Implementation of the MSFD to the

Deep Mediterranean Sea

IDEM

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Report 2.1. Review and collection of the available datasets on indicators and human pressures/impacts on Mediterranean deep-sea ecosystems

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Table of Content

INTRODUCTION

The main aim of the current document is the review of datasets concerning deep-sea indicators and criteria for each Marine Strategy Framework Directive (MSFD) descriptor. The compilation of existing datasets was obtained from scientific literature, public datasets related to monitoring programs and open access (OA) repositories. Specific keywords such as Vulnerable Marine Ecosystems, Cold-Water Corals, MEDITS, hydrography, habitat mapping, fishes, elasmobranchs, zooplankton, meiofauna, macrofauna, benthos, and synonymous terms, with the addition of “Mediterranean” and “deep sea”, were used to generate a list of available literature. Papers and reports that had been reviewed as part of IDEM Task 1.1 (Review of literature on MSFD implementation) were also included.

A collection of relevant datasets has been created and summarized through excel spreadsheets with common options and key-words, filled in with the information provided by each dataset and organized per each descriptor. The collected database includes both datasets from literature surveys and from public repositories such as EMODnet (European Marine Observation and Data Network), Copernicus or similar where available. For each dataset/repository at least the following information is reported: Descriptors covered by the dataset; Variables for each dataset and unit of measure; Area and water depth covered; gaps (Geographical/bathymetric); Gaps in habitat/species (in the case of D1, D2, and D3). Quantitative pressures/impacts (papers reporting changes in terms of mean and SD or other errors/extract shifts on variables from the datasets, e.g. for T, S, O_2) are highlighted. However, the options displayed in the spreadsheet only allowed a broad definition of the ecosystem and habitat studied. Data content was the most important feature that needed to be stated for each study. Additional specifications concerning how data is displayed and if they are directly available were added to facilitate subsequent meta-analysis. When reviewing the available literature, papers that included data for more than one “category” were counted more than once (e.g. if a paper contained data for two different types of habitats, it was included in the count of ‘number of papers’ for both habitats). Eleven different spreadsheets have been produced, divided according to descriptor number. They are provided in the Attachment Section.

The data compiled will be used for the assessment of the deep Mediterranean status applying meta-analysis and ecosystem-pressure mapping in GIS.

The compilation of datasets and studies exposed the current knowledge and research available for each topic. However, one of the most important outcomes was the disclosure of knowledge and data gaps. A brief introduction to the most relevant ones can be found in the next Sections, organized per each descriptor.

1 DESCRIPTORS 1 AND 6: BIODIVERSITY AND BENTHIC HABITATS

This Section includes an overview of literature on species groups (relating to D1, criteria D1C1-D1C5), pelagic habitats (relating to D1, criteria D1C6) and benthic habitats (relating to D1 and D6, criteria D6C4-D6C5). Ecosystems including food webs (relating to D1 and D4, criteria D4C1-D4C4) are presented in the review for D4 (Section 4 of the present report), while literature regarding 'pressures' criteria for seafloor integrity (i.e. D6C1-D6C3, which relate to D6 only) is reviewed in the Section on D6 (Section 6).

Main outcomes and gaps

A total of 180 papers were collected as regards descriptor 1, including the two criteria D6C4 and D6C5 that also relate to descriptor 6 (the two criteria D6C4 and D6C5 apply equally to descriptor 1 and descriptor 6, according to 2017/848/EC). Of these, 51 covered the whole Mediterranean Sea, 60 included information for the Western sub-basin, 53 for the Central-Ionian sub-basin and 23 for the Aegean-Levantine sub-basin (Table 1.1). Therefore, overall, the Western and Central-Ionian sub-basins are better represented than the Aegean-Levantine basin.

Table 1.1. *Number of papers or reports including information on descriptor 1 for the deep Mediterranean Sea in different sub-basins.*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	51
Western Basin only	54
Central-Ionian Basin only	47
Aegean-Levantine Basin only	21
Both Western & Central-Ionian basins	5
Both Western & Aegean-Levantine basins	1
Both Central-Ionian & Aegean Levantine basins	1

Most of the studies conducted on the deep Mediterranean Sea cover a range from 200 meters down to over 1000 meters depth. This is true for almost all the four sub-basins with the exception of the Aegean-Levantine, where the depth range 200-500 m was less represented than any of the others (Figure 1.1).

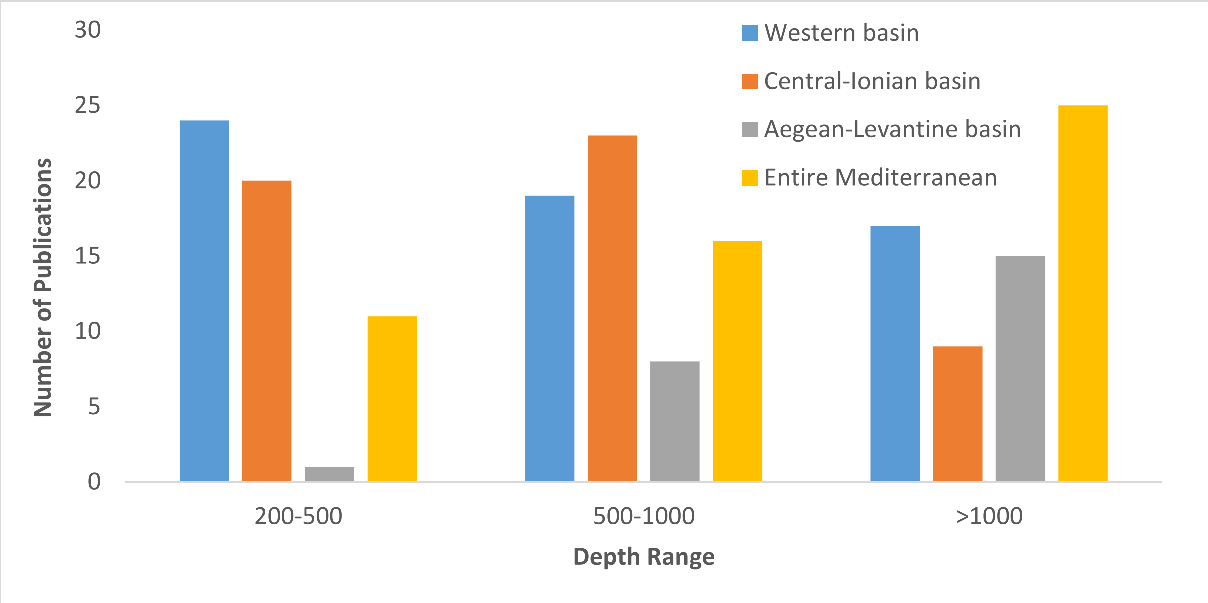

Figure 1.1. *Number of publications including information for three different depth ranges in the deep Mediterranean Sea.*

The type of data available was categorised as follows:

- Quantitative data (i.e. including Abundance/Occurrence frequency/ Diversity index))
- Distribution/Species list (i.e. no quantitative data available)
- Age determination
- Other (including Modelling and Molecular/Morphological analysis)

Overall, the majority of the publications included either quantitative measures of abundance/diversity or non-quantitative data on the species present, while very few of the literature reviewed included data on other parameters (Figure 1.2). The availability of quantitative data is higher for the Western Mediterranean basin, whereas a higher proportion of the published studies in the Central-Ionian include only non-quantitative results.

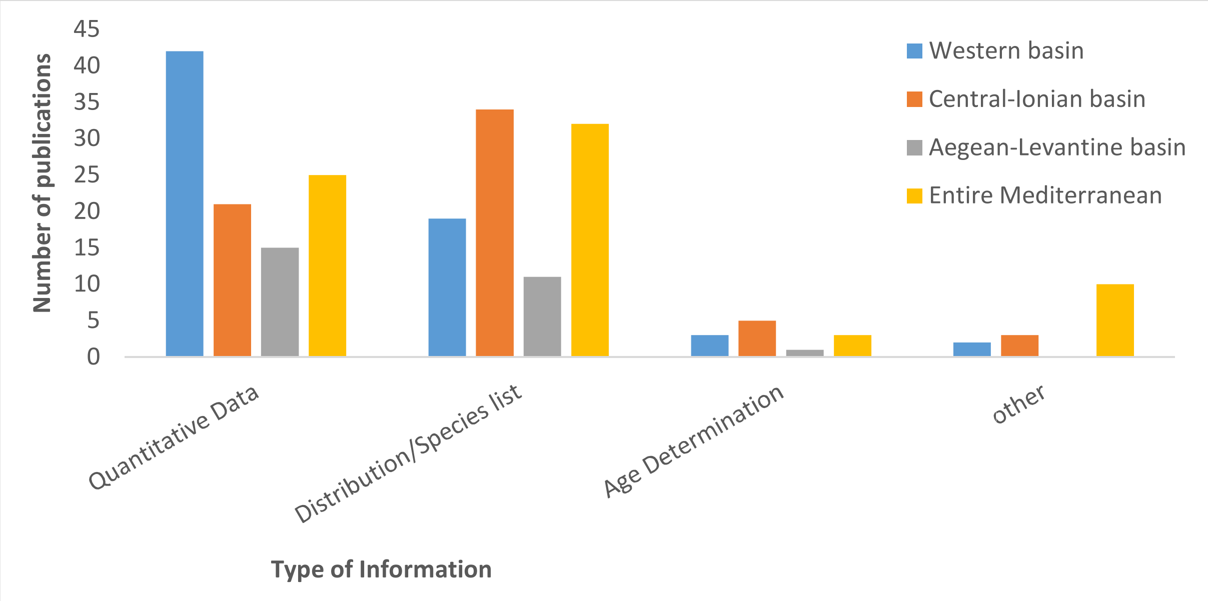

Figure 1.2. Number of publications including different types of data for the deep Mediterranean Sea.

With regards to the species considered in the reviewed publications, cold-water corals (CWCs) and 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 microscopic communities are generally underrepresented. Overall, the same trends in terms of relative proportion of publications for different species groups are seen in all three deep Mediterranean sub-basins, except in the case of CWCs, which are much less studied in the Aegean-Levantine compared to the other two sub-basins (Figure 1.3).

