JRC SCIENCE FOR POLICY REPORT

Pelagic habitats under MSFD D1: scientific advice of policy relevance

Recommendations to frame problems and solutions for the pelagic habitats' assessment

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Contents

Abstract 1
Executive summary 3
1 Introduction 5
1.1 Policy context and gaps 5
1.2 Aim and objectives 5
2 Spatio-temporal complexity of pelagic habitats 7
2.1 D1C6 elements: evaluation of essential characteristics of pelagic habitats 7
2.2 D1C6 scale and areas: the pressure-response relationship 8
3 Indicators for pelagic habitat assessment 11
3.1 D1C6 indicator selection: spatial consistency, relevance and feasibility 11
3.2 D1C6 Good Environmental Status (GES) 11
4 The way forward the D1C6 assessment 15
References 18
List of abbreviations and definitions 21
List of boxes 22
Annexes 23
Annex 1. Workshop's agenda and format 23
Annex 2. Pelagic habitats' direct and indirect pressures. 27
Annex 3. Indicators' selection at regional and EU-wide scales. 38

Abstract

Pelagic habitats are a policy priority below Descriptor 1 (Biodiversity) of the Marine Strategy Framework Directive (MSFD). They are addressed under the D1C6 criterion, stating "*the condition of the habitat type, including its biotic and abiotic structure and its functions…, is not adversely affected due to anthropogenic pressures*". The evaluation of pelagic habitats status is challenged by the functional and structural characteristics of pelagic habitat diversity and processes. To date, pelagic habitats assessments are lacking in common criteria and methodologies that characterize the habitat while accounting for the effects of anthropogenic pressures to achieve the Good Environmental Status (GES). It is therefore necessary to prioritise communication between scientific and policy communities and frame pelagic research to agree on common methods and approaches at regional or EU scale. This is key for achieving harmonised and comparable pelagic assessments for the MSFD. This report summarizes the outcomes on the assessment workflow of pelagic habitats of the JRC "MSFD pelagic habitats" workshop (9th and 10th March 2021), and the need for coordinated evaluations of the scientific challenges of policy relevance. Recommendations on the MSFD implementation of D1C6, that were generated from the experts during the workshop, will be communicated to the MSFD policy groups and the EU Member States competent authorities to support future harmonised assessment of pelagic habitats.

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Executive summary

The pelagic habitat is the largest biome on Earth, key for temperature regulation, oxygen, and food production. Its physical and biological components and processes vary spatially and temporally depending on multiple drivers. Understanding this variability, processes and interactions is fundamental to identify the drivers of changes and properly assess pelagic habitats under the Marine Strategy Framework Directive (MSFD). A JRC workshop was organised to align scientific and policy expectations for an improved MSFD pelagic habitat assessment. The workshop brought together experts from the 17 EU Member States and other organisations (e.g. Regional Sea Conventions) across Europe to share knowledge and methods and provide a coordinated regional input towards a harmonised assessment. This report summarizes the workshop outcomes and the way forward for pelagic Good Environmental Status (GES) determination.

Policy context

Pelagic habitats are a policy priority below Descriptor 1 (Biodiversity) of the MSFD. They are addressed by the MSFD D1C6 criterion (Commission Decision 2017/848/EU, 2017) which states "*the condition of the habitat type, including its biotic and abiotic structure and its functions…, is not adversely affected due to anthropogenic pressures*". The criterion must be finally assessed as extent of habitat adversely affected in square kilometres (km^2) or as a proportion (percentage) of the total extent of the habitat type. Habitat type refers to broad habitat types (i.e. variable salinity, coastal, shelf and oceanic/beyond shelf) or to additional habitat types selected by Member States as meeting scientific and practical criteria (Commission Decision 2017/848/EU, 2017).

Key conclusions

The evaluation of pelagic habitats status is challenged by the diversity of the functional and structural characteristics of pelagic habitats.
The adoption of common criteria and methodologies for their MSFD characterization can be achieved by reinforcing the coordination between MS and therefore promoting:

1. consistency of spatial and temporal data collection to the pelagic habitat variability and corresponding GES assessment.
2. specific workshops on data and indicators to harmonize data collection, quality control, analysis, and access.
3. collaboration among experts from different scientific fields and marine regions to investigate links between indicators, environmental variables and anthropogenic pressures.

Long-term funding, notably of data collection, is identified as a key condition for achieving MSFD D1C6 characterization.

A proposal was made to separate the GES evaluation of the multi-decadal processes (climate change effects and permanent bottom layer hypoxia) from the short-term processes evaluation (6-year MSFD cycle), thus resulting in two parallel assessments. This clear separation of time scales would have the merit to effectively mark the progresses made by MS at short timescale while monitoring and keeping awareness of the long-term issues.

Main findings

Criterion elements and scales: the assessment area and the data sampling are two key aspects to account for the spatio-temporal variability of pelagic habitat characteristics. A vertical and a horizontal definition are proposed for testing to account for physical and biological differences of the pelagic realm across marine regions. Regular sampling of biotic and abiotic factors is fundamental to detect the natural variability and anthropogenic impacts on the habitat. In situ-based indicators can be extrapolated on a regular grid using satellite data and/or model predictions as a complementary process to account for the spatio-temporal dynamics of pelagic habitats (hereafter gridded approach).

Indicators: fourteen out of sixteen indicators that were evaluated by the experts have an EU-wide scale of applicability but regional or subregional thresholds. Although these indicators are less accurate than regional indicators, they can be applicable inter-regionally. Species-specific indicators (e.g. *M. leidyi* and *N. scintillans*) have a regional application but spatio-temporally limited. Regarding biodiversity-based indicators (e.g. PH3), taxonomic identification by experts is more accurate (and resource demanding) than semi-automatic software (e.g. Zooscan) for plankton classification, and therefore crucial for biodiversity monitoring. Across regional marine areas, links with biotic and abiotic environmental variables are identified but research is required to investigate these linkages and the indicators sensitivity. The methods for integrating the indicators for overall GES assessment are not yet agreed. However, proposal was made to first integrate the indicators of the same category or ecosystem component (e.g. phytoplankton, zooplankton) followed by their integration for the final GES assessment.

GES: the estimation of GES in km^2 or percentage does not inform on the overall system functioning because it would be biased by the sampling strategy of the selected indicators.

Related and future JRC work

The outcomes of the report will be communicated to the MSFD Working Group GES and to the Marine Strategy Coordination Group (MSGS), and it will be the input for the ongoing revisions of D1 in the MSFD Art. 8 Guidelines. Indicator-specific groups and closer collaboration with experts from different scientific fields (remote sensing, food web and biogeochemical modelling) will constitute opportunities for testing methods, achieve inter-regional harmonization, and relate to other MSFD descriptors (e.g. D2, D3, D4, D5, D7, D8).

Quick guide

The report follows the assessment flow of the Art. 8 Guidance document which was presented in the 17th GES working group Common Implementation Strategy 17. Each section includes a short summary of the outstanding issues related to pelagic habitats assessment and the feedback from the workshop's participants. The report covers the evaluation of the essential characteristics of pelagic habitats and the pressure-response relationship (Section 2), the indicator selection (e.g. spatial consistency, relevance and feasibility) and GES determination (Section 3). Finally, the way forward in the GES determination along with challenges and uncertainties is presented in Section 4.

