internationally recognised best practices.

As such, stocks should (i) be exploited sustainably in a way that provides high long-term yields, (ii) retain their reproductive capacity so that stock biomass can be maintained, and (iii) older and larger fish / shellfish should be maintained, indicating healthy stocks.

From these objectives, three primary criteria were defined:

- Criterion D3C1 - Fishing Mortality

Fishing mortality (F) gives an estimate of the pressure that fishing has on a stock. The fishing mortality rate (F) of commercially exploited species should be maintained at or below the level of the reference point of the fishing mortality at maximum sustainable yield (MSY).

- Criterion D3C2 - Spawning stock biomass

The amount of spawners (Spawning Stock Biomass, SSB) measures the ability of a stock to reproduce.

- Criterion D3C3 - Demographic Characteristics

The distribution by age and size of individuals in populations of commercially exploited species demonstrates the good health of the stock (Shin et al., 2005). This is characterized by a high proportion of old / large individuals, and limited adverse effects of exploitation on genetic diversity (ICES, 2015a).

Depending on the data available and the nature of the assessment, stocks may be classified into 6 categories (ICES, 2012)

- Category 1: stocks with comprehensive analytical estimates and forecasts;
- Category 2: stocks with negligible landings compared to discards;
- Category 3: stocks with qualitative analytical assessments and forecasts including quantitative assessments and forecasts which, for various reasons, are merely indicative of trends in fishing mortality, recruitment and biomass;
- Categories 4 to 6: stocks with trends from scientific surveys (robust indices on total mortality, recruitment, biomass); stocks with solid catch data on short time series; data-limited stocks (only landings available).

2.3.1 General gaps

D3-G1: Low number of assessed stocks

The number of stocks benefiting from an assessment in the Mediterranean is very low. Only 48 of the 235 stocks exploited in the western Mediterranean benefit from a scientific evaluation and even less in the Eastern Mediterranean Sea (Foucher and Delaunay, 2018). Nevertheless, many unevaluated species may contribute significantly to the landings in both weight and value. In general, Mediterranean stock assessments are affected by a lack of data and economic resources. In particular, the available time-series are short, age readings that could allow age-based assessments are rarely available, and information on discards is often lacking so that stock assessments have to be based on landings data. Moreover, maturity ogives which have to be used in stock assessments models to compute the SSB are not always available. There are often difficulties in the calculation of stock-recruitment relationships because of the shortness of data series. The definition of stock boundaries is poorly known and remains still unsolved for some stocks (Fiorentino et al., 2014).

D3-G2: Spatial discrepancies and depth aggregation

Fisheries dependent data is reported at the scale of GFCM Geographic Sub Areas, which have boundaries that do not match the MSFD sub-areas. Moreover, the current fisheries data collection protocols do not require recording data on depth, and as such, the available data cannot be used to distinguish bathymetric limits of catches. In this perspective, only the use of complex modelling approaches combining landings and VMS/AIS data would allow to split quantitative data into bathymetric strata.

D3-G3: Data access to survey data

Fishery independent data are limited to DC-MAP funded surveys which cover only one season, the northern coasts of the Mediterranean and are limited to sedimentary bottoms at 800 m depth. Moreover, using the MEDITS gear up to 800 m in practice is difficult, because of the rough bottom conditions at the end of the continental shelf and the upper slope (where canyons are common in some parts of the Mediterranean Sea). Another type of sampling gear able to survey uneven, rocky bottoms should thus ideally be used to complement MEDITS gear. Moreover, the MEDITS survey does not benefit from a common and open data base as it is the case for similar Atlantic surveys (e.g. the ICES Database of Trawl Surveys 'DATRAS'); instead the use of MEDITS data requires bilateral collaboration with each separate survey team, which complicates and slows down data accessibility.

D3-G4: Lacking international coordination at MFSD sub-area scale

Enhanced international coordination is needed at the Mediterranean level to achieve a standardized and coherent approach to assessing GES of populations of commercial fish species, as is required by the MSFD. The list of the species evaluated by the different countries is often different even in the same sub-region (ICES, 2014). This is the result of different interpretations by EU Member States, due to a lack of sub-regional and regional coordination, inconsistent stock selection, different application of reference points, and variable definitions of GES and the associated environmental targets (Raicevich et al., 2017).

2.3.2 Gaps in criteria

D3C1.G1: Using approximate reference point for fishery mortality

Fishing mortality (F) reference points, including F at maximum sustainable yield (F_{MSY}), can only be calculated for category 1 and 2 stocks. However, F_{MSY} cannot be defined for the vast majority of demersal stocks in EU Mediterranean waters due to data limitations. GFCM and STECF have instead adopted $F_{0.1}$ as the target reference point for demersal stocks (i.e. as a proxy of F_{MSY}) and this is being used as the basis for management advice. $F_{0.1}$ is the fishing mortality rate corresponding to 10% of the slope of the yield-per-recruit curve at the origin (Gulland and Boerema, 1973). Therefore, in the absence of the appropriate reference point, GES aims at a fishing mortality level that would be below or equal to this F_{MSY} proxy.

D3C1.G2: Unknown fishing mortality in many cases

If yield values based on quantitative assessments are not available to estimate fishing mortality, due to inadequate data, other variables such as the catch-to-biomass ratio may be used as a substitute method (e.g. for category 3 stocks). In this case, an appropriate empirical method of trend analysis is adopted (for example, the value at the time of assessment can be compared to the long-term historical average, including if possible, the period where the stock was not exploited). However long-term monitoring of catch, fishing effort and biomass is often lacking, and stocks that fall into category 3 are therefore generally not assessed. Stocks in category 4 or 5 or for which there is no data available are not reported either, and the fishing mortality thus remains unknown.

D3C2.G1: Unknown objective for SSB

SSB is computed from quantitative models (based on the evolution of the total biomass in respect to the catches and with the use of maturity ogives) or analytical models (structured by age or length). Such calculations can only be carried out for category 1 stocks. B_{MSY} is the Spawning Stock Biomass (SSB) that results from fishing at F_{MSY} for a long time. The actual spawning stock biomass should be equal or higher than B_{MSY} to indicate a sufficient number of mature individuals (i.e. spawners) to enable safe population renewal and maintain sustainable yield. The determination of the threshold value is generally difficult as it should be determined after the analysis of a period during which the stock was exploited at F_{MSY}. In the Mediterranean, stocks assessments are performed using standardized approaches and F_{MSY} proxy reference points, but B_{MSY} estimates are generally lacking. This is due to the lack of established stock/recruitment relationships (as a result of data series which are too short to compute good stock/recruitment relationships), and the absence of long time series of landings/catch data. The precautionary approach biomass (B_{PA}) reference point may be used as a proxy, but it's estimation also requires a long time series of data, including a period where the SSB was very high (ICES, 2015b). Moreover, even when SSB data is available, it is often not possible to compute an objective threshold to test the GES. For a lot of stocks assessed at the GFCM, the final diagnosis is therefore not based on B_{PA}. Instead empirical reference points can be proposed based on a comparison between the actual current SSB value, and the 33th and 66th percentile of the longest data series available.

D3C2.G2: Unknown SSB

For category 2 and 3 stocks, a spawning stock biomass index should be used. If yield values based on quantitative assessments are not available due to inadequate data, other biomass indices such as catch per unit effort or abundance indices from fisheries independent studies can be used as a substitute method. However, these still require long-term historical averages to be known to enable trend analyses. Such long-term data is generally lacking.

D3C3.G1: Unknown demographic characteristics

The demographic characteristics indicator is not yet operational since a threshold has yet to be defined (ICES, 2016). In addition, the interpretation of this descriptor may also prove difficult since demographic patterns may fluctuate naturally, for instance in the event of a large recruitment. Moreover, the definition of thresholds would require developing generic concepts to identify the reference demographic values of each stock in respect to the GES. Since fishery monitoring started after the beginning of exploitation, it is in most cases it is no longer possible to observe pristine population age and size-structures, or when exploited at MSY. This should therefore be simulated but this could lead to statistical redundancy with data used for D3C1 and D3C2 (ICES, 2017a, b). The recommendation is to monitor trends rather than setting thresholds for this descriptor in order to prevent stock demographic degradation (ICES, 2015b).

As a result of these uncertainties, only criteria D3C1 (Fishery Caused Mortality) and D3C2 (Spawning Stock Biomass)are evaluated at the moment, and only for those stocks for which these primary indicators exist, i.e. the very few Mediterranean stocks for which reference points (at maximum sustainable yield) can be computed.

2.3.3 Connections between descriptors

Relationships between gaps identified in D3 and other descriptors are illustrated as dark grey coloured cells in Table 2.2.

	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**	**D11**
D3-G1	▨		▨	▨				▨		▨	▨
D3-G2	▨		▨	▨		▨					
D3-G3	▨	▨	▨	▨		▨					
D3-G4	▨		▨	▨							
D3C1.G1	▨		▨	▨							
D3C1.G2	▨		▨	▨							
D3C2.G1	▨		▨	▨							
D3C2.G2	▨		▨	▨							
D3C3.G1	▨		▨	▨							

Table 2.2. *Representation of the connections between D3-identifed gaps and the rest of MSFD descriptors. Dark grey cells represent interconnections between the D3-gaps and the rest of descriptors. Format based on Cochrane et al. (2010). The left panels contain the gaps identified and described for Descriptor 3:* ***D3-G1*** *Low number of assessed stocks.* ***D3-G2*** *Spatial discrepancies and depth aggregation.* ***D3-G3*** *Data access to survey data.* ***D3-G4*** *Lacking international coordination at MFSD sub-area scale.* ***D3C1.G1*** *Using approximate reference point for fishery mortality.* ***D3C1.G2*** *Unknown fishing mortality in many cases.* ***D3C2.G1*** *Unknown objective for SSB.* ***D3C2.G2*** *Unknown SSB.* ***D3C3.G1*** *Unknown demographic characteristics.*

2.4 *DESCRIPTOR 4: ECOSYSTEMS, INCLUDING FOOD WEBS*

2.4.1 Major knowledge gaps concerning specific indicators and criteria

A correctly functioning marine food web is essential to maintain healthy marine ecosystem. This Descriptor is meant to cover the functional aspects of marine food webs, particularly rate and directions of energy transfer, and levels of productivity. However, the current knowledge about energy transfer between trophic levels and species interactions is not sufficient to meaningfully cover these, within the targets for this Descriptor. A pragmatic approach has been proposed, focused on the abundance, diversity, size distribution and productivity of key species and trophic groups within the food web. This implied a significant overlap with Descriptor 1, but also with D3, as fish and other species targeted by fishing activities are at the top of marine food webs, and D5, as alteration of food inputs, can impact in turn deep-sea food webs. Particularly, regarding D5 the concept of eutrophication *per se* is hardly attributed to the deep sea and the own name of D5 is not appropriate for deep ecosystems. The concepts of trophic guild, inputs of organic matter to the deep, changes in oxygen concentration need to be combined in a way that accounts for the functional requirements of the state descriptors to ensure efficient implementation of the MSFD. Further, the criteria and indicators established for this descriptor are not fully useful for the deep sea. We need to restore the «food» context to the eutrophication concept, by referring to changes in the trophic state (changes in food availability). Under this perspective, descriptors 4 and 5 have to be necessarily grouped when referring to deep-sea ecosystems. According to Commission Decision (EU) 2017/848, relevant pressures to be considered under D5 are the input of nutrients and of organic matter, two variables which are extremely useful for D4 determination in the deep sea. Specifically, the monitoring of nutrients levels and on those parameters, which are directly (e.g. Chl-a concentration, phytoplankton abundance and composition) or indirectly affected by them have clear implications for D4, as production in the deep is mostly related to organic carbon produced in the photic zone. Variation in nutrient levels may be linked in turn to environmental variability and anthropogenic activity and have to be taken into account on considerations of GES for D4. Further, according also to ICES indications (2015a), indicators' development should explicitly explore the role of lower trophic guilds on the likely assessment of GES for D4, the role of size in food web stability, and management strategy evaluations of the sensitivity of D4 indicators to anthropogenic pressures.

The Commission Decision (EU) 2017/848 identified the following criteria for Descriptor 4:

- D4C1 (primary): The diversity (species composition and their relative abundance) of the trophic guild is not adversely affected due to anthropogenic pressure.
- D4C2 (primary): The balance of total abundance between the trophic guilds is not adversely affected due to anthropogenic pressures.
- D4C3 (secondary): The size distribution of individuals across the trophic guild is not adversely affected due to anthropogenic pressure.
- D4C4 (secondary) (to be used in support of criterion D4C2, where necessary): Productivity of the trophic guild is not adversely affected due to anthropogenic pressures.

For this descriptor, a general lack of pertinent data for deep areas was underlined. The lack of data concerning experimental and functional ecology as well as energy fluxes was also highlighted revealing the existing problem of the knowledge gap and the need for further development.

As for the other descriptors, the collection of information must go along with a critical review of the data. As highlighted during tasks 2.1, 2.2. and 2.3, in the case of D4, online repositories do not enable the collection and organization of data, and few useful data for D4 could be derived from EMODnet database, within the portals on biology and human activities, especially regarding fishery impacts (IDEM Project, 2018c).

Moreover, the selection criteria stipulate that at least one trophic guild should be at the primary producer trophic guild. This is the major drawback for this descriptor as, with the exceptions of few and very localized ecosystems, i.e. based on chemosynthesis, such as hydrothermal vents, cold seeps or wood and whale falls, the vast majority of the deep sea lacks of primary production. In addition, connectivity among deep-sea ecosystems is poorly known. Therefore, for deep-sea ecosystems this constrains need to be removed and other trophic guilds at the base of the food web, such as deposit or suspension feeders (which are secondary consumers of low trophic level) can be considered alternatively.

Further, a precise definition of which anthropogenic pressures can affect the diversity of trophic guild is needed. Essentially two main human stressors can act adversely in modifying species composition and abundance of the trophic guilds in the deep sea: 1) bottom trawling activities and 2) pollution, in terms of contaminants, marine litter and micro/nanoplastics. Finally, although the ecological importance and impact of non-indigenous species is increasingly recognised in shallow water ecosystems, especially in the Mediterranean, which has been described as the most invaded sea in the world (Edelist et al., 2013), their presence beyond the shelf has scarcely been documented (Galil et al. 2018).

Here, we summarize the main effects these stressors may have on food webs, highlighting their repercussions for some or all the criteria established for D4.
In the case of bottom trawling, this can affect food webs in different ways:

i. By directly removing top predators and in general large size fish and thus producing the well-known “fishing down food webs” described by Pauly et al. (1998) and already highlighted for the deep sea (Morato et al., 2006).
ii. By impacting benthic communities, causing mortality of many benthic species because they are crushed directly by the trawl or become caught and have died by the time they are taken on deck and returned to the sea. This causes in turn changes in size structure and production (Jennings et al., 2002).

Thus, in general, mortality is size dependent, with larger bivalves suffering very high mortality vs. smaller bivalves and polychaetes with lower mortality (de Groot and Lindeboom 1994; Bergman and van Santbrink 2000). This suggests that intensive trawling may favour smaller species and, since these have higher P:B ratios, they may be more productive and compensate for the loss of production among larger species.

This has clear implications for all the criteria established by COMM/DEC/848/2017, in terms of changes in species composition and their relative abundance (D4C1), balance of total abundance between the trophic guilds (D4C2), size distribution of individuals across the trophic guild (D4C3) and productivity of the trophic guild (D4C4).

The same considerations can be applied regarding the second major stressor, i.e. pollution, although the impact, depending on the type of pollutants *lato sensu*, can be highly variable, both in terms of geographical (from very localized to generalized effects), and to the detrimental extent (from species reduction to mortality).

For example, in the case of marine litter, i.e. “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment” (UNEP definition), while clinkers are found to be a suitable substratum for some species, such as the brachiopod *Gryphus vitreus* in the Mediterranean, this substratum is not colonized by other sessile metazoan species (Ramirez-Llodra et al., 2013). Concerning microplastics, several studies have shown that their ingestion by invertebrates could facilitate the transport of hydrophobic contaminants (Teuten et al., 2007) and the release of potentially toxic bisphenol A and PS oligomers during plastic breakdown, which can disrupt hormonal functioning and reproductive systems in the fauna (Saido et al., 2009).

This represents of course a major gap, primarily for D10, as studies in the deep sea are practically non-existent and an urgent assessment of the impact of microplastics on deep-sea fauna, and the consequent implications for food web structure and functioning, is needed.

Finally, although very limited information on the occurrence of alien species in deep sea regions and their potential impact exists, they can represent, in the future a major threat for deep-sea communities and food web structure and functioning, as demonstrated for coastal fish communities in Lebanese water (Fanelli et al., 2015). This is particularly true under a climate change scenario, with a Mediterranean becoming increasingly warm, also in the deep-water masses.

For example, the *Pterois miles*/*volitans* complex, after their first occurrence (Golani and Sonin, 1992; Gurlek et al., 2016), are increasingly recorded in the Levantine basin (Kletou et al., 2016; Bariche et al., 2013), and *P. miles* also in the Central Mediterranean (Azzurro et al., 2017) need to be considered with extreme caution, as this species is known to profoundly affect native food webs, by influencing different levels of the trophic chain through the inclusion in their diet of a variety of invertebrates, small fishes and juveniles of larger species (review by Hixon 2015) in the Caribbean and throughout the whole Atlantic coast from USA (Layman & Allgeier, 2012) to Brazil (Bumbeer et al., 2018). Although, it is known as a coastal species, it was found in deep waters in the western Atlantic (to 304 m off Bermuda) (Gress et al., 2017) or Honduras (at 250 m, with water temperature 15°C, off Roatan island), and this call for efforts to establish the maximum depth distribution of lionfish in the Mediterranean Sea.

Main gaps regard also the lack of spatial coverage of data and long-term data series, and this is applicable to all the criteria identified for D4. As data for D4 are mainly derived by MEDITS data or those collected during the data collection framework, both related to EU members states, there is a clear gap in knowledge at spatial scale, as the non-EU states are less or no covered by GFCM (also due to political problems, see Libya for example). Moreover, despite MEDITS data are available since 1984, additional information on species belonging to lower trophic level have been collected since later (i.e. 2000-ongoing). Thus, long-term data series exist only for EU Member states and regarding species in the “G1 category”, which means, for deep-sea communities, red shrimps, Norway lobster, rose shrimp among crustaceans, all sharks including strictly deep-sea species, the horned octopus (*Eledone cirrhosa*) among cephalopods, and some bony fishes (i.e. *Merluccius merluccius*, *Lophius* spp., *Pagellus acarne*, *Micromesistius poutassou* and *Mullus* spp. at the upper boundaries of their distribution).

Finally, a general gap, also applicable to all criteria is the absence of knowledge regarding threshold and reference values, as many member states at the moment have no monitoring program for D4 or in general scarcely considered this descriptor.

Here below are briefly summarized <u>these three gaps for the 4 criteria</u>.

D4C1.G1. Lack of data on pressures (i.e. estimation of the impact of trawling, pollution and NIS) on the diversity of higher, intermediate and lower trophic levels;
D4C1.G2. Lack of spatial coverage of data and long-term data series to assess the diversity of higher, intermediate and lower trophic levels;
D4C1.G3. Absence of knowledge regarding threshold and reference values on the diversity of higher, intermediate and lower trophic levels;

D4C2.G1. Lack of data on pressures on the balance of total abundance of higher, intermediate and lower trophic levels
D4C2.G2. Lack of spatial coverage of data and long-term data series to assess the balance of total abundance of higher, intermediate and lower trophic levels;
D4C2.G3. Absence of knowledge regarding threshold and reference values on the balance of total abundance of higher, intermediate and lower trophic levels;

D4C3.G1. Lack of data on pressures on the size distribution of individuals of higher, intermediate and lower trophic levels
D4C3.G2. Lack of spatial coverage of data and long-term data series on the size distribution of individuals of higher, intermediate and lower trophic levels
D4C3.G3. Absence of knowledge regarding threshold and reference values on the size distribution of individuals of higher, intermediate and lower trophic levels.

D4C4.G1. Lack of data on pressures on the productivity of higher, intermediate and lower trophic levels
D4C3.G2. Lack of spatial coverage of data and long-term data series on the productivity of higher, intermediate and lower trophic levels
D4C3.G3. Absence of knowledge regarding threshold and reference values on the productivity of higher, intermediate and lower trophic levels.

2.4.2 Additional gaps concerning relevant topics poorly or not addressed within the existing MSFD-defined criteria

D4AG.G1. Omission of fisheries discards as artificial nutrient input to the benthic compartment
As highlighted also for D6, great number of marine organisms are discarded in areas of commercial fishing. When the discarding occurs regularly, these additional inputs constitute a major trophic resource for the whole ecosystem (Bozzano and Sardà, 2002). Such anthropogenic food inputs may affect surface, mid-water and benthic communities, altering the structure and functioning of food webs. This gap is relevant also for descriptors 1, 3 and 6.

D4AG.G2 Omission of changes in oceanographic variables, i.e. temperature and salinity increase/oxygen depletion as drivers of changes in food web structure and functioning
Deep-sea fauna is strongly affected by changes in water masses characteristics. For example, the general warming trend observed in the deep waters of the western Mediterranean with an increase in temperature by ~0.12°C over the past 30 yr (Williams 1998, Rixen et al. 2005) has reduced bacterial density and activity, and, together with the trend of decreasing oxygen levels in deep waters, is contributing to the reduced remineralisation of organic matter (Danovaro et al. 2001). Still, the increased salinity in the Levantine Intermediate Water (LIW) has been correlated with the decline of deep-living shrimps (Cartes et al. 2011) and sharks (Cartes et al. 2013). A recent study (Fanelli et al., 2016) showed how changes in oceanographic variables have caused a decrease in the mean trophic level (in terms of a δ^{15}N drop) of deep-sea species.

The study examined 21 species, collected below 1000 m (i.e. on deep-sea bottoms not affected by trawl-fishery) over a period of 30 years and found a drop in $\delta^{15}N$ in the bulk of them, ultimately related to measured increase of bottom temperature and salinity and decrease of bottom oxygen concentration. Thus, a correct estimation of D4 criteria has to take into account also measures of essential oceanographic variables such as temperature, salinity and oxygen concentration, in cross-relation with D5 and D7.

2.4.3 Geographical gaps

This section refers to the main geographical gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of geographical gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018a).

D4GG.G1 Heterogeneous geographical data coverage

As highlighted in Report 2.1 e 2.2 for this descriptor, there is a clear geographic gradient regarding knowledge and data from North to South Mediterranean and from the western to the eastern basins. Overall, the analysis of literature evidenced only five papers for the Central/Ionian basin and six from the Aegean/Levantine. Concerning the Western Basin, most studies focused on isotopic data, which allows deriving information for the primary criterion D4C1) and in part for one of the secondary criteria (D4C3). This latter case occurred in some of the papers, as few reported data on abundance/biomass or size of the specimens analysed and/or of the population where the samples come from. Further, as already highlighted for other descriptors, apart from analysing gaps between large sub-regions (i.e. southern vs. northern Mediterranean Sea), smaller spatial scales should be considered as well.

2.4.4 Bathymetric gaps

This section refers to the main bathymetric gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of bathymetric gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018a).

D4BG.G1 Uninspected depth-ranges

Regarding bathymetry, the main gap involves depths below 800 m, as the bulk of information come from “fishery independent” and “fishery-dependent” data, which focused on commercially exploited stocks, located above 800 m of depth, as described above.

Below 800-1000 meters, there are very few studies, considering one of the two approaches examined in Report 2.1, identified as the most suitable to quantify marine food webs, i.e. stable isotope analysis and modelling (*sensu* Ecopath with Ecosim). Still, when data exist, these studies are generally local/regional. Additionally, the connection between the pelagic and benthic compartments in the deep sea should deserve further studies.

2.4.5 Habitats and species gaps

The concept within this section is mostly relevant for descriptors D1, D2, D3 and certainly, for D4. However, as reported above, most of studies have been performed along canyons and open slope.

D4HS.G1 Conservation of unique habitats of the deep Mediterranean Sea

The WWF Mediterranean Program and the IUCN Centre for Mediterranean Cooperation generated a proposal for conservation (Cartes et al., 2004), including a list of unique environments of the deep Mediterranean Sea, namely:

- Cold seeps
- Brine pools
- Cold-water corals (CWC) inhabiting the deep-sea
- Seamounts

Besides some studies regarding CWC in Western Mediterranean and Central-Ionian submarine canyons and escarpments (e.g. Orejas et al., 2009; Lastras et al., 2016; D'Onghia et al., 2017) and a few seamounts (Galil and Zibrowius, 1998; Clark, 2009; Taranto et al., 2012; Pham et al., 2013, 2014; Woodall et al., 2015), state assessments and pressure identification studies are still missing for a large part of these unique habitats and for most of the locations where they occur.

Further, concerning D4, there is one study, based on isotopic data (hereafter named SIA), carried out in the "S. Maria Di Leuca CWC province", where authors compared stable isotopic values of some benthic and demersal fishes collected in the province with samples from adjacent areas, potentially affected by deep-sea fishery (Carlier et al., 2009). Another study was carried out in the Napoli and Amsterdam mud volcanoes, in order to assess the energetic pathways and carbon sources on deep Mediterranean cold seep communities (Carlier et al., 2010). However, despite the detailed information reported in these two papers, they are very local, and it is difficult to extrapolate general data for state assessments and pressure identification of these two habitats (i.e. CWCs and cold seeps).

D4HS.G2 Lack of accurate assessments and pressure identification analyses of deep-sea habitats in Mediterranean Sea EBSAs

The Convention on Biological Diversity[9] promotes the designation of Ecologically or Biologically Significant Areas (EBSA) to support the conservation of the oceans. A total of 15 EBSA have been defined for the Mediterranean Sea[10], namely from west to east:

- North-western Mediterranean Benthic Ecosystems
- North-western Mediterranean Pelagic Ecosystems
- Sicilian Channel
- Gulf of Gabès, off Tunisia
- Gulf of Sirte, off Lybia
- Northern Adriatic
- Jabuko/Pomo Pit, in the central Adriatic Sea
- South Adriatic Ionian Strait
- Hellenic Trench
- North Aegean

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[9] https://www.cbd.int/.

[10] https://www.cbd.int/ebsa/.

- Central Aegean Sea
- North-East Levantine Sea
- Akamas and Chrysochou Bay, in Cyprus
- East Levantine Canyons (ELCA)
- Nile Delta Fan

Revisions of the habitats located within these EBSAs, most of which correspond to deep-sea areas, should be performed in order to provide accurate assessments and pressure identification analyses.

D4HS.G3 Effects of dense-shelf water cascading (DSWC) on deep-sea food webs (extended to all 4 criteria)

Cascading events play a relevant role in biogeochemical cycles (Shapiro et al., 2003), particularly in the Mediterranean oligotrophic system, with increasing oligotrophy eastwards, low surface primary production and in turn low organic matter sinking to deep waters. In the areas of the Mediterranean, where DSWC is known to occur (i.e. the Gulf of Lion, The Southern Adriatic Sea and the Aegean Sea), DSW cascading sustains transport of particles and organic matter from shallow areas to the deep sea (Canals et al., 2006; Tesi et al., 2008; Sanchez-Vidal et al., 2012). Thus, new food inputs from cascading events have a strong influence on deep-water communities by altering food availability and especially the origin of food sources for deep-sea food webs. A recent study (Conese et al., in press), based on SIA data, showed that the deep-sea zooplankton collected in the sediment traps along the southern Adriatic margin and in the Bari canyon, were affected by both a vertical flux from the euphotic zone, but also by a lateral flux driven by physical processes related to sediment transfer through DSW cascading (Langone et al., 2016). Thus, the monitoring of criteria related to descriptor 4 should be carried out, in those critical deep-sea ecosystems interested by cascading events, such as the slopes of the Gulf of Lions, the southern Adriatic Sea and the deeper portion of the northern Aegean Sea. Finally, a complete evaluation of the state of these deep-sea areas and the identification and quantification of the main pressures that they are exposed to are currently lacking (IDEM Project, 2017).

2.4.6 Methods and technologies gaps

D4MT.G1 Lack of standardized methods and detailed guidelines for assessments

Commission Decision (EU) 2017/848 reports that, for beyond coastal water, the criteria elements and the threshold values should be chosen and established by Member States through regional or subregional cooperation. There is the need to adapt methodologies developed within previous directives (i.e., WFD) to offshore and deep-sea areas, which constitutes a crucial gap for the MSFD.

D4MT.G2 Lack of monitoring networks and online platforms/database for data sharing regarding eutrophication/organic enrichment in the deep sea

Most of data available regarding coastal environments were acquired in programs within the framework of other directives and initiatives (such as the WFD, the Habitat Directive and the Natura 2000 network), within European projects (such as IRIS-SES, PERSEUS, EMODNET) or EU monitoring programs of fishery resources, such as MEDITS (MEDiterranean International Trawl Survey), DCF (Data Collection Framework) or MEDIAS (MEDiterranean International Acoustic Survey). Online databases enable the collection and organization of large amounts of data that could be easily shared by the scientific community. Considering the importance of such repositories, it is recommended also for Descriptor 4 to define standard protocols for data acquisition and common procedures for data sharing (agreed among Member States), besides representative sites and key areas for monitoring programs.