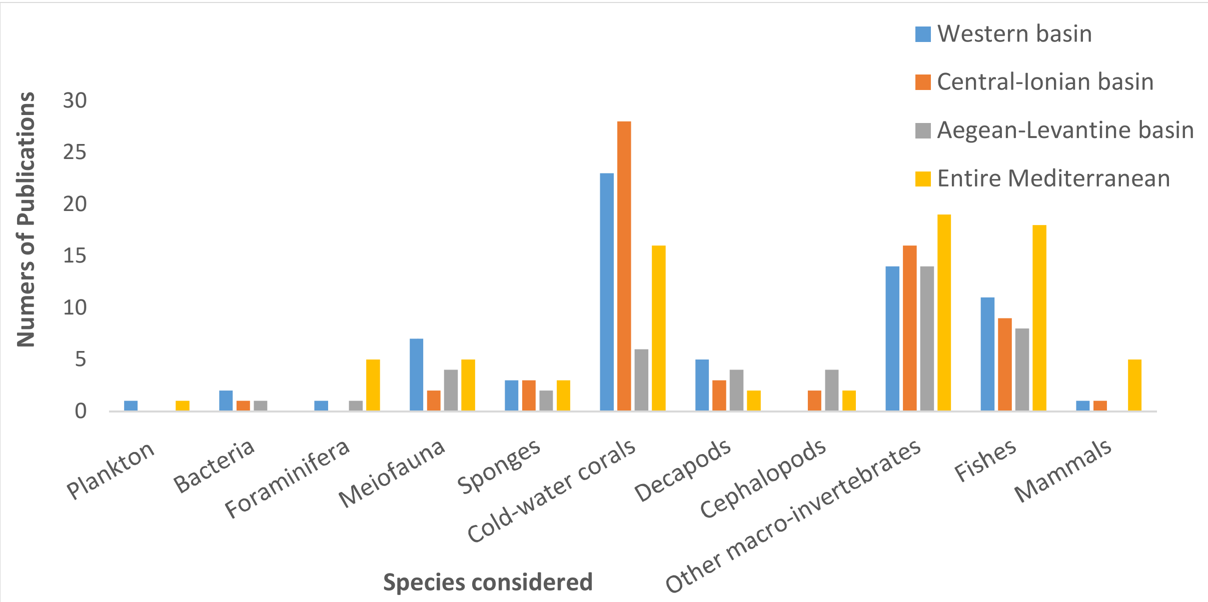

Figure 1.3. Number of publications including data on different species groups for the deep Mediterranean Sea.

In terms of the habitats studied, the majority of works focused on open slopes, canyons, or CWC habitats, but this differed according to the region (Figure 1.4). In the Western Mediterranean, the number of studies on canyons and open slopes outnumber those on CWCs, whereas CWCs are the most studied habitat in the Central-Ionian region. On the other hand, in the Aegean-Levantine basin, the largest number of studies is on open slopes followed by chemosynthetic habitats. In general, there are fewer studies on other habitat types including chemosynthetic habitats, continental shelves and seamounts, while only a single publication on the water column habitat in the deep Mediterranean Sea is available in the compiled dataset.

With regards to OA repositories, a total of 10 repositories containing data relevant to descriptor 1 and benthic habitats for the deep Mediterranean Sea were found. Several of these contain data on distributions of individual species only; two repositories include data on seabed habitats in general, while two others contain data on specific habitat types (vulnerable marine ecosystems, and ecologically/biologically significant marine areas). Finally, the IUCN red list includes assessment of threatened species including those occurring in the Mediterranean Sea.

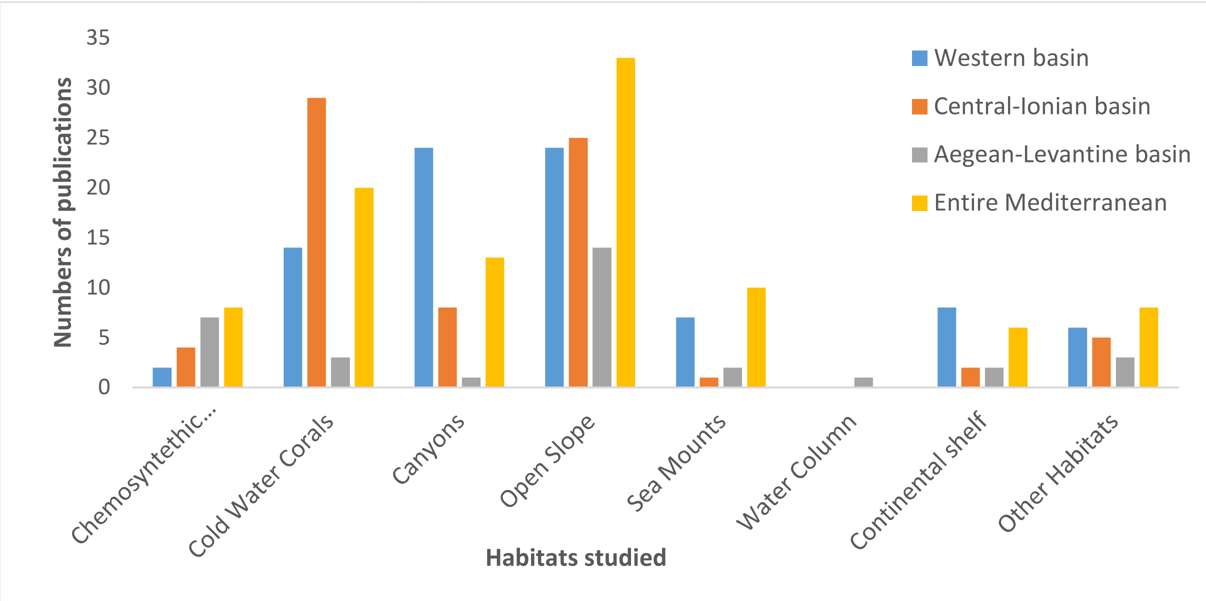

Figure 1.4. *Number of publications including data on different habitats for the deep Mediterranean Sea.*

2 DESCRIPTOR 2: NON-INDIGENOUS SPECIES

The present Section is based on the analysis of 10 scientific articles presenting data on the non-indigenous species (NIS) in the deep Mediterranean Sea. This is a recent phenomenon – the earliest data was published in 2008.

General comment

The MSFD aims to achieve or maintain GES in the marine environment by the year 2020 using a set of environmental targets and associated indicators, including the number of newly introduced NIS, abundance and spatial distribution of established NIS, and spatial extent of adversely altered habitat (European Commission 2017b). However, the latest assessment of the Member States' monitoring programs under the MSFD reveals that only 5% of the programs 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" (European Commission 2017b). Crucially, none of the NIS monitoring programs targeted lower shelf and upper slope habitats, though deep-sea communities are in urgent need of conservation.

It is concluded that the present scarcity of data regarding NIS presence in the deep Mediterranean Sea precludes an accurate evaluation of their richness, abundance and spatial spread.

It is suggested that in order to address the glaring gap in knowledge concerning NIS in deep-sea habitats, studies of their presence, distribution, ecology, pathway, need to be conducted, as well as assessment of the threats they present to the unique, diverse and fragile mesophotic communities.

The importance of this report is in calling attention to a yet undiscussed issue, in serving as a step towards monitoring deep dwelling bioinvasions and their harm to sensitive slope habitats, and in helping to establish appropriate protocols to support baselines, targets, and their spatial variability in defining GES for descriptor 2 in mesophotic habitats.

Main outcomes and gaps

The records of deep-living NIS are limited to the Levant (Israel, Lebanon, Mediterranean coast of Turkey and the SE Aegean Sea (Table 2.1)).

In the past decade several Erythraean species, some newly arrived, some well-established, have been collected on the Levantine lower shelf and upper slope, mostly at 100 to 200 m depth. The records comprise 8 Erythraean NIS: 5 fishes (*Apogon queketti, Champsodon nudivittis, Lagocephalus sceleratus, Nemipterus randalli, Tylerius spinosissimus*), 2 decapod crustaceans (*Charybdis longicollis, Gonioinfradens giardi*), and a single stomatopod (*Erugosquilla massavensis*). The deepest record, at 250 m, was a population of the Erythraean portunid crab *C. longicollis*, off the coast of Israel. All the records were discovered fortuitously.

Table 2.1. Erythraean species recorded on upper slope of the Mediterranean Sea

Species	Order	Locality	depth (m)	year	Reference
A. queketti	Perciformes	Turkey	140-150	2010	Gökoğlu et al. 2011
C. nudivittis	Perciformes	Greece, SE Aegean	150	2012	Kalogirou & Corsini-Foka 2012
C. nudivittis	Perciformes	Israel	100,120	2011	Goren et al. 2011
C. nudivittis	Perciformes	Lebanon	150	2010	Bariche 2010
C. longicollis	Decapoda	Israel	250	2008-2012	Innocenti et al. 2017
E. massavensis	Stomatopoda	Turkey	150-200	2007	Özcan et al. 2008
G. giardi	Decapoda	Greece, SE Aegean	200	2010	Corsini-Foka et al. 2010
L. sceleratus	Perciformes	Turkey	150	2009-2010	Özbek et al. 2017
N. randalli	Perciformes	Israel	100,120	2010-2011	Stern et al. 2014
T. spinosissimus	Perciformes	Israel	120,140	2010	Golani et al. 2011

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

The present Section is based mostly on data from the European Data Collection Multiannual Programme (DC-MAP), the General Fisheries Commission for the Mediterranean (GFCM) Data Collection Reference Framework (DCRF) and stock assessment reports produced either by the GFCM or the Scientific, Technical and Economic Committee for Fisheries (STECF).

The DC-MAP includes, among other parameters, catches and landings of the most important "*métiers*"[1] in the EU Mediterranean Member States, the biological data of the most important fishery target species, the collection of socio-economic data, and the estimation of ecosystem indicators. It goes beyond the objective of collecting data for commercial species by also including '*Species to be monitored under protection programmes in the Union or under international obligations*' to cater for the revised Common Fishery Policy's increased focus on environmental effects of fishing. The DCMAP also includes the collection of fisheries independent survey data, including the Mediterranean International Trawl Survey (MEDITS), which is conducted at depths of 10-800 m for the assessment of demersal fish species.

The GFCM DCRF represents a comprehensive framework for the collection and submission of fisheries-related data in the Mediterranean and Black Sea, that encompass area-based information on national fishing fleets and their activities, catch and effort data, biological information on the main target species, and data on incidental catches of vulnerable species as well as discards. In addition, GFCM contracting parties are required to collect socio-economic data in order to assess the economic situation of fishing enterprises and employment trends.

Repositories of fisheries data collected under the EU DCF / GFCM DCRF are mostly reported here since (i) almost all relevant scientific papers are based on these data sources, and (ii) the computation of meaningful D3 indicators for the deep-sea will require access to long time series of raw data, which generally cannot be extracted from scientific publications.

General comment

Descriptor 3 stipulates that "*all populations of all commercially exploited fish and shellfish should be within safe biological limits, exhibiting a population age and size distribution that is indicative of healthy stocks*". This implies that stocks should (i) be exploited sustainably in a manner 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. The MSFD builds on existing EU legislation as the Common Fisheries Policy (CFP) and criteria describing stocks status are based on internationally recognised best practices. The exploitation of fisheries resources in the Mediterranean marine sub-regions is monitored internationally by the Scientific Advisory Committee (SAC) of the GFCM, the STECF of the European Commission, and the International Commission for the Conservation of Atlantic

[1] Definition of 'metier' included in Commission Decision 2010/93/EU: a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterised by a similar exploitation pattern.

Tunas (ICCAT). The indicators of the D3 were developed to be applied to entire stocks regardless of their bathymetric distribution. Therefore, the distinction of depth strata is irrelevant to the way the evaluation of this descriptor is done. Moreover, many stocks are distributed and exploited over large depth range (not exclusively above or below the 200 meters limit), and are evaluated at that scale. Data for all species targeted at depths below 200 m, and data for those which are exploited both above and below 200 m depth (regardless of the fishing depth) are therefore considered here.

Main outcomes and gaps

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 (Foucher and Delaunay, 2017). Nevertheless, many unevaluated species may contribute significantly to the landings in either weight or monetary value. Furthermore, following the decline of shallow coastal water resources, a shift of fishing effort to deeper waters has been documented in many fisheries, facilitated by increasing fishing vessel engine powers and technological advances.