1 Introduction

1.1 Policy context and gaps

The Marine Strategy Framework Directive (MSFD, Directive (EC) 2008/56, 2008) includes pelagic habitats under Descriptor 1 (Biodiversity), criterion D1C6 (Commission Decision 2017/848/EU (2017), hereafter referred to as GES Decision) and forces their assessment for the determination of Good Environmental Status (GES).

As for the Article 17(2) of the MSFD, Member States (MS) require updating their marine strategy every six years and therefore to report on Articles 8 (initial assessment), 9 (Determination of the Good Environmental Status) and 10 (Establishment of Environmental Targets). These articles inform on specific actions for D1C6 review and revision, where necessary, of the level of development and ambition of the criterion set of the next reporting cycle (2018-2024).

The JRC's workshop on pelagic habitats was driven by the report "Review and analyses of Member States' 2018 reports for Articles 8, 9, and 10" (Magliozzi et al., 2021a) which analysed and evaluated the D1C6 assessment from the MS MSFD official reports (2012-2018). It showed that: i) the assessment, when complete, is carried out at indicator level or at specific regions (e.g. ecohydrodynamic regions in OSPAR), and not by criterion elements (i.e. broad habitat types: variable salinity, coastal, shelf, oceanic beyond shelf), ii) indicators are characterized by different threshold across marine regions, iii) a lack of supporting information and harmonised approach when GES is reported as "achieved", iv) a lack of agreement on the integration methods among indicators, and iv) the environmental targets are not measurable to inform on the distance to GES.

The outcome of the MS reports was the basis for a technical review on the state-of-the-art of indicators and approaches related to the pelagic habitats' assessment in EU waters (Magliozzi et al., 2021b). The review summarises current methods to assess D1C6 with a focus on the limitations and challenges to comply with the MSFD requirements. **Four main recommendations were outlined**. First, there is the need to **account for the spatio-temporal variability of pelagic habitats** by revising the classification of criterion elements as in the GES Decision (i.e. broad habitat types and other habitat types). Second, the **identification of major anthropogenic pressures** is recommended to evaluate the assessment of the indicators that reflect pressure-response relationships. Third, the **indicators should reflect relevance and feasibility at regional and EU scales**. Finally, the need for **harmonized approaches to GES determination and evaluation**.

Addressing these challenges and focusing on the gaps for the pelagic habitats' assessment, require coordinated work and exchanges between scientific communities. To this end, appointed national experts by the MS and representatives of the Regional Sea Conventions (RSCs) were invited to participate to an online workshop to align scientific and policy expectations for improving the coherence of the D1C6 assessment.

1.2 Aim and objectives

This report summarizes the scientific discussions on data and methodologies for the MSFD-GES assessment of pelagic habitats. It follows the assessment flow (Figure A1) and the specific workshop's objectives (Annex 1), from general experts' discussions on GES definition and determination (e.g. conditions for good and not-good status, pressure-indicator relationship) to specific exchanges on criterion elements and pressure-indicator relationships (e.g. spatial and temporal definition of pelagic habitats, selection of regional and EU indicators). The report's outputs include the way forward for the GES determination and MSFD assessment of pelagic habitats along with their challenges and uncertainties.

Objective 1: To define pelagic habitats and adapt the criteria elements (e.g. habitat types) by considering the scale-specific processes that determine the variation in pelagic habitats status. This is key to accounting for the spatio-temporal specificities of pelagic habitats (highly dynamic fluid) across the EU marine regions.

Objective 2: To identify the pelagic habitats' direct and indirect pressures, i.e. the physical/chemical characteristics and biological responses. This is key to uncover the linkages between pelagic physical/chemical and biological processes.

Objective 3: To determine the appropriate spatial and temporal scales useful for the consistent and comparable assessment within and across marine regions. This implies to screen the available data, data consistency, as well as data gaps. Key for this objective is the identification of the dynamics of main anthropogenic pressures.

Objective 4: To select the regional and EU-wide indicators or combination of indicators that best reflect the pressure-response relationship, evaluate their applicability across marine regions and describe how they can ensure consistency of GES assessment (MSFD Art. 8) in EU waters.

Objective 5: The ultimate scope is to provide recommendations for a quantitative and regionally harmonised GES determination (MSFD Art. 9) for pelagic habitats.

2 Spatio-temporal complexity of pelagic habitats

2.1 D1C6 elements: evaluation of essential characteristics of pelagic habitats

The pelagic habitat originates from the interaction of the physical (i.e. water masses movements and properties) and biological (i.e. lifeforms) systems over multiple spatio-temporal scales (see examples in Magliozzi et al., 2021b). A thorough understanding of the hydrographic and biological variability is needed to identify the essential characteristics (i.e. elements, Step 2, Figure A1) and the scale of analysis for D1C6 assessment (Magliozzi et al., 2021b). To this end, the following questions were raised during the workshop:

- How to best account for the spatio-temporal variability of pelagic habitats in D1C6 GES?
- Are the four broad habitat types (Box 1) reflecting the spatio-temporal variability of pelagic habitat processes?

Workshop's outcome and recommendation:

Two aspects are key to account for the spatio-temporal variability of pelagic habitat processes: definition of the assessment area (i.e. habitat) and data sampling (i.e. collection and analysis).

Assessment area

Pelagic habitats, as fluid in movement, should be defined based on hydrological and biotic data. It is however very difficult and resource-intensive to characterize the scale of these processes as they vary in time and space. Different EU-funded projects, i.e. EUNOSAT, HELCOM BLUES, OSPAR NEA PANACEA, and ABIOMMED, could help with the assessment area definition. To this end, a vertical delimitation of pelagic habitats for testing would consider physical and biological differences of the pelagic realm across marine regions (Figure A2). It was proposed in seasonally temperature-stratified seas (e.g. Mediterranean Sea) that the vertical delineation would include from surface to the seabed, while in permanent halocline areas (e.g. Baltic and Black Seas) from surface to the upper hypoxic layer. Sea bottom layers subject to permanent hypoxia in semi-enclosed seas, as areas extremely vulnerable to the effect of eutrophication, were suggested to be excluded from the 6-year assessment since time-scales for potential improvement are several-fold longer and, instead, a longer time-scale assessment showing trends was proposed in parallel together with the temperature increase as a result of climate change. The assessment would thus result in two parallel and independent evaluations, on one hand the long-term evaluation that includes climate change effects (e.g. multi-decadal temperature increase) and geomorphological-induced bottom layer hypoxia (areas with permanent halocline and low water renewal time), and the short-term processes evaluation for all the others pressures on the other hand. This clear separation of the short- and long-term processes in the GES assessment has the merit to effectively mark the progresses made by MS at short timescale (6-year cycle) while monitoring and keeping awareness of the longer-term issues (multidecadal), which is also addressed in assessments of other descriptors, e.g. eutrophication by short-term and long-term trends.