D4MT.G3 Inadequacy of integrative models for food webs in the deep sea

"Marine food webs" are well represented in current models reviewed by Piroddi et al. 2015, who listed 43 models acceptable for "food webs". Some of them are "End-to-end" models, which are probably the best candidate to address food webs in the deep-sea. Other valid models can be "multispecies" or "habitat suitability" models, however all these models, including "end-to-end" ones, may fault in representing major links, nodes or sink, if lower trophic levels and/or very small-size species, (i.e. from meiofauna to microbes) are not considered in the study. Ecological models may be very helpful in depicting future scenario of food web structure and functioning, under increasing human footprint, such as fishery or increased temperature/decreased oxygen in deep waters. The development and extended use of integrative models encompassing physical drivers, biodiversity and ecosystem processes, would be useful for the monitoring of deep-water benthic ecosystems.

D4MT.G4 Uncertainties on assessment methods for some additional criteria

Currently no clear standardized or harmonized methodologies are used for D4 assessment. Some Member states (i.e. France, Italy) have proposed the use of stable isotopes analysis. SIA are based on well-defined and standardized protocols, but harmonization of procedures and intercalibration of instruments are needed, as instrument bias can occur (Mill et al., 2008).

On the other hand, the UK in 2012 proposed to monitor large fishes, as indicative of sustainable populations and in turn of GES for D4. However, in order to have data on large individuals in fish populations, an extension of the present monitoring programs is required. As previously highlighted, the current EU programs for the assessment of demersal or pelagic resources target commercial species, which not represent the whole deep-sea food- web key- species.

Finally, as for other descriptors (D1, D2 or D5), the monitoring of some small compartments such as meiofauna or micro/mesozooplankton, may represent a severe constrain linked to organism identification. Highly specialized taxonomic expertise is needed to support extensive monitoring activities. The cost and effort to sort, count, and identify benthic or zooplanktonic invertebrates can be significant, requiring trade-offs between expenses and the desired level of confidence. In addition to taxonomic identification, benthic/pelagic invertebrate metrics may require knowledge of the feeding group to which a species belongs (i.e. suspension or deposit feeders and even sub-surface or surface deposit feeders). The advent and recent widely use of metabarcoding to identify macro and meiofauna can fasten their identification and open new perspective also for biodiversity monitoring and GES assessment (Aylagas et al., 2014; Carugati et al., 2015).

2.4.7 Connections between D4 gaps and the rest of descriptors

This section focuses in illustrating D4 related gaps that are also relevant for other descriptors.

Relationships between gaps and descriptors are illustrated as dark grey coloured cells in Table 2.3. The interconnections are identified when a gap described for D5 is also relevant for other descriptors, affecting other ecosystem components represented by state descriptors (i.e. D1, D3 and D4) or complementing pressures defined by pressure-based descriptors (i.e. D2, D5, D7, D8, D9, D10 and D11). The gaps defined under sections 2.4.3, 2.4.4 and 2.4.5 are not added to the table since all identified deficiencies are already considered relevant for all descriptors.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D4C1.G1	▓		▓	▓		░					
D4C1.G2	▓			▓	░			░	░	░	
D4C2.G3	▓	▓		▓							
D4C2.G1	▓		▓	▓		░					
D4C2.G2	▓			▓	░			░	░	░	
D4C3.G3	▓	▓		▓							
D4C3.G1	▓		▓	▓		░					
D4C3.G2	▓			▓	░			░	░	░	
D4C3.G3	▓	▓		▓							
D4C4.G1	▓		▓	▓		░					
D4C4.G2	▓			▓	░			░	░	░	
D4C4.G3	▓	▓		▓							
D4AG.G1	▓		▓	▓	░	░					
D4AG.G2	▓		▓	▓	░		░				
D4GG.G1	▓		▓	▓							
D4BG.G2	▓			▓							
D4HS.G1	▓			▓		░					
D4HS.G2	▓			▓		░					
D4HS.G3	▓		▓	▓		░	░				
D4MT.G1	▓	▓	▓	▓							
D4MT.G2	▓	▓	▓	▓							
D4MT.G3	▓	▓	▓	▓							
D4MT.G4	▓	▓	▓	▓							

Table 2.3**.** *Representation of the connections between D4-identified gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D4-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 4*: ***D4C1-C4.G1*** *Lack of data on pressures (i.e. estimation of the impact of trawling, pollution and NIS) on the diversity (D4C1), balance of total abundance (D4C2), pressures on the size distribution of individuals (D4C3) and on the productivity (D4C4) of higher, intermediate and lower trophic levels.* ***D4C1-4.G2*** *Lack of spatial coverage of data and long-term data series to assess the diversity (D4C1), balance of total abundance (D4C2), pressures on the size distribution of individuals (D4C3) and on the productivity (D4C4) of higher, intermediate and lower trophic levels.* ***D4C1-4.G3*** *Absence of knowledge regarding threshold and reference values on the diversity (D4C1), balance of total abundance (D4C2), pressures on the size distribution of individuals (D4C3) and on the productivity (D4C4) of higher, intermediate and lower trophic levels.* ***D4AG.G1.*** *Omission of fisheries discards as artificial nutrient input to the benthic compartment.* ***D4AG.G2*** *Omission of changes in oceanographic variables, i.e. temperature and salinity increase/oxygen depletion as driver of changes in food web structure and functioning.* ***D4GG.G1*** *Heterogeneous geographical data coverage****.*** ***D4BG.G1*** *Uninspected depth-ranges.* ***D4HS.G1*** *Conservation of unique habitats of the deep Mediterranean Sea.* ***D4HS.G2*** *Lack of accurate assessments and pressure identification analyses of deep-sea habitats in Mediterranean Sea EBSAs.* ***D4HS.G3*** *Effects of dense-shelf water cascading (DSWC) on deep-sea food webs.* ***D4MT.G1*** *Lack of standardized methods and detailed guidelines for assessments.* ***D4MT.G2*** *Lack of monitoring networks and online platforms/database for data sharing regarding food web structure and functioning in the deep sea.* ***D4MT.G3*** *Inadequacy of integrative models for food webs in the deep sea.* ***D4MT.G4*** *Uncertainties on assessment methods for some additional criteria*

2.5 *DESCRIPTOR 5: EUTROPHICATION*

2.5.1 Major knowledge gaps concerning specific indicators and criteria

DATA AVAILABILITY

Eutrophication is a severe problem particularly in shallow sub-basins with limited flushing, such as the Adriatic Sea and along the Mediterranean's southern shore. The CorrGEST meeting held in February 2014 in Athens agreed on the following common indicators with regards to ecological objective 5 on Eutrophication: i) Concentration of key nutrients in the water column and ii) Chlorophyll α concentration in the water column. However, threshold values for eutrophication related parameters are still lacking for some coastal areas and have to be developed (UNEP-MAP, 2015).

Scientific and grey literature dealing with eutrophication in the Mediterranean Sea is exclusively related to coastal environments. Indeed, the deep sea has been historically considered as a food-poor ecosystem. This is not completely true since some massive phytodetritus exports from surface waters to the deep-sea floor have been previously reported (Billet et al., 1983; Canals et al., 2006), with important consequences on the abundance, biomass, biodiversity, metabolism, and distribution of deep-sea species (Danovaro et al., 2014). Some deep-sea areas either along the water column, at the water sediment interface, or within the sediment may experience severe effects of oxygen depletion linked to the excess of organic matter deposition deriving from eutrophication (Danovaro et al., 2014). In short, some deep-sea areas are more eutrophic than previously thought.

Two main types of gaps appear as the most relevant regarding D5 in the deep Mediterranean Sea: i) lack of data pertaining to Descriptor 5 and ii) the lack of thresholds of indicators. These gaps complicate the assessment of GES related to eutrophication in the deep Mediterranean Sea.

Descriptor 5, Criterion 1 (D5C1): Nutrients in the water column

According to Commission Decision (EU) 2017/848, the concentrations of nutrients in the water column should be at levels that do not indicate adverse eutrophication effects. In coastal waters, the criteria elements shall be selected and used in accordance with the Directive 2000/60/EC. Whereas, beyond coastal waters, Member States may decide at regional or sub-regional level to not use one or several of these nutrient elements. The Commission Decision (EU) 2017/848 specifies that information on the pathways (atmospheric, land- or sea-based) for nutrients entering the marine environment shall be collected, where feasible.

The D5C1 can be applied to the deep sea but provide very limited indications on the potential effect of eutrophication and these measures should be considered only as support measures. In addition, all the parameters developed under WFD need to be adapted to deep-sea and offshore areas.

D5C1.G1 Lack of spatial coverage of data and long-term data series

The available data regarding nutrients in the water column are mostly related to coastal areas for which many countries have extensive datasets acquired through national monitoring programs in the framework of WFD and MSFD implementation or the Regional Sea Conventions, national or international research programs, technical reports, scientific publications and satellite imagery (Crise et al., 2015). Conversely, data on open waters and deep-sea environments lack spatial coverage and long term series to allow the choice of appropriate criteria elements and thus the assessment of GES (Crise et al., 2015).

D5C1.G2 Lack of data on pressures

Very few information regarding pressures (monthly/seasonal variation, natural/anthropogenic sources) on nutrient dynamics are supported by a sufficient data base in the deep sea (Crise et al., 2015).

D5C1.G3 Absence of knowledge regarding threshold and reference values

As reported in Commission Decision (EU) 2017/848, the threshold values are as follows: (a) in coastal waters, the values should be set in accordance with the Directive 2000/60/EC; (b) beyond coastal waters, values should be consistent with those for coastal waters under Directive 2000/60/EC. Member States shall establish those values through regional or subregional cooperation. Several countries are able to propose thresholds for this criterion, as an operational methodology was developed in the framework of previous directives (i.e., the WFD). However, the available methodologies are only adapted to coastal waters. All countries highlight the need to adapt these methodologies to offshore and deep-sea areas. Thresholds and reference conditions for nutrients in the deep Mediterranean Sea must be set, in the near future, through dedicated monitoring and workshops. Nutrient thresholds and reference values may not be identical for all areas, since each area present specific environmental conditions and thus each area must define the most appropriate ones (UNEP-MAP, 2015).

D5C1. G4 Unsuitable criterion for oligotrophic regions

The concentration of nutrients does not represent the most suitable criterion to assess Descriptor 5 in oligotrophic regions. Deep-sea ecosystems are commonly considered as oligotrophic, but some deep-sea areas may experience severe hypoxic or anoxic conditions linked to the excess of organic matter loads (Danovaro et al., 2014). Oxygen depletion and biological criteria/indicators (biodiversity and taxonomic composition of benthic assemblages) should be used besides nutrient concentrations, being in some cases more representative for eutrophication than the latter.

Descriptor 5, Criterion 2 (D5C2): Chlorophyll-a in the water column

According to the Commission Decision (EU) 2017/848, Chlorophyll-a concentrations should be not at levels that indicate adverse effects of nutrient enrichment. Member States may in addition use phytoplankton species composition and abundance in coastal waters, but these indicators are not applicable to the deep sea. As for D5C1, the exiting WFD parameters need to be adapted to offshore and deep-sea areas.

Criterion D5C2 is not applicable as it is to the deep sea.
The determination of chl-a concentration in sediments can provide important insights into the trophic state of the area. See below “additional gaps”.

Descriptor 5, Criterion 3 (D5C3). Harmful algal blooms (e.g. cyanobacteria) in the water column

According to Commission Decision (EU) 2017/848, the number, spatial extent and duration of harmful algal bloom events are not at levels that indicate adverse effects of nutrient enrichment. As stated for D5C2, for the assessment of D5C3, Member States may in addition use phytoplankton species composition and abundance, but they cannot be applied to the deep sea.

Criterion D5C3 is not applicable as it is to the deep sea.

It is indeed more important to monitor cysts of harmful algae in deep-sea sediments (Ferreira et al., 2007; Danovaro, 2010). See below “additional gaps”.

Descriptor 5, Criterion 4 (D5C4). Photic limit (transparency) of the water column

Criterion D5C4 is not applicable to the deep sea.

Descriptor 5, Criterion 5 (D5C5). Dissolved oxygen in the bottom of the water column

According to the Commission Decision (EU) 2017/848, D5C5 refers to concentration of dissolved oxygen that is not reduced due to nutrient enrichment to levels that indicate adverse effects on benthic habitats (including associated biota and mobile species) or other eutrophication effects.

Gap types described within D5C1 section are also relevant for criterion D5C5. Amongst them, the lack of data for offshore and deep-sea areas is particularly relevant.
In addition to measures of oxygen concentration in the water column, the potential oxygen depletion in sediments must be monitored as it affects benthic assemblages and in turn biodiversity and ecosystem functioning. See below, “additional gaps”.

Descriptor 5, Criterion 6 (D5C6). Opportunistic macroalgae of benthic habitats

Criterion D5C6 is not applicable to the deep sea.

Descriptor 5, Criterion 7 (D5C7). Macrophyte communities of benthic habitats

Criterion D5C7 is not applicable to the deep sea.

Descriptor 5, Criterion 8 (D5C8). Macrofaunal communities of benthic habitats

For criterion D5C8, the Commission Decision (EU) 2017/848 reports that the taxonomic composition and values of relative abundance of macrofaunal communities are at levels that do not indicate any adverse effects due to nutrient and organic enrichment. Species composition shall be analysed referring to the lowest taxonomic level appropriate for the assessment.

Organic matter enrichment in deep-sea sediments can cause hypoxic/anoxic conditions, which in turn can affect benthic assemblages, causing a reduction of the most sensitive components (Kemp and Boynton, 1992; Heip, 1995; Ritter and Montagna, 1999). The benthic assemblages can be utilized to investigate and characterize the habitat where the community lives. Indeed, benthic fauna plays a pivotal role in sedimentary organic matter diagenesis and nutrient cycling and, at the same time, is a very sensitive component to environmental changes, including oxygen depletion (Brown et al., 2004).

Macrofaunal biodiversity, whose ecological traits have been widely associated to ecological alteration, is commonly utilized for the classification of the ecological status of marine benthic ecosystems (Borja and Dauer, 2008). Macro-invertebrates are sensitive to disturbances and respond fairly quickly with changes in abundance and species composition. Each macro-invertebrate species has sensitive life stages that respond to stress and integrate effects of short-term environmental variations. Community composition depends on long-term environmental conditions.

Gap types described within D5C1 section are also relevant for criterion D5C8. Amongst them, the lack of data spatial and temporal coverage and threshold values especially for offshore and deep-sea areas are particularly relevant.
In addition to macrofaunal assessment, it is highly recommended to include the monitoring of meiofauna in MSFD as it is also sensitive to organic matter enrichment and oxygen depletion. See below, "additional gaps".

D5C8.G1 Lack of spatial coverage of data and long-term data series
The available data regarding macrofaunal assemblages vary depending on species groups and habitat types. Most of the data published in scientific papers cover few habitat types, i.e., open slopes, canyons and cold-water coral ecosystems. Thus, we need to increase the spatial coverage of data, including neglected habitats, and collect long-term data series to allow the appropriate assessment of this criterion.

D5C8.G2 Lack of data on pressures
There is a lack of quantitative data on nutrient dynamics and organic enrichment and their effects on benthic assemblages in the deep Mediterranean Sea.

D5C8.G3 Absence of knowledge regarding threshold and reference values
The threshold values defined by the Commission Decision 2017/848 are as follows: (a) in coastal waters, the values should be set in accordance with Directive 2000/60/EC; (b) beyond coastal waters, values should be consistent with those for coastal waters under Directive 2000/60/EC. Methodologies developed under WFD and MEDPOL shall be adapted to offshore and deep-sea areas, in order to set threshold values for this criterion also for the deep Mediterranean Sea (Laroche et al., 2013).

2.5.2 Additional gaps concerning relevant topics poorly or not addressed within the existing MSFD-defined criteria

In coastal ecosystems, the main cause that induces eutrophication is nutrient input. As a result, the excess of biomass undergoes decomposition processes determining a rapid oxygen consumption (due to chemical and biological oxidations processes) which causes, in turn, a reduction in dissolved oxygen availability, with important and in some cases lethal effects on organisms (Vaquer-Sunyer and Duarte, 2008).
Druon et al. (2004) reported that, in deep sea, hypoxia or anoxia are not typically caused by anthropogenic activities and their relative direct impacts. No severe oxygen deficiency or depletion are expected to arise from anthropogenic sources such as terrestrial input. Deeper than 100 m depth, in the absence of a permanent stratification, the rate of organic matter remineralisation is high enough to prevent any important oxygen deficiency near the sea bottom.
However, an excess of organic matter deriving from any source, comprising primary production, and exported to the deep-sea floor, might determine detrimental effects when the excess of organic matter loads causes a reduction in oxygen availability (Dell'Anno et al., 2002; Pusceddu et al., 2010). Climate change and coastal eutrophication may enhance oxygen deficiency in some deep-sea regions such as the Ionian Sea receiving inputs from the Adriatic Sea, or in deep-sea sediments facing highly productive areas such as Gulf of Lion or in the northern Aegean Sea.

The deep-sea initial assessments, aimed at responding to the requirements of the MSFD criteria, tended to extrapolate the existing information from the coastal areas to the open seas. This is a major pitfall in MSFD initial assessments, since the analysis of the pressure/impact show how, even considering similar pressures, the states and impacts may be different in deep sea than coastal ecosystems. However, the consequences of the variations in trophic state and oxygen availability on deep-sea biodiversity and ecosystem functioning are still poorly studied (Crise et al., 2015).

Most of the criteria related to descriptor 5 proposed by the MSFD and revised by the Commission Decision (EU) 2017/848 are not applicable as they are to the deep sea.
A new Descriptor devoted to the measurement of organic enrichment, oxygen depletion and their consequences on benthic biodiversity and ecosystem functioning should be developed specifically for the deep sea.

In this regard we here below describe relevant topics poorly or not addressed within the existing MSFD-defined criteria, and thus to be included in a new definition of Descriptor 5 for deep sea.

D5AG.G1Lack of knowledge about pressures on the deep Mediterranean Sea

Currently, indicators for assessing macro-benthic communities have been proposed by several authors and for different marine regions. However, as outlined above, quantitative indicators concerning pressures on nutrients dynamics and oxygen concentrations are still lacking. Therefore, assessment of pressures and the development of appropriate indicators for deep sea represent priorities for the near future (Crise et al., 2015).

D5AG.G2 Lack of knowledge on cysts of harmful algae in the deep sea

Deep-sea sediments can be repositories of cysts of harmful algae. These cysts (either in quiescence of diapauses) can suddenly determine bloom reaching the coastal areas through upwellings. Thus, their presence should be monitored through standard international approaches and methodologies (Ferreira et al., 2007).

D5AG.G3 Oblivion of oxygen concentrations in deep-sea sediments

Oxygen depletion is one of the main causes of benthic faunal mortality, also in deep-sea areas. The upper oxidised part of the sediment is separated from the reduced one occurring below a recognizable division layer known as the redox potential discontinuity (RPD) (Fenchel and Riedl, 1970). The measure of RPD gives useful information especially in relation to sedimentary pattern and organic loading processes which can affect benthic assemblages. It is highly recommended to measure temporal and spatial evolutions of redox potential in deep-sea sediments (Pusceddu et al., 2009).

D5AG.G4 Oblivion of meiofauna

Besides macrofauna, also meiofauna, due to their high abundance and diversity (Vincx et al., 1994), high turnover rates and lack of larval pelagic dispersal, have attracted increasing attention as a tool for detecting anthropogenic impacts and for ranking the environmental quality status both in coastal and deep-sea ecosystems (Danovaro et al., 1995; Mazzola et al., 2000; Fraschetti et al., 2006; Pusceddu et al., 2007; Gambi et al., 2009; Mirto et al., 2010; Pusceddu et al., 2011; Mirto et al., 2014; Pusceddu et al., 2014; Bianchelli et al., 2016; Pusceddu et al., 2016). Meiofauna are ubiquitous and play important roles in the processing and redistribution of food reaching the abyssal seafloor (Rex and Etter, 2010). Meiofauna, including foraminifera, are sensitive to environmental disturbances, particularly to organic enrichment and eutrophication (Vollenweider et al., 1998; Pusceddu et al., 2011; Bianchelli et al., 2016).
Since meiofauna and macrofauna have different ecological roles in marine ecosystems (Coull and Palmer, 1984), they may respond to environmental changes at different spatial and temporal scales. Indeed, with its planktonic larval dispersal, macrofauna could be indicative of effects over larger spatial and longer temporal scales. On the other hand, with direct benthic development, and short generation times,

meiofauna (i.e., metazoan component) may indicate effects over smaller spatial and shorter temporal scales than macrofauna (Coull and Palmer, 1984). Thus, meiofauna, in terms of biodiversity and taxonomic composition, should be included as new indicator of Descriptor 5 (IDEM Project, 2017).

D5AG.G5 Oblivion of quantity and quality of sedimentary organic matter and its bioavailable fraction
Clear evidence shows that lateral advection delivers much of the organic flux on continental margins to the deep-sea floor with massive and frequent downward transport (Canals et al., 2006).
The sedimentary contents of the main biochemical organic matter compounds as protein, carbohydrate, lipid, biopolymeric C (the sum of C deriving from protein, carbohydrate and lipid) and its algal fraction have been repeatedly utilized to assess the benthic trophic status of several marine coastal ecosystems in Mediterranean sub-basins, also impacted by human activities (Dell'Anno et al., 2002; Pusceddu et al., 2009; Pusceddu et al., 2011; Pusceddu et al., 2014; Bianchelli et al., 2016). Quantity and biochemical composition of the sedimentary organic matter have been increasingly used to assess the benthic trophic status of marine ecosystems also in deep-sea habitats and thus should be included as criteria to assess GES.
In addition, in the past, food availability to the benthos has been quantified simply by measuring bulk organic matter or characterizing its composition in detail but without considering the importance of its bioavailability to consumers. In systems rich in organic matter, rapid transformation of organic molecules, and particularly biopolymers, leads to complexation processes that produce high molecular weight compounds (e.g., humic and fulvic acids) that consumers cannot digest easily. Therefore, the higher palatable deep-sea fraction might significantly offset the low overall quantity of organic carbon observed in many deep-sea sediments, reducing differences from their shallow counterparts (Danovaro et al., 2014). For these reasons, it is also important to include in the GES assessment the bioavailability of organic matter to consumers.

2.5.3 Geographical gaps

This section refers to the main geographical gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of geographical gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018a).

D5GG.G1 Heterogeneous geographical data coverage
Central/Ionian and Aegean/Levantine basins of the Mediterranean Sea clearly appear as the largest geographical data gaps concerning Descriptor D5 since only 4 studies, in total, were identified there. Concerning the Western Basin, most studies focus on the concentrations of Chlorophyll-a (IDEM Project, 2018c). Consequently, spatial fragmentation of knowledge and data becomes apparent. Apart from analysing gaps between large subregions (i.e. southern vs. northern Mediterranean Sea), smaller spatial scales should be considered as well.

2.5.4 Bathymetric gaps

This section refers to the main bathymetric gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of bathymetric gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018a).

D5BG.G1 Uninspected depth-ranges
Most of the studies revised regarding to Descriptor D5 omit depths below 2000 m. The deepest parts of the Mediterranean Sea (> 2,000 m depth) are practically neglected in the current literature. Additionally, the connection between the pelagic and benthic compartments in the deep-sea should deserve further studies.

2.5.5 Habitats and species gaps

The concept within this section is mostly relevant for descriptors D1, D2, D3 and D4. However, as reported above, most of studies have been performed along canyons and open slope.

D5HS.G1Conservation of unique habitats of the deep Mediterranean Sea
For descriptor 5 the same applies as stated above for D4HS.G1 (Section 2.4.5).

D5HS.G2Lack of accurate assessments and pressure identification analyses of deep-sea habitats in Mediterranean Sea EBSAs
For descriptor 5 the same applies as stated above for D4HS.G2 (Section 2.4.5).

D5HS.G3 Absence of a full assessment on the state of deep-sea areas influenced by high energy oceanographic processes (i.e. DSWC)
Recent studies have demonstrated the relevance for the Mediterranean Sea of mass and energy transfers from shallow continental shelf to the deep basins through high-energy, episodic processes like dense shelf water cascading (DSWC), open sea convection and severe coastal storms. Such events carry huge amounts of sediments, organic matter and volcanic dust playing a fertilizing role also in the deep sea (Canals et al., 2006; Sanchez-Vidal et al., 2012; Durrieu de Madron et al., 2013; Pedrosa-Pàmies et al., 2016).
These events can directly influence primary production and biodiversity, at least at local and sub-basin scales. For example, the Northwestern Mediterranean Sea, and in particular, the Catalan, Gulf of Lion and Ligurian margins are particularly influenced by high-energy, episodic processes, as the DSWC.
The monitoring of criteria related to descriptor 5 should be carried out, in those critical deep-sea ecosystems (e.g., the slopes of the Gulf of Lions, the southern Adriatic Sea (Pomo pit) and the deeper portion of the northern Aegean Sea). A comprehensive assessment on the state of these deep-sea areas and an analysis of the main pressures that they are exposed to are currently lacking (IDEM Project, 2017).

2.5.6 Methods and technologies gaps

D5MT.G1 Lack of standardized methods and detailed guidelines for assessments
For descriptor 5 the same applies as stated above for D4MT.G1 (Section 2.4.6).

D5MT.G2 Lack of monitoring networks and online platforms/database for data sharing regarding eutrophication/organic enrichment in the deep sea
For descriptor 5 the same applies as stated above for D4MT.G2 (Section 2.4.6).

D5MT.G3 Inadequacy of integrative models for eutrophication in the deep sea
Eutrophication is well addressed by the current models revised by Pirroddi et al. (2015), such as, for example, the BAltic Sea Long-Term large-Scale Eutrophication Model (BALTSEM) and St. Petersburg

Eutrophication Model (SPBEM). However, most of them are physical-biogeochemical models, not considering deep sea (waters below 200 m depth). Ecological models are powerful tools to assess and predict the consequences of organic matter enrichment and oxygen depletion on biological compounds. The development and extended use of integrative models encompassing physical drivers, biodiversity and ecosystem processes, would be useful for the monitoring of deep-water benthic ecosystems, as already stated in D4MT.G3 for descriptor 4.

D5MT.G4 Uncertainties on assessment methods for some additional criteria

Different methods have been proposed to measure chlorophyll-a concentrations in marine sediments. However, they can provide under-or over-estimates, also because of the relative importance of the chlorophylls' degradation products (Pinckney et al., 1994). For consistency with previous studies, chloroplastic pigments (chlorophyll-a and phaeopigments) can be analysed fluorometrically (Danovaro et al., 2010). Total phytopigment concentrations can be utilized as a proxy for the organic material of algal origin and are defined as the sum of chlorophyll-a and phaeopigment concentrations, after conversion into C equivalents (Pusceddu et al., 2009; Pusceddu et al., 2010). The percentage contribution of total phytopigments to biopolymeric C is an estimate of the freshness of the organic material deposited in the sediment: since photosynthetic pigments and their degradation products are assumed to be labile compounds in a trophodynamic perspective, the lower their contribution to sediment organic C the more aged the organic material (Pusceddu et al., 2010).

Besides measures of oxygen concentration along the water column (by CTD profilers), the measurement of oxygen concentration across the top 20 cm of the sediments is also recommended. In particular, the position of the RPD can be analysed by electrodes (Fenchel, 1969) or digitally, analysing the apparent RPD (aRPD) in sediment profile images (SPIs) (Rhoads and Germano, 1986).

For benthic fauna monitoring (D5C8) there are some limitations regarding organism identification, as already stated for descriptor 4 in D4MT.G4. Highly specialized taxonomic expertise is needed to support extensive monitoring activities.

2.5.7 Connections between D5 gaps and the rest of descriptors

This section focuses in illustrating D5 related gaps that are also relevant for other descriptors.