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, there are often difficulties in the calculation of stock-recruitment relationships, and stock boundaries remain poorly known.

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 Vessel Monitoring System (VMS) and/or Automatic Identification System (AIS) data would allow to have quantitative data also by bathymetric strata.

Available repositories providing information on the status of the stocks (e.g. http://sirs.agrocampus-ouest.fr/stecf_balance_2017/) or scientific publications (e.g. Froese et al., 2018) as well as other sources of fisheries dependent datasets (e.g. http://www.emodnet-mediterranean.eu/portfolio/fisheries/ or http://www.seaaroundus.org/data/#/search) do not directly provide statistics for the estimation of D3 indicators for the deep-sea.

Fishery independent data are limited to DC-MAP funded surveys (i.e. the MEDITS program) which cover only one season, the northern coasts of the Mediterranean and are limited to 800m depth. MEDITS does not benefit from a common and open database; instead the use of MEDITS data requires bilateral collaboration with each separate survey team which complicates and slows data accessibility. A common online repository similar to DATRAS (the Database of Trawl Surveys) maintained by ICES for Northern Europe would greatly facilitate the calculation of D3 indicators.

In conclusion, not all relevant data collected in the EU Mediterranean waters is readily accessible, and the data available to calculate D3 indicators for the deep sea does not fully meet MSFD requirements.

4 DESCRIPTOR 4: ECOSYSTEMS, INCLUDING FOOD WEBS

Descriptor 4 is still controversial within the Marine Strategy approach, as in many member states it is assimilated within descriptor 3. Specifically, concerning the deep sea Mediterranean, the literature review (Task 1.1, Report D1) evidenced the use of two main approaches: (1) data from stomach contents, stable isotope analyses and/or fatty acid trophic markers (Fanelli and Cartes, 2010; Fanelli et al., 2013); and (2) data from modelling techniques, such as Ecopath with Ecosim (EwE) (Coll and Libralato, 2012). The two primary criteria established by COMM DEC 2017/848 for D4 refer to i. diversity of the trophic guild (D4C1) and ii. balance of total abundance between the trophic guilds (D4C2), while secondary criteria are iii. size distribution of individuals across the trophic guild (D4C3) and iv. productivity of the trophic guild (D4C4). In this context the analysis of datasets available from literature have been mostly focused on papers reporting i. data from stable isotopes analysis which provide information on the diversity of trophic guilds (D4C1) and generally the size distribution of species analysed (D4C3) and, although with less frequency, also on the total abundance between trophic guilds (D4C2), and ii. inputs and outputs data from EwE modelling which contribute to the definition of criteria D4C2 and D4C4, coherently with the approach used for report D1.

General comment

Descriptor 4 bibliography consisted of 56 revised articles and one open access repository, which only partially cover the requests of MSFD for D4 (i.e. EMODnet biology). Three sharepoints for fishery data can be found within EMODnet, although, as for EMODnet biology, they only cover in part the requirements for D4. These datasets regard 1. landings by species and year, for mass and number; 2. discards by species and year, for mass and number and 3. by catch by species and year, for mass and number.

Further, studies not directly targeting the descriptor 4 but related to size and abundance of deep-sea fish, decapods or cephalopods, cross-cutting descriptor 3 were not considered in this compilation.

Main outcomes and gaps

The compilation of datasets and studies exposed the current knowledge and research available for D4. However, one of the most important outcomes was the collection of novel data and the identification of gaps.

The most evident deficiency was the existing fragmented knowledge, regarding the number of species considered (mostly commercial species for modelling) and trophic guilds (microscopic component almost ignored). Spatial but also temporal gaps were clearly observed while reviewing the datasets (see Table 4.1). Local studies, collection of data within particular campaigns and the almost completely absence of long-term data, with the exception of very few works, were the main causes of such patchy knowledge.

While the stable isotope approach generally prevents from the simultaneous analysis of multiple pressures as it is mostly focused on depicting food web structure and highlighting food sources, the modelling approach is useful to investigate cumulative effects. Overall, no standard or reference level is proposed in the articles analysed and this represents a main gap for the descriptor. As previously highlighted by the literature review for this descriptor, the lack of data on the response of deep-sea communities to anthropogenic stressors, prevents from the establishment of thresholds.

Another main gap is reflected by missing articles exposing trends and/or suggesting thresholds and reference levels.

Revising the impacts related to pressures affecting food webs, the bulk of the literature considered two main stressors: fishery and pollution. The effect of fishery on food web functioning and abundance/biomass of trophic groups was mostly explored by the modelling approach (EwE), examining also future scenarios under increasing fishery pressure (12 papers). The incorporation of heavy metals (especially mercury) and other contaminants such as PCB were considered in few papers by plotting the trophic level of the species considered (in terms of δ^{15}N) against the heavy metal/contaminant analysed (3 papers). Generally no papers related (if not at level of discussion) D4 with D5, i.e. changes in nutrient inputs with cascading effects on the whole food-webs including deep-sea food webs, and presently the occurrence of microplastics in deep-sea species stomach contents from the Mediterranean has been the focus of only one paper (Romeo et al., 2016).

Forty-five studies have been published in the last 10 years and only 11 before 2008, but in general not early than 1999. On the other hand, very few papers examined long-term data series. Spatial fragmentation is evident because of the predominance of local studies and specifically from the Western Mediterranean reflecting a gap in the rest of basins.

A clear geographic gradient regarding knowledge and data was observed from North to South Mediterranean and from the western to the eastern (see Table 4.1). As for the other descriptors, these gradients reflect the differences in research investment between regions, especially between EU and non-EU countries. Regarding bathymetry, the main gap involves depths below 800-1000 meters, although some studies using the two approaches (modelling and SIA) regard also deep-sea communities up to 2000 m, but they are generally local/regional.

Table 4.1. *Number of papers or reports including information on descriptor 4 for the deep Mediterranean Sea in different sub-basins*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	9
Western Basin	36
Central/Ionian Basin	5
Aegean/Levantine Basin	6

5 DESCRIPTOR 5: EUTROPHICATION

Eutrophication effects have been so far almost completely ignored in the Mediterranean deep sea.

Data from papers could be found regarding the concentration of nutrients and chlorophyll-a in the water column from the eastern (40-1570 m depth) to the western (0-2500 m depth) parts of the Mediterranean Sea. However, the D5C1 can provide very limited indications on the potential effect of eutrophication and these measures should be considered only as support measures. The D5C2 is not applicable as it is to the deep sea. Despite this, the determination of Chl-a concentration in sediments can provide important insights into the trophic state of the area. Chl-a and phaeopigment concentrations in deep-sea sediments have been widely reported in a considerable number of recently published papers focusing on the western, central and eastern Mediterranean sub-basins, covering a depth range from 200 m to 4000 m (Danovaro et al., 2008; Pusceddu et al., 2010).

Harmful algal blooms in the water column (D5C3) cannot be applied as it is to the deep sea. However, deep-sea sediments can be also repositories of cysts of harmful algae (Ferreira et al., 2007; Danovaro, 2010). These cysts either in quiescence or diapauses can suddenly determine bloom reaching the coastal areas through upwelling. Harmful algal blooms can cause beach fouling, oxygen deficiency, clogging of fish gills, and in extreme conditions, oxygen deficiency in deep waters, resulting in mass mortality of benthic animals. Their presence should be monitored through standard international approaches and methodologies. The role of cysts of harmful algae have been widely studied in coastal waters, whereas their presence and potential toxicity have been seldom considered in deep-sea sediments of Mediterranean basin (Ferreira et al., 2007; Danovaro, 2010).

Main outcomes and gaps

Druon et al. (2004) reported that deep-water hypoxia or anoxia are assumed, in a first approximation, not to arise from anthropogenic activity. Deeper than 100 m, remineralisation of the organic matter in the water column is sufficient to prevent any important oxygen deficiency near the sea bottom in the absence of a permanent stratification. No severe oxygen deficiency or depletion are expected to arise from anthropogenic sources such as terrestrial input.

Climate change and coastal eutrophication may increase oxygen deficiency in some 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.

All the data available regarding D5 in deep Mediterranean Sea are reported in 16 published papers (Table 5.1), but they do not cover all the criteria defined by the MSFD. In addition, thresholds to identify the GES based on D5 have not been identified yet for the deep Mediterranean. Most countries had extensive datasets on eutrophication for coastal waters acquired through national monitoring programs in the framework of WFD implementation or the Regional Sea Conventions, but there is much less offshore data on nutrients and dissolved oxygen compared to shallow water ecosystems. No data are available regarding the effect of nutrient and organic enrichment on deep-sea macro- or meiofaunal assemblages in the Mediterranean Sea (i.e., D5C8).

There is a lack of quantitative data on pressures (monthly/seasonal variation, natural/anthropogenic sources) and on transport mechanisms from the surface to the deep sea. The consequences of river outflows and organic enrichment have been widely studied mostly on shallow-water benthic communities. In the offshore waters a dramatic change was registered for the first time in the Northern Adriatic Sea, in

1977, as the consequence of flagellate (e.g., *Noctiluca scintillans*) bloom known as red tide. Red tides are monospecific dinoflagellate blooms related to fresh water inputs rich in nutrients, fast heating of the surface layer at the beginning of summer and grazing inefficiency. The ultimate effect of the bloom was a drastic depletion of oxygen in bottom layers during summer and autumn. Mass-mortalities of benthic invertebrates were registered in central and western North Adriatic as well as escape-migrations of demersal fish and crustaceans (Stirn, 1993). More recently, massive mucous aggregates, whose ultimate effects are about the same as above, have been recorded in the Adriatic Sea. Po River nutrient inputs in spring and early summer triggered intense phytoplankton blooms and organic matter accumulation. Aggregates developed autonomously wherever the required initial nutrient levels in combination with calm sea conditions, high temperature, and intense solar radiation were present. The focal area of aggregate formation was the enriched western Adriatic Sea and from there the aggregates spread over large areas, including Central and Southern Adriatic. Drastic changes of the nutrient concentrations and ratios were induced, stimulating exudate degradation by bacteria. As a consequence of degradation of sinking aggregates, changes in dissolved oxygen and nutrient recycling occurred, resulting in hypoxic conditions and thus mass mortalities of benthic invertebrates. Drastic ecosystem disequilibria, along with multiple harmful effects, including losses in fisheries resources were recorded (Stirn, 1993). Despite the occurrence of these blooms also in offshore waters, we lack studies evaluating their effects in the deep Mediterranean basins.

In the open sea pressures related to nutrient dynamics and deep ocean circulation, related but not equivalent to eutrophication, are supported by a sufficient data base (Crise et al., 2015), whereas only data on benthic trophic status are available in the scientific literature for the deep sea (Pusceddu et al., 2010; 2014). Consequences of changes in the trophic status and oxygen availability on the structure of the deep-sea communities, food web and carbon fluxes are still poorly studied (Crise et al., 2015).