A gridded approach applied to any broad habitat subdivision can be used (also on existing sub-areas of assessment) depending on regional specifications and data availability (Figure A3). Priority should be given to preserving the current assessment spatial scales as they are linked to different monitoring designs, when existing. Also “other habitat types” as criterion elements, must be defined.

Data

Data collection: sampling of biotic and abiotic factors with a frequency adapted to the local variability, is key to detect relevant natural and anthropogenic changes and their impacts on the habitat. Sampling would cover also offshore sampling stations to answer to the MSFD requirements for assessing D1C6 broad habitat types, while current monitoring is often spatially limited to coastal areas (e.g. Romanian coasts). Most of the MSFD monitoring programmes rely on existing monitoring surveys historically developed for the WFD.

With the exception of the ship-of-opportunity Continuous Plankton Recorder (CPR)[1] survey, open sea areas are often sampled at specific times of the year. For example, in Greece (i.e. Aegean Sea, and partially Ionian and Levantine Seas) stratified and mixed waters are specifically sampled. Also, sampling stations representative of an anthropogenic pressure (e.g. power plant) can be established in coastal areas for long-term monitoring (e.g. Saronikos Gulf, Greece).
Long-term monitoring sites (e.g. Long Term Ecological Research Network- LTER) are very important to study biological trends and to depict natural variability from direct anthropogenic pressures, but their data are often rare, especially in coastal areas. Both fixed-site and opportunistic (CPR since 1958) long-term data collection should be supported to ensure monitoring of biodiversity multidecadal changes.

Sampling frequency and coverage differ across marine regions according to the main physical and biological characteristics of the area and to the available funding of the monitoring programs. In fact, data acquisition offshore is heterogeneous in space and time and depends on costly sea-campaigns. If data collection occurs within e.g. fisheries surveys, it does not necessarily provide the required seasonal coverage. In France, to achieve cost-effective monitoring, offshore sampling is optimized by innovative technologies (e.g. automated systems deployment, optical remote sensing data) providing useful information on the distribution of plankton dynamics and phenology.

Data analysis: Fixed-point and spatial survey (e.g. CPR) sampling can be integrated with satellite data, oceanographic processes such as advection, research vessels data, and model predictions to better capture the spatio-temporal variability of pelagic physical and biological processes. This requires considering new methodological and computational approaches (i.e. machine learning), and additional source of information (e.g. environmental DNA).

In France, operational modelling is used to have information on stratification and mixing layers on coastal, shelf and ocean seascapes. For example, upwelling index and other physical indices at seascape scale are computed from these models also integrating satellite data.

Box 1. Definition of habitat type for D1C6

The GES Decision specifies four broad habitat types: variable salinity, coastal, shelf and oceanic/beyond shelf. Variable salinity refers to "*retained for situations where estuarine plumes extend beyond waters designated as Transitional Waters under Directive 2000/60/EC*", and coastal "*shall be understood on the basis of physical, hydrological and ecological parameters and is not limited to coastal water as defined in Article 2(7) of Directive 2000/60/EC*".

MS by regional and subregional cooperation can select additional habitat types, if meeting the following criteria (GES Decision): i) scientific criteria: e.g. representative of the ecosystem (e.g. high biodiversity), specific anthropogenic pressure, extent, and species; ii) practical criteria: e.g. monitoring viability and costs, timeseries.

2.2 D1C6 scale and areas: the pressure-response relationship

The identification of the major anthropogenic pressures is key for determining the appropriate scale of pelagic habitats assessment. However, this is a challenge because the temporal and spatial dimensions of pelagic processes interact with multiple pressures (e.g. hydro-meteorological factors, contaminants and litter inputs, human physical interventions; Magliozzi et al., 2021b). According to the GES Decision, the MSFD indicators need to reflect clear pressure-response relationships. To this end, the following aspects were raised during the workshop:

- How to tackle the pressure-indicator relationship? (discussion session)

- Identify the direct and indirect pressure in your marine region and their spatial and temporal scales (excel tables exercise)

[1] The CPR survey which has sampled plankton communities (~700 taxa) throughout the North Atlantic and North Sea since 1958 using a consistent method. This is the world's most spatially and temporally-extensive marine biodiversity dataset and is one of the few that samples at a monthly time scale in offshore and open ocean waters. CPR data are freely available online and via the Marine Biological Association, who run the survey.

Workshop's outcome and recommendation:

Discussion session: pressure-indicator relationship

The pressure-indicator relationship is not linear (i.e. the indicator's change is not enough to link to a pressure) and requires a step-by-step approach to be investigated.

First, we need a thorough understanding of the effect of the pressures and their interactions in the marine realm. This step includes considering multiple pressures, anthropogenic and natural, at different temporal scales, and integrating descriptors, e.g. D1 and D4 (diversity, abundance, biomass, productivity, trophic transfer).

Second, we need to detect changes in the indicator. This step aims at studying the variability of the indicator and disentangling its drivers of change (i.e. pressures: e.g. SST, nutrients, etc.). To do this, multiple approaches can be adopted as, for example, the analysis of different time-series lengths and sampling strategies to highlight links to different pressures and depict extreme events (e.g. Bedford et al., 2020). Complementary tools can be risk metrics, as used for the cumulative risk assessments of benthic habitats, or sensibility matrices that can help to assess the connections between a pressure and the indicator. Research is also testing the behaviour of biodiversity indicators in relation to multiple anthropogenic pressures defined categorically as impact levels (Francé et al., 2021) and of functional-based plankton indicators (i.e. PH1/FW5)[2]. For example, using complementary approaches, i.e. ocean colour data and *in situ* phytopigment concentrations (HPLC measurements), France has adapted the PHYSAT-MED tool developed by Navarro et al. (2017) to a local scale allowing the biomass identification of the major phytoplankton functional groups in coastal waters. The adaptation of the PHYSAT-MED tool led to the development of the OC5-PHYSAT prototype that offers a promising application in the framework of the MSFD (D1, D4, D5).

Finally, issues related to climate-driven changes should be addressed uniformly for all biological indicators using commonly accepted climate change model for a given region.

Summary tables on the spatio-temporal variability of indicators and pressures by marine region (Annex 2)

The main pressures on pelagic habitats (e.g. type of pressure, link with MSFD descriptor, unit) were summarized by marine region in a table format following what reported in Magliozzi et al. (2021b) (see Annex 2). The operational and under-development indicators were linked to each pressure and the indicator confidence estimated based on the low, moderate or strong relationship (i.e. 1 to 5, where 1 is low level relationship) with the pressure (Annex 2, Table A2). Pressures and indicators were also discussed by analysing the indicator temporal and spatial sampling (Annex 2, Table A3), the pressures-scale of variability (Annex 2, Table A4), and the data gaps (Annex 2, Table A5).