Relationships between gaps and descriptors are illustrated as dark grey coloured cells in Table 2.4. The interconnections are identified when a gap described for D5 is also relevant for other descriptors, affecting other ecosystem components represented by state descriptors (i.e. D1, D3 and D4) or complementing pressures defined by pressure-based descriptors (i.e. D2, D5, D7, D8, D9, D10 and D11). The gaps defined under sections 2.5.3, 2.5.4 and 2.5.5 are not added to the table since all identified deficiencies are already considered relevant for all descriptors.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D5C1.G1	■			■	■						
D5C1.G2	■			■	■						
D5C1.G3				■	■						
D5C1.G4				■	■						
D5C8.G1	■			■	■						
D5C8.G2	■			■	■						
D5C8.G3	■			■	■						
D5AG.G1	■		■	■	■	■	■	■	■	■	■
D5AG.G2	■		■	■	■						
D5AG.G3	■		■	■	■		■				
D5AG.G4	■			■	■						
D5AG.G5	■			■	■						
D5MT.G1	■			■	■		■				
D5MT.G2	■			■	■	■	■				
D5MT.G3	■		■	■	■		■				
D5MT.G4	■		■	■	■		■				

***Table 2.4*. *Representation of the connections between D5-identified gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D5-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 5:* **D5C1.G1** *Lack of spatial coverage of data and long-term data series.* **D5C1.G2** *Lack of data on pressures.* **D5C1.G3** *Absence of knowledge regarding threshold and reference values.* **D5C1.G4** *Unsuitable criteria for oligotrophic regions.* **D5C8.G1** *Lack of spatial coverage of data and long-term data series.* **D5C8.G2** *Lack of data on pressures.* **D5C8.G3** *Absence of knowledge regarding threshold and reference values.* **D5AG.G1** *Lack of knowledge about pressures on the deep Mediterranean Sea.* **D5AG.G2** *Lack of knowledge on cysts of harmful algae in the deep sea.* **D5AG.G3** *Oblivion of oxygen concentrations in deep-sea sediments.* **D5AG.G4** *Oblivion of meiofauna.* **D5AG.G5** *Oblivion of quantity and quality of sedimentary organic matter and its bioavailable fraction.* **D5MT.G1** *Lack of standardized methods and detailed guidelines for assessments.* **D5MT.G2** *Lack of monitoring networks and online platforms/database for data sharing regarding eutrophication/organic enrichment in the deep sea.* **D5MT.G3** *Inadequacy of integrative models for eutrophication.* **D5MT.G4** *Uncertainties on assessment methods for some additional criteria.*

2.6 *DESCRIPTOR 6: SEAFLOOR INTEGRITY*

2.6.1 Major knowledge gaps concerning specific indicators and criteria

DATA AVAILABILITY

Several countries assessing GES in Mediterranean sub-basins have reported on existing knowledge and data gaps. Most of the available data was acquired in programs within the framework of other directives and initiatives such as the WFD, the Habitats Directive and the Natura 2000 network, and EUNIS and MEDITS conventions (Laroche et al., 2013). However, the majority of the frameworks do not include deep-sea ecosystems, thus largely reducing the amount of available data for the deep Mediterranean Sea. Besides the general lack of data and knowledge, monitoring challenges and low consensus on what would be a GES in terms of deep seafloor integrity complicates the evaluation of the descriptor(Rice et al., 2010).

The compilation of information must go along with a critical review of the data. This revision should include data typology (quantitative vs. non-quantitative), content (parameters analysed) and coverage (spatial and temporal). Online repositories enable the collection and organization of large amounts of data that could be shared by the scientific community. In the EMODnet database, which includes marine data for all Europe, the two most relevant portals for descriptor D6 are those on seabed habitats and human activities(IDEM Project, 2018c). Whereas the existence of these repositories is important, the spreading of the open data concept within the research community is essential.

Descriptor 6, Criterion 1 (D6C1): Spatial extent and distribution of physical loss (permanent change) of the natural seabed

It must be noted that, according to Commission Decision (EU) 2017/848 laying down criteria and methodological standards on GES of marine waters and specifications and standardised methods for monitoring and assessment, physical loss “shall be understood as a permanent change to the seabed which has lasted or is expected to last for a period of two reporting Cycles (12 years) or more”. Therefore, the concept of “permanent change” actually means at least 12 years. Since there is no actual experience on the persistence of major seabed changes, such as those caused by bottom trawling, in practice this criterion involves an open-end unknown. Furthermore, the persistence of major seabed changes caused by a given activity may vary significantly from one place to another as a function of seafloor nature, sediment dynamics and oceanographic setting. The slow dynamics of deep-sea environments, compared to the shallow ones, also involves that recovery following disturbance and physical loss may take rather long-time spans (cf. D6C2 below) (Gollner et al., 2017; Jones et al., 2017; Miller et al., 2018).

Two main types of information gaps appear as the most relevant regarding Descriptor D6 in the deep Mediterranean Sea: (i) lack of information about bottom trawling activities and their intensity, and (ii) incomplete knowledge of the habitat biodiversity, and/or partial data on species interactions, both within the habitat and between different habitats.

D6C1.G1 Precise quantification of seabed damage by deep-water fisheries

Bottom trawling is the main human activity leading to physical loss of the natural deep seabed. Quantitative indicators are required to assess the impacts of bottom trawling and monitor progress towards GES for Descriptor D6. A detailed framework for assessing the actual extent and the impacts of fishing gear on the seabed and sub-seabed, including the collection of quantitative data, is much needed (Eigaard et al., 2016, 2017). It should encompass differences in habitat sensitivity and at least the most common fishing gear used for deep-water bottom trawling (Diesing et al., 2013). An important development reducing uncertainties about this first gap is satellite-aided location of trawlers, either from AIS and/or VMS systems. However, VMS data are managed in different ways by different countries and accessing to the data is sometimes tough to impossible, which prevents an optimum usage. Some independent initiatives, such us Global Fishing Watch (https://globalfishingwatch.org/) aim at bringing light to the lack of transparency and accessibility issue. This gap is also relevant for D6C5 criterion, since the ecological impact of bottom trawling also needs to be assessed and quantified (Bolam et al., 2014; Eigaard et al., 2017; Rijnsdorp et al., 2016).

The view of the IDEM consortium is that the full extent of seabed modification by bottom trawling is not considered in its full dimension within the MSFD frame. The crossing of VMS data and high-resolution multibeam bathymetry has shown that bottom trawling may cause large-scale seascape change in vast areas of the deep seafloor in European seas, including the Mediterranean Sea, and beyond (Puig et al., 2012). In essence, recurrent trawling over the same grounds may transform contour normal seafloor drainage patterns into contour parallel relieves over extensive areas of hundreds to thousands of square kilometres in every basin or sub-basin, depending on the size of the fishing grounds. In canyon flanks, where some of most priced fisheries (e.g. *A. antennatus* and *A. foliacea*) are practiced in the deep Mediterranean Sea, prominent gullied seascapes are thus transformed in flattened terraces. There is no change for recovery for this major seascape change, as the original seascape cannot be restored. Therefore, the already documented large-scale seascape change represents a tipping point for the deep-sea floor. Furthermore, such a change does not come alone but very likely has major consequences, at the same or even larger spatial scales, on at least (i) resuspension of seabed sediment leading to the release and cycling of organic matter, chemical pollutants and litter; (ii) subsequent alteration of sediment fluxes and of natural erosion / accumulation rates, subsequently leading to suffocation and increased accumulation on and flattening of canyon floors; (iii) biodiversity and ecosystem functioning; and (iv) alteration of biogeochemical fluxes. Current knowledge on such consequences, and other probably still unidentified, is poor to inexistent knowledge (Puig et al., 2012; Pusceddu et al., 2014). Resuspension events, for instance, occur daily on fishing grounds, therefore altering the natural condition of the lower water column and connected pelagic and benthic habitats. Large-scale seascape change by bottom trawling and the seafloor alteration it causes may lead to contradictory situations, such as that of apparently sustainable fisheries (e.g. *A. antennatus* and *A. foliacea*) on totally destroyed benthic habitats. In conclusion, large-scale seascape change and associated consequences must be included in GES assessments for them to be sound and credible. This is or could be highly relevant not just for D6 but also for descriptors D1, D3, D4, D7, D8, D9 and D10.

D6C1.G2 Reach of seabed damage by hydrocarbon exploration and exploitation[11]

Activities undertaken by the offshore oil and gas industry may cause physical loss of the natural deep seabed. Even though this gap is included within Descriptor D6, it holds the potential to influence the GES of marine ecosystems in many ways, and therefore is also relevant for other GES descriptors. Hydrocarbon exploration, testing and field development involves a large amount of activities impacting the seabed and beyond[12], including those derived from geotechnical, exploration and production holes and from the

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[11] This subsection is more extensive than other of the same type given the generally low level of knowledge on seabed impacts caused by the offshore oil and gas industry, the potential relevance of such impacts and the likely growth of this industry in the deep Mediterranean Sea in the near future.

[12] A classical drilling environmental impact assessment by the oil and gas industry would include the following potentially significant impacts on the seabed: (i) impacts from vibration from drilling on seabed features; (ii) impacts from potential anchoring on seabed features; (iii) impacts from routine drilling rig and vessel discharges; (iv) impacts from standard waste generation and disposal; (v) impacts of drilling cuttings and drilling fluid on seabed features; (vi) impacts from accidental loss of solid hazardous or

placement of a variety of structures and products. A survey of the biota fouling the Mari-B/Tamar gas production platforms located approximately 25 km off the Israeli coast in water depths of 200 to 250 m revealed all identified molluscs (*Alectryonella plicatula, Chama pacifica, Malleus regula, Pinctada radiata, Spondylus spinosus*) are Erythraean NIS (CSA Ocean Sciences, 2018). Their presence confirms that NIS propagules occur offshore, and when appropriate conditions present themselves, may settle and establish populations. Nowadays, in Europe, environment impact assessments (EIA) are required prior to drilling, either for exploration or production purposes, and monitoring of potential impacts is sometimes performed (see further down), but EIA are not exhaustive as they do not include important aspect such for example the probability of NIS settlement on the platforms or on the seabed cuttings.

In consequence, offshore hydrocarbon exploration and extraction must be considered when assessing physical loss and disturbance of the deep seafloor. The offshore oil and gas industry cause physical (and chemical) impacts on the seafloor and subseafloor, ranging from the installation of drilling rigs, wellheads, pipelines and other structures on the seabed to the accumulation of litter including lost or abandoned equipment, consumables and other materials. It is to be noted also that some marine fields require major seabed levelling works to accommodate it to the needs of exploitation, subsequently causing major physical disturbance to the affected areas, as illustrated by the development of the deep-water Ormen Lange gas field off Norway[13].

Drilling muds, chemicals, cement and products (rock chips or cuttings, oil) coming from the subseafloor can also accumulate around wellheads and spread to variable distances. During drilling, mud is used to maintain well pressure and wall stability, to cool and lubricate the drill bit and to carry the cuttings generated during the drilling process away from the cutting head to the platform. Drilling mud is continuously circulated between the well and the platform through a ‘riser pipe’. There are two types of drilling muds: water based muds (WBM) and oil based muds (OBM). In the past, the bulk of cleaned OBM cuttings were discharged to the seabed along with their residual oily mud contamination. Extensive monitoring studies showed that this caused changes to the seabed via a combination of smothering, organic enrichment and toxicity effects. These were seen to be most severe close to discharging platforms where the ‘pile proper’ formed, but they commonly extended up to a distance of 1 or 2 km. These discharges are no longer allowed[14].

A wide variety of chemicals are used to treat the oil, gas and water that are gathered from offshore reservoirs. In the United Kingdom, for instance, these are regulated under a harmonised mandatory control scheme negotiated under the auspices of the OSPAR Convention. Cements are used to give stability to hole sections and during plugging of geotechnical holes[15].

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non-hazardous wastes; (vii) impacts from dropped objects on offshore benthic communities; (viii) impacts from loss of well control resulting in an oil or gas release, eventually leading to blowout. Other potentially significant impacts to the environment would be those caused by underwater sound, lighting generated by the drilling rig and support vessel, and introduction of invasive marine species (from http://www.woodside.com.au/Working-Sustainably/Consultation%20Activities/A-7%20Drilling%20Environmental%20Impact%20Assessment%20Report%20June%202018%20Executive%20Summary%20(Myanmar).pdf).

[13] https://www.uio.no/studier/emner/matnat/math/MEK4450/h11/undervisningsmateriale/modul-1/2%20-%20Field%20development.pdf.

[14] https://www2.gov.scot/Uploads/Documents/AE09Environmental.pdf.

[15] https://www.bp.com/content/dam/bp-country/en_az/pdf/ESIAs/SD2_Chapter_9_Drilling_EIA.pdf.

Blowouts, oil leaks and oil spillages can lead to catastrophic situations causing severe seabed disturbance and marine pollution with impacts that are initially local in character but tend to spread to larger areas (cf. Descriptor D8).

Proper decommissioning at the end of the life of oil and gas filed is a critical component. Actually, some decommissioning operations have by themselves the potential to impact the seabed environment. In that respect, there are two main areas of interest in the decommissioning context: cuttings piles and on surface large pipelines. On the other side, the establishment of exclusion zones in the immediate vicinity of installations might help preserving the benthic environment locally, at least from fishing. But, if allowed, fishing can also help spreading the large cuttings piles beneath the installations after these are completely removed during decommissioning.

Environmental monitoring in the oil and gas industry traditionally concentrated on the near-field effects of cuttings piles (see above) discharges at the main drill sites. Although monitoring of the impacts of piles remains a focus of interest, attention is now being directed towards detecting more subtle changes in contamination patterns in the further field[16]. Also, there is little doubt that complete installation removal, cuttings piles recovery, and the wisdom of allowing fishing over piles if they are exposed, will deserve much attention in the coming years.

Despite the above, often face-saving efforts, the fact is that both EIAs and environmental monitoring tasks by the offshore oil and gas industry are made in a way that is totally disconnected from the MSFD and other directives, and according to different standards and criteria. Requirements for EIAs may change from country to country. Unified criteria aligned with MSFD ones and a centralized authority at European and basin neighbouring countries level would be highly beneficial, also to avoid dispersal and loss of information. The information contained in EIAs is highly valuable, at least potentially, in terms of GES evaluations. Furthermore, in addition of initial EIAs, which are done before operations at sea start, it would be wise performing EIAs (or in depth, long-term monitoring efforts) during offshore operations and after their cessation to know the full reach of impacts and, eventually, the recovery of the impacted ecosystems along a reasonable time span.

Furthermore, underwater noise and vibration, resulting from the drilling of geotechnical holes and wells and vessel movements during drilling, completion and intervention activities has the potential to impact biological/ecological receptors (specifically marine mammals and fish) in the marine environment (cf. Descriptor D11 and footnote).

Exploration wells have been drilled during the last five decades in many places of the Mediterranean Basin, including its Western, Central and Eastern sub-basins, most of them in water depths less than 200 m. However, 94% of Mediterranean offshore oil reserves are estimated to occur off Libya, Algeria and Egypt (Piante and Ody, 2015). Today’s deep-water (>200 m) oil and gas production in the Mediterranean Sea, or advanced prospects for it, takes place essentially offshore Egypt, Israel, Lebanon, Syria and Cyprus (The Petroleum Economist Ltd, 2013). The relevant marine fields are associated to pipelines for oil transport to land terminals. Also, there are several pipelines across the deep Mediterranean Sea not directly connected to oilfields. In addition, there is shallow water (< 200 m) production in the Adriatic Sea, offshore Tunisia and Libya, and very minor off the Ebro Delta in Spain.

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[16] https://www2.gov.scot/Uploads/Documents/AE09Environmental.pdf.

The Eastern Mediterranean Basin is the most promising hydrocarbon province in the entire Mediterranean Sea. There, the Tamar field, located 80 km west of Haifa at a depth of 1,700 meters, in Israel's Exclusive Economic Zone (EEZ), was the first gas discovery in the Levant Basin. The Tamar field began commercial production on 30 March 2013 after four years of extensive development works. Since Tamar's discovery, other large gas discoveries were made elsewhere in the region. In 2000, a modest discovery was made when a 33-billion-cubic-metre natural-gas field was located offshore Ashkelon, called MARI-B, with commercial production starting in 2004, at a depth of about 240 m. In 2010, the much larger Leviathan field was discovered in the Israel EEZ. A year later, the Aphrodite field was found in the Cyprus EEZ. Gas prospection is currently under way in the Levant Basin offshore Lebanon and Syria. Lebanon launched its first gas licensing round in May 2013. The Levant Basin, the Nile Delta Basin, and the Aegean Basin are expected to hold considerable reserves of oil and gas, which could transform the Eastern Mediterranean into an important energy-producing region (Livnat, 2014).

In the Mediterranean Sea, the Offshore Protocol of the Barcelona Convention (the Protocol for the Protection of the Mediterranean Sea against Pollution Resulting from Exploration and Exploitation of the Continental Shelf and the Seabed and its Subsoil, 1994) would oblige countries to perform comprehensive EIAs for activities as oil and gas exploration, but has not yet entered into force. This should include, among other aspects, a description of the initial state of the environment of the area and a description of the foreseeable direct or indirect short and long-term effects of the proposed activities on the environment. Also, in response to the Deepwater Horizon catastrophe in the Gulf of Mexico, the EU adopted the Directive on Safety of Offshore Oil and Gas Prospection, Exploration and Production Activities17in July 2013. EU MS including Cyprus and Greece are required to implement this Directive, which imposes safety obligations on EU energy companies involved in offshore activities throughout the world. For countries such as Israel and other non-EU countries in the Eastern Mediterranean that are new to the energy industry, the Directive provides a blueprint of the best international practice, which they could use when adopting their own national legislation (Livnat, 2014). In Israel research institutes affiliated with and funded by the Earth Sciences Research Administration of the Ministry of National Infrastructures, Energy and Water (in charge of managing and regulating offshore exploration and production), prepared for their ministry analysis of the environmental information and a proposal for vulnerability criteria in connection with engineering activities exploration and production of oil and natural gas in Israel's maritime space, as part of the 'Strategic environmental assessment for marine exploration and production of oil and gas'. The report analysed 20 samples of mostly large and vagile slope and bathyalepifauna and concluded that their analysis "…does not allow to separate the bathyal and the slope to different habitats" based on the trawl-obtained samples (Tom et al., 2015).

A summary of potential impacts from oil and gas exploration and exploitation activities can be found, for the deep Mediterranean Sea off Israel, which is one of the most relevant areas in the region, in Galil and Herut (2011). In this context, the incomplete knowledge of the habitat biodiversity and species interactions hinder prediction capacities of habitat renewal potential following an impact or a set of impacts, and require strict safety margins for anthropogenic activities, such as those related to the oil and gas industry. Whereas information gaps do not actually influence the vulnerability *per se*, they do reduce our ability to determine it. Some countries active in the deep-water oil and gas industry of the Mediterranean Sea, such

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[17] Directive 2013/30/EU of the European Parliament and of the Council of June 12, 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC, Official Journal of the European Union, L178/66, 28 June, 2013.

as Israel, have decided not to include the information gap into the vulnerability index, but to display it alongside the sensitivity level (Geoprospect Ltd. and Israel Oceanographic and Limnologic Research, 2016). That report considers, based on Tom et al. (2015), that the entire slope and bathyal is “low sensitivity”. This conclusion was adopted by the National Planning Commission, despite studies detailing unique assemblages in the SE Levant.

D6C1.G3 Seabed occupation by the placement of submarine communication cables and pipelines, and associated impacts

Such placements cause physical loss of the natural deep seabed along narrow bottom corridors or in wider areas where they concentrate and cross. Modern submarine cables are laid either directly on the seafloor or buried. In deep water beyond the reach of trawlers (generally >1500 m deep) and in some shallow water areas unsuitable for burial, cables are deployed on the seafloor. Despite most of the assessments classify placement of cables as a low-impact human activity (Carter et al., 2009), they still interact with the benthic environment, especially in multiple cable crossings and at other places where cable density is high. Pipelines for various usages (e.g. oil and gas transport) usually are laid on the seabed or entrenched, the later especially in shallow waters close to shore. Pipelines and also cables may interact with other human activities like fishing, causing synergetic effects that are not considered in the assessments.

D6C1.G4 Poor and incomplete quantification of seabed alteration by waste disposal

Waste disposal may cause physical loss of the natural deep seabed. Many types of waste have been disposed in the sea, generating overlooked dumps that require careful assessment. Site-specific disposals such as aluminum red mud, coal ash fly, polluted dredged sediments and industrial waste discharges in the deep Mediterranean Sea have been already investigated (IDEM Project, 2017). However, other dumped materials such as clinker or ammunitions (see below) also deposited in the sea are omitted or poorly analysed, constituting an important gap (Ramirez-Llodra et al., 2011; UNEP-MAP, 2009; Würtz, 2012). According to Ramirez-Llodra et al. (2011) other waste to be eventually considered would include larger structures such as wrecks and containers. Wastes dumped in the past (e.g. clinker) without any environmental risk assessment need to be investigated and their potential impacts clarified.

Ammunitions in the Mediterranean Sea: useless and obsolete ammunitions, explosives and war material have been dumped in the sea for decades. UNEP-MAP performed a first assessment in 2009 that allowed identifying some of the dumping areas (UNEP-MAP, 2009). It was also acknowledged that the number of identified disposal sites was lower than the actual one. In addition, there are many firing practice areas, also in the deep Mediterranean Sea. The UNEP-MAP report includes the location, source of information, depth and a brief description for each dumping location. Most ammunitions dumping areas in the Mediterranean Sea are in shallow waters, but there are also in deep-water in the Alboran Sea (1,250 m), the northern Balearic Sea (2,000 m), the Ligurian Sea (1,300 m), the Sardinia Sea (down to 500 m), the Sicily Channel (200 m), the southern Adriatic Sea (various sites, from 300 m to 1,200 m), the Libyan Sea (720 m), the northern Ionian Sea (1,100 m), and the Eastern Mediterranean Basin (2,000 m). Detection of all ammunition dumping sites, and sound quantitative analyses of the impacts on ecosystems are required.

D6C1.G5 Reach of seabed damage because of deep-sea exploration and exploitation for unconventional mineral and energy resources

The following described activities may cause physical loss of the natural deep seabed. Current targets for deep-sea mining include polymetallic massive sulphides, polymetallic nodules and cobalt-rich ferromanganese crusts. According to Piante and Ody (2015), Rare Earth Elements (REEs) in deep-sea mud may also become mining objectives at a longer time scale. In addition, extraction of offshore gas hydrates, as a source of hydrocarbons, could become a future threat. No deep-sea mining activities *s.str.* are currently taking place in the Mediterranean Basin. However, exploration licenses for polymetallic sulphides in the Tyrrhenian Sea have been solicited, and other sulphide deposits have been identified along the Greek coastline (Boschen et al., 2013; ECORYS, 2014; Piante and Ody, 2015). Precautionary approaches and meticulous risk assessments are needed.

Descriptor 6, Criterion 2 (D6C2): Spatial extent and distribution of physical disturbance pressures on the seabed

It is important to note that, according to Commission Decision (EU) 2017/848 laying down criteria and methodological standards on GES of marine waters and specifications and standardised methods for monitoring and assessment, physical disturbance "shall be understood as a change to the seabed **from which it can recover** if the activity causing the disturbance pressure ceases". In contrast with the description of "permanent change" in the same document (cf. D6C1 above), no time span is associated to the "recovery" concept. However, the slow dynamics of most deep-sea environments implies that recovery following disturbance and physical loss may take long. Recovery and recolonization assessments have been performed in very deep water outside the Mediterranean Sea (Gollner et al., 2017; Jones et al., 2017; Miller et al., 2018). However, given the differentiated character of its biota and the special environmental conditions of the deep Mediterranean Sea, with maximum depths much shallower than those from the main oceans, rather saltier and warm intermediate and deep waters (38.4 – 39.1 PSU, and 12.7 - 15.5ºC) in contact with the seabed, and the strong influence of fluxes derived from the coastal sea and shallower continental margin, extreme caution is required before transposing any recovery results from other regions of the world ocean. So far, no recovery experiment has been undertaken on a disturbed seabed within the Mediterranean deep basins.

Gap types described within D6C1 section are also relevant for criterion D6C2 as they all represent pressures too. Amongst them, bottom-trawling fisheries are particularly relevant. In addition to activities leading to permanent physical loss of the natural seabed, as described under D6C1 above, there are other pressures that should be considered within Descriptor D6 gap identification as they may cause (recoverable) physical disturbance on the seabed.

D6C2.G1Absence of knowledge on interactions between natural factors and human-induced disturbances affecting seafloor integrity

Deep-sea habitats are influenced and shaped by physical and biogeochemical parameters. Seafloor integrity and benthic habitats are affected by temperature, salinity, pH, oxygen availability, organic matter concentrations, species and size composition, the presence of bioengineering species, trophodynamics and life history traits, which should be included in assessments as natural factors influencing seafloor dynamics and how human-induced disturbances can lead to indirect impacts on system components. Since all these are overlooked topics, it becomes clear than in this context detailed analyses of the dynamic interaction between human pressures and ecosystem attributes deserve further attention (Rice et al., 2010).

D6C2.G2 Lack of information on the effects of naturally occurring hazardous substances in deep seabed sediments

The seafloor is the end-point of oceanographic processes leading to vertical transfers. In consequence, benthic sediments can accumulate a range of components including toxic chemicals and metals introduced into the ocean(Rice et al., 2010). However, this gap concerns naturally occurring dangerous substances, since anthropogenic contaminants are targeted by descriptor D8 and D9. Uncontrolled releases of hydrocarbons or methane hydrates ex-solutions triggered by human activities can be extremely detrimental for the deep-sea ecosystems. Additional pressures such as bottom trawling, hydrocarbon extraction or sediment removal could enhance the release and bioavailability of these components and, therefore, their potential to harm benthic habitats(Rice et al., 2010). Accurate mapping of high-risk zones should be performed and evaluated. This gap is relevant for descriptors D8 and D9 too since it also relates to the identification and monitoring of bioindicators for this type of pollution.

D6C2.G3 Lack of knowledge on the implications of bioprospecting

This field of activity is defined as the exploration of biodiversity to obtain commercially valuable genetic and biochemical resources (Arico and Salpin, 2005). The knowledge gap encompasses a number of components, from basic information on the precise extent of bioprospecting to issues such as measurements and monitoring, potential environmental impacts, technologies that apply, jurisdiction and regulations, and socioeconomic and ethical aspects (Rademaekers et al., 2015). The impacts of both basic and applied scientific research included within bioprospecting activities need to be fully considered. Potential threats include the destruction of benthic habitats, unsustainable collection of organisms and pollution. Specific characteristics and responses from each habitat and cumulative impacts should also be included in the assessments.

Descriptor 6, Criteria 3, 4 and 5 (D6C3-C5). Impacts on habitats (changes in biotic and abiotic structure, and functions by physical disturbance; habitat condition and habitat loss from anthropogenic pressures)

The three criteria under this heading are very closely related one to each other, also in terms of wording, and it is not obvious to discern amongst them.

Following Commission Decision (EU) 2017/848, D6C3 refers to the spatial extent of each habitat type that is “adversely affected, through change in its biotic and abiotic structure and its functions (e.g. through changes in species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), by physical disturbance”. D6C3 is assessed in relation to the total natural extent of each benthic habitat type assessed. For D6C3 species composition shall be understood to refer to the lowest taxonomic level appropriate for the assessment. Together with criteria D6C1 and D6C2, D6C3 relates only to the pressures ‘physical loss’ and ‘physical disturbance’ and their impacts, whereas criteria D6C4 and D6C5 address the overall assessment of Descriptor D6, together with that for benthic habitats under Descriptor D1.

Commission Decision (EU) 2017/848 describes D6C4 as “the extent of loss of the habitat type, resulting from anthropogenic pressures”, so that it “does not exceed a specified proportion of the natural extent of the habitat type in the assessment area”.

D6C5 refers to “the extent of adverse effects from anthropogenic pressures on the condition of the habitat type, including alteration to its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), does not exceed a specified proportion of the natural extent of the habitat type in the assessment area”.

D6C3-5.G1 Insufficient benthic habitat characterization

Analysis of deep-sea pressures and impacts are usually missing a proper characterization of the ecosystems and habitats. Multimetric indexes are needed to assess benthic community condition and functionality (Bremmer et al., 2006; Lampadariou et al., 2008; Borja et al., 2009; Simboura et al., 2012). Benthic habitats description is the first step to understand their role in providing services and other benefits to humans. Baseline maps and characterizations are also needed in order to identify changes in state. Habitat mapping improves also the application of several criteria and indicators targeting GES in relation to D1 and D6 principally but also the rest of MSFD descriptors (Galparsoro et al., 2015).

D6C3-5.G2 Lack of standardized, systematic mapping of current threats and impacts on deep Mediterranean benthic habitats and seafloor integrity

In order to assess and eventually maintain the GES of the deep Mediterranean Sea, spatial information on current impacts and on vulnerable habitats is required. The value of mapping habitats and impacts has already been demonstrated and recommended for environmental assessments within the MSFD (Galparsoro et al., 2013). An effort towards that direction was performed within the COCONET project (Grande and Foglini, 2016): “Towards COast to COastNETworks of marine protected areas(from the shore to the high and deep sea), coupled with sea-based wind energy potential”[18]. However, the deep-sea was poorly addressed. Mapping of cumulative impacts on marine sensitive ecosystems is crucial for evaluating the current state and also for identifying future MPA and establishing monitoring networks and plans of measures (Halpern et al., 2008; Micheli et al., 2013; Ramírez et al., 2018), especially considering that present day deep MPAs are mostly “paper entities”, with absent knowledge of their biota, environmental dynamics, and management.

D6C3-5.G3 Absence of in-depth local impact assessments of biodiversity hotspots and extreme environments of the deep Mediterranean Sea

This includes habitats such as trenches, submarine canyons, seamounts, cold-water coral communities, deep-water soft-bottom meadows, hydrothermal vents, cold seeps and brine pools. Of those, submarine canyons from some parts of the Mediterranean Sea are the most studied. These habitats encompass unique biodiversity and are hotspots of primary production, goods and services. However, they are also a target for fisheries and other human impacts (i.e. waste disposal). Some of these habitats, like seamounts, are already included in some regional conventions (i.e. OSPAR)as threatened and declining habitats because of the accumulation of impacts related to bottom trawling and deep-sea mining interests (Morato et al., 2013). Trawling destroys reef-building organisms and seamount endemic communities. This could likely be also the case for future seafloor mining. In the Mediterranean Sea there have been some initiatives to steer the protection of submarine canyons and seamounts, such as those referred in Würtz (2012) and Würtz and Rovere (2015). EC funding is also contributing to mitigate the situation, namely through LIFE, LIFE+ and LIFE IP research projects, such as INTEMARES[19]. Some NGOs, such as Oceana, have been also active in the field (e.g. Oceana, 2011, 2012). All this demonstrates the interest and need of an accurate analysis of the impacts on these valuable habitats, for which effective management programs are urgently required.