Table 5.1. *Number of papers or reports including information on descriptor 5 for the deep Mediterranean Sea in different sub-basins*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	5
Western Basin	7
Central/Ionian Basin	2
Aegean/Levantine Basin	2

6 DESCRIPTOR 6: SEAFLOOR INTEGRITY

Descriptor 6 bibliography consisted of 33 revised studies categorized in 27 articles and 6 reports/webpages. Relevant studies not directly targeting the deep seafloor were excluded from the main compilation but listed at the end as supplementary material. Additional information from each study was added to the provided spreadsheet in order to perform a complete outline. The criteria addressed and the methodology applied by each study were incorporated. Specifying the ecosystem typology analysed by each project is relevant for each descriptor, but particularly for D6. The main and most important conclusion is the scarcity of data and knowledge regarding descriptor 6 for the deep Mediterranean Sea. In consequence, a complete, accurate evaluation is not feasible nowadays.

Main outcomes and gaps

A clear geographic gradient regarding knowledge and data was observed from North to South and from West to East Mediterranean (see Table 6.1). The gradients reflect the differences in research investment and in environmental concern between regions, especially between EU and non-EU countries. Regarding bathymetry, the main gap involves depths below 800-1000 meters. The deep-sea as a whole is the lowest studied compartment of the marine environment. Additionally, even some studies included in the dataset compilation provided information regarding the deep sea with one single point of study or with only one single sample. Finally, considering both geography and bathymetry, MPA constitute an important gap since they are essential ecosystems in need for conservation. Consequently, they should accumulate multiple and diverse studies that are currently lacking.

Table 6.1. *Number of papers or reports including information on descriptor 6 for the deep Mediterranean Sea in different sub-basins*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	1
Western Basin	24
Central/Ionian Basin	5
Aegean/Levantine Basin	6

The main gap is reflected by missing articles exposing trends and/or suggesting thresholds and reference levels. Revision of the impacts related to criteria 1 and 2 exposed the narrow evaluation of pressures affecting seafloor integrity. Although fishing is the pressure with the highest impact on marine ecosystems, acknowledgement and characterization of the other ones is also required. Bottom trawling and related impacts are the focus of the majority of compiled articles. Outdated data or no data concerning the following pressures was observed: waste disposal, discards from fisheries, maritime transport, renewable energy, oil and gas offshore installations and bioprospecting. Regarding criterion 3, weak characterization of the habitats and lack of quantitative indicators were the main gaps identified. Literature on benthic habitats (relating D1 and D6 and criteria D6C4-D6C5) is also included in the descriptor 1 Section. Temporal and spatially fragmented knowledge is an important gap for descriptor 6 (see Table 6.2). Half of the collected studies are almost 10 years old, throwing the reflected data into question. Studies on waste disposal effects dated from 20 years ago cannot be used for assessing the current situation. In addition, absence of long-term monitoring limits the assessments. Spatial fragmentation is evident because of the predominance of local studies. As example, bottom trawling pressure is mostly analysed in canyons from Western Mediterranean reflecting a gap in the rest of basins.

Table 6.2. *Temporal and topic distribution of the compiled bibliography illustrated in number of papers related to D6.*

	Number of papers/report
Dated: 2008 – 2018	18
Dated: 1986 – 2008	13
Criteria	
D6C1	14
D6C2	15
D6C3	19

Lack of online repositories and data

The main consulted database was the EMODnet. The repository consists of eight data portals useful for different descriptors. Regarding descriptor 6, seabed habitats and human activities were the most relevant ones. The stored data can be either displayed in a map or downloaded, providing also the sources of information. The organization of the dataset did not fit within the spreadsheet model provided. In consequence, an additional document was generated specifying the data and the source for each human activity causing impacts to the deep sea (see Annex 1). However, maps and dataset connecting habitats (MPA and vulnerable habitats) and impacts are still missing for the deep Mediterranean Sea.

7 DESCRIPTOR 7: PERMANENT ALTERATION OF HYDROGRAPHICAL CONDITIONS

General Comment

As described in the Deliverable 1.1, descriptor 7 focuses on the permanent alteration of hydrographical conditions due to human activities, either directly (by large scale infrastructures) or indirectly (e.g. through human-induced climate change). Therefore, the concept of "hydrographical conditions" is rather wide, also considering the critical definition of "permanency" in ocean dynamic environment. The revision of the MSFD (2017/848/EU) highlighted that *"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"*, but to this purpose a very long time perspective (and dataset) should be needed and still missing.
However, it is still difficult to differentiate between the impact of direct anthropogenic pressures and indirect human effects as global change. Furthermore, the present Section, following the recommendation provided by the MSFD Expert Network on MSFD descriptor 7 (Gonzalez et al., 2015), also presents a review of the datasets dealing with hydrographic conditions in general, considering that the monitoring of this descriptor should also provide background information at different spatial (from sub-region to local) and temporal scales on variations of hydrographical conditions, which might not be connected (at least not directly) to human activities. Literature regarding sediment transport and erosion is reviewed in the Section on D6 (see Section 6).

Online repositories and data

There is plenty of literature during the last 50 years, but open access repositories constitute the real mine of information, thanks to the inclusion of data from ship tracks and regular monitoring arrays. Specific hydrographic monitoring aims to evaluate alterations and impacts in areas where significant changes due to human activities can be expected. The majority of data derive from devices such as CTDs (mainly), Argo drifters, gliders and XBTs and from mooring lines equipped with CTDs or/and current meters.

Historical data from the beginning of the 19th century up to 2012 are openly available through the MEDAR/MEDATLAS database (http://www.ifremer.fr/medar/), while newer platforms make available and update hydrographical data from the Mediterranean Sea until almost present time. In particular, most of information is stored in the SeaDataNet portal (http://seadatanet.maris2.nl/v_cdi_v3/result.asp), whereas the data ingestion process of the EMODnet Physics portal (http://www.emodnet-physics.eu/Portal) is reporting some delay in the timely provision of datasets (both for historical and present data) and, at present, contains data only from Argo drifters, gliders and few mooring lines. Indeed the EMODnet Data Ingestion Project is presently running to identify the most valuable candidate datasets per EMODnet theme, to better populate the system.

As regards quality control of the data, it should be mentioned that in the Mediterranean there is a large experience of QA/QC of hydrographical data following the IOC/UNESCO QA/QC rules. Both EMODnet and SeaDataNet apply standard data quality control procedures on all data with specific quality flag.

Main outcomes and gaps

Unlike other descriptors, there is plenty of potentially useful data for the deep sea from all over the Mediterranean sub-basins, especially regarding temperature and salinity measurements, also thanks to several international projects developed in the last three decades. The data sources considered consist of 174 datasets, comprising 22 webpages and 152 articles/reviews, generated by monitoring programs, research projects and model products (Table 7.1). As regards the latter, 22 covered the whole Mediterranean Sea, 104 included information for the Western basin, 19 for the Central-Ionian basin and 16 for the Aegean-Levantine basin (Table 7.1). Therefore, overall, the Western basin is much more represented than the other basins.

Table 7.1. *Number of papers or reports including information on descriptor 7 for the deep Mediterranean Sea in different sub-basins*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	22
Western Basin	104
Central/Ionian Basin	19
Aegean/Levantine Basin	16

As concerns D7, changes in thermohaline properties, dissolved oxygen and pH of seawater are the identified pressures with the highest impact on marine ecosystems and the focus of the majority of the reviewed datasets (assuming both literature and online repositories). Besides several regional studies, that have regularly covered the main sites of dense water formation (NW Mediterranean, Southern Adriatic, Aegean), starting in the mid 1980s, large international observational programs and modelling studies were developed in the whole Mediterranean Sea (e.g. POEM, PRIMO, WMCE, EU/MAST/MTP, EU/MATER), which allowed a detailed description of the water mass properties and general circulation (see for example Tsimplis et al., 2006). In the 1990s, a great number of studies were conducted to follow the abrupt shift of the deep-water formation sites and rates in the Eastern Mediterranean Sea (Roether et al., 1996; Tanhua et al., 2013), commonly known as the Eastern Mediterranean Transient (EMT), causing the increase of temperature and salinity (D7C1) in the new Eastern Mediterranean Deep Water. The EMT signal was subsequently transferred to the Western Mediterranean Sea, as saltier and warmer intermediate waters entering from the Sicily Channel, which, in turn, produced significant changes in the characteristics of the Western Mediterranean Deep Water. In the mid-2000s, a major renewal of the deepest water masses, with subsequent major changes in their properties, occurred in the Western Mediterranean sub-basin, as a result of dense shelf water formation and cascading, and offshore convection in the Gulf of Lion (Lopez-Jurado et al., 2005; Canals et al., 2006; Smith and Bryden, 2008; Puig et al., 2013; Schroeder et al., 2016). This event, similarly to the effect of the above-mentioned EMT in the Eastern sub-basin, has been named the Western Mediterranean Transient (Tanhua et al., 2013). Great attention was also devoted to long-term monitoring of fluxes at the straits, mainly Sicily, Gibraltar and Corsica, identified as key areas where changes in the thermohaline properties of the water masses taking place in the different sub-basins are registered (Fusco et al., 2008; Schroeder et al., 2017). In the 2000's large national and international programmes (e.g. EU-PERSEUS and MedSeA, IT-VECTOR, FR-MERMEX, E-RADMED) produced a new general overview of the whole Mediterranean Basin. In the same period (after 2000) new instruments and infrastructures became operative (Argo floats, gliders). Data distribution through time is provided in Figures

7.1 and 7.2. XBT measurements are available since the 50's, but, in general, quite sparse up to the 1980s. Regular monitoring of the whole basin was carried out during the Mediterranean Forecasting System Pilot Project (MFSPP) funded by the UE between 1998 and 2001. The objective of MFSPP was to demonstrate that multiparametric operational monitoring and near real-time (NRT) forecasts of the mesoscale currents in the basin were feasible. In this context, the first Ship Of Opportunity Program (SOOP) in the Mediterranean Sea was funded as part of MFSPP, starting in September 1999, producing a peak of data in the relevant period. Although relatively few studies were reported from the Tyrrhenian Sea, rather long time-series (about 15 years long) of XBT data are available from this sub-basin, along a N-S transect, still maintained, which runs along the route joining the Italian harbours of Genova and Palermo.

Data recorded by CTD probes spread from the 1970s to present time. Most of them 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 straits where significant water mass exchanges take place, specific hydrological structures such as fronts and steady current systems, and also the closeness of research centres to given areas. Most of this effort occurred since the 1980s principally by the Mediterranean oceanographic community, with contributions from some non-Mediterranean nations. The highest peaks in terms of number of data collected correspond to years 1999, 2000, 2004, 2005 and 2015 for temperature data (Figure 7.1) and to 1997 and 1998 for dissolved oxygen (Figure 7.2), in accordance with the historical changes recorded as EMT and Western Mediterranean Transient (WMT).

The peak in temperature data in 2015, and in general most of the temperature data from 2010 onwards, relate to the spread of gliders and Argo drifters, mainly placed in the Ionian and Tyrrhenian seas.