Among the anthropogenic pressures listed in the GES Decision (Box 2), eutrophication and non-indigenous species were characterized by the highest indicators' confidence of pressure-indicator relationship (i.e. 4 and 5). For eutrophication, the pressure-response relationship is well represented (confidence scores between 3 to 5, Table A2) by the indicators: i) Chlorophyll-a (*in-situ* and satellite), which is commonly used across three marine regions (e.g. Mediterranean, Baltic and Black Seas), ii) Zooplankton Mean Size and Total Stock (MSTS) in the Mediterranean and Baltic Seas, and iii) micro phytoplankton abundance in the Mediterranean and the Black seas. Also, there are two phytoplankton indicators exclusively scored in the Baltic Sea: the Cyanobacterial Bloom Index and the Seasonal Successional of Dominating Phytoplankton Group (Table A2). Finally, one more indicator, i.e. "microbial species indicator" (Ferrera et al., 2020), was added as potentially relevant to identify eutrophication impacts at subregional scale in the North West Mediterranean Sea (Table A2). Non-indigenous species represent a pressure in many subdivisions of the Mediterranean Sea, in the Black and the Baltic Seas. *Mnemiopsis leidyi* biomass is an operational indicator in the Black Sea and could also be used in the Adriatic Sea, although pressure-impact relationship was not yet tested in the Mediterranean Sea. While in the Baltic Sea, the biomass of *Cercopagis pengoi* could be used to complement *M. leidyi.*
Climate change and overfishing were added to the list of pressures as having a strong link with combined phyto- and zooplankton indicators in the North-East Atlantic (i.e. OSPAR's indicators: PH1/FW5, PH2) and with the size-

[2] The PH1/FW5 used in the North-East Atlantic assessment area, combines phyto- and zooplankton abundances and lifeforms (e.g. size, motility, trophic preferences) to investigate changes from primary to secondary producers, and to top predators (Mcquatters-Gollop et al., 2019).

based indicator Zooplankton Mean Size and Total Stock in the Baltic Sea (Table A2). Besides, OSPAR's indicators were scored low to medium confidence (1-3) for eutrophication.
Ten more indicators and metrics (e.g. multiple biodiversity and evenness indices) were listed to investigate the possible relationships with overfishing and multiple-acting pressures (i.e. eutrophication, overfishing, climate change) in the Mediterranean Sea (Table A2).
Links between pelagic habitats and hydrographical conditions (D7) and contaminants (D8) have not been explored yet. However, eco-hydrodynamic regions which are currently used as spatial scales in the NEA region, could be the base for harmonising the assessment scale and exploring possible links between state and pressures descriptors.

The temporal and spatial sampling for each indicator at regional scale and across marine regions is presented in Table A3 (Annex 2). For example, *in-situ* data of Chlorophyll-a are collected monthly to seasonally in the Mediterranean Sea, with differences of sampling coverage depending on the MS, and bi-weekly to monthly in the Baltic Sea (Table A3). Although monthly sampling is required for most plankton indicator assessments in the Baltic Sea, e.g. seasonal succession of dominating phytoplankton groups, there are some data gaps due to different monitoring strategies in MS, which require adjustments in frequency and spatial coverage to improve assessment results for pelagic indicators. In the North-East Atlantic, a combination of monthly data from fixed-point station and CPR (since 1958) is used for PH1/FW5, PH2, and PH3 indicators (Table A3). However, there are several gaps because i) not all time-series capture all lifeforms and are of different duration (i.e. PH1/FW5) and ii) of the under sampling of small phytoplankton and zooplankton by some time-series (i.e. PH1/FW5, PH2, PH3); nevertheless, there are few datasets that can support indicators at such a spatial-temporal scale and few indicators that are so ambitious. Physical data at regional scale (multidecadal) and nutrient data (timeseries <20 years) are collected at the same fixed-point stations (Table A3).
In the Black Sea, most of the data for the indicators are sampled in the warm (May to September) and cold seasons (Table A3) and across coastal, variable salinity and shelf waters (Table A4).

Box 2. Anthropogenic pressures listed in the GES Decision and linked to D1C6

In the definition of D1C6 of the GES Decision: "*The condition of the habitat type…is not adversely affected due to anthropogenic pressures*", anthropogenic pressures refer to the adverse effects from pressures assessed by the MSFD pressure Descriptors 2, 5, 7, 8 and criteria:

- D2C3: Adverse effects of Non-Indigenous Species (NIS)
- D5C2: Chlorophyll-a concentration in the water column
- D5C3: Harmful algal blooms (extent, frequency, duration)
- D5C4: Photic limit (transparency of the water column)
- D7C1: Permanent alteration of hydrographical conditions
- D8C2: Adverse effects of contaminants
- D8C4: Adverse effect of significant acute pollution events

3 Indicators for pelagic habitat assessment

3.1 D1C6 indicator selection: spatial consistency, relevance and feasibility

The D1C6 elements and methodological standards (e.g. indicators) have to ensure consistency between marine regions or subregions (GES Decision). Therefore, the selection of indicators would reflect their relevance and feasibility at large scale and suggest linkages with abiotic and biotic variables (Magliozzi et al., 2021b). This section is about spatial consistency (at sub-regional, regional or EU level) and indicators advantages and disadvantages. The MS reports of D1C6 (2012-2018 reporting cycle) show differences in the selection of habitat types and lack of agreed indicators and assessing methods (Magliozzi et al., 2021a).

To this end, the following aspects were raised during the workshop:

- How to ensure the spatial consistency (by sub-region, region and/or at EU level) of pelagic habitat GES assessment? (Discussion session)

- Selection of regional and EU-wide indicators for their relevance and feasibility (summary tables)

Workshop's outcome and recommendation:

Spatial consistency
Three aspects are key to allow consistency of assessments between regional seas:

i) The definition of habitat types that considers environmental (biotic and abiotic) variables and anthropogenic pressures.
ii) The selection of indicators and the process for setting thresholds should conceptually be similar and methodologically traceable. The monitoring networks characterized by harmonized methods for collection, quality control and analysis would help to capture the drivers of change of the plankton community.
iii) The definition of GES and related thresholds.

Regional collaboration across MS is needed for progressing on these aspects and harmonizing the assessment methods.

Indicator selection
Fourteen out of sixteen indicators have an EU-wide scale of applicability but regional thresholds (Table A6). Only two species-specific indicators, i.e. *M. leidyi* and *N. scintillans*, have a regional application (Table A6). The indicators' links with biotic and abiotic environmental variables, which could be used to extrapolate the *in situ*-based indicators, were identified for i) satellite Chlorophyll-a, Chl-a horizontal gradient, ii) SST, iii) salinity, iv) inorganic and organic nutrients, and v) pH (Table A6). Research is required to investigate these linkages and the sensitivity of indicators to drivers and velocity of change (Table A7, e.g. Flo et al. (2019) in the WFD framework). The North-East Atlantic and Mediterranean Sea working groups highlighted the need to integrating D4 (food webs) indicators with D1C6.

3.2 D1C6 Good Environmental Status (GES)

The overall GES for marine resources in the MSFD means that their different uses are conducted at a sustainable level, ensuring their continuity for future generations (Article 1(3) of the MSFD). In addition, the overall MSFD GES means that:

i. ecosystems, including their hydro-morphological (i.e. the structure and evolution of the water resources), physical and chemical conditions, are fully functioning and resilient to human-induced environmental change;
ii. the decline of biodiversity caused by human activities is prevented and biodiversity is protected;
iii. human activities introducing substances and energy into the marine environment do not cause pollution effects. Noise from human activities is compatible with the marine environment and its ecosystems.