D6C3-5.G4 Insufficient characterization of the relations between benthic and pelagic habitats

In order to understand the responses of benthic habitats, knowledge of all system components and their relationships with surrounding environments is needed. In consequence, pelagic ecosystems affecting benthic patterns and processes should be considered (Boero et al., 2016).

D6C3-5.G5 Omission of fisheries discards as artificial nutrient input to the benthic compartment

The update of the Common Fisheries Policy of 2013 (Regulation EU No 1380/2013) addresses the problem of fisheries discards establishing a gradual plan for reducing this practice by introducing the landing

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[18] https://cordis.europa.eu/project/rcn/101654_en.html.

[19] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=6101.

obligation[20]. This requirement demands the landing and counting against quota of all catches of regulated commercial species. This obligation it is gradually being applied across fisheries and species. By 2019 all species subject to TAC limits (Total Allowance Catch) and Minimum Conservation Reference Sizes will be incorporated in landing obligation. The latest temporary discard plan was published on November 2017 and will be valid until 31 December 2020. Although this regulation will surely decrease the amount of discards, current discards are impacting the marine systems. When the discarding occurs regularly, these additional inputs constitute a major trophic resource for the whole ecosystem (Bozzano and Sardà, 2002). Such anthropogenic food inputs may affect surface, mid-water and benthic communities, altering the ecology and functioning of the entire ecosystem. This gap is relevant also for descriptors 1, 3 and 4.

2.6.2 Additional gaps concerning relevant topics poorly or not addressed within the existing MSFD-defined criteria

D6AG.G1 Unavailability of quantitative state and pressure indicators of the deep Mediterranean seafloor

Quantitative assessments should be enhanced in order to provide standardized evaluations through all Mediterranean basins. Currently, quantitative indicators for fishing pressures and for assessing benthic communities have been proposed by a number of authors and for different marine regions (Simboura et al., 2012; Bolam et al., 2014; Borja et al., 2009; Diesing et al., 2013; Rijnsdorp et al., 2016; Eigaard et al., 2017). However, previous gaps have already described relevant topics and pressures related to the deep-sea that remain poorly quantified (e.g. D6C1.G1, D6C1.G2, D6C1.G4, D6C1.G5, D6C2.G1, D6C2.G2, D6C3-5.G1, D6C3-5.G3). For example, quantitative indicators concerning ecosystem functioning, resilience potential, the impacts of seafloor exploitation or the effects of waste disposal are not available for environmental assessments. Because of the lack of quantitative indicators, insufficient data and knowledge hinder appropriate marine conservation studies that are mostly qualitative, based only on experts' opinions (Claudet and Fraschetti, 2010). Therefore, appropriate integrative quantitative assessments still constitute an important gap for the deep Mediterranean Sea.

D6AG.G2 Oblivion of the microbiological component of deep-sea habitats and its integrity

Bacteria prevail in the ocean in terms of abundance, diversity and metabolic activity. They interact in multiple ways with all components of marine ecosystems. Different microbial taxa are essential for all biogeochemical cycles, as primary producers or as recyclers of organic matter (Corinaldesi, 2015). Pathogens interact and influence the behaviour and dynamics of multiple populations. In the deep-sea, they are also responsible for dense aggregations of life as primary producers (e.g. in hydrothermal vents). Actually, bacteria and other microbiological groups structure some deep-sea habitats (Azam and Malfatti, 2007). Anthropogenic pressures, including climate change, are impacting and modifying microbial assemblages, potentially destabilizing ecosystems and influencing seafloor integrity (Corinaldesi, 2015).We consider of the utmost relevance a comprehensive assessment of the microbiological component of habitats and the integrity of this component in the deep Mediterranean Sea (Caruso et al., 2015).

2.6.3 Geographical gaps

This section refers to the main geographical gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of geographical gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section

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[20] https://ec.europa.eu/fisheries/cfp/fishing_rules/discards_en

summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, meta-analysis and data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018b, 2018a).

D6GG.G1 Heterogeneous geographical data coverage
The southern Mediterranean Sea clearly appears as the largest geographical data gap concerning Descriptor D6 since almost no study was identified there. This mostly reflects a major difference in research effort between European and non-European countries. In the northern Mediterranean Sea, the Aegean-Levantine Basin and the Adriatic and Ionian seas appear as relative geographic data gaps. Concerning the Western Basin, most studies focus on bottom trawling impacts in canyons from the Catalan margin and the Gulf of Lions. In contrast, the Ligurian and Alboran seas remain almost unstudied regarding sea-floor integrity. Consequently, spatial fragmentation of knowledge and data becomes apparent. Apart from analysing gaps between large subregions (i.e. southern vs. northern Mediterranean Sea), smaller spatial scales should be considered as well.

2.6.4 Bathymetric gaps

This section refers to the main bathymetric gaps identified while revising the datasets collected for IDEM tasks 2.1 and 2.2. A detailed enumeration of bathymetric gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, meta-analysis and data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018b, 2018a).

D6BG.G1 Uninspected depth-ranges
The majority of the studies revised as related to Descriptor D6 omit depths below 800-1000 m. The deepest parts of the Mediterranean Sea (>2,000 m depth) are practically neglected in the current literature. Additionally, as described in gap D6C3-5.G4, the connection between the pelagic and benthic compartments in the deep-sea should deserve consideration.

2.6.5 Habitats and species gaps

The concept within this section is mostly relevant for descriptors D1, D2, D3 and D4. However, the identification of unstudied habitats regarding Descriptor D6 could be also appropriate.

Therefore, gaps D6C3-5.G1, D6C3-5.G2 and D6C3-5.G3 could be added here. Task 2.2 evinced the low number of scientific articles addressing D6-related effects on ecosystems(IDEM Project, 2018b). The papers found mostly concern to specific groups of organisms, such as cold-water corals (CWC) or given species of crustaceans and demersal fishes. Studies targeting deep-sea communities are locally and temporally restricted. Therefore, systemic impacts remained overlooked(IDEM Project, 2018b, 2018a). An introduction to relevant Mediterranean habitats and regions in need for accurate assessments is available below.

D6HS.G1 Conservation of unique habitats of the deep Mediterranean Sea
For descriptor 6 the same applies as stated above for D4HS.G1 (Section 2.4.5).

D6HS.G2 Lack of accurate assessments and pressure identification analyses of deep-sea habitats in Mediterranean Sea EBSAs
For descriptor 6 the same applies as stated above for D4HS.G2 (Section 2.4.5).

D6HS.G3 Absence of a full assessment on the state of deep VME of the Mediterranean Sea
The Food and Agriculture Organization (FAO) of the United Nations defined the concept of vulnerable marine ecosystems (VME) as groups of species, communities or habitats that may be vulnerable to impacts from fishing activities. In 2016 a revision of the VME was published including a section regarding the Mediterranean and Black seas(Thompson et al., 2016). This document identifies, in connection with the GFCM, several deep-sea benthic sensitive habitats and essential fish habitats closed to fishing, essential fish habitats with effort restrictions, and deep-water fisheries restricted areas (FRA) along the Mediterranean Basin. This protection figures include the Nile delta area cold hydrocarbon seeps, the Eratosthenes Seamount, the CWC *Lophelia* reef off Capo Santa Maria di Leuca in Italy, a segment of the continental slope in the Eastern Gulf of Lion, banks and basins in the Sicily Channel, and the extensive deeper central regions of the various Mediterranean sub-basins. A comprehensive assessment on the state of these ecosystems and an analysis of the main pressures that they are exposed to are currently lacking.

2.6.6 Methods and technologies gaps

D6MT.G1 Insufficient standardization of methods and lack of detailed guidelines for assessments
The data available shows some degree of method harmonization. However, heterogeneity in the measured targets and lack of quantitative indicators hinder standardization (Laroche et al., 2013). Commission Decision (EU) 2017/848 could have included the definition of concise targets, in order to promote the uniformity of descriptor D6-related contents.

D6MT.G2 Lack of a comprehensive inventory of platforms, tools, resources and monitoring networks relevant for seafloor integrity assessment
In order to make the most of the existing platforms and technologies, an inventory of tools and resources available and relevant for Descriptor D6 could be highly useful, eventually building on existing marine inventories at European level. JPI-Oceans started a long-term approach in order to create a technological and engineering community for maritime operations and platforms[21]. Additionally, they generated the Marine Research Infrastructures (MRI) Database in order to gather information on more than 785 facilities, providing the contact to each of the infrastructures listed[22] . Similar approaches regarding remote tracking and monitoring networks should be further developed to guarantee a continuous flow of consistent data from representative sites. Tracking of human activities is suggested as the first objective for such a monitoring network. Key areas for monitoring programs will be discussed and presented within IDEM task 3.3 deliverable. Currently, other existing scientific platforms such as the European Marine Board[23] and the MARS network[24] , promote the interconnection of researchers, stakeholders and research managers around Europe facilitating the exchange of tools and resources.

D6MT.G3Absence of technologies and guidelines for restoration
The principle of restoration appeared already in the 1980 Convention on the Conservation of Antarctic Marine Living Resources and in the 1982 Convention on the Law of the Sea, article 62.3. However, both conventions only applied this concept to commercial overfished stocks (Garcia et al., 2003). Rebuilding or at least recovery of key impacted ecosystems, also in deep-water, such as CWC, could be worth considering and investigating.

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[21] http://www.jpi-oceans.eu/technology-and-sensor-developments
[22] http://www.jpi-oceans.eu/eurocean-rid
[23] http://www.marineboard.eu/about-european-marine-board
[24] https://www.marinestations.org/

D6MT.G4 Inadequacy of integrative models for seafloor integrity assessment

Numerical and ecological models are powerful tools that enable assessments and predictions regarding complex issues such as sedimentary and environmental dynamics, human impacts or climate change-lead scenarios. The DEVOTES project reviewed the most common models that can be useful for the MSFD, focusing on biodiversity-related descriptors (Piroddi et al., 2015). The project identified descriptors and topics poorly addressed by models. D2 and D6 were the biodiversity-related descriptors less considered by the existing models. Additionally, the project also identified topics not reflected in MSFD indicators but addressed by some models, such as ecosystem services, benefits and functions. From the models revised, a set of model-derived indicators were proposed and grouped in 7 major categories (biomass, diversity indicators, primary or secondary production, spatial distribution indicators, species life-history, ecological network analysis indicators and physical, hydrological and chemical). Regarding D6, indicators derived from models were proposed for the study of the benthic habitats and communities and for identifying the affected seabed. Pressure modelling was also revised, showing that the most neglected subjects were radionuclides contamination, non-indigenous species, microbial pathogens, underwater noise and marine litter. Additionally, a plethora of sediment dynamics and physical stress conditions at the seafloor exist (Galparsoro et al., 2013; Ulses et al., 2008). The development and extended usage of integrative models encompassing both physical drivers and ecological responses, together with human impacts, would be highly beneficial for the assessment and supervision of deep-water benthic ecosystems.

D6MT.G5Uncertainties on sampling targets and technologies

It is a matter of fact that a large majority of historical and current deep-sea samples present noticeable degrees of uncertainty related, for instance, to lack of accurate bottom positioning or representativeness. In addition, sampling targets for evaluating seafloor integrity could be difficult to identify (Rice et al., 2012). Also, the deep-sea environment *per se* hinders the collection of samples and their accurate conservation at *in situ* conditions. This gap also relates to the development of environmental-friendly techniques for deep-sea mining, bioprospecting and exploration to the maximum possible extent (Rademaekers et al., 2015).

2.6.7 Connections between D6 gaps and the rest of descriptors

This section focuses in illustrating D6 related gaps that are also relevant for other descriptors. Identification of the connections between descriptors' gaps will endorse the establishment of an integrative approach regarding all project tasks. Therefore, when describing new indicators within task 3.2, these connections need to be considered since indicators filling a D6 gap could also be applied to other descriptors. The concept of displaying relationships between descriptors is based on the approach presented in Cochrane et al. (2010).

Relationships between gaps and descriptors are illustrated as dark grey coloured cells in Table 2.5. The interconnections are identified when a gap described for D6 is also relevant for other descriptors, affecting other ecosystem components represented by state descriptors (i.e. D1, D3 and D4) or complementing pressures defined by pressure-based descriptors (i.e. D2, D5, D7, D8, D9, D10 and D11). The gaps defined under sections 2.6.3, 2.6.4 and 2.6.5 are not added to the table since all identified deficiencies are already considered relevant for all descriptors.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D6C1.G1	■		■			■				■	■
D6C1.G2	■					■	■	■	■	■	■
D6C1.G3						■				■	■
D6C1.G4	■					■		■	■	■	
D6C1.G5	■					■		■		■	■
D6C2.G1	■			■	■	■	■				
D6C2.G2						■		■	■	■	
D6C2.G3						■				■	■
D6C3-5.G1	■		■	■		■					
D6C3-5.G2	■	■			■	■	■	■		■	■
D6C3-5.G3	■	■	■	■	■	■	■	■	■	■	■
D6C3-5.G4	■			■	■	■	■			■	
D6C3-5.G5	■		■	■		■					
D6AG.G1	■			■	■	■	■			■	■
D6AG.G2	■	■	■	■	■	■			■	■	
D6MT.G1	■			■	■	■	■			■	■
D6MT.G2	■					■				■	■
D6MT.G3	■	■		■	■	■	■	■	■	■	■
D6MT.G4		■				■				■	■
D6MT.G5	■			■	■	■				■	■

***Table 2.5**. Representation of the connections between D6-identifed gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D6-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 6: **D6C1.G1** Precise quantification of seabed damage by deep-water fisheries. **D6C1.G2** Reach of seabed damage by hydrocarbon exploration and exploitation. **D6C1.G3** Seabed occupation by the placement of submarine communication cables and pipelines, and associated impacts. **D6C1.G4** Poor and incomplete quantification of seabed alteration by waste disposal. **D6C1.G5** Reach of seabed damage because of deep-sea exploration and exploitation for unconventional mineral and energy resources. **D6C2.G1** Absence of knowledge on interactions between natural factors and human-induced disturbances affecting seafloor integrity. **D6C2.G2** Lack of information on the effects of naturally occurring hazardous substances in deep seabed sediments. **D6C2.G3** Lack of knowledge on the implications of bioprospecting. **D6C3-5.G1** Insufficient benthic habitat characterization. **D6C3-5.G2** Lack of standardized, systematic mapping of current threats and impacts on deep Mediterranean benthic habitats and seafloor integrity. **D6C3-5.G3** Absence of in-depth local impact assessments of biodiversity hotspots and extreme environments of the deep Mediterranean Sea. **D6C3-5.G4** Ignorance of interrelations between benthic and pelagic habitats. **D6C3-5.G5** Omission of fisheries discards as artificial nutrient*

input to the benthic compartment. ***D6AG.G1****Unavailability of quantitative state and pressure indicators of the deep Mediterranean seafloor.* ***D6AG.G2*** *Oblivion of the microbiological component of deep-sea habitats and its integrity.* ***D6MT.G1*** *Insufficient standardization of methods and lack of detailed guidelines for assessments.* ***D6MT.G2*** *Absence of technologies and guidelines for restoration.* ***D6MT.G3*** *Uncertainties on sampling targets and technologies.* ***D6MT.G4*** *Lack of a comprehensive inventory of platforms, tools, resources and monitoring networks relevant for seafloor integrity assessment.* ***D6MT.G5*** *Inadequacy of integrative models for seafloor integrity assessment.*

2.7 *DESCRIPTOR 7: PERMANENT ALTERATION OF HYDROGRAPHICAL CONDITIONS*

2.7.1 Major knowledge gaps concerning specific indicators and criteria

DATA AVAILABILITY

Concerning Descriptor 7, similarly to Descriptor 6, during GES assessment, Mediterranean Countries have reported on existing knowledge and data gaps. Overall, the understanding of the scope of this descriptor is still vague and heterogeneous among different countries (Laroche et al., 2013). Most of the available data was acquired in monitoring programs and research projects. Contrary to the other descriptors, modelling is an additional powerful source of data for D7, enriching the amount of available data for the deep Mediterranean Sea. However, models should be supported by “in situ” monitoring dataset, which gaps are reported by almost all the countries. Furthermore, the lack of long time-series is evident (Laroche et al., 2013 and Zampoukas et al. 2014), and the need for optimized monitoring programs and representative multidisciplinary seafloor/water-column observatories is pressing.

Online repositories host large amounts of significant data for Descriptor 7, especially if considering that the monitoring of this descriptor should also provide environmental background information, useful for all the Descriptors (Gonzalez et al., 2015). In particular, most of information is stored in the SeaDataNet portal[25], and in the EMODnet Physics portal[26] (IDEM Project, 2018c). Whereas the existence of these repositories is important, the spreading of the open data concept within the research community is essential and it is still far from being reality (as demonstrated by the delay recorded by the data ingestion process of the EMODnet Physics portal).

Descriptor 7, Criterion 1 (D7C1): Spatial extent and distribution of permanent alteration of hydrographical conditions (e.g. changes in wave action, currents, salinity, temperature) to the seabed and water column, associated in particular with physical loss of the natural seabed

It must be noted that, again, as stated for D6, according to Commission Decision (EU) 2017/848 physical loss shall be understood as a permanent change to the seabed which has lasted or is expected to last for a period of two reporting cycles (12 years) or more.

On the contrary, the scale at which the assessment should be made remains quite imprecise. For criteria 7.1 it is possible to consider two different analysis scales: a “big scale”, including climate change considerations, and a “small scale” caused by a given anthropogenic pressures. Modelling or semi-quantitative estimate may help at both levels. However, this approach involves gaps, as modelling still need to be developed and as data and knowledge are missing to allow a robust assessment.

D7C1.G1 Lack of information in the relationship between hydrographical data and human pressures

Information on relevant pressures to be considered as causing permanent alterations is limited. Quantitative data are missing regarding both pressures on the water column and on the seabed.

D7C1.G2 Lack of long time-series in several areas

Time-series observations form a critical element of oceanography especially for deep sea. The lack of long time-series datasets is especially identified for D7 and in consequence monitoring programs need to be optimized. Data availability is drastically reduced if only long-term monitoring information with a duration of at least 6 months are extracted from the SeaDataNet website: temperature and salinity data are still

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[25] http://seadatanet.maris2.nl/v_cdi_v3/result.asp

[26] http://www.emodnet-physics.eu/Portal

being recorded in the Alboran, Balearic, Ligurian, Tyrrhenian, Adriatic and Ionian seas, and in the Sicily Channel but equivalent data lack in all the southern and eastern parts of the Mediterranean Basin. Dissolved oxygen information seems to be exclusively in the Adriatic Sea and in the Gulf of Lion.

D7C1.G3 Lack of reference/baseline

Overall, there is a lack of methodological operational elements. This descriptor also illustrates the difficulty to differentiate the impacts of direct anthropogenic pressures and the global change consequences. To assess permanent changes a reliable reference data is necessary and still missing. The definition of at least a 30-year reference period is mandatory to assess “permanent changes”, in order to be able to differentiate if an area is affected or not and if the change is permanent and not a signal of natural variability (Gonzalez et al. 2015).

D7C1.G4 Lack of knowledge on targets or limits for natural information

Concerning the level of pressure, the main difficulty is the separation between changes directly linked to large-scale human activities and natural multi-decadal variability and slow long-term changes like climate changes and/or ocean acidification. Again, the existence of an adequate monitoring programme together with long time series dataset would be essential for D7 and for the MSFD in general, allowing the assessment of these background large-scale changes.

D7C1.G5 Lack of knowledge on the understanding and the characterization of unexplored deep dynamics

Defining the alteration of hydrographical conditions in water depth more than 200 m means, first of all, understanding their dynamics. At these depths the wind action is no more relevant, but bottom and mixing processes become predominant. The heat contained in the ocean represents a fundamental and critical parameter for understanding climate changes as it dominates the Earth’s energy budget. However experimental data on its variability are missing, particularly in abyssal waters, where the latest published studies are dated and only referred to the Western Mediterranean (Rixen et al., 2005). Numerical models, in this case, seems often useless, since they are too sensitive to vertical eddy diffusivity and largely affected by inaccuracy at deep layers.
Consequently, the analysis of in situ measurements is crucial for understanding the actual role of mixing in the deep ocean circulation and heat content distribution. As a fact, where existent, in situ observations show as the deep layer is a non-negligible reservoir of heat (see for example the case of abyssal Ionian Sea in Artale et al., 2018).
The needs for and uses of deep ocean temperature data extend well beyond closing the global heat budget. Deep ocean temperature data are needed to initialize and constrain ocean models and improve their representation of mixing of heat downwards/upwards (Ferrari et al., 2016) within the deep ocean. Changes in deep ocean temperature are a measure of change in the large-scale ocean circulation (Purkey and Johnson, 2013). Warming of the deep ocean contributes to the thermal expansion of the ocean that is a contributor to sea-level rise.

The understanding of mechanisms and rates that control the bottom flows is essential to quantify re-transfer towards the upper layers of the energy stored at the seafloor (de Lavergne et al., 2016). In term of climate variability these processes sensibly affect the ocean system and could contribute to accelerate the rising trends. In term of ocean heat content, the progressive heat release from bottom layers can act as a positive feedback inducing a warming of the sub-superficial layers and influencing the ability of the ocean to retain and transform CO_2.

The understanding and the characterization of these unexplored deep dynamics will allow to carry on tailored parameterization providing essential outcomes for the implementation of climate models (such as model used by IPCC reports) that, at present, are not yet able to represent the dynamics under the 2000-m depth.

Descriptor 7, Criterion 2 (D7C2): Impacts on benthic habitats

Following Commission Decision (EU) 2017/848, D7C2 refers to the spatial extent of each benthic habitat type that is "adversely affected, (physical and hydrographical characteristics and associated biological communities) due to permanent alteration of hydrographical conditions". D7C2 is assessed in relation to the total natural extent of each benthic habitat type assessed.
Many gaps affect criterion 2 of Descriptor 7, because of the lack of data. The understanding of impacts caused by the pressures considered under Descriptor 7 is rather restricted, with limited available data and knowledge (Gonzalez et al., 2015).
The affected areas, as described by indicator 7.1.1 ("Extent of the area affected by permanent alterations"), would need to be crossed with the indicators considered for the biological descriptors D1, D4 and especially D6. So, the same gaps, as already described for D1, D4 and D6, still apply. In particular gaps D6-C3-5.G1, D6-C3-5.G2 AND D6-C3-5.G4, already described for descriptor 6-C3-5, are also relevant for D7C2.
On the other hand, a crossing of information would allow the assessment of the impacts of considered modifications.

Gap types described within D7C1 section are also relevant for criterion D7C2 as they all represent pressures too.

D7C2.G1 Missing information about permanent alterations to ecosystem functioning
The assessment of the impact level is really complicated for this descriptor as the alteration of hydrographical conditions has a combined effect on both ecosystem processes and functions. For example, variability of the circulation and thermohaline properties can induce further changes to sediment transportation, which might lead to further positive or negative impacts on biological communities as a result of changes to their immediate dynamic environment or through food chain effects. Changes in currents and salinity can also influence the spreading pattern of larvae and breeding and spawning areas. Furthermore, there are areas of very high natural variability where the assessment of impact would be particularly difficult (Zampoukas et al., 2014).

2.7.2 Geographical gaps

A detailed enumeration of geographical gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, meta-analysis and data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018b, 2018a).

D7GG.G1 Heterogeneous geographical data coverage
The Western basin is much more represented than the other basins: 68% of the reviewed studies were identified there. Another information gradient applies moving from Northern to Southern Mediterranean Sea: deep waters offshore the southern and eastern non-EU regions (as Libya, Egypt, Gaza, Israel, Lebanon and Syria) are characterized by few data.
Moving from large subregions to smaller spatial scales, most of the oceanographic studies concentrate in the northern Levantine and Aegean seas, the southern Adriatic Sea and Otranto Strait, the Sicily Channel,

and the northernmost, west-central and westernmost Western Basin including the Alboran Sea. Such distribution reflects the interest of the oceanographic community on choke points where significant water mass exchanges take place.

2.7.3 Bathymetric gaps

A detailed enumeration of bathymetric gaps can be found for each dataset in the descriptor-specific spreadsheets produced within the project. Deliverable 2.1 includes a section summarizing the gaps regarding geography and bathymetry (IDEM Project, 2018c). Additionally, meta-analysis and data mapping in GIS performed within tasks 2.2 and 2.3, respectively, again evince these gaps (IDEM Project, 2018b, 2018a).

D7BG.G1 Uninspected depth-ranges

Although surface drifters and commercial and research ships provide in situ temperature observations near the ocean surface and satellite remote sensing provides spatial coverage by mapping sea surface temperature, the need of temperature observations at depth has been identified as a crucial measurement to account for heat movement and storage in deeper layers of the ocean.

The majority of the literature studies revised for Descriptor D7 report information for depths within 1000 m (IDEM Project, 2018c). The deepest parts of the Mediterranean Sea (> 2,000 m depth) are described in the current literature only in the case of studies related to long-term deep-sea observatories, such applies for the EMSO sites, while few data are recorded especially in the Sicily Channel (mostly due to maritime traffic issues), in the south and eastern Levantine Basin, but also in the deepest part of the Tyrrhenian Sea.

Figure 8.1 (also partially shown in IDEM Project, 2018b), summarizes data availability and distribution, considering temperature and salinity from SeaDataNet[27]. As noted above, data for water column greater than 200 m are sensibly less than the total amount of recordings. Furthermore, by adding the instrument depth filter, they decrease again, especially below 2000 m (see the right panels in the same figure).

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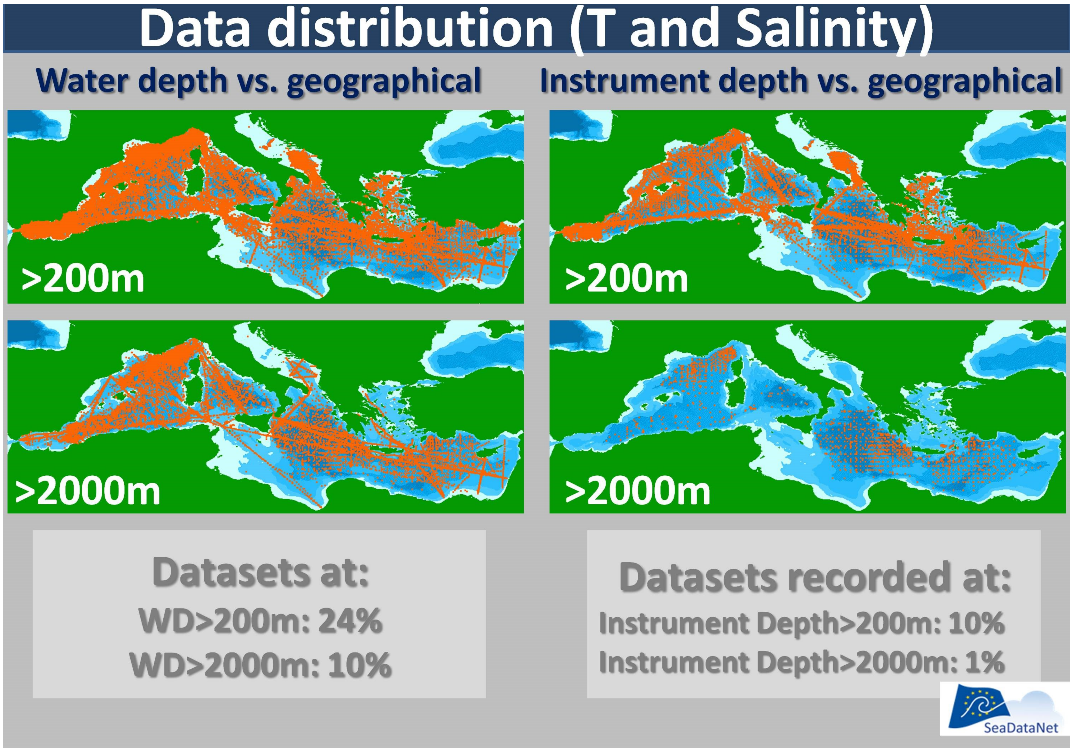
[27] http://seadatanet.maris2.nl/v_cdi_v3/search.asp



Data distribution (T and Salinity)

Water depth vs. geographical

Instrument depth vs. geographical

Datasets at:
WD>200m: 24%
WD>2000m: 10%

Datasets recorded at:
Instrument Depth>200m: 10%
Instrument Depth>2000m: 1%

Figure 2.1. *Summary of data availability and distribution for D7 considering temperature and salinity by water depth (left panels) and instrument depth (right panels). Each of the orange dots from the SeaDataNet maps corresponds to a dataset. Data accessed on 29/01/2019 considering the period 1911-2019 (total T and Salinity datasets from the surface to the bottom equal to 238336).*

2.7.4 Methods and technologies gaps

D7MT.G1 Lack of agreed common monitoring strategies

Overall, there is a lack of methodological operational elements. The lack of common understanding on the scope of Descriptor 7 prevents from harmonization in the assessment approaches. Specific guidance document developed at EU level is especially needed for this Descriptor. To stay in the MSFD tracks, the indicators should be pragmatics and quantify metrics, which could be positively impacted by the program of measure.