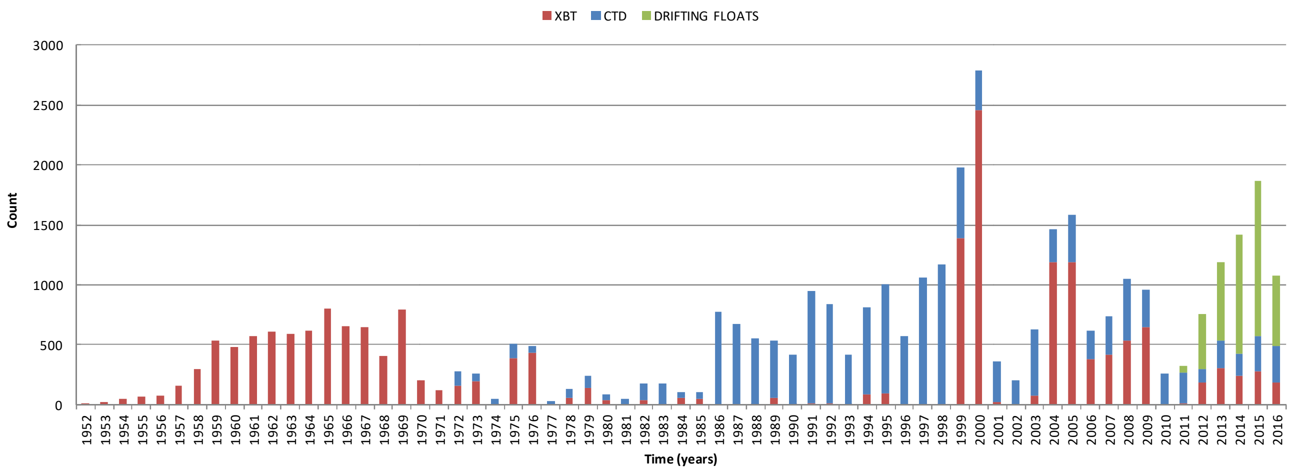

Figure 7.1. Time distribution of temperature data in the deep Mediterranean Sea (>200 m) from the SeaDataNet Portal covering the 1952 to 2016 period, organized by recording instrument (colour-coded). Note that the graph depicts four main periods according to the prevailing instrument used to collect temperature data: 1) 1952-79 dominated by XBT-sourced data; 2) 1979-98 dominated by CTD-sourced data; 3) 1999-2011 dominated by a mix of CTD and XBT data following a revival of the later, which tend to become predominant within the period; and 4) 2011-present dominating by data collected by autonomous instruments such as drifters and floats.

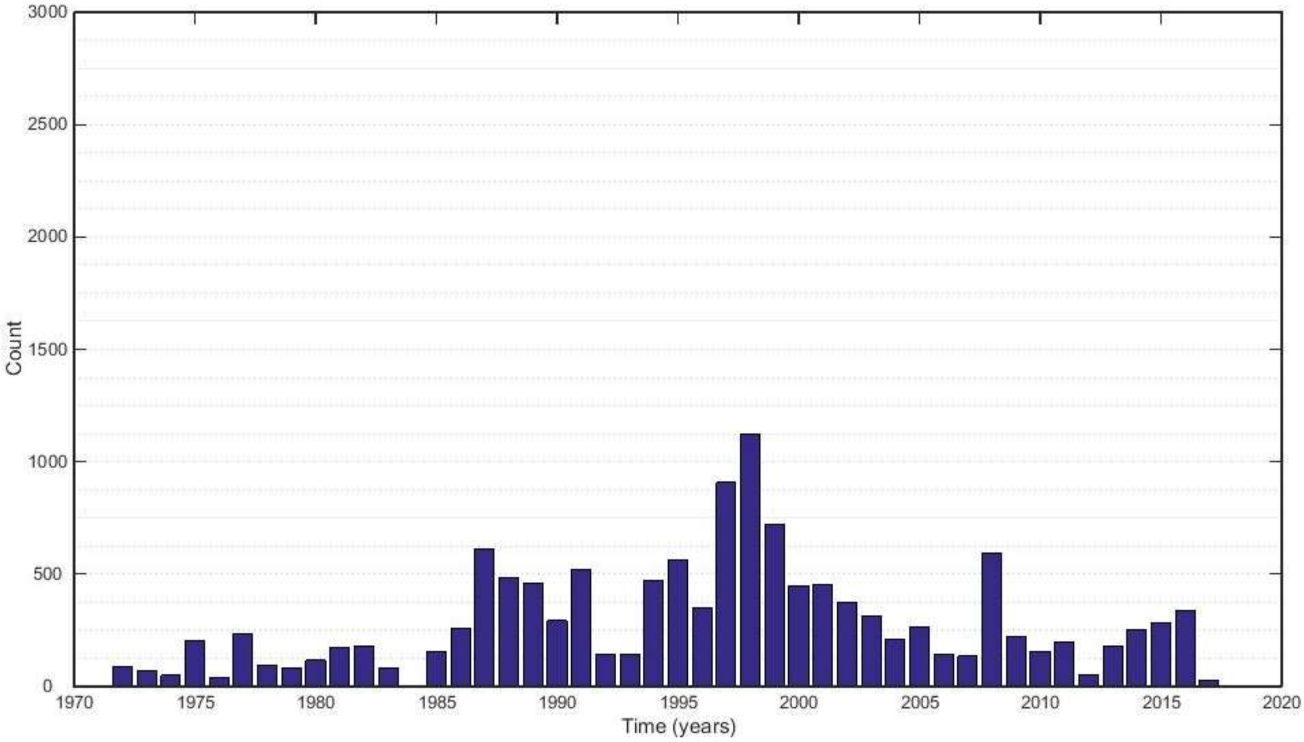

Figure 7.2. *Time distribution of dissolved oxygen annual data in the deep Mediterranean Sea (>200 m) from the SeaDataNet Portal covering the 1972-2017 period.*

Additional near bottom data can be achieved from fixed point observations like those obtained by the HYDROCHANGES (see table 2 in Schroeder et al., 2013) and FixO3 (Fixed point Open Ocean Observatory network, http://earthvo.fixo3.eu/, as reported in Table 8.1) programmes and from the EMSO (European Multidisciplinary Seafloor and water column Observatories, http://emso.eu/) EU Infrastructure.

Hence, considering both literature and online repositories, the spatial distribution of **salinity, temperature and dissolved oxygen** data beneath 200 m depth presents good data coverage in both the Western and the Eastern Mediterranean basins (for time ranges from 1911 to 2017). Mostly deep waters offshore the southern and eastern non-EU regions (as Libya, Egypt, Gaza, Israel, Lebanon and Syria) are characterized by few data, especially for salinity and oxygen observations. If only data recorded at the deepest parts of the basin are considered, the picture changes slightly: fewer data are recorded especially in the Sicily Channel, in the south and eastern Levantine Basin, but also in the deepest part of the Tyrrhenian Sea.

The SeaDataNet website also allows extracting the uploaded information about long-term monitoring of basic hydrological parameters, starting from the common data index file and identifying time series, which are available in all the basins, with the exception of their southern parts. Such availability is drastically reduced if only time series longer than 6 months are displayed: temperature and salinity data are still 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 (Figure 7.3).

Instrument type or Model (e.g. XBT, CTD, Gliders, Argo, Mooring time series etc.)	Sub-Basin (W= Western, CI= Central/Ionian, AL= Aegean/Levantine, Med=Whole Mediterranean)	Variables for each dataset and unit of measure	Year (from)	Year (to)	Area covered	Depth range (m)
BUOY/MOORING (LION)	W	Temperature (°C) Salinity (psu) Vertical/Horizontal Current speed (m/s)	2009	2014	42°N 5°E (Gulf of Lion)	50-2330
BUOY/MOORING (ANTARES)	W	Temperature (°C) Salinity (psu) Oxigen Saturation (from 2010 to 2011)	2005	2011	42.8°N 6.17°E	2500
BUOY/MOORING (DYFAMED)	W	Temperature (°C) Salinity (psu) Vertical/Horizontal Current speed (m/s) Dissolved Oxigen (micromole/kg)	2008	2016	43.42°N 7.87°E (Ligurian Sea)	0-2300
BUOY/MOORING (E2M3A)	CI	Temperature (°C) Salinity (psu) Conductivity (S/m) pCO2 (µatm) pH (-) O2 conc(ml/l)	2006	2013	41.84°N 17.76°E (South Adriatic)	200-1200
BUOY/MOORING (NEMO-SN1)	CI	Temperature (°C) Conductivity (S/m)	2012	2013	37.5°N 15.4°E (Western Ionian Sea, offshore Catania (Sicily)	2040
BUOY/MOORING (PYLOS)	CI	Temperature (°C) Salinity (psu) Dissolved Oxigen (ml/l) Fluorescence (mg/m3) Turbidity Horizontal Current Speed (m/s)	2008	2017	36.8°N 21.6°E (Cross road of Adriatic and Eastern Mediterranean basins)	0-1673
BUOY/MOORING (E1-M3A)	AL	Temperature (°C) Salinity (psu) Dissolved Oxigen (ml/l) Fluorescence (mg/m3) pH Horizontal Current Speed (m/s) Total Chlorophyll-a (milligram/m3) Turbidity	2011	2017	35.44°N 25.07°E (Eastern Mediterranean offshore Crete Island)	0-1000

***Table 7.2**. Oceanographic metadata from deep-sea observatories in the Mediterranean FixO3 network (extracted from Attachment DATASET_OA_repositories.xlsx).*

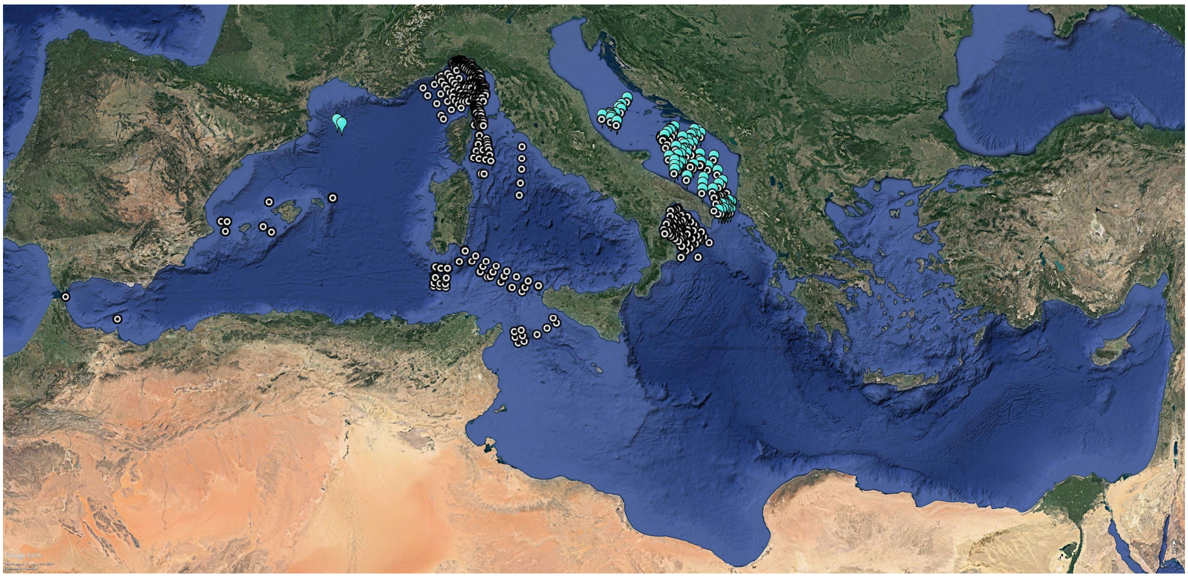

***Figure 7.3.** Geographical distribution of temperature and salinity (white circles) and dissolved oxygen (blue flags) time series longer than 6 months in the deep Mediterranean Sea (>200 m) from the SeaDataNet Portal covering the 1911 to 2017 period.*

Few studies are available about the possible changes of hydrological conditions produced by oil and gas operations, while studies of the interactions between climate-related variables (temperature, oxygen, pH, CO_2) and drilling impacts are rare or non-existent. At the most basic level, experimental work has shown that climate and ocean change, including higher temperatures, expansion of oxygen minimum zones, and ocean acidification, will exacerbate the more direct impacts of the oil and gas industry through increased metabolic demand and increased toxicity of petroleum hydrocarbons and other compounds (Cordes et al., 2016).