This section focuses on the qualitative definition of good and not-good status of D1C6 pelagic habitats indicators (hereafter D1C6 GES), their comparability and integration for the overall criterion assessment. To this end, the following aspects were raised during the workshop:

- What does good and not-good status (qualitatively) mean for each indicator? Is D1C6 GES consistent across comparable indicators (e.g., the phytoplankton-related types of indicators)? How specific/general the D1C6 indicators should be as regards to relevance and spatial consistency? How to combine the resulting indicators for D1C6 GES status? What is the acceptable surface area in GES by region? (threshold value of criterion)

Workshop's outcome and recommendation:

Indicators: good and not-good status

The qualitative definition of good and not-good status for the indicators in Annex 2 is strictly linked with regional seas characteristics and the availability of long-term datasets using appropriate monitoring practices. To this end, long-term data allow identification of the drivers of change of plankton communities.

For example, important changes of phytoplankton biomass in the North-East Atlantic are driven by human pressure, including climate change, rather than natural variability. When changes are driven by local anthropogenic pressures, the not-good status can be identified by comparing biomass with data from subregions with similar abiotic and biotic characteristics. When considering biomass changes compared to baseline data, the difficulties are how to define i) baseline, ii) best length of time series and iii) the condition of shifting from the baseline due to anthropogenic pressures.

For Chlorophyll-a, GES depends on the natural vertical and horizontal gradients, therefore it is first necessary to evaluate the properties of the water masses. This will be investigated in the ABIOMMED project (https://ec.europa.eu/environment/marine/projects/index_en.htm). In the Mediterranean Sea, Chl-a is evaluated in coastal waters up to 1 nautical mile, following the classification system defined during the intercalibration exercise of Water Framework Directive Mediterranean Geographical Intercalibration Group and set in the Commission decision (EU) 2018/229, while different thresholds might apply beyond coastal waters. Depth of Chl-a sampling is an important point to clarify as the current levels are inherited by the WFD. This work should be coordinated with the on-going work under Descriptor 5. Additionally, in the Mediterranean region research work is still ongoing for many subregional indicators (e.g. zooplankton indices, Table A2). For example, non-indigenous *M. leidyi* is found in the Adriatic Sea where it can form dense aggregations. Here, GES definition could be strongly linked to the possibility of mitigating high densities, i.e. the species high abundance corresponds to not-good status, while its absence/low abundance do not necessary inform on GES. Phytoplankton and Zooplankton abundance/biomass and diversity, including pigment signatures of phytoplankton communities and phytoplankton blooms and community composition assessed using pigment signature are also suggested because they can reflect environmental change. Good and not-good status can be established as a deviation of natural variability defined at habitat types level (to be defined at subregional/regional level). This deviation could be related to environmental pressures. With the exception of PH2 which uses phytoplankton biomass, at present, the use of these indicators is still in the early stages of testing. It is also considered very useful in the Mediterranean to apply indicators based on phytoplankton or zooplankton functional traits, in particular morphological (size classes, colonies) and physiological (silica demand, trophic position-production type for zooplankton, toxin production etc.). In this context, for example, OSPAR indicator PH1/FW5 was designed to apply also on functional traits and can be used on any dataset and in any region.

Specifically in the Baltic Sea, the MSTS indicator was designed from the food-web perspective, and it is related to fish predation and eutrophication. The mean size of a zooplankter in the community is indicative of both grazing pressure on phytoplankton and fish feeding conditions. Large stocks of zooplankton composed of large-bodied organisms have a higher capacity for transferring the energy of primary producers (phytoplankton) to fish than smaller-bodied organisms. Therefore, good status is defined when there is high energy transfer efficiency. For the Seasonal Successional of Dominating Phytoplankton groups, changes in species composition and phenology reflect deviations from normal variability based on the long-term observations in each Baltic subbasin. Deviation from this normal variability indicates not-good status. For example, the lack of large diatoms in spring is a symptom of poor sedimentation and poor food to benthos.

Indicators: spatial consistency and comparability for D1C6 assessment

Spatial representativity is a key indicator property for detecting changes. It can be ensured by i) linking state and pressure indicators to local conditions, ii) giving adequate research and monitoring resources for all diversity indicators (these are as good as the data which populate them), and iii) preserving time-series and taxonomy as key to having good data.

For example, in the Baltic Sea, Chl-a values as Ecological Quality Ratio (EQR) are already used to establish thresholds for MSTS to account for eutrophication pressure and will be tested for the Seasonal Succession of Dominating Phytoplankton Group indicator. Further investigations will be carried out by the EU-funded project HELCOM BLUES in 2021.

As for how should D1C6 indicators be as regards to relevance and spatial consistency, a compromise between EU-common and regional-specific indicators must be found to link with anthropogenic pressures and balance costs and data availability, especially regarding the indicators that translate a regional-specific expression of eutrophication. There are several advantages and disadvantages in the selection of more general and specific indicators.

General indicators could allow comparing the marine regions but might not be relevant or less accurate to assess the pelagic habitats condition in regional seas or they might require an adjustment (e.g. Chl-a, phytoplankton and zooplankton biomass indicators).

For example, surface Chl-a has the advantage of being estimated by satellites although limited to the upper optical depth of the water column. This satellite-based indicator well reflects eutrophication pressure, but it does not detect the deeper primary production that is an important process in subregions of the Western and Eastern Mediterranean Sea. During the stratification period from late spring to autumn, there is a deepening of the nutricline followed by the progressive deepening of the Chl-a maximum and primary production even below 50 m, which cannot be depicted by satellite. Therefore, the satellite Chl-a requires to be complemented by *in-situ* sampling. On the other hand, sampling deeper waters could inform on the cumulative impact of anthropogenic pressures. A recent study by Francé et al. (2021) found that the effects of anthropogenic pressures (e.g. both on land and coastal anthropogenic activities) on phytoplankton biodiversity indices (e.g. evenness, dominance, diversity) are more evident with increasing depth surface, where the communities are more uniform and less dominated by single species at low-impact than at high-impact sites.

Specific (regional) indicators have the advantage to reflect changes at regional scale and for time periods supporting policy implementation. They can be upscaled to other marine regions by using locally relevant taxa and looking at local pressures. For example, the PH1/FW5 indicator does not require species-level data because it is based on lifeforms and not only taxonomy, which widens its applicability across datasets. In the Mediterranean Sea, the combined use of multiple biodiversity indices of phytoplankton and zooplankton (evenness and dominance also) is under evaluation to link to regional scale pressures.

It is important to set indicators that significantly reflect the environmental pressures, which is often difficult in pelagic habitats. A way forward would be to combine general pressure indicators of phytoplankton/zooplankton communities (such as chlorophyll a, jellyfish blooms, anomalous presence of NIS species) with species-specific functional traits or others status indicators in order to evaluate deviations with respect to pelagic communities where anthropogenic pressures are considered as not significant.