No common monitoring strategies are implemented. Again, guidance on monitoring requirements is needed and should be agreed at regional and European Scales with a minimum list of variables and key areas for monitoring programs, as being discussed and presented within IDEM task 3.3 deliverable. The broader scale of hydrographical changes (in part basin wide) also implies that a distinction should be made between indicator-related monitoring for D7 requirements, as specified in COM Decision 2010/477/EU, and the need for basic hydrographical data (e.g. temperature, salinity, Secchi depth, ocean acidification etc.) which are not necessarily indicators but are required to pick up long-term changes in the ecosystems and are relevant for implementing indicators and interpreting indicator results.

D7MT.G2 Lack of operating models to characterize the hydrographical conditions on short scales and the impact of infrastructure development

The need to develop further operational models on hydrographical conditions is urgent (Laroche et al., 2013). Modelling the changes in hydrographical conditions like currents, waves and salinity could be used to help quantify the effects of human pressures, to assess the extent of the possible affected area and the intensity of the changes to determine the effect on habitats. Models can be a powerful tool to first define the scale of the effect, and then decide what has to be monitored. For example, modelling can be used to investigate the impact of the ecosystem first to avoid unnecessary and costly monitoring on habitat level. Operating models can be used to investigate the accumulation of small-scale impacts.

D7MT.G3 Technology challenge to monitor below 2000 m water depth

The past general idea that the ocean-deepest circulation is in quasi-stationary motion has conditioned the observations of the abyssal layers for a long time, excluding them from the majority of the surveys around the ocean world. An underestimation of the deep ocean processes has continued to persist for decades, due also to the difficulty to make reliable observations at depth below the 2000 m. The real awareness about the unsteady state of the abyssal layers has only risen recently and it encourages wondering how the deep mechanisms can induce an internal instability and, consequently, affect the ocean circulation. However, although surface drifters and commercial and research ships provide in situ temperature observations near the ocean surface and satellite remote sensing provides spatial coverage by mapping sea surface temperature, the need of temperature observations at depth has been identified as a crucial measurement to account for heat movement and storage in deeper layers of the ocean.

Despite rapid advances in ocean measuring capabilities, a continuous gap between the available instruments and what we want to measure is still big and increasing, preventing to solve oceanographic processes in the deepest sea. For example, the MEDARGO program maintains an array of profiling floats in the Mediterranean Sea (Poulain et al., 2007), providing data very useful in the description of deep-water formation (Smith et al., 2008). But, since the implementation of the Argo program, the operational limit of profiling floats was the top half of the sea (0-2000 m) and the accuracy of sensors was similarly limited to upper ocean levels of temperature and salinity variability. As a fact, at the end of their drifting time, standard Argo floats dive to 2000 m and collect a profile of temperature and salinity during the upcast (see data in MedArgo[28], the official Argo Regional Centre for the Mediterranean and Black Seas.

Nevertheless, the scientific community agrees that a systematic sampling of the full ocean depth is needed to close the planetary budgets of heat and freshwater, and the global sea level budget. Recent advances in ocean monitoring system and new sampling technologies will go to face this issue, answering the big question mark on the knowledge of the abyssal area: a new generation of autonomous floats called Deep Argo will sample the full ocean volume, capable of reaching 4000-6000 m. A standing Deep Argo array in the Mediterranean Sea is advisable together with the promotion of Deep Argo Pilot Projects, similarly to what is already going to happen in the Southwest Pacific Basin, South Australian Basin, Australian Antarctic Basin, and North Atlantic Ocean. This transition to systematic full-depth global ocean observations could permit to uncover the deepest ocean data with deep Argo and to fix both related knowledge and technological gaps.

D7MT.G4 Need to implement a network of fixed stations for sea observation

In general, the lack of long-term oceanographic records precludes a more profound knowledge of permanent alteration of hydrographical conditions due to human pressures and in general of the marine response to the climatic forcings. Oceanographic trends are generally estimated throughout CTD data, highly scattered in time and space, implying a series of heavy limitations as detailed in Schroeder et al., 2013. On the other hand, since a regular monitoring of the climate system cannot be applied to all temporal and spatial scales over the whole Mediterranean, and not all parameters can be monitored, the advisable approach should be the definition of “sentinel stations” for the continuous monitoring of

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[28] http://nettuno.ogs.trieste.it/sire/medargo/active/index.php

hydrological long-term variability in key sites. Fixed strategic long-term observatories, even if limited in number, would allow comparisons and thus inferences about the propagation of impacts, the circulation and the functioning of the sea. The present status of the monitored sites is shown in Figure 2.2.

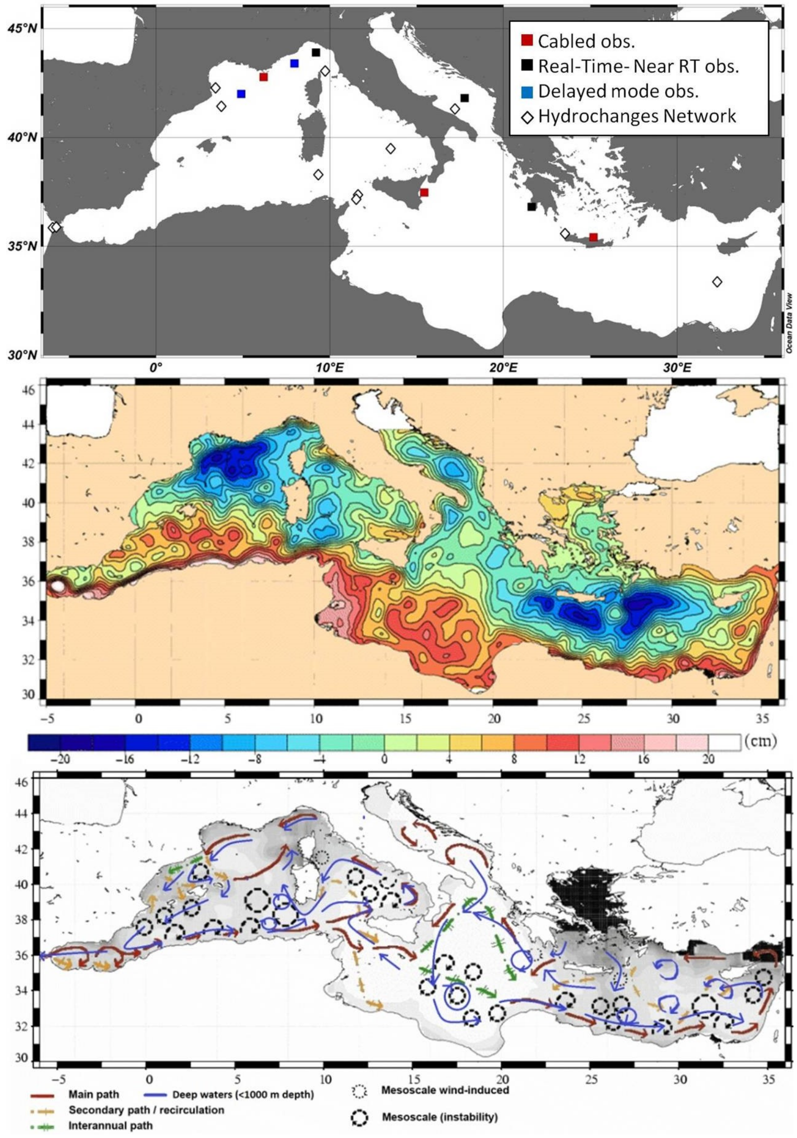

Figure 2.2. Present status of deep-sea fixed point monitoring network vs. mean surface circulation. White diamonds represent stations from the HYDROCHANGES network (Schroeder et al., 2013), while the other observatories (square symbols) are within FixO3 Program and/or the EMSO Infrastructures. Colours have been used to discriminate the data transmission type (refer to the legend for more details). Mean Dynamic Topography 1993-1999 (sea surface topography due to mean ocean circulation), general circulation of surface currents and the dynamics of deep waters have been reported for reference (adapted from https://www.aviso.altimetry.fr/en/news/idm/2006/sep-2006-mediterranean-currents.html)

Floating lab for climate studies, set in strategic area should be developed, as for example the already existing Lampedusa fixed buoy[29], installed since 2015 in a sea stretch where air masses originating over Europe and Africa cross each other, particularly suitable for monitoring the state of the Mediterranean Sea. The sea is a significant energy resource and the heat exchange with the atmosphere is fundamental for climate determination on a regional and global scale, because it influences air temperature, weather mechanisms, the hydrologic cycle and the transfer of gas and particulate matter. These fixed buoys could be used to study the energy exchange between the sea and the atmosphere, to track marine carbon cycle variation, to support fisheries studies and for ground-truth to validate and calibrate satellite measurements.

On parallel, where maritime traffic and fishing activities limit operability, near bottom installations in choke points should provide additional data, extending coverage of the HYDROCHANGES (see table 2 in Schroeder et al., 2013 and FixO3[30] (Fixed point Open Ocean Observatory network) programmes and of the EMSO (European Multidisciplinary Seafloor and water column Observatories[31]) EU Infrastructure.

D7MT.G5 Improving interdisciplinary impact of Lagrangian studies in monitoring other Descriptors under the MSFD

Lagrangian drifters are oceanographic devices used to study circulation patterns in the ocean. The devices are typically passive, mainly driven by the ocean currents. In the last decades a rapidly increasing amount of data becomes available from Lagrangian drifters, generally used to tag and track the ocean currents similar to "travelling CTDs", traced by satellites. However, the largest set of Lagrangian data available monitoring hydrographical conditions in the Mediterranean Sea are still underused in their interdisciplinary potential. For example, a practical application can be under D10 to estimate the probability of marine litter to reach different subareas of the Mediterranean, with the main objective of singling out possible retention areas and suggesting ad hoc marine litter observation campaigns. For example, recent studies carried out on the basis of observed Lagrangian displacements suggest a general tendency of floating matter to collect in the southern portion of the basin, and in particular a long-term accumulation in the southern and southeastern Levantine basin (Zambianchi et al., 2017).

Furthermore, Lagrangian data can be a useful tool to better explain biological phenomena, as the detected circulation patterns induce movements of effluents, larvae, and other microorganisms. Drifters can illustrate how fisheries dynamics are affected by fish migration, and can be used as an operating model to test the robustness of management strategies for fisheries stock. Migration hypotheses, such as the cyclic movement between feeding and spawning areas, can be used as the underlying pattern that drives the movement of individuals through space in a Lagrangian model.

Indeed, Lagrangian applications are very appealing for biogeophysical applications, since they can be used as a tool for automatically extracting transport structures and providing synthetic parameters connected to biogeochemical sub/surface dynamics, though, for example, the Finite Size Lyapunov Exponents FSLEs method (see Artale et al. 1997). Maps of FSLEs and Orientations of associated eigenvectors are already computed over 21-year altimetry period and over global ocean[32] and could be used for biological purposes (as done in the Antarctic; Region by Cotté et al., 2015). More cooperation between oceanographers and marine biologists is envisaged to this purpose.

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[29] http://www.lampedusa.enea.it

[30] http://earthvo.fixo3.eu

[31] http://emso.eu

[32] https://www.aviso.altimetry.fr/en/data/products/value-added-products/fsle-finite-size-lyapunov-exponents

2.7.5 *Connections between D7 gaps and the rest of descriptors*

This section focuses in illustrating D7 related gaps that are also relevant for other descriptors. Identification of the connections between descriptors' gaps will endorse the establishment of an integrative approach regarding all project tasks. Therefore, when describing new indicators within task 3.2, these connections need to be considered since indicators filling a D7 gap could also be applied to other descriptors. The concept of displaying relationships between descriptors is based on the approach presented in Cochrane et al. (2010).

Relationships between gaps and descriptors are illustrated as dark grey coloured cells in Table 2.6. The interconnections are identified when a gap described for D7 is also relevant for other descriptors, affecting other ecosystem components represented by state descriptors (i.e. D1, D3 and D4) or complementing pressures defined by pressure-based descriptors (i.e. D2, D5, D8, D9, D10 and D11). Again, coherently with D6, bathymetric and geographical gaps are not added to the table since are already considered relevant for all descriptors.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D7C1.G1	■		■			■	■				
D7C1.G2	■		■			■	■				
D7C1.G3							■				
D7C1.G4							■				
D7C1.G5	■		■	■	■	■	■	■	■	■	■
D7C2.G1	■	■	■	■	■		■				
D7MT.G1	■	■	■	■	■	■	■	■	■	■	■
D7MT.G2	■	■	■	■	■	■	■	■	■		
D7MT.G3						■	■				
D7MT.G4	■	■	■	■	■	■	■	■	■	■	■
D7MT.G5	■	■	■		■		■	■	■	■	

Table 2.6. *Representation of the connections between D7-identified gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D7-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 7:* ***D7C1.G1****. Lack of information in the relationship between hydrographical data and human pressures.* ***D7C1.G2*** *Lack of long time-series in several areas.* ***D7C1.G3*** *Lack of reference/baseline.* ***D7C1.G4*** *Lack of knowledge on targets or limits for natural information.* ***D7C1.G5*** *Lack of knowledge on the understanding and the characterization of unexplored deep dynamics.* ***D7C2.G1*** *Missing information about permanent alterations to ecosystem functioning.* ***D7MT.G1*** *Lack of agreed common monitoring strategies****.*** ***D7MT.G2*** *Lack of operating models to characterize the hydrographical conditions on short scales and the impact of infrastructure development.* ***D7MT.G3*** *Technology challenge to monitor below 2000 m water depth.* ***D7MT.G4*** *Need to implement a network of fixed stations for sea observation.* ***D7MT.G5*** *Improving interdisciplinary impact of Lagrangian studies in monitoring other Descriptors under the MSFD.*

2.8 *DESCRIPTOR 8: CONCENTRATIONS OF CONTAMINANTS*

2.8.1 *Major knowledge gaps concerning specific indicators and criteria*

The Mediterranean Sea is a concentration basin. The anti-estuarine exchange of water with the Atlantic Ocean leads to export nutrients and pollutants discharged into the Mediterranean waters. This process tends to maintain the Mediterranean waters with high transparency and oxygenation because of low algal growth. The area in which the Mediterranean Sea is located receives strong insolation which, combined with the transparent upper water column, involves important photo-oxidation processes and pollutant degradation. The average water temperatures also facilitate microbial degradation in the oxygenated water column.

All these aspects tend to reduce the enormous impact of the anthropogenic activities developed in the coastal areas, with large cities located close to the sea shore. Thus, about 170 million people is presently living in coastal regions, mostly in the western Mediterranean, the western shore of the Adriatic Sea, the eastern shore of the Aegean-Levantine region and the Nile Delta. Other pollution inputs arriving to the Mediterranean Sea are introduced by the main rivers, Nile, Rhône, Ebro and Po, being generated by the urban areas and industries present in their basins. Atmospheric deposition is the third main input mechanism adding pollutants to the whole Mediterranean Basin, part of these inputs is related to the anthropogenic activities in the coast and part are due to long-range transported pollutants (Arellano et al., 2014; 2015; Lamborg et al., 2014; van Drooge et al., 2004). In addition, Saharan dust may also be responsible for the long-range transport and deposition of some of these pollutants (Kuzu, 2016; Garrison et al., 2014).

D8C1.G1 Primary. Missing information beyond territorial waters

The overall combination of pollution inputs and Mediterranean water hydrology leads to the accumulation of chemically-stable pollutants of low volatility and high hydrophobicity in the deep Mediterranean environments. The deep Mediterranean Sea is the sink for many of these compounds. The combined process of pollution discharges and water dynamics may lead to the improper perception of a clean marine environment because most waters are transparent and the concentrations of a large number of pollutants in the water column are low. However, the open sea and deep marine areas accumulate a large amount of pollution at the bottom. That is, the compounds that are more recalcitrant to microbial and chemical degradation which are often re-incorporated to the food web and impact the marine fauna and humans.

Information is available on the occurrence of these compounds, e.g. mercury, in some coastal areas under important stress as consequence of industrial inputs, e.g. Haifa and the Israeli coast (Herut et al., 1997; Hornung et al., 1989; Shoham-Frider al., 2012). Unfortunately, the information on deep sea open areas is very limited.

One major and huge gap is related with the lack of knowledge of the extent of this chemical pollution in the marine sediments of deep-sea areas, both those located at some distance of the main pollution sources, e.g. rivers and coastal cities, and those in pelagic areas. The transfer of pollutants and radionuclides from coastal zones to deep open sea areas is sometimes mediated by dense shelf cascading events which transfer the sediments accumulated close to the coast, and their associated pollutants, to deep pelagic areas (Canals et al., 2006; Salvadó et al., 2012; 2017). From this point of view the continental shelf may be considered among the main sources of contamination for the deep sea.

D8C2.G1 Habitats. Insufficient studies of the sedimentary column

Sediments store the history of the pollution accumulated in the Mediterranean Sea. Studies of the marine sedimentary column would be useful to recover this information which, in turn, would provide significant data for assessments of the effects of the overall anthropogenic activities in the Mediterranean Basin. At this aim, radionuclides play a double role, as contaminants and as tracer of recent sedimentation (Tamburrino et al., 2019). Information on the temporal changes of the pollution impact by chemical compounds into the Mediterranean would be very useful as feedback of the success of regulatory measures. Unfortunately, this information is not available except in a few locations (Tolosa et al., 1995; Salvadó et al., 2013). This lack of information is critical as it is generally considered that the health of species and the condition of habitats is not adversely affected by contaminants (EU 2017/848) but the studies of enzymes that respond to oxidative pollution stress in fish from deep environments show that there are effects (Porte et al., 2000).

2.8.2 Geographical gaps

D8GG.G1 Heterogeneous geographical data coverage

The scarce data available on the marine pollution accumulated in the deep sea do not provide uniform spatial coverage. Most of the studies have been concentrated in the North-western Mediterranean, mostly in the area of the Gulf of Lyons and the Catalan Sea (Cossa and Coquery, 2005; Ferrara and Maserti, 1992; Gomez-Gutierrez et al., 2007; Kotnik et al., 2014; Ogrinc et al., 2007; Salvado et al., 2013). The Adriatic Sea is the other area from which more information is available (Kotnik et al., 2015). Even in these areas, the amount of information is clearly insufficient for a description of the pollutants accumulated in the deep sea and their threats to the ecosystem and food chain. In most of the remaining Mediterranean Sea there is no information at all.

The following sites should be chosen to obtain the best description of the pollution load accumulated in the Mediterranean Basin:

a) areas of transport of deep waters from the diverse Mediterranean Basins: Alboran Sea (Gibraltar Strait), Sicily Channel, Southern Aegean Sea-Levantine Region (Cretan Straits) and Southern Adriatic Sea-Ionian Sea (Strait of Otranto)
b) central areas of the main Mediterranean Basins: North-western Mediterranean, South-western Mediterranean, Balearic Sea, Alboran Sea, Tyrrhenian Sea, Ionian Sea, Adriatic Sea, Aegean Sea, Levantine Region and Southern Eastern Mediterranean.
c) open sea areas under the influence of submarine canyons
d) offshore areas in front of the deltas of the main rivers
e) offshore areas in from of the main cities

2.8.3 Methods and technologies gaps

D8MT.G1 Lack of agreed common monitoring strategies

The basic knowledge on the physical-chemical properties of the main pollutants, either metals or organic compounds, determining their distribution in the marine environment is available. However, this theoretical background is useless in the absence of sufficient data measurements on the concentrations of these compounds in the deep-sea environments. The compounds that should be analysed during monitoring should be preferentially those with high toxicity, low volatility, high hydrophobicity and chemical stability. Sediment core profiles of these compounds should be obtained. Here, there is an indicative list of compounds for study:

Organochlorine compounds:
Cis- and trans-Chlordane, oxychlordane, cis- trans-nonachlor, Heptachlor (Heptachlor epoxide), 4,4'-DDT, 4,4'-DDE, 4,4'-DDD, 2,4'-DDT, 2,4'-DDE. 2,4'-DDD, Endrin and endrin aldehyde, Dieldrin, Hexachlorobenzene, β- and γ-Hexachlorocyclohexanes, Mirex, Chlorothalonyl, Methoxyxchlor, Etridiazole, Polychlorobiphenyls: Non-dioxin-like: CB28, CB52, CB101, CB138, CB153, CB170, CB180. Mono-ortho-substituted: CB105, CB118.

Organobromine compounds:
Polybromodiphenyl ether congeners: diBDE17, triBDE28, tetrBDE47, tetrBDE66, tetrBDE71, pentBDE85, pentBDE99, pentBDE100, hexBDE138, hexBDE153, hexBDE154, heptBDE183, heptBDE190, decBDE209.
Methoxypolybromodiphenyl ether congeners: 5-MeO-BDE-47, 6-MeO-BDE-47, 4-Me-BDE-49, 2-MeO-BDE-68, 5'-MeO-BDE-99, 5-MeO-BDE-100, 4'-MeO-BDE-101, 4-MeO-BDE-103. 2,2',4,4',5,5'-Hexabromobiphenyl, hexabromobenzene, pentabromoethyl benzene, decabromodiphenyl ethane.

Metals:
Antimony, total arsenic, organic and inorganic species, barium, beryllium, cadmium, cobalt, lead, methylmercury and total mercury, thallium, tungsten

Polycyclic aromatic hydrocarbons:
Phenanthrene, alkylphenanthrenes, anthracene, fluoranthene, acephenanthrylene, pyrene, benzo[a]fluorene, retene, benzo[ghi]fluoranthene, cyclopenta[cd]pyrene, benz[a]anthracene, chrysene+triphenylene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]fluoranthene, benzo[e]pyrene, benzo[a]pyrene, perylene, indeno[7,1,2,3-cdef]chrysene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, dibenz[ah]anthracene, coronene

Cyclic and linear methyl siloxanes:
hexamethylcyclotrisiloxane, octamethylcyclotetrasiloxane, decamethylcyclopentasiloxane, octamethyltrisiloxane, decamethyltetrasiloxane, dodecamethylpentasiloxane, dodecamethylcyclohexasiloxane, tetradecamethylhexasiloxane

Phthalates and metabolites:
methylphthalate (metabolite of dimethylph), ethylphthalate (diethylph), benzylphthalate (benzylbutylph), isobutylphthalate, 2OH-iso-butylphthalate (di-isobutylph), n-butylphthalate (di-n-butylph and benzylbutylph), 3-OH-n-butylphthalate (di-n-butylph), cyclohexylphthalate (dicyclohexylph), n-pentylphthalate (di-n-pentylph), 2-ethylhexylphthalate, (2-ethyl-5-hydroxyhexyl)phthalate, (2-ethyl-5-oxohexyl)phthalate, (2-ethyl-5-carboxypentyl)phthalate (di-2-ethylhexylph), 7-OH-(methyl-octyl)phthalate, 7-oxo-(methyl-octyl)phthalate, 7-oxo-(methyl-octyl)phthalate (di-iso-nonylph), 6-OH-propyl-heptylphthalate, 6-oxo-propyl-heptylphthalate, 6-oxo-propyl-heptylphthalate (di-iso-decylph and di-propyl-heptylph), n-octylphthalate (di-n-octylph).

Artificial radionuclides:
^{239,240}Pu ^{241}Am ^{137}Cs ^{90}Sr

This list is devoted to explore the impact of chemical and radiological pollution in the deep sea environment. Obviously, it should be extended to more contaminants if a global assessment including the whole water column was considered but the main compounds reaching deep waters and the sedimentary environment are those indicated above.

D8MT.G2 Missing methodologies
Methodologies for increasing the sensitivity of the analytical methods for analysis of trace amounts of the above mentioned pollutants are under development. Methodologies for increasing the reliability of the sampled sedimentary columns avoiding losses of the top sediments are needed.

However, the EU 2017/848 for Descriptor 8 indicated that for waters outside territorial areas of the member states the criteria for contaminants under coastal and territorial waters should be considered (EU 2008/105). This regulation only concerns water quality and as expected open sea waters and deep waters fulfil the quality criteria of this directive. For instance, the maximum concentrations of mercury are regulated at 50 ng/L. The observed concentrations of this metal in either dissolved or particulate phase are well below this threshold (below 5 ng/L; Ferrara and Maserti, 1992; Cinnirella et al., 2013; Cossa et al., 1997; Horvat et al., 2003; Kotnik et al., 2007; 2017). However, the few data available on the mercury concentration of Mediterranean deep water fish (Koenig et al., 2013c) sampled at four sites of the Mediterranean Sea shows that more than 92% specimens examined have concentrations of this metal above 0.5 µg/g wet weight which is the threshold indicated by the European Union as adequate for human consumption (EU2006/1881). This contradiction is not surprising considering the low solubility of mercury in water.

Further insight into the health status of deep-water fish can be assessed by examination of several markers of oxidation toxicity stress. Again, very few data are available. Furthermore, the interpretation of the data available has to be performed with care because it is extrapolated from fish studies of surface waters, and some stress markers may be influenced by the strong pressures and low temperatures of deep-water environments. However, in some cases the few studies available (Porte et al., 2000) show so high values of ethoxyresorufin-O-deethylase (EROD), pentoxyresorufin-O-deethylase (PROD), carboxylesterase (CbE) , glutathione S-transferase (GST), total glutathione peroxidase (GPX), glutathione reductase (GR), catalase (CAT), superoxide-dismutase (SOD) activities and lipid peroxidation levels for some fish species such as *Alepocephalus rostratus*, *Lepidion lepidion*, *Aristeus antennatus Coryphaenoides guentheri* and *Bathypterois mediterraneus* that most likely they reflect metabolic alterations as consequence of pollution stress. Again, directive regulations only focussed on water concentrations are not sufficiently to protect the deep-water environments.

D8MT.G3 Insufficient standardization of methods and lack of detailed guidelines for assessments
Whereas the basic knowledge on the analytical methods for the analysis of the organic and inorganic pollutants is available, there is not reference methodology to be implemented to increase the comparability of the data obtained from different research groups. Furthermore, the number of intercalibration exercises is limited. This is an aspect for improvement. Another aspect for improvement concerns the need for standard sampling methods.

D8MT.G4 Lack of thresholds and reference levels
No thresholds are available as guidelines for assessment of the deleterious effects of the pollution load. As mentioned above, extrapolation of the threshold for surface waters is not sufficient for a description of health status of the deep-sea environments and for identification of the main processes leading to pollutant accumulation in these areas. Development of these thresholds will require combined chemical and ecotoxicological studies performed on representative organisms of the trophic web. In order to keep knowledge of reference levels of natural and artificial radionuclides, some reference station should be identified in central areas of the main Mediterranean Basins, where measures should be repeated on a decadal scale.

D8MT.G5 General lack of data and knowledge

As mentioned above the data available is clearly insufficient to describe the health status of the Mediterranean Sea. In large areas of this water basin there is simply no data.

In the absence of sufficient data, the knowledge available on the health conditions of the Mediterranean Sea has major deficiencies.

As mentioned above, the regulation criteria implemented for pollution control are not adequately tailored for assessment of the contaminant load arriving to deep water environments. One aspect that should be considered is the study of the pollutants accumulated in the continental margins for their potential transport to deep water environments. In addition, a specific assessment of the atmospheric inputs is needed as they may represent significant contributions of some pollutants in open deep-sea environments.

2.8.4 Connections between D8 gaps and the rest of descriptors

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D8C1.G1								■	■	■	
D8C2.G1								■			
D8GG.G1								■	■	■	
D8MT.G1								■	■	■	
D8MT.G2								■	■	■	
D8MT.G3								■	■	■	
D8MT.G4								■	■	■	
D8MT.G5								■	■	■	

Table 2.7. *Representation of the connections between D8-identified gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D8-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 8:* ***D8C1.G1****: Missing information beyond territorial waters.* ***D8C2.G1****: Insufficient studies of the sedimentary column.* ***D8GG.G1****: Heterogeneous geographical data coverage.* ***D8MT.G1****: Lack of agreed common monitoring strategies.* ***D8MT.G2****: Missing methodologies.* ***D8MT.G3****: Insufficient standardization of methods and lack of detailed guidelines for assessment.* ***D8MT.G4****: Lack of threshold and reference levels.* ***D8MT.G5****: General lack of data and knowledge.*

2.9 DESCRIPTOR 9: CONTAMINANTS IN FISH AND OTHER SEAFOOD FOR HUMAN CONSUMPTION

2.9.1 Major knowledge gaps concerning specific indicators and criteria

As indicated in descriptor 8, the Mediterranean Basin is receiving a strong input of chemical pollution from the cities located at the coast, the rivers and small water courses and atmospheric fallout. However, the natural hydrology of this sea is anti-estuarine which involves a considerable removal of these pollutants from the upper water column, transport to deep water environments and ultimate export through the Gibraltar straight. The strong insolation of the Mediterranean waters combined with the transparent upper water column enhances photo-oxidation and therefore pollutant degradation.