Although data coverage is far from being consistent and homogeneous, surprisingly, good, although quite recent, datasets exist for T**otal Dissolved Carbon, Alkalinity, pH and the derived variable Anthropogenic Carbon** (C_{ANT}). These parameters have been measured in a series of oceanographic campaigns covering the whole Mediterranean Sea in 2001 (Schneider et al., 2010), 2007-2008 (Rivaro et al., 2010; Touratier et al., 2012), 2011 (Alvarez et al., 2014) and 2013 (Hassoun et al., 2015). The five campaigns examined the most important deep basins of the Mediterranean Sea and offer valuable synoptic pictures. All studies give information on data quality procedures and on the method used for the estimation C_{ANT}. To these datasets, observations obtained in a few key areas must be added, such as the Gulf of Lion and the Southern Adriatic. Particularly relevant, although with some gaps and data obtained with different methodologies, is the DYFAMED time-series station in the NW Ligurian Sea (measurements started in 1991). Information on pCO_2 in surface waters (important as source term) is also available at the 3 permanent stations of the ICOS network, two of which are in open sea: W1-M3A in the Ligurian Sea and E2M3A in the Southern Adriatic. Analytical procedures at these stations are strictly defined and controlled as required by the ICOS program (https://otc.icos-cp.eu/). All Mediterranean (deep) basins are invaded by C_{ANT} due to the overturning circulation and there is a strict correlation between C_{ANT} and water masses. All Mediterranean waters are consequently acidified, particularly those in the Western Basin, where deep-water renewal is faster. Information looks sufficient to define recent changes (e.g. acidification of intermediate and deep waters due to the EMT, Touratier and Goyet, 2011), some of which are connected to the variability of the general circulation. Long time series of the carbonate system properties are not available yet (except at the DYFAMED Station) and it is difficult to discriminate between variability and permanent changes and there is large uncertainty on the long-term effect of increased acidification of Mediterranean intermediate and deep -water masses.

Cascading of dense shelf water has been reported to transfer huge amounts of suspended particulate matter and associated pollutants, organic matter and nutrients to the deep sea in two main areas: the NW Mediterranean and the Adriatic Sea (Martín et al., 2010; Canals et al., 2009).

In order to partially overcome general data distribution inhomogeneities, gridded products have been generated through the objective analysis of the available observations (such as numerical models with data assimilation delivered by Copernicus reported in Attachment *DATASET_OA_repositories.xlsx*). Copernicus downstream services (http://marine.copernicus.eu/services-portfolio/access-to-products/) can be used as source of information especially about currents, mixing characteristics, residence time and salinity. In particular, The Mediterranean Forecasting System, MFS, (Pinardi et al., 2003; Pinardi and Coppini, 2010) is providing, since year 2000, analysis and short term forecasts of the main physical parameters in the Mediterranean Sea with 1/24° x 1/24° horizontal resolution and 141 unevenly spaced vertical levels.

8 DESCRIPTOR 8 AND 9: CONCENTRATIONS OF CONTAMINANTS/CONTAMINANTS IN FISH AND OTHER SEAFOOD FOR HUMAN COMSUMPTION

A total of 97 scientific articles have been reviewed regarding data on the contaminant pollution in sediments, water and biota in the deep environment (>200 m) of the Mediterranean Sea: 83 articles deal with descriptor 8 "Concentrations of contaminants", while 14 articles include data on organisms for human consumption as primary descriptor (descriptor 9 "Contaminants in fishes and other seafood for human consumption). Data in the selected papers range from 1960 up to 2015.

Main outcomes and gaps

The spatial distribution of the literature for D8 in the Mediterranean Sea is shown in Table 8.1.

Contaminant temporal trends range from a minimum of few days to a maximum of three years. Physical, chemical and radionuclide data is provided in tables and also shown in depth profiles. The contaminants are studied in different marine environments from the shelf to the abyssal plains, with a maximum investigated depth equal to 4300 m. Contaminants are studied in different matrices as follows: around 30% of scientific articles are focused on sediments, around 30% on seawater, around 35% on marine organisms and fish and only around 5% on air.

Table 8.1. *Number of papers or reports including information on descriptor 8 for the deep Mediterranean Sea in different sub-basins*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	22
Western Basin	43
Central/Ionian Basin	12
Aegean/Levantine Basin	6

The spatial distribution of the literature for D9 in the Mediterranean Sea is shown in Table 8.4.

Table 8.2. *Number of papers or reports including information on descriptor 9 for the deep Mediterranean Sea in different sub-basins*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	1
Western Basin	11
Central/Ionian Basin	3
Aegean/Levantine Basin	0

Concerning this dataset, the most studied area is the Gulf of Lion (Western Mediterranean), while very few data has been collected in the Levantine Basin apart from the area directly in front of Israel coast.

An analysis of studied contaminants for both D8 and D9 is summarised in Table 8.3, while the following Table 8.4 shows the spatial distribution of the studied contaminants in the 97 scientific papers in the deep-sea sub-basins of the Mediterranean Sea.

Table 8.3. *Studied contaminants in the collected scientific papers for D8 and D9. Other organic compounds include DDTs, Organotin, POPs, TBT.*

Contaminants	**Number of papers/reports**
Hg	26
PAH	20
PCB	25
Radionuclides	13
Metals	12
Biomarkers	2
Other organic compounds	28

Table 8.4. *Spatial distribution of the studied contaminants for D8 and D9 in the deep-sea basins of the Mediterranean Sea.*

	Number of papers/reports						
Region Covered	Hg	PAH	PCB	Radionuclides	Metals	Biomarkers	Other organic compounds
Entire Mediterranean Sea	10	2	3	6	3	1	3
Western Basin	9	15	17	6	5	1	17
Central/Ionian Basin	6	0	4	0	3	0	9
Aegean/Levantine Basin	1	3	2	1	1	0	0
Total	**26**	**20**	**26**	**13**	**12**	**2**	**29**

Since advection of water masses is an important mechanism that transports dissolved contaminants from the sea surface to the deep environments, particular interest should be given to areas characterised by dense water formation, in correlation with D6 and D7. While the zone of dense water formation in the Western Mediterranean Sea is well characterised, the formation areas of Levantine Intermediate Water (Rhodes basin) and Eastern Mediterranean Deep Water (Aegean Sea) have not been studied in details.

Only one paper contains data from the Aegean Sea (^{137}Cs in deep waters). In the Levantine Basin, 3 scientific articles concern anthropic local impacts, i.e. contaminants levels associated with nearby gas well drilling and dumping sites (dredge-material, fly ash).

The most studied contaminants are Hg and PCB. Only few (5) papers contain data on emerging contaminants. Four of them refer to biota and one to sediments and transformation during transport.

Bioaccumulation/biomagnification was mainly treated for mercury (6 papers), while only 2 papers address this topic for other contaminants. Radionuclides concentration never reaches values relevant for human health or ecosystems.

One paper explores the expected responses of marine ecosystems to climate and anthropogenic forcing.

Six papers give information on biomarkers and relationship to contaminant concentration/accumulation (D8C2/C4).

9 DESCRIPTOR 10: MARINE LITTER

Descriptor 10 collection of relevant references included 31 datasets, comprising 20 articles and 11 reports/webpages. Moreover, relevant studies not directly targeting the deep seafloor were listed at the end as supplementary material. The spreadsheet was complemented with additional information to include relevant specifications such as the particular criteria addressed or the methodology applied by each study. The main observation was the scarcity of data and knowledge regarding descriptor 10 for the deep Mediterranean Sea. In consequence, the information available does not allow a complete, accurate evaluation.

Main outcomes and gaps

A clear geographic gradient regarding knowledge and data was observed from North to South Mediterranean. Differences between East and West Mediterranean were also depicted by a smoother gradient for descriptor 10 (see Table 9.1). The gradients reflect different investment in research and in environmental issues between regions, especially between EU and non-EU countries. Regarding bathymetry, the main gap involves depths below 800-1000 meters. Furthermore, some studies regarding the deep sea only included one single point of study of or even one single sample. MPA constitute an important gap including both geography and bathymetry. Considering MPA as regions in need for conservation, they should collect multiple and diverse researches, currently lacking.

Table 9.1. *Number of papers or reports including information on descriptor 10 for the deep Mediterranean Sea in different sub-basins*

Region Covered	Number of papers/reports
Entire Mediterranean Sea	2
Western Basin	11
Central/Ionian Basin	13
Aegean/Levantine Basin	9
Global oceans	4

The majority of compiled studies were local analysis of marine litter diversity and classification focused on macro-plastics (see Table 9.2, D10C1). Marine compartments accumulating most of the research are beaches and surface waters from coastal zones. Regarding the deep-sea, important knowledge and data gaps were noticed, causing deficiencies in trend identification and threshold establishment. Awareness of marine litter as an important marine impact is quite recent. The positive consequence is the increased public and scientific interest for the topic. However, the subsequent topics still need investigation or at least acknowledgment: degradation and fragmentation, vertical and horizontal transport, colonization, potential for contaminant transference, sources and sinks, removal techniques and usefulness of bioindicators. Micro-plastics constitute an important independent gap that also includes all other commented deficiencies (see Table 9.2, D10C2). The priority issues concerning micro-plastics are the harmonization of methodologies and sampling techniques to obtain comparable data. The major gap concerning criteria 3 and 4 is defined by a restricted number of deep-sea species and habitats considered. Temporal knowledge fragmentation is not an important gap since marine litter is a novel topic and therefore the data is quite actual as exposed in Table 9.2. However, because of the difficulties of sampling in the deep sea, few articles provide new data. Spatial fragmentation is actually relevant to fully understand the actual entity of the pressure. Collection of data from all compartments and basins is essential and missing at present.

Table 9.2 Temporal and topic distribution of the compiled bibliography illustrated in number of papers related to D10.

	Number of papers/reports
Dated: 2008 – 2018	23
Dated: 1986 – 2008	9
Criteria	
D10C1	27
D10C2	7
D10C3	1
D10C4	4

Lack of online repositories and data

PANGEA database (Data Publisher for Earth & Environmental Science) contains few datasets regarding deep-sea marine litter. The principal dataset identified was related to one article already described in the spreadsheet. The global maps and models found only illustrated abundance and density of surface macro-litter. Analysis and models concerning marine deep-sea litter of the Mediterranean Sea should be urgently developed.