Overall, general/EU-wide indicators tend to be less accurate than regional/specific indicators, they however allow testing inter-regional consistency. The satellite-based Chl-a indicator furthermore allow the frequent monitoring of surface pelagic habitats at local scale with relevant patterns to GES (e.g. changes in frequency, time of initiation, duration and peak of blooms). Satellite-based Chl-a combined with hydrographic variables would inform about processes. In situ-based (general and specific) indicators, because of under-sampling in time and space, can fruitfully be extrapolated on a grid that reflects the pelagic habitat variability provided a link is found with environmental variables. Such extrapolation would enhance the quality of in situ-based indicators while accounting for most of the spatio-temporal variability of pelagic habitats.

In the future, 3-D physical - biogeochemical and spatially-explicit ecosystem models will be promising complementary tools since, by construction, the effect of the main pressures on the ecosystem functioning can be quantified.

Integrating indicators for an overall GES assessment

The integration of indicators requires evaluating both the characteristics of the indicator, i.e. state or pressure, and its importance for assessing the pelagic habitat condition. A prerequisite for the indicator integration is the understanding of the major environmental factors and of their effects on pelagic habitat condition. Therefore, the choice of the integration method, e.g. hierarchical and weighting, between indicators is linked to the indicators' confidence and relevance regarding GES assessment.

A recommendation for testing would be to combine indicators for each pelagic component (i.e phytoplankton indicators, zooplankton indicators) with a multi-metric approach for each component. The average of the indicator values within a pelagic component could define the component GES. The overall D1C6 GES (of all the pelagic components) could then be defined by the one-out all-out integration rule.

For example, if a strong species indicator of eutrophication is not-good status, the overall assessment could also be not-good.

In the North-East Atlantic and Baltic marine regions, the NEA PANACEA and HELCOM BLUES projects are going to test indicator changes in relation to the ecosystem functioning and integration approaches. Similarly, in the Mediterranean Sea, the ABIOMMED project will explore how common methodologies and indicators can improve coherence of pelagic habitat assessments.

In the Black Sea, it was proposed that the combination of three main indicators covering phytoplankton, zooplankton and Chl-a could provide a scientific sound assessment for the pelagic habitats. As such the assessment of selected, i.e. phytoplankton biomass, total mesozooplankton biomass and Copepoda biomass, could be integrated using an averaging method. Such indicators, which are well-covered by the established monitoring programmes could achieve consistent assessment at regional level, at least for the Black Sea.

Finally, in addition to eutrophication descriptor (D5), the integration of the food web MSFD Descriptor (D4) in D1C6 would need consideration, given the existing strong link between pelagic biodiversity and food web functioning.

Once a list of indicators is set and tested by region, different integration methods should be tested accounting for the relevance and reliability to GES, but a first integration level could be done at indicator type level (e.g. phytoplankton or zooplankton indicators) and then between different indicator types. The GES assessment of long-term processes (climate change and permanent hypoxia) could be kept independent to the other shorter-term processes in order to disentangle the possible progresses made over an assessment cycle (6 years) from the multidecadal trends.

GES extent for pelagic habitats

The MSFD requests to provide the fraction of surface area in percentage or square kilometres that is in GES for each broad habitat in a marine region. However, given the physical and biological variability of pelagic habitats, the estimation of GES in km^2 or percentage does not inform on the system functioning because it would be biased by the assessment system of selected indicators and the related sampling strategy (e.g. seasonal *versus* annual sampling, integrations between stations, regions, and basins). Moreover, this estimation would imply that available data are fully representative of the pelagic habitat. Standardizing sampling strategies is a key step to compare GES between marine regions. For MS like Romania that have provided a final GES assessment in the reporting cycle 2012-2018, the evaluation was based on statistical analysis and expert judgement.

As a result, the final GES assessment relies upon the definition of habitat and spatio-temporal consistency of the assessment areas (Section 2.1). One should question whether a necessarily limited network of sampling stations (stationary and of opportunity) and subsequent interpolation of GES assessment at sub-regional level (broad habitat types) is consistent with the pelagic habitat variability in space and time. The gridded approach, based on spatial indicators (e.g. satellite-based Chl-a) and on the extrapolation of *in situ*-based indicators, is a complementary spatio-temporal strategy to account for the dynamics of pelagic habitats. This extrapolation step would be data-driven and directly allow mapping GES assessment at the scale of the pelagic habitat variability no longer needing broad habitat types. Furthermore, a temporal assessment (e.g. annual) of this highly spatial complementary step would valuably inform on the GES trend over the assessment period, and thus, on the relative distance to the GES objective.

4 The way forward the D1C6 assessment

In the MSFD perspective, **a key aspect for harmonizing sampling strategies and standardizing protocols is to reinforce the coordination among MS**. It can be achieved by promoting:

i) specific workshops on data- and indicators,
ii) collaboration among experts from different fields (e.g. remote sensing, food web and biogeochemical modelling) and marine regions,
iii) long-term funding.

Workshops for harmonizing sampling strategies and protocols

Monitoring data is limited in space and time so that sampling should be optimized for investigating pressure-response relationships and the spatial representativity of the GES assessment. In a second step, a better harmonized sampling strategy would help being compliant with statistical tools for indicators and threshold settings and lead to a better assessment in the gridded approach.

In the Mediterranean Sea, there are sub-regional differences in the frequency, duration, and spatial coverage of plankton data. Also, data access is currently limited to EU-funded projects and upon requests on national websites. In Slovenia for example, only Chl-a monitoring is carried out, while phytoplankton is sampled at one station which is included in the Long Term Ecological Research Network (LTER) and considered as reference condition. On the contrary, the zooplankton monitoring was dismissed due to lack of agreement on a common assessment methodology. In Greece (representing the Aegean, and partially the Ionian and Levantine seas), the MSFD monitoring network for plankton biodiversity (phytoplankton and zooplankton) is at present focused on open waters. This network is under revision and considered to be extended to coastal waters also (hot spot areas mostly), and from 6 to 12 nm for open waters in the Ionian Sea only. Chl-a monitoring is conducted in coastal stations by the WFD network and in open water stations by the MSFD network, therefore Chl-a is covered in all marine water bodies of Greece, France, Italy and Spain. HCMR is currently building a dedicated database for the access of monitoring parameters for all Descriptors in the frame of the MSFD monitoring program in Greece. France is building an information system (SIMM; Système d'Information Milieu Marin[3] combining data collected in the frame of European Directives (e.g. WFD, Natura 2000, MSFD) and integrating activities pressure and impacts on marine ecosystems. In the Black Sea region, sampling protocols are already harmonized among countries, but intercalibration exercises are necessary to share expertise and capabilities. Beyond the added value of workshops for sharing expertise and capabilities, intercalibration exercises would decrease the risk of bias when data are compared among systems (data consistency).

In the HELCOM area, indicator-based assessments should be adjusted to the monitoring design, whereby it is important to identify data gaps and address them through adaptations. The harmonization of sampling protocols was already addressed by HELCOM COMBINE (Cooperative Monitoring in the Baltic Marine Environment) and applied in the Holistic Assessment of Ecosystem Health Status (HOLAS).