However, in this system the bottom sediments constitute a good store of the pollutants most recalcitrant to chemical degradation having hydrophobic properties and low volatility. The presence of this type of pollutants in the deep environments is likely deleterious for the fauna living in these waters. The lack of information on this issue constitute the main gap concerning this descriptor.

D9C1.G1 Primary. Few studies about contaminants and their effects
The few cases in which deep water fish have been studied corroborate that these organisms are exposed to high pollution levels of compounds with properties involving accumulation into the deep sedimentary environments. Thus, the concentrations of the ICES PCBs at 1000 m depth in the Gulf of Lion range between 14-14 ng/g ww and those of total DDTs between 7.4 and 13 ng/g ww (Solé et al., 2001) whereas the observed range in fish captured near Menorca (including surface waters, demersal and deep waters) range between 0.15 and 4.5 ng/g ww for PCBs and 0.082-6.9 ng/g ww for total DDTs (Junqué et al., 2018). Other studies on deep water fish collected at the open slope areas (1200-1500 m depth) in front of submarine canyons also show high concentrations of the ICES PCBs, 5.8-9.9 ng/g ww, and total DDTs, 6-13 ng/g ww (Koenig et al., 2013a). This comparison shows that deep areas are impacted by the above mentioned pollutants. Furthermore, the elevated xenobiotic-metabolizing (ethoxyresorufin-O-deethylase and pentoxyresorufin-O-deethylase) and antioxidant enzymes (catalase and total glutathione peroxidase) of fish from the deep areas nearby the canyons showed physiology alterations that were related to exposure to these compounds (Koenig et al., 2013b). Equivalent studies in open deep-sea environments are needed for assessing whether these effects are related to coastal influence into the deep environments or they are general in the whole Mediterranean Basin.

A similar contrast can be established for mercury, a metal with physical-chemical properties equivalent to those of the organochlorine compounds. The concentrations of this metal in 48 specimens of deep-water fish species collected in the Catalan Sea, Western Mediterranean, Sicily Straight and Eastern Basin ranged between 0.27 and 4.4 µg/g ww (Koenig et al., 2013c). These concentrations were higher than those found in lean fish specimens for human consumption from surface waters, demersal and deep waters from the Balearic Islands (between not detected and 3.1 µg/g ww; Llull et al., 2017) or Menorca (between not detected and 3.1 µg/g ww; Junqué et al., 2018). In another study, the concentrations of mercury in fish from different sources in Menorca ranged between 0.11 and 3.8 µg/g ww (Junqué et al., 2017). In some cases, these high concentrations of mercury in deep waters are in contrast with previous studies such as the one in the Eastern Basin in which all concentrations observed were below 1 µg/g ww (Kress et al., 1998). However, the number of specimens analysed is very limited which, again, emphasizes the importance of increasing the amount of data on the fish mercury concentrations (and other metals) in the deep Mediterranean environments.

These observed mercury concentrations also have strong implications for human health. Thus, the concentrations in many fish specimens of dusky grouper (100% of the examined specimens), common dentex (65%), conger (45%), common sole (38%), hake (26%) and angler (15%) collected nearby the Balearic Islands (Llull et al., 2017) were higher than the threshold levels indicated by the European Union for human consumption (European Commission, 2006). The proportion of fish with mercury above this threshold in the specimens collected nearby Menorca were 39% and 66% in the studies of Junqué et al. (2018) and (2017), respectively. However, the most striking result is the one observed in fish specifically collected in deep waters from four sites of the Mediterranean Basin because 98% of the observed concentrations (47 specimens out of 48) were above this threshold. The high mercury concentrations in deep water fish are not only relevant for the good health status of the deep Mediterranean environments but also for eventual human exposure upon commercial capture and consumption. All these aspects emphasize even more the need for an understanding of the concentrations of this metal as well as other metals and persistent pollutants in the deep-sea environments.

2.9.2 Geographical gaps

D9GG.G1 Heterogeneous geographical data coverage

The scarce data available on the marine pollution bio-accumulated in the deep sea do not provide uniform spatial coverage. According to what stated in the Section before, the following sites should be chosen to obtain the best description of the pollution load impact in fish from the deep waters of the Mediterranean Basin:

a) areas of transport of deep waters from the diverse Mediterranean Basins: Alboran Sea (Gibraltar Strait), Sicily Channel, Southern Aegean Sea-Levantine Region (Cretan Straits) and Southern Adriatic Sea-Ionian Sea (Strait of Otranto)
b) central areas of the main Mediterranean Basins: North-western Mediterranean, South-western Mediterranean, Balearic Sea, Alboran Sea, Tyrrhenian Sea, Ionian Sea, Adriatic Sea, Aegean Sea, Levantine Region and Southern Eastern Mediterranean.
c) open sea areas under the influence of submarine canyons
d) offshore areas in front of the deltas of the main rivers
e) offshore areas in from of the main cities

2.9.3 Methods and technologies gaps

D9MT.G1 Lack of agreed common monitoring strategies

The lack of information on the environmental status of deep-water fish is not limited by analytical technologies. As a fact, the operational methodologies for the study of pollutants in fish at the environmental concentration levels are available. Intercalibration exercises have been performed and the comparability of results between different laboratories is adequate. However, this methodological background is useless in the absence of sufficient data measurements and agreed common monitoring strategies on the concentrations of these compounds in the deep-sea environments.
The compounds that should be analysed in fish should be preferentially those with high toxicity, low volatility, high hydrophobicity and chemical stability. Here, there is an indicative list:

<u>In muscle:</u>
Organochlorine compounds:

Cis- and trans-Chlordane, oxychlordane, cis- trans-nonachlor, Heptachlor (Heptachlor epoxide), 4,4’-DDT, 4,4’-DDE, 4,4’-DDD, 2,4’-DDT, 2,4’-DDE. 2,4’-DDD, Endrin and endrin aldehyde, Dieldrin, Hexachlorobenzene, β- and γ-Hexachlorocyclohexanes, Mirex, Chlorothalonyl, Methoxyxchlor, Etridiazole, Polychlorobiphenyls: Non-dioxin-like: CB28, CB52, CB101, CB138, CB153, CB170, CB180. Mono-ortho-substituted: CB105, CB118.

Organobromine compounds:
Polybromodiphenyl ether congeners: diBDE17, triBDE28, tetrBDE47, tetrBDE66, tetrBDE71, pentBDE85, pentBDE99, pentBDE100, hexBDE138, hexBDE153, hexBDE154, heptBDE183, heptBDE190, decBDE209.
Methoxypolybromodiphenyl ether congeners: 5-MeO-BDE-47, 6-MeO-BDE-47, 4-Me-BDE-49, 2-MeO-BDE-68, 5’-MeO-BDE-99, 5-MeO-BDE-100, 4’-MeO-BDE-101, 4-MeO-BDE-103. 2,2’,4,4’,5,5’-Hexabromobiphenyl, hexabromobenzene, pentabromoethyl benzene, decabromodiphenyl ethane.

Metals:
Antimony, barium, beryllium, cadmium, cobalt, lead, methylmercury and total mercury, thallium, tin, tungsten

Natural radionuclide:
^{210}Po

Polycyclic aromatic hydrocarbons:
benzo[a]pyrene

<u>In liver:</u>
Polycyclic aromatic hydrocarbons:
Phenanthrene, alkylphenanthrenes, anthracene, fluoranthene, acephenanthrylene, pyrene, benzo[a]fluorene, retene, benzo[ghi]fluoranthene, cyclopenta[cd]pyrene, benz[a]anthracene, chrysene+triphenylene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]fluoranthene, benzo[e]pyrene, benzo[a]pyrene, perylene, indeno[7,1,2,3-cdef]chrysene, indeno[1,2,3-cd]pyrene, benzo[ghi]perylene, dibenz[ah]anthracene, coronene

This list is devoted to explore the impact of chemical pollution in the deep sea environment. It is a much larger list than the one reported for descriptor 9 in the EU 2006/1881 Directive. Nevertheless, it should be extended to more chemicals if a global assessment including the whole water column was considered. However, the main compounds reaching deep waters and fish from these environments are those indicated above.

Enzymes for assessment of the health status of the deep-water organisms should also be considered. These include ethoxyresorufin-O-deethylase (EROD), pentoxyresorufin-O-deethylase (PROD), carboxylesterase (CbE), glutathione S-transferase (GST), total glutathione peroxidase (GPX), glutathione reductase (GR), catalase (CAT), superoxide-dismutase (SOD) activities and lipid peroxidation.

D9MT.G2 Lack of thresholds and reference levels

The thresholds of pollutants for human consumption have already been defined by the Environmental Community (EU 2006/1881). Other thresholds involving physiological damage following the enzyme list provided above for the deep-water fish should be investigated.

D9MT.G3 General lack of data and knowledge

Very scarce data is available that by no means is indicative of the real pollution status of deep-sea Mediterranean fish. However, the limited amount of information indicates that most of fish from these deep-sea environments have concentrations of some metals such as mercury above the EU threshold for human consumption. Elucidation of the pollution status of a representative sample of fish from these environments is urgent.
There is a strong uncertainty on the health status of deep-water fish in the absence of data.

2.9.4 Connections between D9 gaps and the rest of descriptors

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D9C1.G1			■	■		■		■	■	■	■
D9GG.G1			■	■		■		■	■	■	■
D9MT.G1			■	■		■		■	■	■	
D9MT.G2			■	■		■		■	■	■	
D9MT.G3			■	■		■		■	■	■	

Table 2.8. *Representation of the connections between D9-identified gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D9-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 9:* ***D9C1.G1****: Few studies about contaminants and their effects.* ***D9GG.G1****: Heterogeneous geographical data coverage.* ***D9MT.G1****: Lack of agreed common monitoring strategies.* ***D9MT.G2****: Lack of agreed common monitoring strategies.* ***D9MT.G2****: Lack of thresholds and reference levels.* ***D9MT.G3****: General lack of data and knowledge.*

2.10 *DESCRIPTOR 10: MARINE LITTER*

2.10.1 Major knowledge gaps concerning specific indicators and criteria

Descriptor 10, Criterion 1 (D10C1): Composition, amount and spatial distribution of litter on the seabed

Data availability. The assessment performed by the European Commission of Member's States (MS) submissions on the MSFD found that only 55% of MS assessments considered litter pressures on the seabed. Regarding data availability, only 40% reported to have enough data, 20% had limited data and 40% didn't have any (Palialexis et al., 2014). Comparisons between marine compartments allowed the analysis of data availability (from best to worst case): pressure on the seacoast > pressure on seabed > impacts on marine animals > pressure in the water column/water surface > pressure regarding microplastics.

D10C1.G1 Debris transfer and spreading in the deep Mediterranean Sea
Information on debris transfer and spreading should include hydrodynamics of the deep sea (deep-sea currents, turbidity, density of water masses, and other forcing variables) and major geomorphological elements (submarine canyons, seamounts, trenches and other relevant landforms and associated habitats)**.** Model simulations should also be a priority (Eriksen et al., 2014; van Sebille et al., 2015). Knowing how human activities, namely bottom trawling, interfere with litter transfer and spreading is also part of this gap.

D10C1.G2 Composition, amounts and distribution of litter in deep-sea habitats of high relevance
Deep-sea environments of high relevance include submarine canyons, seamounts, trenches, biogenic substrates, hydrothermal vents, cold seeps, brine pools and the habitats they host (Pham et al., 2013; Woodall et al., 2015). Studies targeting relevant deep-sea environments and habitats are currently limited. Most of the analyses have been conducted in canyons, particularly in the Gulf of Lion, and in some cold-water coral (CWC) habitats. Such studies have reported significant impacts by litter on banks and seamounts, with fishing identified as the main litter source (Mecho et al., 2017; Consoli et al., 2018). The role of litter as substrate and shelter for organisms (e.g. Tubau et al., 2015) may have an impact on local biological diversity and on the functioning of the whole system. In any case, the number of studies on litter in relevant deep-sea habitats is limited.

D10C1.G3 Identification and analysis of areas with high potential for accumulating litter ("litter hotspots")
This topic depends on gap 1 (D10C1.G1), since the detection of accumulation-prone areas should be the first step in any assessment. Preferential litter accumulation areas are normally defined by low current speeds and high sediment accumulation rates, which commonly correspond to depressions of various sizes, the down current sides of seamounts, canyon axes (despite currents could peak there) and lower canyon courses, and deep basins (Canals et al., 2013). Overcoming or reducing the gap would require analyses of the current state of these areas and the development of predictive capabilities about potential impacts caused by high debris accumulation. Remediation possibilities should also be investigated, even though at first sight they might seem hardly feasible. Investigating if technologies developed for cleaning up litter on the sea surface and coastal areas could be applied to the deep sea should deserve attention. In addition, some initiatives involving fishermen have been developed in order to trawl litter in coastal areas. However, there is a lack of proposals regarding the deep seafloor, either because they have not been developed or published.

Descriptor 10, Criterion 2 (D10C2): Composition, amount and spatial distribution of micro-litter in seabed sediment

Data availability. The assessment performed by the European Commission on Member's states submissions on the MSFD revealed that only 20% of MS included microplastic pressure in the assessments. The main cause was the scarcity of data since only 5% of the MS stated to have data. 10% reported limited and 5% very limited data availability. Finally, the remaining 80% of MS assessments communicated the absence of data (Palialexis et al., 2014).

D10C2.G1 Microlitter composition, amounts and distribution in sediments of the deep Mediterranean Sea

Detection and assessment of microplastics in beach and shallow water sediments, and in the water column, are described in the quickly growing literature on this topic. However, this is a novel, poorly studied topic for deep-sea sediments (van Cauwenberghe et al., 2013, Sanchez-Vidal et al., 2018). For instance, the results presented in Task 2.2 show that only 7% of the publications inspected microlitter (i.e. microplastic fragments and microfibers) in deep-sea sediments. Since it is postulated that the deep sea may be a major sink for litter and especially for microlitter, this gap seems particularly relevant.

D10C2.G2 Composition, amount and distribution of microlitter in deep-sea habitats of high relevance

Deep-sea ecosystems encompassing submarine canyons, seamounts and biogenic substrates have huge implications on biological diversity, commercial fish stocks, and on other goods and services provided by the deep-sea (Woodall et al., 2015). Hydrothermal vents, cold seeps and brine pools are also relevant in terms of biodiversity and, potentially, for mineral resources and bioprospecting. The accumulation of microplastics and their co-occurrence with organisms could cause that highly diverse deep-sea ecosystems become hotspots for microlitter ingestion (and also of adsorbed and absorbed chemicals) with unknown effects on the whole ecosystem functioning. The view that microlitter ingestion would have little effect as it is compensated by excretion has to be demonstrated yet, particularly in animals of slow metabolism, such as those in the deep-sea.

D10C2.G3 Sources, transfer and spreading of microparticles in the deep Mediterranean Sea

Gap D10C1.G1 refers to the missing knowledge on debris transfer and spreading in the deeper zones of the Mediterranean Sea and, more generally, in the global ocean. However, information regarding sources and dispersal of microplastics and fibers in the deep-sea is even scarcer (Barrows et al., 2018). For instance, large amounts of litter, microplastics and microfibres are likely transported over the deep seafloor by high speed near bottom currents resulting from episodic dense shelf water cascading and offshore convection (Tubau et al., 2015; Sanchez-Vidal et al., 2018). There is an urgent need for acquiring knowledge regarding drivers and factors influencing microplastic transfer, spreading and accumulation, and also the associated biological impacts (cf. D10C2.G2).

Descriptor 10, Criteria 3 and 4 (D10C3-4): The amount of litter and microlitter ingested by marine animals; and the number of individuals of each species which are adversely affected

The two criteria under this heading are loosely related one to each other, also in practice it could be not obvious to discern amongst them. This is the reason why they are presented together.

Data availability. The assessment performed by the European Commission of Member's states submission on the MSFD revealed that only 45% of MS assessments included levels of impacts on marine animals. The main cause was the lack of available data. Only 20% MS reported to have sufficient data, whereas 20% and 5% reported to have limited and very limited data, respectively. Most MS reported to have absence of data (55%) (Palialexis et al., 2014).

D10C3-4.G1 Amount and effects of microplastics and microfibers ingested on demersal, epi and infauna from the deep Mediterranean Sea

Ingestion of plastics and microplastics by a variety of organisms has been described in numerous articles focused in marine mammals, turtles, seabirds and fishes (e.g. Taylor et al., 2016; Courtene-Jones et al., 2017). However, precise studies regarding ingestion rates and consequences for deep-sea (Mediterranean) organisms are far less abundant. The few articles found mostly concern demersal fishes (Anastasopoulou et al., 2013) or shrimps (Carreras-Colom et al., 2018). Individual impacts of different types of litter and associated chemicals on different species must be assessed to understand the relative risk that plastic poses to the different species, and at what life cycle stages. Future *in situ* experiments and modelling should be given particular attention.

D10C3-4.G2 Transfer of microplastics through the food webs. Potential implications on populations, communities and ecosystems

Microplastics impacts are not restricted to the species and organism levels. They can influence the population structure modifying community and ecosystem dynamics (Alison et al., 2015; Galloway et al., 2017).

2.10.2 Additional knowledge gaps concerning relevant topics poorly or not addressed within the MSFD-defined criteria

D10AG.G1 Transport of litter and microlitter (plastics) to the deep: spatial and temporal variations

In order to understand the dynamics of deep-sea litter sources and transport mechanisms should be identified. Multiple abiotic and biotic factors have been suggested as drivers of plastic spreading and accumulation (Tubau et al., 2015; Canals et al., 2013). A detailed characterization and quantification of all mechanisms involved is needed to assess the amount and behaviour of litter and microlitter in the deep-sea. Some abiotic factors have been characterized for some Mediterranean areas. However, the identification of all biotic elements influencing particularly microplastic transport is particularly complex. Mechanisms influencing plastic sinking and transport include processes such as biofouling (Kaiser et al., 2017), ingestion and accumulation within the marine food web (Clark et al., 2016), mineral ballast (Kowalski et al., 2016), and incorporation into fecal material (Cole et al., 2016), settling detritus (Long et al., 2015) and marine aggregates (de Haan et al., 2019), followed by their downward export through the action of the biological pump (Turner et al., 2015). Finally, there is even less knowledge regarding the transport and fate of other types of litter besides plastics. Properties including floatability, density, wind effects, fouling and degradation rates need to be studied to determine the behaviour of each litter category at sea (Zobkov, 2017).

D10AG.G2 Plastic degradation and fragmentation

Understanding the degradation of plastics in the ocean is one essential element for the assessment of their impacts in the marine environment. Abiotic and biotic mechanisms act simultaneously. The degradation rate is mainly affected by the plastic chemical composition and the environmental context. Weathering, erosion, photo and temperature-induced oxidation and biofouling have been characterized for beach and sea surface plastics (Andrady, 2011). One of the outcomes of these processes is the generation of microplastics that can sink and accumulate into deep sediments. However, degradation of plastics, including biodegradable ones, and other macrolitter on the seafloor is poorly described. Environmental conditions in the deep-sea are suspected to slow down the fragmentation and degradation process of plastics. For instance, plastics that lay on the seafloor or get buried in sediment are likely to have reduced degradation rates than those lying on the shoreline, as the latter are subject to UV-induced oxidation, higher temperatures and abrasion (UNEP, 2015). Degradation and fragmentation models considering the different rates and processes of litter degradation are needed globally. Degradability of different types of polymers in different environmental conditions should also be tested. Results should assure applicability to natural conditions.

D10AG.G3 Colonization of plastic debris

Biofouling is defined as the accumulation of organisms on surfaces. Plastic debris constitute hydrophobic, long-lasting substrates that are ideal for colonization. The extent of fouling depends on multiple factors (ambient conditions, polymer age, size, location, possibly composition) and influences multiple processes (Werner et al., 2016). Some of the main implications are described below:

Transport of plastics and microplastics from beaches, coasts and surface waters to the deep sea. Biofouling is one main factor enhancing sinking of debris by increasing sinking velocities and enhancing the sinking of polymers with densities lower than seawater (Kaiser et al., 2017).

Biodegradation. Fragmentation of plastic debris comprises multiple abiotic processes but also biotic mechanisms such as biological fouling. Partial mineralization of polymer compounds by specific microorganisms has been demonstrated, yet only prompted by advanced degradation states of polymers and hardly encountered at sea, where complex microbial communities interact with multiple environmental factors (Andrady, 2011).

Ecosystem structure. Biofouling implies the development of biological communities on plastic debris. Such communities may include, amongst other, algae, cnidarians, sponges, molluscs, barnacles and potential pathogenic bacteria (Kirstein et al., 2016; Kaiser et al., 2017). These new communities are significantly different from the ones found in surrounding waters (Zettler et al., 2013a). The introduction of a novel habitat, with different predominant species (such as hydrocarbon degrading bacteria or filamentous cyanobacteria) constitutes a disturbance for the ecosystem, influencing the ocean food webs. Sinking fouled particles constitute a new food source for heterotrophic organisms from the water column and the deep seafloor where organic material is scarce. In addition, sessile organisms are provided by long-lasting substrates, promoting their growth and survival. Finally, when litter sinks to the seabed it creates an artificial habitat that can be colonized by non-indigenous organisms.

Vectors of different species. Horizontal and vertical distribution of plastics implies the transport of the communities living on them. Multiple consequences may arise, including increased abundance and distribution of animal and human pathogens (Kirstein et al., 2016), the dispersion of harmful algal species (Masó et al. 2003) or the colonization of multiple habitats by non-indigenous species (Gregory et al., 2009).

Overall, biofouling of plastic debris on beaches and surface waters is currently being studied. However, biological processes occurring in sinking and seafloor debris are practically overlooked. Considering the sensitivity of benthic habitats, these impacts need to be analysed.

D10AG.G4 Smothering of the seafloor by marine litter

Litter, especially polymer sheets, films and nets, may cover bottom sediments reducing oxygen levels and leading to a reduction of fitness or even the death of benthic sessile organisms (Kühn et al., 2015). Smothering may modify fluid exchanges between the sediment and the water column, thus altering the concentration of gases and, in consequence, disturbing the indigenous habitats and communities (Gregory et al., 2009). The addition of different types of microplastic polymers to sediment in outdoor mesocosms has shown increased stress responses of infauna, reduced algal coverage, and polymer type bounded effects on nutrient cycling in sediments (Green et al., 2015). In addition, the effects of microplastics on the filtration rates of bivalves, sediment nutrient pools and fluxes, algal biomass and infaunal assemblages have been related to differences regarding polymer types and microplastic concentrations (Green et al., 2017). Therefore, the effects of chemical leaching, nutrient sequestration rates and stress responses to microplastics on sediment infauna require further assessment. Different environmental settings and polymer types also need to be investigated.

D10AG.G5 Potential sorption, transfer and release of organic and other pollutants from plastic debris and the surrounding environment

Two main topics are included within this gap:

Sorption and posterior transfer of absorbed persistent organic pollutants from the ocean. Plastic debris can accumulate pollutants in concentrations orders of magnitude greater than the surrounding water. In addition, the ingested plastics may transfer these chemicals to the consumers entering the food web (Teuten et al., 2009).

Release and transfer of harmful chemicals from plastic manufacturing (plasticizers, antimicrobials, flame retardant chemicals). Leaching and degradation of plasticizers and other polymers can lead to accumulation of toxic chemicals on seawater, sediments and fauna ingesting plastics (Rochman et al., 2013).

Multiple factors influence both topics: type and composition of the plastic, environmental conditions, concentration, ingestion rates and retention degree. Establishment of the relative importance and extent of contaminant transference by plastics needs detailed assessment.

D10AG.G6 Quantification of litter and microlitter sources (sea-based vs land-based)

Multiple studies have already focused on the identification of litter sources. However, detailed quantification of each input to the Mediterranean Sea, including both litter and micro-litter, is missing. This gap is one of the most complex and fundamental ones. It includes multiple processes and topics considered within other gaps, such as fragmentation of plastics (D10AG.G2), fishing gear implications (D10AG.G10), transport (D10AG.G1) and distribution of litter (D10C1.G1, D10C2.G1, D10C2.G3). An accurate assessment for each basin and sub-basin is urgently needed. Unattended point sources and litter types such as paint particles from ship hulls or city dust (e.g. asphalt and car tires) should deserve further attention. Moreover, additional inputs besides land and sea-based supplies such as atmospheric deposition are poorly investigated (Dris et al., 2016). Concerning specifically ocean sources and microplastic inputs, atmospheric deposition should be carefully evaluated.

D10AG.G7 Effects of nanoplastics

This knowledge gap includes particles in the <100 nm size range. Nanoplastics are the latest discovered and the group of plastics for which there is less knowledge on its environmental impacts. They have been postulated as likely being one of most hazardous ones. Evidences for bioaccumulation in organisms and transfer of pollutants and other chemicals are two of the multiple threats suggested (Koelmans et al., 2015). Since information regarding sources, distribution and effects is really limited, nano-sized plastics could be suggested as a new criteria or descriptor in order to enhance the consciousness and in-depth study of this litter group.

D10AG.G8 Bioindicators for plastic contamination

Monitoring of marine litter is one of the main troubles regarding litter assessment. Identification of representative bioindicators would support the measuring of litter and microliter in different environments (Fossi et al., 2017). Simultaneously, the analysis of harms caused to organisms by litter itself or because of plastic contaminants could also be evaluated.

D10AG.G9 Fate and toxicity of microplastics in humans and chronic effects of plastic exposure

The ubiquitous distribution of plastics and microplastics leads to an unavoidable exposure through multiple ways. Different routes and hazards are involved when considered the toxicity and effects of plastic exposure. Besides direct exposure, presence of micro and nanoplastics in food items is also a matter of concern (Galloway, 2015). Moreover, contaminants and microorganisms accumulated in the plastics could increase their toxicity. Chronic exposure is also considered worrisome since most effects are expected to be dose-dependent (Wright and Kelly, 2017). Exposure levels are currently unknown.

D10AG.G10 Impacts by lost and abandoned fishing gear

Fisheries are one of the main sea-based sources of litter. Fishing gear may be lost at sea by accident or abandoned on purpose into the marine environment. Particularly in regions with increased fishing pressure such as seamounts or canyons, fishing activities release the greater amount of litter (Woodall et al., 2015). Consequences of lost debris are numerous, encompassing smothering, ghost fishing and several biota-related impacts (Amaral-Zettler et al., 2016). Identification of the impacts of each gear type is essential to implement better fishing practices in terms of reducing impacts on the ecosystem. Ghost fishing represents one of the effects of derelict fishing gear, causing mortality of fish and other species without control (Brown and Macfadyen, 2007).

D10AG.G11 Uncertainties on plastic biodegradability

Plastics that are susceptible to degrade by biological activity and be mineralized into carbon dioxide, water and biomass are termed biodegradable. Common biodegradable polymers are made of starch blends, PLA (polylactic acid), PCL (polycaprolactone), PBS (polybutylene succinate), PVA (polyvinyl alcohol) and PLGA (polylactic-co-glycolic acid). Biodegradation rates of plastics depend upon the concentration of enzymes, microorganisms, temperature, pH value, oxygen supply, light and the polymer type (Haider et al., 2018). Biodegradation readily occurs under controlled optimal conditions for enzyme activity (e.g. industrial compost sites). However, many information gaps remain on the degradation process of different polymers in natural environments, such as in soils, seawater and in the deep-sea, where most of them are likely to not biodegrade (Suaria et al., 2016; Bagheri et al., 2017). Biodegradation rates in such environments remains challenging due to the wide span of environmental conditions that concur. For instance, current knowledge shows that some deep-sea bacteria are capable to biodegrade only PCL, whereas other biodegradable polymers remain unaffected (Sekiguchi et al., 2010). Actually, most papers on marine plastic litter do not consider plastic biodegradability but rather focus in a generic category simply referred to as “plastics”. To better understand their physical and biological fate in the deep-sea, laboratory assays must focus on the biodegradation of different polymers considering realistic and variable environmental conditions. The potential biological effects of biodegradable plastics on different organisms should also be evaluated, including their biodegradability caused by gastrointestinal fluids, and considering long-term exposures.

D10AG.G12 Assessment of marine animal welfare as related to interaction with litter
The harm caused by marine litter is not limited to the alteration of the ecosystem functioning and impacts on populations as it also encompasses individual animals. Animal welfare can be defined as the physical and psychological condition of an animal (Werner et al., 2016). The term is of paramount interest both scientifically and in social terms as marine litter often is ingested and also entangled by marine organisms. Marine litter may affect individual species by generating acute or chronic impacts, including trauma, damage, asphyxiation, reduced locomotion, drowning, infections, debilitation, and hormonal changes, among others. Most sub-lethal effects often result in long-lasting (i.e. from weeks to years) and torturous death of individuals, which constitute an important ethical problem. However, the weighing of the stress or suffering of different animals is challenging due to the vast diversity of species and different behaviours in the environment (Butterworth et al., 2012). Human perception also plays a role, as the concept of animal suffering is perceived more acutely for some groups (e.g. marine mammals) than for others (e.g. polychaetes). We suggest evaluating the creation of a well-established assessment scoring and a dataset allowing comparison of the severity of different types of litter harm between species and groups. This could start by considering a limited number of species and groups first. The duration of exposure should also be taken into consideration. Furthermore, research has usually omitted measurements of animal welfare and sub-lethal effects are scarcely witnessed. For instance, whales or pinnipeds may get entangled, suffer and eventually die without notice. Therefore, reporting detailed descriptions of the appearance of wounds, such as the scars and marks on animals is of the utmost importance.