10 DESCRIPTOR 11: INTRODUCTION OF ENERGY

Very few datasets (5 papers in total and any open access repositories at the moment) are available for this descriptor for the deep Mediterranean, essentially provided by the two neutrino telescope detectors, ANTARES in France and KM3NET, in Italy off Cape Passero in Sicily.

These studies essentially used the Passive Acoustic Monitoring (PAM) to detect large marine mammals such as sperm whale (*Physeter macrocephalus*) and fin whale (*Balaenoptera physalus*) in the waters close to the cabled observatory. The greater information (4 out of 5 papers) was derived by the PAM system of KM3Net/NEMO1 observatory located off Capo Passero (South of Sicily) and off Catania, with papers concerning population size, structure and displacement of sperm whales and fin whales. Only two papers reported data collected at ANTARES.

Main outcomes and gaps

The most evident deficiency is the very high level of fragmented knowledge, with only five papers published for this descriptor concerning the deep Mediterranean. Spatial but also temporal gaps were clearly observed while reviewing the datasets, with only two studies from the western Mediterranean and none from the Aegean-Levantine basin. In addition, the studies from the Central Ionian and the Western Mediterranean, apart from their very low number, are essentially local and referred to the measurement of noise in the close proximity of the fixed infrastructures. Temporal gaps concern the almost completely absence of long-term data, with the papers including data from 2005 to 2013.

Another main gap is reflected by missing articles exposing trends and/or suggesting thresholds and reference levels.

Finally, regarding bathymetry, the main gap involves depths from 200 to 2000 m as the observatories are located below 2000 m of depth.

11 CONCLUSIONS AND FUTURE WORK

The current review of the collection of available datasets summarizes the main retrieved outcomes. Task 2.1 exposed the available knowledge and data, but also the most relevant and outstanding gaps. This document is important for establishing the state of the art from where the other actions will develop. Subsequent meta-analysis and knowledge integration in maps will be performed based on the information compiled. Consequently, the analysis of data gaps is also directly linked to this collection. Overall, these actions are the first steps for the assessment of the deep Mediterranean Sea status.

General and common gaps include the topics described right after. The most noticeable shortage was the existing fragmented knowledge. Spatial but also temporal gaps were clearly observed while reviewing the datasets. Local studies, collection of data within particular campaigns and difficulties for obtaining long-term data were the main causes of fragmented knowledge. The simultaneous analysis of multiple pressures is a complex task and consequently, cumulative effects are rarely investigated. Absence of articles proposing standards or reference levels is a main gap for all descriptors. Knowledge scarcity hinders the establishment of thresholds that in turn complicates the implementation of measures. Finally, characterization of deep-sea habitats and ecosystems, at a meso- and large scale, is poorly addressed by current studies. Despite the complexity, this topic is essential for understanding how each habitat will respond to the different impacts determining the obtaining of Good Environmental Status (GES). Nowadays, the link between ecosystem functioning, services provided and human benefits is still under described. This last gap introduces the importance of analyzing the socioeconomic effects of each detected pressure. Accurate description of habitats should be a priority for Marine Protected Areas (MPA) and areas experiencing high pressure and containing vulnerable, relevant ecosystems.

The dataset compilation evinces that available research is restricted to a narrow set of indicators. Moreover, different interpretations of the indicators are one of the main causes provoking heterogeneous reporting, inconsistencies and non-comparable results. This issue is replicated when focusing in descriptors' criteria. Besides clearer framing of current indicators, development and application of quantitative ones is required. Concerning criteria, the ones established were not able to frame all identified topics for each descriptor. Only some of the knowledge and data gaps exposed by the dataset collection could be included within the defined criteria. The rest exposed the need for designation of new criteria. Finally, during the bibliographic review of the datasets, relevant gaps could not be clearly related to one single descriptor. Consequently, one of the most important outcomes of task 2.1 was the recognition of overlooked topics. These issues need to be considered and may be designated as new descriptors. Detailed characterization of the just identified and other new descriptors and criteria will be performed within Task 3.

Open online datasets enable the compilation of knowledge from multiple studies, supporting accurate assessments of environmental issues. Actually, they are crucial for international programs where coordination and data sharing are mandatory. Nowadays, limited information is available in online repositories. The IDEM project Task 2 could contribute to this gap by developing an online dataset. Relevant references, data and meta-analysis results for each descriptor could be included.

12 ANNEX 1

DATABASE/PORTAL: HUMAN ACTIVITIES DATA PORTAL. EMODNET - EUROPEAN MARINE OBSERVATION AND DATA NETWORK

Reference: (European Marine Observation and Data Network 2017) - **European Marine Observation and Data Network. 2017. "EMODnet - Data Portals: Human Activities."** http://www.emodnet.eu/human-activities (March 14, 2018).

Variables and units (information/data about D6C1, D6C2, D6C3)

Brief comment: huge data portal related to the previous listed categories. Here is described the data categories related to human activities. However, EMODnet also contains data and maps associated to other fields (Bathymetry, Biology, Chemistry, Geology, Physics and Seabed habitats). The webpage have two important tabs*: 1. View data*: The data can be displayed in a map to observe the distribution of each human activity. The deployment of data can be filtered for specification and subcategories. In addition, when you click on a particular point all the related available information is show (for instance: area affected by the impact, depth, start and end year of the human activity, distance from the coast and other). *2. Search data:* database that can be filter by theme and by subcategories. For each topic you can download the data (from the points depicted on the map) and the metadata (data submitted to EMODnet). The webpage also provides different information about the dataset, like the sources and contact details for each set of data. Datasets are also available via OGC compliant web feature service (WFS) or web map services (WMS).

DATA	SOURCES
Cables	
Telecommunication Cables (actual route locations) REVISION DATE 2014-12-22	-BSH Contis, DE -Greg's Cable Map, ZA -Packet Clearing House -SIG Cables, Orange ©, FR -TeleGeography, US
Cultural heritage	
Submerges Prehistoric Archaeology and Landscape CREATION DATE 2009-01-01	SPLASHCOS EU project
Environment protected areas	
Natura 2000 Nationally Designated Areas REVISION DATE 2016-04-13	European Environmental Agency's (EEA) datasets "Natura 2000" and "Nationally designated areas (CDDA)"
Fisheries (fishery zones)	
Fish Catches by FAO Fishery Statistical Areas REVISION DATE 2016-03-09	Aggregation of EUROSTAT's fish catches datasets fish_ca_atl 27, fish_ca_atl 34, fish_ca_atl 37
First Sales of Fish REVISION DATE 2016-09-14	Data on monthly first sales of fish made available by the European Market for Fisheries and Aquaculture products (EUMOFA)

Hydrocarbon Extraction	
Active licenses: Where available each polygon has the following attributes: country, code, name, type (exploration, exploitation), licensing round, area (square km), area info, starting year, ending year, operator REVISION DATE 2016-07-13	Datasets provided by several EU and non-EU sources. It is updated every year, and is available for viewing and download on EMODnet
Boreholes: Each point has the following attributes (where available): status (active, abandoned, suspended, other), country, code, name, year, purpose (exploration, exploitation, other), content (crude oil, natural gas, crude oil and natural gas, dry, other), operator, drilling company/facility, distance to coast (meter) and water depth (meter). REVISION DATE 2017-09-04	Datasets provided by several sources from all across the EU (plus Norway). Available for viewing and download on EMODnet
Offshore installations: The database includes the name and ID number, location, operator, water depth, production start, current status, category and function of the installation REVISION DATE 2016-06-20	It is modelled on OSPAR's dataset on offshore installations, having the same fields and attributes
Pipelines (only in Croatia)	
Attributes (where available): status (in service, decommissioned, under construction, proposed, planned), country, code, name, year, medium (air, condensate, 'control', cooling water, gas, geothermal heating, glycol, methanol, oil, sewage, water), operator, from and to locality or facility, length (meter) and size (inches) REVISION DATE 2017-12-20	Datasets provided by several EU and non-EU sources. It is available for viewing and download on EMODnet
Waste disposal	
Dredge Spoil Dumping (Points) REVISION DATE 2016-05-20	Information was picked from different sources depending on the country
Dumped Munitions (Points) REVISION DATE 2015-05-15	Information was picked from different sources depending on the country

13 ATTACHMENTS

DATASET_D1.xlsx

DATASET_D2.xlsx

DATASET_D3.xlsx

DATASET_D4.xlsx

DATASET_D5.xlsx

DATASET_D6.xlsx

DATASET_D7.xlsx

DATASET_D8&D9.xlsx

DATASET_D10.xlsx

DATASET_D11.xlsx

DATASET_OA_repositories.xlsx

14 REFERENCES

Álvarez, M., Sanleón-Bartolomé, H.,Tanhua, T., Mintrop, L., Luchetta, A., Cantoni, C., Schroeder, K., Civitarese, G., 2014. The CO2 system in the Mediterranean Sea: a basin wide perspective, Ocean Science 10, 1, 69-92.

Bariche, M., 2010. Champsodon vorax (Teleostei: Champsodontidae), a new alien fish in the Mediterranean. Aqua 16, 197–200.

Canals, M., Danovaro, R., Heussner, S., Lykousis, V., Puig, P., Trincardi, F., Calafat, A.M., Durrieud de Madron, X., Palanques, A., Sànchez-Vidal, A., 2009. Cascades in Mediterranean submarine grand canyons. Oceanography 22, 1, 26-43, doi: 10.5670/oceanog.2009.03.

Canals, M., Puig P., Durrieu de Madron, X., Heussner, S., Palanques, A., Fabres, J., 2006. Flushing submarine canyons, Nature 444, 354-357, doi: 10.1038/nature05271.

Coll, M., Libralato, S., 2012. Contributions of food web modelling to the ecosystem approach to marine resource management in the Mediterranean Sea, Fish and Fisheries 13, 1: 60-88, doi: 10.1111/j.1467-2979.2011.00420.x.

Cordes, E.E. et al., 2016. Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. Front. Environ. Sci. 4:58, doi: 10.3389/fenvs.2016.00058.

Corsini-Foka, M., Pancucci-Papadopoulo. A., Kondilatos, G., Kalogirou, S., 2010. Gonioinfradens paucidentatus (A. Milne Edwards, 1861) (Crustacea, Decapoda, Portunidae): a new alien crab in the Mediterranean Sea. Med. Mar. Sci. 11/2, 331–340.

Crise A., Kaberi H., Ruiz J., Zatsepin, A., Arashkevich, E., Giani, M., Karageorgis, A.P., Prieto, L., Pantazi, M., Gonzalez-Fernandez, D., et al., 2015. A MSFD complementary approach for the assessment of pressures, knowledge and data gaps in Southern European Seas: The PERSEUS experience. Marine Pollution Bulletin 95, 28–39, doi: 10.1016/j.marpolbul.2015.03.024.

Danovaro, R., 2010. Methods for the Study of Deep-sea Sediments, Their Functioning and Biodiversity. CRC Press Taylor & Francis Group.

Danovaro, R., Gambi, C., Lampadariou, N., Tselepides, A., 2008. Deep-sea nematode biodiversity in the Mediterranean Basin: testing for longitudinal, bathymetric and energetic gradients. Ecography 31, 231–244, doi: 10.1111/j.0906-7590.2008.5484.x.