In the OSPAR region, continuation of existing monitoring is key to support long-time series and informing MSFD indicators (e.g. the CPR).

3 https://www.milieumarinfrance.fr/Nos-rubriques/Cadre-reglementaire/Directive-Cadre-strategie-pour-le-milieu-marin

Box 3. Workshops on sampling strategies and methods are important to:

- set data networks at regional scale to harmonize plankton data collection, quality control and methods of analysis.
- promote data access at regional scale to test and evaluate common and new protocols.
- secure long-term funding at regional scale to allow data exploration and evaluation of regular monitoring data and its extension in areas with low spatial and temporal coverage.

Workshops on indicators

Many questions are still unsolved about indicators spatial consistency at sub-regional, regional or EU levels, and what indicators are better pressure-representative across marine regions. Moreover, there is a need to discuss if and how integration among indicators types (e.g. general and specific) is to be carried out for D1C6 assessment, and of potential methods.

In terms of indicator development, taxonomic accuracy is key to functional and diversity indicators and can be highly variable depending on the operator's expertise. Taxonomic identification by trained operators can be complemented – but not substituted - by automated technologies (e.g. CytoSense, ZooScan, FlowCam), that are still characterized by large differences in outputs depending on the targeted taxa and sampling method. More research is needed to integrate these different types of data (e.g. this is one of the objectives of NEA PANACEA) and facilitate the aggregation of datasets across MS, laboratories and research teams. The harmonization of data measurements, analysis and products from automated approaches has been explored by the H2020 INFRAIA projects JERICO-NEXT and JERICO S3[4].

When spatial and temporal protocols are available, priority should be given to developing flexible indicators that can be used with different dataset types and account for different sampling regimes (e.g. PH1/FW5, PH2, PH3).

Finally, links between the main indicators and environmental variables need to be investigated and discussed in targeted working groups in association with environmental data experts (satellite remote sensing and operational physical models) to explore the extrapolation potentials by indicator and region.

Joint work at the Regional Seas Convention level

Promoting collaborations between RSCs is particularly needed for those MS with assessment areas in two regional Seas, which could also increase inter-regional harmonization and comparability in the GES assessment. To this end, the foreseen exchanges between the new EU-funded projects, the NEA PANACEA, HELCOM BLUES and ABIOMMED would support this level of collaboration.

Box 4. Workshops on indicators are key to:

- share experience and discuss advantages and disadvantages of the plankton indicators that are considered in the different regions.
- develop flexible indicators to datasets.
- involve experts from different scientific disciplines, e.g. remote sensing, food webs, biogeochemical modelling, for investigating the link with the environmental variables (extrapolation to a spatial grid).
- promote data access at regional scale to test and evaluate common and new protocols.

[4] www.jerico-ri.eu

Long-term funding for monitoring

The assessment of pelagic habitats is challenged by insufficient funding that, in turn, affect data collection (i.e. monitoring), quality (i.e. curation issues), accessibility (i.e. data storage, format), and analysis (i.e. workflow) (e.g. HELCOM BalticDataFlows project). When monitoring protocols are already available, stable funding is key to ensure spatial and temporal consistency of the time series collection. To this end, the integration of novel monitoring methods based, for example, on real time satellite observations and molecular approaches has to be considered complementary to current monitoring design.

Finally, joint efforts for peer-review publications would help sharing the scientific challenges of relevance for the MSFD pelagic assessment at regional and EU scales.

Box 5. Secure long-term EU funding at regional scale to:

- allow data exploration and evaluation of regular monitoring data and its extension in areas with low spatial and temporal coverage.
- recognize and support groups of taxonomy experts as they are critical for continuing supplying data for the MSFD assessment.
- fund RSCs (BAL NEA MED BLK) as:
    - regional coordination is ecologically consistent (similar needs of sampling within one region).
    - specific funding would engage MS to collaborate giving the means to the RSCs to effectively coordinate the sampling strategies.
    - streamlined governance at EU level would ensure that (a) the regional sampling coordination serves the EU marine policies, and (b) the RSCs collaborate between them for a consistency at EU level (standards, sampling strategies, environmental assessments, good practices, data quality/storage/access).

References

Bedford, J., Ostle, C., Johns, D. G., Budria, A., & Mcquatters-gollop, A. (2020). The influence of temporal scale selection on pelagic habitat biodiversity indicators. Ecological Indicators, 114(December 2019), 106311. https://doi.org/10.1016/j.ecolind.2020.106311

BSIMAP. (2017). BLACK SEA INTEGRATED MONITORING AND ASSESSMENT PROGRAM List (Vol. 2022). https://ec.europa.eu/environment/marine/international-cooperation/regional-seaconventions/bucharest/pdf/BSIMAP_2017_to_2022_en.pd

Directive (EU) 2008/56. (2008) DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy, Official Journal of the European Union 19 (2008). http://data.europa.eu/eli/dir/2008/56/oj

Directive (EU) 2010/60. (2010) DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy, Official Journal of the European Communities (2000). http://data.europa.eu/eli/dir/2000/60/oj

Commission Decision (EU) 2018/229 (2018). Commission Decision (EU) 2018/229 of 12 February 2018 establishing, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, the values of the Member State monitoring system classifications as a result of the intercalibration exercise and repealing Commission Decision 2013/480/EU (notified under document C (2018) 696) In Official Journal of the European Union (pp. 1–91). http://data.europa.eu/eli/dec/2018/229/oj

Commission Decision (EU) 2017/848. (2017). COMMISSION DECISION (EU) 2017/848 of 17 May 2017 aying 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. In Official Journal of the European Union (pp. 43–74). https://doi.org/https://eur-lex.europa.eu/eli/dec/2017/848/oj

European Commission. (2020). COMMISSION STAFF WORKING DOCUMENT Background document for the Marine Strategy Framework Directive on the determination of good environmental status and its links to assessments and the setting of environmental targets Accompanying the Report from the Comm (Vol. 53, Issue 9). https://doi.org/10.1017/CBO9781107415324.004

Ferrera, I., Reñé, A., Funosas, D., Camp, J., Massana, R., Gasol, J. M., & Garcés, E. (2020). Assessment of microbial plankton diversity as an ecological indicator in the NW Mediterranean coast. Marine Pollution Bulletin, 160, 111691.

Flo, E., Garcés, E., & Camp, J. (2019). Land uses simplified index (LUSI): determining land pressures and their link with coastal eutrophication. Frontiers in Marine Science, 6, 18.

Francé, J., Varkitzi, I., Stanca, E., Cozzoli, F., Skejić, S., Ungaro, N., Vascotto, I., Mozetič, P., Ninčević Gladan, Z., Assimakopoulou, G., Pavlidou, A., Zervoudaki, S., Pagou, K., & Basset, A (2021). Large-scale testing of phytoplankton diversity indices for environmental assessment in Mediterranean sub-regions (Adriatic, Ionian and Aegean Seas). Ecological Indicators, 126, 107630. https://doi.org/10.1016/j.ecolind.2021.107630

HELCOM (2018a) Chlorophyll- a. Online. [October 2020], [https://helcom.fi/wp-content/uploads/2019/08/Chlorophyll-a-HELCOM-core-indicator-2018.pdf]

HELCOM (2018b) Cyanobacterial Bloom Index (CyaBI). Online [October 2020], [https://helcom.fi/media/core%20indicators/Cyanobacterial-bloom-index-HELCOM-pre-core-indicator-2018.pdf

HELCOM (2018c) Diatom / Dinoflagellate Index. Online. [October 2020], [https://helcom.fi/media/core%20indicators/Diatom-Dinoflagellate-index-HELCOM-pre-core-indicator-2018.pdf].