2.10.3 Geographical gaps

This section defines the main general gaps identified while revising the datasets collected for Task 2.1. A detailed enumeration of geographical and bathymetric gaps can be found for each dataset in the descriptor-specific spreadsheets. Deliverable 2.1 also includes a section summarizing the gap outcomes regarding geography and bathymetry. Additionally, meta-analysis and data mapping in GIS performed within Tasks 2.2 and 2.3 further insist on these gaps (IDEM Project, 2018b, 2018a).

D10GG.G1 Heterogeneous geographical data coverage
Zones concentred in the southern Mediterranean Sea remain unstudied. This is the case of most of the non-EU countries: Morocco, Algeria, Libya, Egypt, Israel, Lebanon, Syria, Turkey and Cyprus. Regarding the northern part, the higher lack of research effort and data was found in the Aegean-Levantine Basin, reflecting the Eastern Mediterranean gap commented already in the above-mentioned deliverable. Finally, most of the studies focus around areas in the Northwestern Mediterranean (i.e. Gulf of Lion and Catalan-Balearic Sea), the Central-western Mediterranean (i.e. Sardinian coast), the Central Mediterranean (i.e. Strait of Sicily) and the Eastern Mediterranean (i.e. Southwestern Aegean Sea), whereas the Adriatic Sea, central Ionian Sea and Levantine Sea experience data deficiency.

2.10.4 Bathymetric gaps

This section defines the main general gaps identified while revising the datasets collected for Task 2.1. A detailed enumeration of geographical and bathymetric gaps can be found for each dataset in the descriptor-specific spreadsheets. Deliverable 2.1 also includes a section summarizing the gap outcomes regarding geography and bathymetry (IDEM Project, 2018c). Additionally, meta-analysis and data mapping in GIS performed within Tasks 2.2 and 2.3 further insist on these gaps (IDEM Project, 2018b, 2018a).

D10BG.G1 Uninspected depth ranges

Only 11% of all deep-sea publications have totally or partially examined the compartment found below 2500 m depth and 53% had to some extent inspected depths between 200 and 2500 m. However, some studies that have reported the inspection of depths below 200 m have either scarce information below that depth or do not report sampling depths. Therefore, it is suspected that the proportion of deep-sea litter information is lower than it could be presumed at first sight and should deserve further consideration. Concerning criteria 3 and 4 of Descriptor 10, the gaps concentrate on the seafloor. Few studies focused in deep-sea demersal fishes. In addition, analysis of impacts of microlitter on epifauna and infauna, like crustaceans and other organisms, from deep seabed in the Mediterranean were even scarcer. The exceptions are articles about CWC communities and canyon habitats from the Western Mediterranean Sea.

2.10.5 *Habitats and species gaps*

The concept within this section is mostly relevant for descriptors D1, D2, D3 and D4. However, the identification of unstudied habitats regarding Descriptor D10 could be also appropriate. Therefore, many gaps encompassed in the criteria defined and additional gaps could be added here, including C1.G2-3, C2.G2, C3.G1-2 and AG.G2-5, AG.G8 and AG.G12. Task 2.2 evinced that most of studies focus in species rather than habitat impacts. For those studies that evaluated the impact of litter on habitats or species, fishing gear was generally pointed out as the main stressor despite the prevalence of plastic items found by most of the studies. It should be also noticed that most of research regarding litter interactions with fauna has focused mainly on known areas with high fishing pressure. Whereas fishing gear is likely to cause major impacts on species and habitats, especially on hard bottom habitats, interactions with plastic items and microlitter are scarcely considered.

D10HS.G1 Litter effects on demersal animals other than fishes, epifauna and infauna

Harm caused by litter to organisms is an actual topic attracting attention since the past years. However, the range of taxa considered is quite limited and focused on large animals such as marine mammals, turtles, seabirds and commercial fish species. With the exception of some studies reporting CWC interacting with litter, invertebrates and other benthic animals are usually omitted, especially in deep-sea habitats. The significance of these taxa in deep-sea ecosystems is notable since they may structure the community as bioengineers or represent the key levels of the food web (Taylor et al., 2016). In addition, they have been proposed as bioindicators for litter contamination. Accurate analysis of litter effects on deep-sea demersal animals (fishes excluded), epifauna and infauna from the Mediterranean Sea are needed in all basins and particularly for MPA, EBSA and VME.

2.10.6 *Methods and technologies*

D10MT.G1 Standardization and harmonization of measurement methods, units and monitoring protocols

The results of the MSFD implementation evince that one of the major gaps is the absence of harmonized methodologies (Laroche et al., 2013). The consequence is different types of data expressed in multiple units that hampers comparisons between countries and the establishment of adequate, intercomparable monitoring programs and measurements. Regarding marine litter, nine different units were used for reporting its occurrence on the seabed (Palialexis et al., 2014). Microplastics reports encompassed also seven different units. The MSFD frame guidelines have been set aiming for a common approach for all European waters. However, the national-focused design and implementation of measures and monitoring programs leads to low coherence levels. Effective cooperation is required between countries sharing basins and resources. Monitoring timescales usually stretch from only a few weeks to months (IDEM Project 2018b) and should also be adapted by using multi-annual frequencies for deep sea floor surveys (Galgani et al., 2014).

D10MT.G2 Collation of existing data on plastic distribution in all environmental compartments

Nowadays, reasonable amounts of quantitative data and model simulations of debris distribution are only available for surface ocean masses. The current lack of data on water column and seabed litter distribution hampers achieving a sound, comprehensive view for these compartments. The ideal assessment should consider horizontal and vertical transport encompassing all ocean waters and seafloor ecosystems (UNEP, 2016).

D10MT.G3 Automated monitoring and sampling

Sampling and monitoring protocols are available for beach, floating, seafloor litter and micro-litter (Galgani et al., 2010). However, the analysis of deep-sea litter is restricted by sampling difficulties and costs. Large-scale coverage is currently missing, and most observations are punctual. Monitoring should preferably be long-term (i.e. from years to decades). New technical approaches should be established, considering the usage of ship or platform-based monitoring cameras and image analysis with automated object identification software. Acoustic technologies could be developed for the detection of derelict fishing gear. In addition, automated water samplers and advanced sediment samplers should deserve attention too. Since microlitter sampling techniques have just started to develop, harmonization should be the first step.

D10MT.G4 Litter removal techniques

Campaigns for the removal of litter have been organized globally, mostly by volunteers and non-profit organizations. Beach cleaning (e.g. International Coastal Cleanup or Clean Up the World) and removal of derelict gear (e.g. Global Ghost Gear Initiative or Healthy Seas Initiative) are amongst the best-known operations. Campaigns organized in coordination with fishing have also been proposed, like the Fishing for litter initiative applied in the Baltic Sea. Innovative equipment and techniques for capturing floating litter have also been developed and implemented in some areas (e.g. Mr Trash Wheel or The Ocean Cleanup system). Regardless of all of these attempts, official legislated programs that oblige the fulfilment of effective clean-ups are still missing. In addition, methods and technologies need to be developed for removal of deep-sea litter and particularly for microlitter from all compartments (Chen, 2015; UNEP, 2016).

2.10.7 Connections between D10 gaps and the rest of descriptors

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D10C1.G1	■	■		■		■		■		■	
D10C1.G2	■	■		■		■		■		■	
D10C1.G3	■	■	■	■	■	■	■	■		■	
D10C2.G1	■	■				■		■		■	
D10C2.G2	■	■		■		■		■		■	
D10C2.G3	■	■		■		■		■		■	
D10C3-4.G1	■		■	■	■				■	■	
D10C3-4.G2	■		■	■	■				■	■	
D10AG.G1	■	■		■				■		■	
D10AG.G2								■		■	
D10AG.G3	■	■		■	■					■	
D10AG.G4	■					■				■	
D10AG.G5	■			■	■	■		■		■	
D10AG.G6	■				■			■	■	■	
D10AG.G7	■	■	■	■	■	■		■	■	■	
D10AG.G8	■	■			■			■		■	
D10AG.G9				■				■	■	■	
D10AG.G10	■		■			■				■	
D10AG.G11	■	■			■	■		■	■	■	
D10AG.G12	■	■		■	■	■		■		■	
D10HS.G1	■		■	■					■	■	
D10MT.G1										■	
D10MT.G2	■			■	■	■		■	■	■	
D10MT.G3		■			■	■		■		■	■
D10MT.G4		■		■	■	■			■	■	■

Table 2.9. *Representation of the connections between D10 identified gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D6-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 10: D10C1.G1 Debris transfer and spreading in the deep Mediterranean Sea.* ***D10C1.G2*** *Composition, amounts and distribution of litter in deep-sea habitats of high relevance.* ***D10C1.G3*** *Identification and analysis of areas with high potential for accumulating litter ("litter hotspots").* ***D10C2.G1*** *Microlitter composition, amounts and distribution in sediments of the deep Mediterranean Sea.* ***D10C2.G2*** *Composition, amount and distribution of micro-litter in deep-sea habitats of high relevance.* ***D10C2.G3*** *Sources, transfer and spreading of microparticles in the in the deep Mediterranean Sea.* ***D10C3-4.G1*** *Amount and effects of micro-plastics and microfibers ingested on demersal, epi and infauna from the deep Mediterranean Sea.* ***D10C3-4.G2*** *Transfer of micro-plastics through the food webs. Potential implications on populations, communities and ecosystems.* ***D10AG.G1*** *Transport of litter and micro-litter (plastics) to the deep. Spatial-temporal variations.* ***D10AG.G2*** *Plastic degradation and fragmentation.* ***D10AG.G3*** *Colonization of plastic debris.* ***D10AG.G4*** *Smothering of the seafloor by marine litter.* ***D10AG.G5*** *Potential sorption, transfer and release of organic and other pollutants from plastic debris and the surrounding environment.* ***D10AG.G6*** *Quantification of litter and micro-litter sources (sea-based vs land-based).* ***D10AG.G7*** *Effects of nanoplastics.* ***D10AG.G8*** *Bio indicators for plastic*

contamination. ***D10AG.G9*** *Fate and toxicity of micro-plastics in humans and chronic effects of plastic exposure.* ***D10AG.G10*** *Impacts by lost and abandoned fishing gear implications and deployment practices to reduce losses.* ***D10AG.G11*** *Uncertainties on plastic biodegradability.* ***D10AG.G12*** *Assessment of marine animal welfare as related to interaction with litter.* ***D10HS.G1*** *Litter effects on demersal animals other than fishes, epifauna and infauna.* ***D10MT.G1*** *Standardization and harmonization of measurement methods, units and monitoring protocols.* ***D10MT.G2*** *Collation of existing data on plastic distribution in all environmental compartments.* ***D10MT.G3*** *Automated monitoring and sampling.* ***D10MT.G4*** *Litter removal techniques and measures. Connections between descriptors of geographical gaps (****D10GG.G1*** *Heterogeneous geographical data coverage) and bathymetrical gaps (****D10BG.G1*** *Uninspected depth ranges) cannot be conceptually constructed and have not been assessed in this table.*

2.11 *DESCRIPTOR 11: INTRODUCTION OF ENERGY*

Descriptor 11 for achieving good environmental status requires that: “Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment”.

2.11.1 Major knowledge gaps concerning specific indicators and criteria

DATA AVAILABILITY

D11 shows a profound lack of knowledge in deep-sea environments (Laroche et al., 2013, Palialexis et al., 2014). When considering the deep sea, few assessments of noise levels have been performed in Mediterranean waters (both continuous and impulsive), while the possible negative impact of noise on species was scarcely addressed. Although recent progresses have been made about the collection of basic knowledge on noise pollution in Mediterranean waters, the effects of shipping and airgun noise on marine organisms is still severely deficient. Consequently, noise thresholds and reference levels are missing and difficult to address. More data and observations are needed to understand the bioecological implications for deep Mediterranean Sea. D11 lists two criteria for the establishment of the GES and both should be agreed at Union level. Here follows a list of existing gaps for Descriptor 11 in Commission Decision (EU) 2017/848 laying down criteria and methodological standards on GES of marine waters, as well as specifications and standardized methods for monitoring and assessment.

Descriptor 11, Criterion 1 (D11C1): The spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources do not exceed levels that adversely affect populations of marine animals.

According to Commission Decision (EU) 2017/848, for D11C1 *t*he GES shall be expressed for each area assessed as “*the duration per calendar year of impulsive sound sources, their distribution within the year and spatially within the assessment area, and whether the threshold values set have been achieved”.* Recommended methods for monitoring and assessment include calculation of “*geographical locations whose shape and areas are to be determined at regional or subregional level”* and *“impulsive sound over the frequency band 10 Hz to 10 kHz.”*

In relation to D11C1, the EU Marine Strategy Framework Directive’s current action plan recommends implementation of a transparent data register on anthropogenic noise sources in the Mediterranean. The common register on Mediterranean noise sources will fill a knowledge gap and will produce a baseline of reference for taking measures to reduce the problem. Member States shall establish the duration per calendar year of impulsive sound sources, their distribution within the year and spatially within the assessment area through cooperation at Union level, taking into account regional or subregional specificities.

D11C1.G1. Lack of standardized, systematic mapping of current impulsive sounds inputs

TG Noise recommendations (Dekeling et al. 2014) addressed the strong need to implement a Mediterranean register of impulsive noise sound sources. Progress have been made in recent years and regional registers are available or under development by Member States, but they still need to be completed and implemented. The Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS) have recently provided information on the spatial extent of different noise-generating activities in the Mediterranean Sea, and yielded the first basin-wide overview on noise distribution of the most impacting sources (Maglio et al., 2016). First results were worrisome, even if authors admit the incompleteness of their datasets and the urgent need of additional efforts in detailing noise sources.

The QUIETMED project funded by DG Environment (ENV), European Commission, has just created (January 2019) an online register of impulsive noises in the Mediterranean Region. The register is intended as a joint tool to provide and to share information regarding anthropogenic impulsive sound in water in support of the implementation of the second cycle of the MSFD in the Mediterranean Sea Region. Member states are asked to upload all the impulsive noise sources to obtain a joint map of impulsive noise stressors in the Mediterranean Sea Region. Thus, for the moment platforms are ready but data need still to be uploaded. Sharing national data and joint processing will produce noise maps that will be able to evidence noisy hotspot areas resulting by impulsive noise and assess if it overlaps critical areas for biodiversity.

The register is strongly needed to estimate the spatial and temporal impact on the environment (the total period and total habitat loss by impulsive noise sources) and for determining reference levels. The register will serve as a baseline on impulsive noise for management purposes (e.g. regulating planning and licensing activities) and assist in marine spatial planning, incorporating displacement mitigation guidelines and reducing the potential for cumulative impacts.

D11C1.G2. Absence of historic OA repositories

For the Mediterranean, no open access repository has been created in the past years. To gather data on the past location, type and trend of impulsive sound sources would extremely help to address the challenge of establishing a baseline level of reference, which is still missing for this criterion.

Descriptor 11, Criterion 2 (D11C2): The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals.

According to Commission Decision (EU) 2017/848, for D11C2 the GES shall be expressed for each area assessed as *“the spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals”.* Recommended methods for monitoring and assessment include the calculation of “*the annual average of the sound level, or other suitable temporal metric (…), per unit area and its spatial distribution within the assessment area, and the extent (%, km^2) of the assessment area over which the threshold values set have been achieved.”*

D11C2.G1 Poor and fragmented knowledge in the Mediterranean Sea

There is the very high level of fragmented knowledge, with only five papers published for this criterion concerning the deep Mediterranean. Spatial but also temporal gaps are evident when reviewing the datasets of published papers, with only two studies from the western Mediterranean and none from the Aegean-Levantine basin. Additionally, the studies from the Central Ionian and the Western Mediterranean are essentially local and referred to the measurement of noise in the close proximity of the fixed infrastructures. Long-term datasets are almost completely absent.

<u>Descriptor 1, Criteria 1 and 2 – Common Gaps</u>

D11C1-2.G1 Absence of long-term trends

At present, there are no data on long-term (decadal) trends of ambient noise in deep Mediterranean waters while impulsive sound data are available for a limited number of countries, sound sources and years of activity. The establishment of long-term trends in underwater noise is the first step to address changes relatively to baseline levels and thresholds defined at a Union level.

Due to the actual scarcity of data available, TSG Noise recommends the combined use of measurements and models (and possibly sound maps) as the best way for Member States to ascertain levels and trends of ambient noise.

D11C1-2.G2 Presence of unavailable data.

There are major data weaknesses on impulsive noise mapping in specific areas, particularly along the coastline of Northern Africa, which are yet to be considered quiet due to a lack of data. Additionally, activities by oil and gas companies as well as the military ones remain largely undisclosed.

For ambient noise assessments, some areas such as the Adriatic Sea, the western Alboran Sea, and the south-western Peloponnese are poorly covered by the AIS service, due to a lack of AIS land stations (Maglio et al. 2016), and this impedes the possibility of indirectly inferring shipping traffic impact in those areas.

2.11.2 Additional gaps concerning relevant topics poorly or not addressed within the existing MSFD-defined criteria

D11AG.G1 Inconsistencies between MPAs and hot spots of noise pollution

Several noise hotspots overlap areas that are of particular importance to marine mammal species, and/or marine protected areas (e.g. the Pelagos Marine Mammal Sanctuary in the Ligurian Sea, the Strait of Sicily, parts of the Hellenic Trench, and waters between the Balearic Islands and continental Spain) (Maglio et al, 2016). Consequently, the risk of noise impact on marine animals in such areas is high. New regulations in the existing MPAs and new MPAs should be recommended to achieve GES for D11 in the Mediterranean basin.

2.11.3 Geographical gaps

D11GG.G1. Insufficient geographical data coverage

For D11C2, all Mediterranean basins present scarce or null representation of data in deep-sea habitats with only two studies from the western Mediterranean and none from the Aegean-Levantine basin. For D11C1, there are still major data weaknesses in specific areas, particularly along the coastline of Northern Africa, which are yet to be considered quiet due to a lack of data.

2.11.4 Bathymetric gaps

D11BG.G1 Lack of studies on noise levels from 200 to 2000m.

Continuous noise level assessments (D11C2) on depths from 200 to 2000 m have been never published for the Mediterranean, as all the observatories are located below 2000 m of depth. For impulsive noise pollution, direct assessments of noise levels in Mediterranean deep-sea are usually not used; data is inferred on the base of noise propagation models from the noise source using information about the sound source (e.g. piling energy), bathymetry, bed characteristics (grain-size distribution) and the wind. At least in a first phase, empiric hydrophonic measurements should accompany models in order to cross-match model's results.

2.11.5 Habitats and species gaps

D11HS.G1 Poor knowledge of deep-sea species and of their sensibility to noise pollution

Knowledge about the biological component of the deep-sea system is still poor, and consequently the impact of noise on it cannot be assessed with certainty. Without such biological knowledge, detailed noise impact mapping is not possible. Effective noise impact on the health and ecology of a given species depends on a variety of factors, some of which are species-specific, such as the animal's hearing ability or its behavioural state (e.g. whether it is mating or foraging). Although there is evidence in literature about the effects of shipping and airgun noise on marine organisms, more data on crustaceans, fish and marine mammals are needed to understand the bioecological implications for deep Mediterranean Sea. Helpful insights regarding the consequences of noise on the hearing, health, and behaviour of other marine organisms might be gathered from studies performed outside the Mediterranean area, which could be still used as a reference for the common species.

2.11.6 Methods and technologies gaps

D11MT.G1 Lack of thresholds and reference levels.

For both criteria (impulsive and continuous noise), thresholds still need to be defined. Member States need to establish threshold values for D11C1 and D11C2 (temporal and spatial threshold; exceedance noise level over time threshold) through cooperation at Union level, taking into account regional or subregional specificities.

For D11C1, there is an urgent need to compile a transparent data register on anthropogenic noise sources in the Mediterranean before taking actions to reduce the problem. The initial step would be to establish the current level and trend of impulsive sounds. Only after this first phase, which still needs to be addressed, thresholds could be identified and proposed.

Dedicated research projects should be carried out to provide new baseline information on both the temporal and spatial coverage, i.e. number of days over a year and number of cells over a grid respectively, at which activities using impulsive noise sources occur. Regulators have often sought to establish a particular noise level that would trigger management action, such as temporary shut-down of the noise source until the cetacean moves away (Weilgart, 2007). Such a noise level has been very difficult to determine, particularly as there is such a wide variety of responses between species, situations, and noise sources, especially in the deep sea.

On the other hand, baseline knowledge about ambient noise levels throughout the Mediterranean is limited, and the effects of noise are not sufficiently known to robustly determine whether existing levels are too high, or if GES has been achieved. A thorough review of available literature on ambient noise in the Mediterranean Sea is needed to identify the thresholds for ambient noise.

D11MT.G2 Necessity to optimize standardization of methods and detailed guidelines for assessments

A higher level of coherency has been already achieved but optimization is needed regarding technical specifications. A common planning on monitoring strategies (such as spatial resolution, long-term monitoring positions, data sharing, ambient noise models benchmark) is necessary.

D11MT.G3 Lack of methods to cover geographical gaps due to unavailable indirect data

The development and broad use of passive acoustic monitoring techniques have the potential to help assessing the large-scale influence of artificial noise on marine organisms and ecosystems. Deep-sea observatories have the potential to play a key role in understanding these recent acoustic changes (e.g. LIDO, Listening to the Deep Ocean Environment[33]). Particularly in areas where data might be unavailable or more difficult to gather (e.g. poor AIS coverage, undisclosed military or oil and gas activities), it would be ideal to locate a permanent station composed of a line of hydrophones spaced at different depths. This system would allow a real depiction of the occurrence of impulsive and continuous noise, the cross-match

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[33] http://www.listentothedeep.com/acoustics/

of data gathered indirectly (databases of impulsive sound sources or AIS) with the recorded files, and allow the study of the biological sounds occurred in the recordings.

D11MT.G4 High costs associated with deep-sea sampling
Deep-sea surveys require dedicated research cruises using vessels equipped with hydrophones that tolerates deep-sea pressures. National budgets can be very limited, and the majority of the countries is not able to finance adequately the costs of such equipment.

2.11.7 Connections between D11 gaps and the rest of descriptors

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
D11C1.G1	■		■	■		■					■
D11C1.G2	■		■	■		■					
D11C2.G1	■	■	■	■	■			■	■	■	
D11C1-2.G1	■		■	■		■					
D11C1-2.G2	■	■	■	■		■					
D11AG.G1	■			■		■					
D11MT.G1	■		■	■		■					
D11MT.G2	■		■	■							
D11MT.G3	■	■	■	■		■					
D11MT.G4	■	■	■	■	■	■	■	■	■	■	

Table 2.10. *Representation of the connections between D11-identified gaps and the rest of MSFD GES descriptors. Dark grey cells represent interconnections between D11-gaps and the rest of descriptors. Format is based on Cochrane et al. (2010). The left panels contain the gaps identified and described for descriptor 11:* ***D11C1.G1*** *Lack of standardized, systematic mapping of current impulsive sounds inputs.* ***D11C1.G2*** *Absence of historic OA repositories.* ***D11C2.G1*** *Poor and fragmented knowledge in the Mediterranean Sea.* ***D11C1-2.G1*** *Absence of long-term trends.* ***D11C1-2.G2*** *Presence of unavailable data.* ***D11AG.G1*** *Inconsistencies between MPAs and hot spots of noise pollution.* ***D11MT.G1*** *Lack of thresholds and reference levels.* ***D11MT.G2*** *Necessity to optimize standardization of methods and detailed guidelines for assessments.* ***D11MT.G3*** *Lack of methods to cover geographical gaps due to unavailable indirect data.* ***D11MT.G4*** *High costs associated with deep-sea sampling.*

3 PART III: DISREGARDED ISSUES (within the MSFD, all descriptors)

The current MSFD framework does not encompass all topics that are relevant for the conservation and, ultimately, the GES of the European marine environments. Some of the disregarded issues are briefly described in this section as gaps. Designation of new descriptors and criteria could help overcoming the missing components. In any case, new descriptors and criteria will be the focus of IDEM's task 3.2 deliverable. The criteria gaps reported below are not ascribed to previous specific descriptor sections, as the topics addressed are relevant for multiple descriptors.

3.1 *Criteria gaps*

Microbial communities

Microbes play a major role in the functioning of all marine ecosystems. They perform functions that are essential for the sustainment of marine life and the health of marine ecosystems, but can also have adverse effects on living resources, human heath, and the marine ecosystem as a whole (Azam and Malfatti, 2007; Corinaldesi, 2015). Moreover, intrinsic characteristics of microorganisms make them potential indicators of the environment's state. Considering all topics within the MSFD frame, our view is that microbial communities should be taken into account as a new criterion.

The significance of microorganisms is currently neglected in the MSFD frame. They are only mentioned in the Annex III of Directive 2008/56/EC as a biological disturbance pressure, simply viewed as "introduction of microbial pathogens". Although phytoplankton and zooplankton might be targeted within some descriptors, the majority of the microbial components and its functions are overlooked (Caruso et al., 2015). Despite the prokaryotic dominance in terms of biomass and production in some ecosystems, they are not considered within the biodiversity Descriptor D1. In addition, the only microbial issue mentioned in the Directive (microbial pathogens) is not specifically addressed by any descriptor, criteria or indicator (Caruso, 2014). Descriptor D9, assessing contaminants levels in fish and seafood, does not include microbiological contaminants although their monitoring is demanded in other policies (Council Directive 20006/88/EC). In consequence, no information regarding this topic has been reported by Member States or by ICES/JRC Task Groups(European Commission, 2011).

Other polices and conventions. The following policies require the control of specific microbial pathogens: Directive 2006/7/EC (Bathing Water Directive), Directive 2000/60/EC (Water Framework Directive) and the above-mentioned Council Directive 2006/88/EC. However, the required environmental monitoring focuses only on faecal pollution indicators and on particular pathogens affecting harvested shellfish species in aquaculture areas(Caruso et al., 2015). No microbiological reference levels or monitoring frameworks are described for the deep-sea regarding the microbial component.

Climate change

Climate change impacts all ecosystem components and influences multiple aspects of ocean's GES, being indirectly involved in multiple descriptors of the MSFD. Global change leads to water warming, acidification, oxygen depletion and possibly shortfalls in productivity, both at surface and in the deep sea, thus having an impact on deep-sea assemblages. Although of global dimension, the impact will not be homogeneous and some regions, such as the semi-enclosed Mediterranean basin, will be primarily impacted. Indeed, climate change does impact deep-sea ecosystems in various ways, such as the propagation of warming to the deeper layers or the modification of the frequency and intensity of major metoceanic events. Our knowledge is still scant regarding the extent and impacts of episodic climate driven events (e.g., dense shelf water cascading events DSWC, Eastern Mediterranean Transient EMT and Western Mediterranean Transition WMT). However, no specific framework is proposed, and no assessment is demanded in the MSFD frame. Based on their initiative, some countries have assessed impacts, vulnerability and adaptation issues due to climate change on their marine environment (e.g. Kersting et al., 2016). Several EC documents also recognize the relevance of climate change in the degradation of marine ecosystems and recommend the revision of GES criteria so that climate change is included as an impact (European Commission, 2011, 2014), in line with prominent studies (e.g. Halpern et al., 2008, 2012, 2015). Adding a climate change criterion in each descriptor could enable the identification and assessment of climate change impacts on GES. With few exceptions, mainly from shallow water, GES assessments suffer of the lack of long-term baseline data on climate change impacts over the marine environments, which are much needed to attribute observed changes (Ramirez-Llodra et al., 2011).

Ecosystem functioning and connectivity

Ecosystem functioning refers to the sum of all biotic components interacting with the abiotic ones, altogether constituting a functional unit (Hooper et al., 2005). It includes organisms, matter and element stocks, processes and fluxes. The biodiversity Descriptor D1 restricts ecosystem functioning to the structural attributes of the different environments. Information describing the interactions between biological components and environmental conditions is crucial for understanding ecosystem functions and services. Although some ecosystem functions are addressed by other descriptors, such as D4 and D6, most of the processes remain overlooked in the MSFD frame. The MSFD Task Group 1 provided a general list of the main functions and the descriptors involved in each of them(Cochrane et al., 2010). Another issue also ignored in the MSFD frame but closely related to ecosystem functioning is the connectivity between ecosystems, a concept that is mentioned only once in the MSFD main frame (cf. document 2010/477/EU). Identification and mapping of the main connected areas in each basin and amongst basins would be highly beneficial in the MSFD framework. Baseline studies of relevant ecosystems are needed to properly assess the above commented topics.