Druon, J.N., Schrimpf, W., Dobricic, S., Stips, A. 2004. Comparative assessment of large-scale marine eutrophication: North Sea area and Adriatic Sea as case studies. Marine Ecology Progress Series, 272: 1–23, doi: 10.3354/meps272001.

European Commission, 2017a. Decision (EU) 2017/848 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU, Official journal of the European Union, L125, 43-74.

European Commission, 2017b. Report from the Commission to the European Parliament and the Council assessing member states' monitoring programmes under the Marine Strategy Framework Directive, European Commission, Brussels, 2017, COM/2017/03 final.

Fanelli, E., Cartes, J.E., 2010. Temporal variations in the feeding habits and trophic levels of three deep-sea demersal fishes from the western Mediterranean Sea, based on stomach contents and stable isotope analyses. Marine Ecology Progress Series 402: 213–232, doi: 10.3354/meps08421.

Fanelli, E., Papiol, V., Cartes, J.E., López-Pérez, C., Rumolo, P., 2013. Trophic webs of deep-sea megafauna on mainland and insular slopes of the NW Mediterranean: a comparison by stable isotope analysis. Marine Ecology Progress Series 490:199-221, doi: 10.3354/meps10430.

Ferreira, J.G., Vale, C., Soares, C.V., Salas, F., Stacey, P.E., Bricker, S.B., Silva, M.C., Marques, J.C., 2007. Monitoring of coastal and transitional waters under the EU Water Framework Directive. Environmental Monitoring and Assessment 135 (1–3), 195–216, doi: 10.1007/s10661-007-9643-0.

Foucher, E., Delaunay, D., 2017. Evaluation 2018 du bon état écologique des espèces exploitées à des fins commerciales au titre du descripteur 3 de la DCSMM.

Froese, R., Winker, H., Coro, G., Demirel, N., Tsikliras, A.C., Dimarchopoulou, D., Scarcella, G., Quaas, M., Matz-Lück, N., 2018. Status and rebuilding of European fisheries. Marine Policy 93 159–170.

Fusco, G. , Artale, V., Cotroneo, Y., Sannino, G., 2008.Thermohaline variability of Mediterranean Water in the Gulf of Cadiz, 1948–1999, Deep-Sea Research I 55, 1624–1638.

Golani, D., Sonin, O., Edelist, D., 2011. Second records of the Lessepsian fish migrants Priacanthus sagittarius and Platax teira in the Mediterranean and distribution extension of Tylerius spinosissimus. Aquat Invasions 6 (Suppl. 1):S7–S11, doi: 10.3391/ai.2011.6.S1.002.

Gonzalez, D., Coughan, C., Stips, A., Stolk, A., Gonzalez Pola, C., Moreno Aranda, I.M., Giorgi, G., Rees, J., Babbini, L., Manca Zeichen, M., et al., 2015. Review of the Commission Decision 2010/477/EU concerning MSFD criteria for assessing Good Environmental Status, Descriptor 7. EUR 27544 EN, doi:10.2788/435059, http://mcc.jrc.ec.europa.eu/documents/201603310431.pdf.

Gökoğlu, M., Ünlüsayin, M., Balci, B.A., Özvarol, Y., Çolak, H., 2011. Two alien fish in the Gulf of Antalya: Apogon queketti Gilchrist, 1903 (Apogonidae) and Champsodon nudivittis (Ogilby, 1895) (Champsodontidae). Zool. Middle East 54, 138–140.

Goren, M., Stern, N., Galil, B.S. and Diamant, A. 2011. On the occurrence of the Indo-Pacific Champsodon nudivittis (Ogilby, 1895) (Perciformes, Champsodontidae) from the Mediterranean coast of Israel, and presence of the species in the Red Sea. Aquatic Invasions, 6 (suppl. 1): 115-117.

Hassoun, A.E.R., Gemayel, E., Krasakopoulou, E., Goyet, C., Abboud-Abi Saab, M., Guglielmi, V., Touratier, F., Falco, C., 2015. Acidification of the Mediterranean Sea from anthropogenic carbon penetration, Deep-Sea Research I 102, 1–15, doi: 10.1016/j.dsr.2015.04.005.

Innocenti, G., Stasolla, G., Goren, M., Stern, N., Levitt-Barmats, Y., Diamant, A., Galil, B.S., 2017. Going down together: invasive host, *Charybdis longicollis* (Decapoda: Brachyura: Portunidae) and invasive parasite, *Heterosaccus dollfusi* (Cirripedia: Rhizocephala: Sacculinidae) on the upper slope off the Mediterranean coast of Israel, Mar. Biol. Res. 13, 2, 229–236, doi: 10.1080/17451000.2016.1240873.

Kalogirou, S., Corsini-Foka, M., 2012. First record of the Indo-Pacific Champsodon nudivittis (Ogilby, 1895) (Perciformes, Champsodontidae) in the Aegean waters (eastern Mediterranean Sea). BioInvasions Rec. 1, 229–233.

Lòpez-Jurado, J.L., Gonzàlez-Pola, C., Vélez-Belchì, P., 2005. Observation of an abrupt disruption of the long-term warming trend at the Balearic Sea, western Mediterranean Sea, in summer 2005, Geophysical Research Letters 32, 24, doi: 10.1029/2005gl024430.

Martín, J., Miquel, J.C. Khripounoff, A., 2010. Impact of open sea deep convection on sediment remobilization in the western Mediterranean, Geophysical Research Letters 37, L13604, doi: 10.1029/2010GL043704.

Özbek, E.O., Çardak, M., Kebapçioğlu, T., 2017. Spatio-temporal patterns of abundance, biomass and length of the silver-cheeked toadfish Lagocephalus sceleratus in the Gulf of Antalya, Turkey (Eastern Mediterranean Sea), Turk. J. Fish. Aquat. Sci. 17, 725–733.

Özcan, T., Ateş, A.S., Katağan, T., 2008. Expanding distribution and occurrence of the Indo-Pacific Stomatopod, Erugosquilla massavensis (Kossmann, 1880) on the Aegean coast of Turkey. Medit. Mar. Sci. 9, 2, 115–118.

Pinardi, N., Allen, I., Demirov, E., De Mey, P., Korres, G., Lascaratos, A., Le Traon, P-Y., Maillard, C., Manzella, G., Tziavos, C., 2003. The Mediterranean ocean forecasting system: first phase of implementation (1998–2001). Ann Geophys. 21:3–20, doi:10.5194/angeo-21–3–2003.

Pinardi, N. and Coppini, G., 2010. Operational oceanography in the Mediterranean sea: the second stage of development. Ocean Sci. 6:263–267.

Puig, P., Durrieu de Madron, X., Salat, J., Schroeder, K. et al., 2013. Thick bottom nepheloid layers in the western Mediterranean generated by deep dense shelf water cascading, Progress in Oceanography 111, 1-23. B49, doi:https://doi.org/10.1016/j.pocean.2012.10.003.

Pusceddu, A., Bianchelli, S., Canals, M., Sanchez-Vidal, A., Durrieu De Madron, X., Heussner, S., Lykousis, V., de Stigter, H., Trincardi, F., Danovaro, R., 2010. Organic matter in sediments of canyons and open slopes of the Portuguese, Catalan, Southern Adriatic and Cretan Sea margins. Deep-Sea Research I 57, 441–457, doi: 10.1016/j.dsr.2009.11.008.

Pusceddu, A., Bianchelli, S., Martín, J., Puig, P., Palanques, A., Masqué, P., Danovaro, R., 2014. Chronic and intensive bottom trawling impairs deep-sea biodiversity and ecosystem functioning. Proceedings of the National Academy of Sciences 111, 8861–8866, doi:10.1073/pnas.1405454111.

Rivaro, P., Messa, R., Massolo, S., and Frache, R., 2010. Distributions of carbonate properties along the water column in the Mediterranean Sea: Spatial and temporal variations, Mar. Chem., 121,236–245.

Roether, W., Manca, B.B., Klein, B., Bregant, D., Georgopoulos, D., Beitzel, V., Kovacevic, V., Luchetta, A., 1996. Recent changes in eastern Mediterranean deep waters, Science 271, 5247, 333-335, doi:10.1126/science.271.5247.333.

Romeo, T., Pedà, C., Fossi, M.C., Andaloro, F., Battaglia, P., 2016. First record of plastic debris in the stomach of Mediterranean lanternfishes. Acta Adriatica 57(1): 115-124.

Schneider, A., Tanhua, T., Körtzinger, A., Wallace, D.W.R., 2010. High anthropogenic carbon content in the eastern Mediterranean, Journal of Geophysical Research 115, C12050.

Schroeder, K., Chiggiato, J., Bryden, H.L., Borghini, M., Ben Ismail, S., 2016. Abrupt climate shift in the Western Mediterranean Sea, Scientific Reports 6, 23009, doi: 10.1038/srep23009.

Schroeder, K., Chiggiato, J., Josey, S.A., Borghini, M., Aracri, S., Sparnocchia, S., 2017. Rapid response to climate change in a marginal sea, Scientific Reports 7, 4065.

Schroeder, K., Millot, C., Bengara, L., Ben Ismail, S., Bensi, M., Borghini, M., Budillon, G., Cardin, V., Coppola, L., Curtil, C., et al., 2013. Long-term monitoring programme of the hydrological variability in the Mediterranean Sea: a first overview of the HYDROCHANGES network, Ocean Science 9, 2, 301-324, doi:10.5194/os-9-301-2013.

Smith, R.O., Bryden, H.L., Stansfield, K., 2008. Observations of new western Mediterranean deep water formation using Argo floats 2004-2006, Ocean Sci. 4, 2, 133-149, doi: 10.5194/os-4-133-2008.

Stern, N., Levitt, Y., Galil, B.S. et al., 2014. Distribution and population structure of the alien Indo-Pacific Randall's threadfin bream Nemipterus randalli in the eastern Mediterranean Sea. J Fish Biol 85:394–406, doi: 10.1111/jfb.12421.

Stirn, J., 1993. Man-made eutrophication in the Mediterranean sea. Prospettive e proposte mediterranee-Rivista di Economia, Agricoltura e Ambiente.

Tanhua, T., Hainbucher, D., Schroeder, K., Cardin, V., Alvarez, M., Civitarese, G., 2013. The Mediterranean Sea system: a review and an introduction to the special issue, Ocean Sci. 9, 789–803, doi: 10.5194/os-9-789-2013.

Touratier, F., Goyet, C., 2011. Impact of the Eastern Mediterranean Transient on the distribution of anthropogenic CO2 and first estimate of acidification for the Mediterranean Sea, Deep-Sea Research Part I - Oceanographic Research Papers 58, 1, 1-15, doi: 10.1016/j.dsr.2010.10.002.

Touratier, F., Guglielmi, V., Goyet, C., Prieur, L., Pujo-Pay, M.,Conan, P., and Falco, C., 2012. Distributions of the carbonate system properties, anthropogenic CO2, and acidification during the 2008 BOUM cruise (Mediterranean Sea), Biogeosciences Discuss., 9, 2709–2753, doi:10.5194/bgd-9-2709-2012.

Tsimplis, M. et al., 2006. Changes in the oceanography of the Mediterranean Sea and their link to climate variability. In Mediterranean Climate Variability, P.Lionello et al. (ed), Elsevier, pp 228-282.