Algae and phytoplankton blooms and other episodic events

Algae and phytoplankton blooms are just one of the different types of episodic events of ecological and economic relevance. Other episodic events would include peak river discharges or in mass settling of airborne particles, both fertilizing the areas of influence. Besides affecting several goods and services provided by ecosystems, blooms can be used as indicators of the state of the environment. Episodic events commonly involve significant ecophysiological modifications and major perturbations of background dynamics including sedimentation, in response to seasonal or punctual shifts in environmental conditions, as it is the case for the Mediterranean Sea. Spatial and temporal patterns need to be characterized in the frame of baseline studies in order to detect alterations that can be linked to pressures (Condon et al., 2012). Blooms and other types of episodic events in the upper water column are highly relevant for deep-sea ecosystems through pelagic-benthic coupling, as they represent major sources of matter and energy for otherwise depleted bottom habitats (Tamburini et al., 2013; Pedrosa-Pàmies et al., 2016). For example, cysts of harmful algal bloom species were found to germinate in bottom sediments far from shore. The role of these deep-water cysts in coastal HABs was studied by means of a mathematical model, which allowed the identification of a mechanism based partly on the behaviour of the toxic organism and partly on the wind-driven transport of a plume of low salinity water trapped in the surface layer. The HAB cells, germinated from deep-water cysts, swim actively towards the light, enter the thin surface layer and are advected to the coast due to favourable onshore winds (Ferreira et al., 2007). Thus, as outlined above, it is crucial to include the monitoring of those cysts in the MSFD. This criterion is significant for several descriptors. DescriptorsD1 and D4 directly target the increase in abundance of one species or functional group altering the overall biodiversity of the ecosystem and the food web (Condon et al., 2012; Boero et al., 2016). Descriptor D5 refers to nutrient concentrations, which have been generally related to algae and phytoplankton blooms causing multiple cascading effects (Moncheva et al., 2001; Bužančić et al., 2016). DescriptorsD7 and D8 also record changes in environmental conditions, which are able to promote or prevent different blooms (Paerl and Huisman, 2009; Condon et al., 2012; Gobler et al., 2017). Finally, marine litter, which is the focus of Descriptor D10, transports organisms and alters species distribution in the marine environment (Amaral-Zettler et al., 2015; Long et al., 2015; Cole et al., 2016). The role of plastics as potential vectors for microbial communities encompassing potential pathogens has been suggested too (McCormick et al., 2014; Kirstein et al., 2016). Plastic debris will continue accumulating in the oceans in the following years, including the deep-sea floor, and their role in modifying ecosystem dynamics should be fully investigated.

Ecosystem response resilience and remediation potential

Habitat sensitivity and the cumulative pressures taking place will determine the habitat’s response. This assessment is not straightforward since ecosystems’ responses to pressures can be itemized in different interconnected constituents. Resilience is described as the ecosystems ability to overcome disturbances by recovering (rapidly) and maintaining their status(Côté and Darling, 2010). In the case of marine habitats, this concept applies to both pelagic and benthic systems, and to shallow and deep environments. Compared to shallow-water areas, the impacts of anthropogenic activities (e.g., bottom trawling) on deep-sea benthic ecosystems are more severe and long-lasting, due to their lower resilience and higher vulnerability (Rex and Etter, 2010). Furthermore, a disturbed habitat (physically or chemically speaking) is more vulnerable to settlement by opportunistic and NI species, thus less amenable to remediation. We thus need to further understand the resilience of deep-sea ecosystems, especially key, vulnerable habitats and their associated biodiversity. Remediation can be accomplished from two different approaches: recovery or restoration. While the first one refers exactly to regaining of the original state, the second one concerns only the reestablishment of a healthy state, which can be different from the initial one. It is true that at present these concepts apply essentially to shallow water environments, but they also have to be considered for deep-water environments, especially in view of the future. While resilience is mentioned in relation to descriptors D1 and D6, remediation is mentioned only once in Annex IV of the Directive 2008/56/ECMSFD. Both concepts, and their implications, should likely deserve further attention in the MSFD framework, eventually through the development of additional criteria. This is particularly relevant for connections between descriptorsD1, D4 and D6, which need to be stated and assessed. Assessing resilience potential and its temporal evolution following the implementation of management plans and, eventually, remediation actions, is essential for obtaining and maintaining the GES of the (deep) marine ecosystem. Also, research on counteracting ecosystem overexploitation and deterioration should be enhanced by marine policies(European Commission, 2011).

Pressures (human activities)

Anthropogenic activities are already affecting and will continue to impact natural ecosystems in the future decades. We need to elucidate the cumulative effects due to climate-related changes and direct anthropogenic impacts. The Aichi Biodiversity Target 10 highlights the need to reduce multiple anthropogenic pressures on vulnerable ecosystems (as deep ocean coral reefs) impacted by climate change or ocean acidification, so as to maintain their integrity and functioning. While some activities are already taken into account in pressure-based descriptors (e.g. D3) or within state indicators (e.g. D6), an in-depth accurate analysis per descriptor of human activities specific of the deep Mediterranean Sea affecting GES, at present and in the foreseeable future, is suggested. An attempt for such an analysis is included in the WWF 2015 report on Blue Growth in the Mediterranean Sea (Piante and Ody, 2015). Applying some of the guidelines in this document could facilitate the incorporation of relevant criteria in a revised MSFD. A detailed assessment of the effects of human activities on the deep marine environment (> 200 m) has also been performed for the North-East Atlantic(Benn et al., 2010), which could be used as a reference.

4 PART IV: RANKING SYSTEM AND GAP SCORE ASSESSMENT

In order to provide a quantitative gap assessment and illustrate the current situation of each MSFD descriptor, an elicitation exercise has been proposed. A gap score has been obtained for each descriptor by assessing quantitatively 12 evaluation parameters. Methodology was adapted from the gap score assessment performed within the PERSEUS Project (Laroche et al. 2013). The PERSEUS assessment was developed taking into account the methodology established by Van der Sluijs et al. (2001) for an expert elicitation workshop. The basis of the elicitation was a set of evaluation parameters that were assessed involving expert judgment, quantified in a numeral scale. The scale was completed with descriptions of each score in order to provide guidance for the assessment. Our elicitation exercise is based on the parameters and scores assigned already within the PERSEUS gap score assessment, adapted for the IDEM objectives.

Concept and methodology

The objective of this ranking system and gap score assessment is the evaluation of the current situation of each descriptor regarding its applicability to the deep Mediterranean Sea. A qualitative assessment of semi-quantitative parameters is based on a matrix assessing the gaps per descriptor and per parameter. In order to minimize arbitrariness and subjectivity in the assessment of the matrix, each item evaluated has been scored according to a discrete numerical scale: 0 (MINOR GAP), 1 (PARTIAL GAP) and 2 (MAJOR GAP). Further information on the description of each level per each parameter is provided in the gap score assessment matrix presented below in Table 4.1. Each project partner has been asked to evaluate all parameters per descriptor (as minor, partial and major gap) according to its expertise. Therefore, each partner has decided how many people involving in the elicitation exercise, including investigators and stakeholders, in order to minimize subjectivity and avoid misinterpretations among the participants. Furthermore, representative persons inside the IDEM Consortium have also detailed their assessment, explaining the reason for their scores (attached in Section 5).

Table 4.1. *Evaluation parameters and scoring matrix. *The word "criteria" in the table refers to the criteria settled per descriptor within the MSFD (EU 2017/848).*

EVALUATION PARAMETERS	**Interpretation**	**MINOR GAP (0)**	**PARTIAL GAP (1)**	**MAJOR GAP (2)**
1- Applicability of MSFD criteria	*Are the defined criteria enough for encompassing all relevant knowledge topics? Are they directly applicable to the deep Mediterranean Sea?*	The current criteria are enough and directly applicable for obtaining an appropriate descriptor assessment. Minor modifications are needed.	Some of the criteria are directly applicable. However, other criteria are not well suited for the deep Mediterranean Sea and would require some modifications. Addition of few extra criteria would also be needed.	Generally, the descriptor formulation is not appropriate for the deep-sea. Most of the criteria need major modifications and description of additional ones is recommended.
2- Sufficient scientific knowledge	*Is the available knowledge sufficient to allow a robust assessment?*	The data and knowledge are sufficient and provide information for all the criteria. No major knowledge gap was identified.	The lack of data and knowledge concerns only some criteria. However, several topics were identified minor data and knowledge gaps.	The lack of data and knowledge concerns most of the criteria. Additional major knowledge gaps were also acknowledged.
3- Data availability	*Is the available data sufficient to allow a robust assessment? Is the data peer reviewed?*	Enough data is available and provides information for all the criteria. The majority comes from peer reviewed sources.	The lack of data concerns only some criteria but allows a partial implementation and assessment. However, some of the assessments cannot be based on peer-reviewed data.	The lack of data concerns most of the criteria. No reliable assessment is possible. The majority of the data doesn't come from peer reviewed sources.
4- Monitoring networks	*Do current monitoring programs allow the study of the descriptor in the deep Mediterranean Sea for each of the criteria defined?*	Monitoring programs already exist for all criteria (even if these methodologies were not initially design for the deep-sea)	There are some networks that enable the study and assessment of the deep-sea, but only including few criteria	No networks are available that allow the study and assessment of the descriptor in the deep-sea
5- Available standards, thresholds, trends and reference conditions	*Are standards/guidelines defined for monitoring? Are*	The existing guidelines cover all criteria. Thresholds, trends and	The guidelines cover partially the defined criteria. Thresholds and	No available guidelines cover the descriptor in the deep-sea.

	thresholds, trends and reference levels available for the different criteria?	reference levels are available and directly applicable to deep-sea environments	reference levels are available for some criteria or at least can be adapted from other environments. Trends only exist for some criteria.	Thresholds and reference levels are also missing for most of the criteria. No trends are currently existing.
6- Geographical information	*Is the existing information covering all Mediterranean basins?*	Available information covers all Mediterranean basins equally and in acceptable levels. Almost no geographical gap is identified.	The lack of information only affects limited geographical locations but allows partial assessment in almost all basins.	Information is lacking for many geographical locations preventing an adequate assessment in most of the basins.
7- Bathymetric information	*Is the existing information covering all depths equally from 200m to the deepest areas?*	Available information covers all depths equally in all basins, allowing a complete assessment from 200m to the *deepest regions*.	The lack of information affects only a particular depth range or a minor number of basins/sub-regions.	The lack of information affects almost all the deep-sea or a significand depth range in almost all basins.
8- Pressures and impacts (human activities)	*Are the pressures and related impacts identified and assessed in the deep Mediterranean Sea?*	All relevant pressures and impacts are identified. Their effects and importance are assessed for most of the deep Mediterranean Sea.	Almost all pressures and impacts are identified. However, only partial assessments are available for most of them. Fragmented knowledge.	There are multiple pressures overlooked. Assessments of the identified ones are not available for the deep-sea. More knowledge and data are required.
9- Connection to other descriptors/synergetic effects considered	*Does the descriptor framework (definition, indicators, criteria) enable the inclusion of synergetic effects and linkages to other descriptors?*	The descriptor framework as defined in the MSFD already includes the acknowledgment of linkages to other descriptors. Therefore, the assessment also includes synergetic effects between descriptors or criteria.	Although the descriptor considers some interconnections and synergetic effects, the overall assessment will be incomplete.	The descriptor does not even introduce possible connections between descriptors and their criteria. Missing direct and indirect influences will hinder an accurate, certain assessment.
10- Adequate MPAs for maintaining GES	*Are the actual MPAs and their regulations enough to maintain*	The existing MPAs will ensure the obtaining and	Some MPAs are adequate for the obtaining and	Almost none of the current MPAs will promote the

	GES for this descriptor in the deep Mediterranean Sea?	maintenance of GES for this descriptor and most of its criteria in the deep-sea. Only small modifications are needed in particular MPAs.	maintenance of GES for this descriptor. However, modifications of some characteristics (regulations, extension, description…) are needed in the protected areas and some extra ones need to be established.	obtaining and maintenance of GES for this descriptor. Major modifications of almost all existing ones are needed. Establishment of new ones is also required for most of the basins.
11- Sufficient legislation	*Is there sufficient legislation, directives, regulations that target this descriptor and control its GES for the deep Mediterranean Sea?*	The descriptor is under the scope of different regulation mechanisms that ensure the obtaining and maintenance of GES.	Some current regulations include some descriptor criteria even if the deep-sea is not considered. The framework defined can be adapted to maintain GES in the deep-sea.	There is no regulation focused on this descriptor in the deep-sea. Therefore, the assessment of the GES is not performed or required.
12-Socioeconomic information/data available	*Does this descriptor include data or at least consideration of socioeconomic information?*	The descriptor involves relevant socio-economic information specific to the deep-sea that enables its inclusion in the assessment.	Limited socio-economic information is available regarding most of the criteria of this descriptor. Most of the basins are covered. However, part of the data does not relate to the deep-sea.	Almost no socio-economic data exists for this descriptor in the majority of the basins, not even general data independent of depth ranges

After the collection of the assessments, the pedigree scores have been aggregated per descriptor, and the scores have been averaged, and normalized on the scale of 0-1. This process enables the analysis of the results and the visualization of gap issues. It aims to provide a broad comparison between descriptors. It is, however, based on expert judgment and should not be considered as exhaustive but rather as indicative. The list of the considered evaluation parameters is not exhaustive, and the underlying data is based on qualitative information.

Results and data processing

The evaluations performed by each partner have been collected and averaged per descriptor. The average scores are normalized on the scale of 0-1 and presented in Table 4.2 (as done in Table 2 by Laroche et al.

2013). In addition, the scores have been aggregated per criterion and per descriptor in order to facilitate comparisons and drawing conclusions.

*Table 4.2. Evaluation parameters and scoring matrix. *The word "criteria" in the table refers to the criteria settled per descriptor within the MSFD (EU 2017/848).*

EVALUATION PARAMETERS	DESCRIPTORS											Aggregated scores per Evaluation Parameter
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	
1- Applicability of MSFD criteria	0.500	0.833	0.500	0.900	1.000	0.400	0.667	0.250	0.000	0.500	0.500	**0.550**
2- Sufficient scientific knowledge	0.938	1.000	0.667	0.600	1.000	0.700	0.500	0.667	1.000	0.875	1.000	**0.813**
3- Data availability	0.750	1.000	0.667	0.600	0.500	0.850	0.625	0.667	1.000	0.938	1.000	**0.781**
4- Monitoring networks	0.750	1.000	0.667	1.000	1.000	0.750	0.750	1.000	1.000	0.500	1.000	**0.856**
5- Available standards, thresholds, trends and reference conditions	0.875	1.000	0.500	1.000	1.000	0.850	1.000	1.000	1.000	1.000	1.000	**0.930**
6- Geographical information	0.750	1.000	0.833	0.600	1.000	0.850	0.500	1.000	1.000	0.875	0.500	**0.810**
7- Bathymetric information	0.813	1.000	0.667	0.600	0.500	0.550	0.625	1.000	1.000	0.938	1.000	**0.790**
8- Pressures and impacts (human activities)	0.625	0.833	0.500	1.000	1.000	0.450	0.833	0.833	1.000	0.500	0.500	**0.734**
9- Connection to other descriptors/synergetic effects considered	0.500	0.833	0.333	0.400	0.500	0.450	0.667	0.333	1.000	0.688	0.000	**0.519**
10- Adequate MPAs for maintaining GES	0.938	1.000	1.000	1.000	1.000	0.550	0.833	0.667	1.000	0.688	0.500	**0.834**
11- Sufficient legislation	0.688	0.833	0.500	0.600	1.000	0.550	0.667	0.500	1.000	0.500	0.500	**0.667**
12-Socioeconomic information/data available	0.875	1.000	0.667	1.000	1.000	0.550	0.833	1.000	1.000	0.625	0.500	**0.823**
Aggregated scores per descriptor	**0.750**	**0.944**	**0.625**	**0.775**	**0.875**	**0.625**	**0.708**	**0.743**	**0.917**	**0.719**	**0.667**	

MINOR GAP	averaged normalized score comprised between 0 and 0.333 (included)
PARTIAL GAP	averaged normalized score comprised between 0.333 and 0.667 (included)
MAJOR GAP	averaged normalized score comprised between 0.667 and 1 (included)

Analysis of the most important gaps

The comparison of aggregated scores per parameter analyses can allow the identification of the most common gaps for the application of the MSFD to the deep Mediterranean Sea, considering all descriptors together.

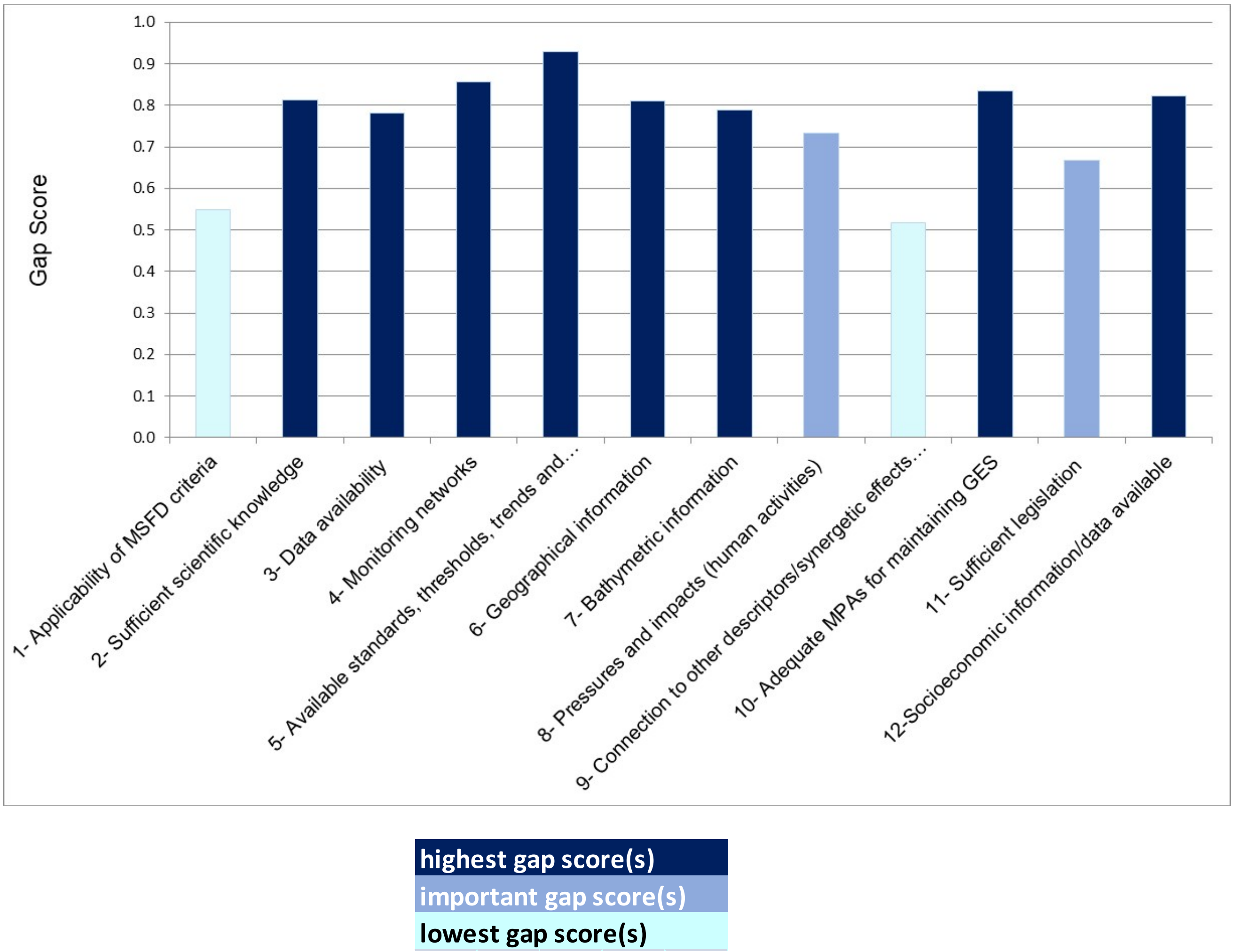

Figure 4.1. Representation of the most important gaps, all descriptor together (aggregated scores per evaluation parameters adapted for the deep sea from Laroche et al., 2013).

We notice that, among the eleven descriptors, the most important gap is the general lack of thresholds and trends, represented in dark blue in the above figure. The lack of data, monitoring network, adequate MPAs, as well as the insufficient knowledge (both scientific, bathy-geographic and socioeconomic) are also really important.

Lower gaps, in light blue in the figure, are represented by the connection to other descriptors and by the applicability of the MSFD defined criteria to the deep Mediterranean Sea. This implies that for many of the MSFD descriptors (except D2, D4 and D5), the criteria defined by the MSFD are enough for encompassing all relevant knowledge topics, being directly applicable to the deep Mediterranean Sea.

In general, this analysis highlights that for the deep sea all the evaluation parameters appear to be critical, differently from what emerged in Laroche et al. (2013), concerning the coastal application of the MSFD.

Comparison of the aggregated gap scores per descriptor

The comparison of aggregated scores per descriptor can illustrate descriptors accumulating more gaps (Figure 4.2). It can also inform of the less suitable descriptors for the deep Mediterranean Sea.

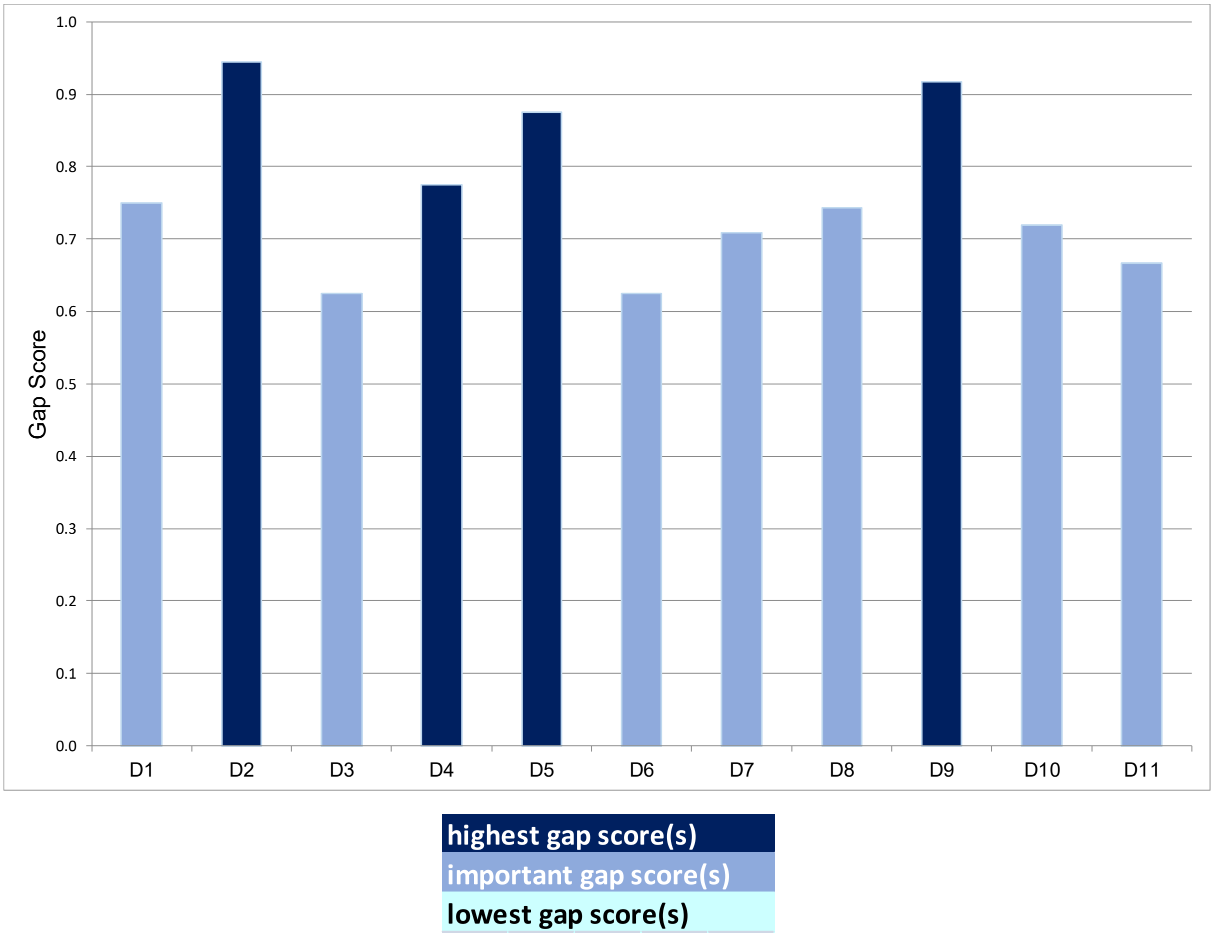

Figure 4.2. *Representation of the eleven aggregated scores per descriptor (adapted for the deep sea from Laroche et al., 2013).*

If we compare these scores, D2 (NIS), D4, (food webs), D5 (eutrophication) and D9 (contaminants and human health) exhibit the highest gap values, represented in dark blue in the above figure, but, in general, important gap scores are present for all the descriptors as regards deep sea. These results fit with the main conclusion of the first part of this deliverable and are represented in detail below.

Relative composition of the aggregated gap scores per descriptor

Pedigree matrixes can illustrate the gap score composition for each descriptor of each evaluation parameter. To this attempt, radar diagrams were used to represent the values from Table 4.2. These diagrams use polygons to present, in our case, the aggregated scores per descriptor, while each axis represents each evaluation score, having 0 in the centre of the polygon and 1 on each corner point.

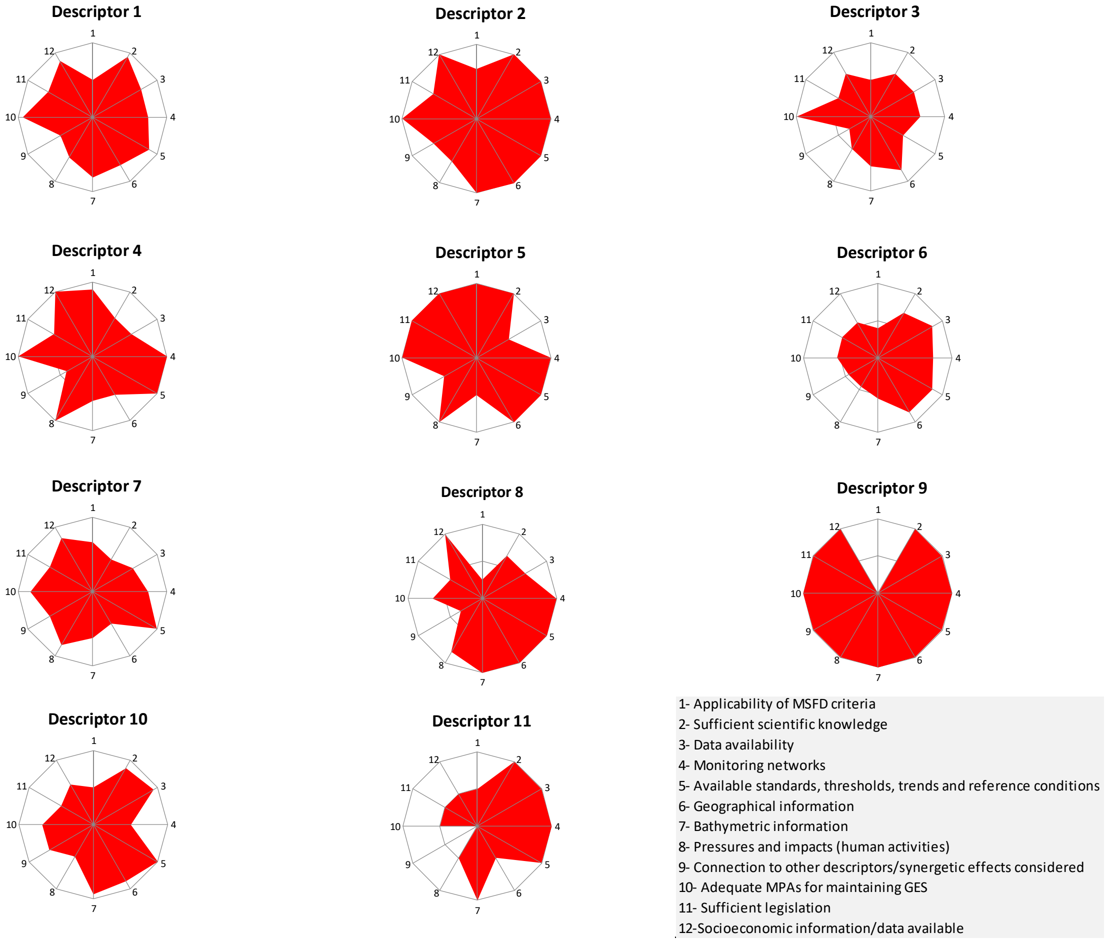

Figure 4.3. *Gap score composition for each descriptor of each evaluation parameters (adapted for the deep sea from Laroche et al., 2013).*

According to these radar graphs, we notice that the applicability of the MSFD (evaluation parameter 1) appears to be an important issue for descriptors 2, 4, 5, and 7.

The lack of sufficient scientific knowledge (evaluation parameter 2) appears to be a concern for descriptors 1, 2, 5, 8, 9, 10 and 11.

Descriptor 2, 4, 5 and 9 are really critical as available knowledge is virtually non-existent because of the lack of data from the deep environments.
Descriptor 3 appears to be the descriptor with minor important gap for the deep sea.

5 ATTACHMENT

D1-D11 Personal Gap score assessment.pdf

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