HELCOM (2018d) Seasonal succession of dominating phytoplankton groups. Online [October 2020], [https://helcom.fi/media/core%20indicators/Seasonal-succession-of-dominating-phytoplankton-groups-HELCOM-core-indicator-2018.pdf].

HELCOM (2018e) Zooplankton mean size and total stock (MSTS). [October 2020], [https://helcom.fi/media/core%20indicators/Zooplankton-mean-size-and-total-stock-HELCOM-core-indicator-2018.pdf

Magliozzi, C., Druon, J.-N., Boschetti, S. T., Palialexis, A. (2021a). Marine Strategy Framework Directive, Descriptor 1 Pelagic Habitats. Review and assessment of EU Member States' 2018 reports for Articles 8, 9 and 10. EUR 30662 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-34199-4 (online), doi:10.2760/09511 (online), JRC124271.

Magliozzi, C., Druon, J.-N., Palialexis, A., Artigas, L. F., Boicenco, L., González-Quirós, R., Gorokhova, E., Heyden, B., McQuatters-Gollop, A., Varkitzi, I. (2021b). Pelagic habitats under MSFD D1: current approaches and priorities, EUR 30619 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-30988-8, doi:10.2760/942589, JRC123960

Mcquatters-Gollop, A., Atkinson, A., Aubert, A., Bedford, J., Best, M., Bresnan, E., Cook, K., Devlin, M., Gowen, R., Johns, D. G., Machairopoulou, M., Mckinney, A., Mellor, A., Ostle, C., Scherer, C., & Tett, P. (2019). Plankton lifeforms as a biodiversity indicator for regional-scale assessment of pelagic habitats for policy. Ecological Indicators, 101(February), 913–925. https://doi.org/10.1016/j.ecolind.2019.02.010

Navarro, G., Almaraz, P., Caballero, I., Vázquez, Á., & Huertas, I. E. (2017). Reproduction of spatio-temporal patterns of major Mediterranean phytoplankton groups from remote sensing oc-cci data. Frontiers in Marine Science, 4, 246.

OSPAR. (2018). OSPAR CEMP Guideline Common indicator : PH1 / FW5 Plankton lifeforms. 1–17. Online. [October 2020], [https://www.ospar.org/documents?v=39001]

OSPAR. (2019a). CEMP Guideline : PH2 "Changes in Phytoplankton Biomass and Zooplankton Abundance " (pp. 1–6). Online. [October 2020], [https://www.ospar.org/documents?v=40972]

OSPAR. (2019b). CEMP Guideline : PH3 Changes in Plankton Diversity. Online. [October 2020], [https://www.ospar.org/documents?v=40973]

Pitois, S. G., Graves, C. A., Close, H., Lynam, C., Scott, J., Tilbury, J., van der Kooij, J., & Culverhouse, P. (2021). A first approach to build and test the Copepod Mean Size and Total Abundance (CMSTA) ecological indicator using in-situ size measurements from the Plankton Imager (PI). Ecological Indicators, 123, 107307. https://doi.org/10.1016/j.ecolind.2020.107307

Pennino, M.G., Coll, M., Albo Puigserver, M., Fernández Fernández, E., Steenbeek, J., González, M., Esteban, A., Bellido, J.M., 2020. Current and future influence of environmental factors on small pelagic fish distributions in the Northwestern Mediterranean Sea. Frontiers in Marine Science, Marine Fisheries, Aquaculture and Living Resources 7.

Ramírez, F., Pennino, G.M., Albo Puigserver, M., Steenbeek, J., Bellido, J.M., Coll, M., 2021. SOS small pelagics: a Safe Operating Space for small pelagic fish in the Western Mediterranean Sea. Science of the Total Environment 756.

Varkitzi, I., Francé, J., Basset, A., Cozzoli, F., Stanca, E., Zervoudaki, S., Giannakourou, A., Assimakopoulou, G., Venetsanopoulou, A., Mozetič, P., Tinta, T., Skejic, S., Vidjak, O., Cadiou, J. F., & Pagou, K. (2018). Pelagic habitats in the Mediterranean Sea: A review of Good Environmental Status (GES) determination for plankton components and identification of gaps and priority needs to improve coherence for the MSFD implementation. Ecological Indicators, 95(July), 203–218. https://doi.org/10.1016/j.ecolind.2018.07.036

Villarino E, Irigoien X, Villate F, Iriarte A, Uriarte I., Zervoudaki S. and others (2020) Response of copepod communities to ocean warming in three time-series across the North Atlantic and Mediterranean Sea.Mar Ecol Prog Ser 636:47-61.https://doi.org/10.3354/meps13209

Walmsley, S. F., Weiss, A., Claussen, U., & Connor, D. (2018). Guidance for Assessments Under Article 8 of the Marine Strategy Framework Directive, Integration of assessment results.

List of abbreviations and definitions

ABIOMMED Assessment of Biodiversity and Measures across Mediterranean

BAL Baltic Sea

BLK Black Sea

CPR Continuous Plankton Recorder

EQR Ecological Quality Ratio

EU European Union

EUNOSAT Eutrophication of the North Sea with Satellite data

GES Good Environmental Status

HELCOM Helsinki Commission (Helsinki Convention)

HELCOM BLUES HELCOM Biodiversity, Litter, Underwater noise and Effective regional measures for the Baltic Sea

HOLAS Holistic Assessment of Ecosystem Health Status

JRC Joint Research Centre

JERICO S3 Joint European Research Infrastructure of Coastal Observatories: Science, Service, Sustainability

JERICO NEXT Joint European Research Infrastructure of Coastal Observatories: Novel European eXpertise for coastal observaTorie

LTER Long Term Ecological Research Network

MS Member States

MSFD Marine Strategy Framework Directive

MSTS Zooplankton Mean Size and Total Stock

MWE Mediterranean Western Mediterranean Sea

NEA PANACEA North East Atlantic Project on Biodiversity and Eutrophication Assessment Integration and Creation of Effective Measures

OSPAR OSPAR Commission (Oslo-Paris Convention)

RSC Regional Sea Convention

WFD Water Framework Directive

UNEP-MAP Barcelona Convention

List of boxes

Box 1. Definition of habitat type for D1C6 8

Box 2. Anthropogenic pressures listed in the GES Decision and linked to D1C6 10

Box 3. Workshops on sampling strategies and methods 16

Box 4. Workshops on indicators 16

Box 5. Secure long-term EU funding at regional scale 17

Annexes

Annex 1. Workshop's agenda and format

This first JRC workshop on MSFD pelagic habitats held online on the 9th and 10th March 2021, brought together 58 participants from 17 EU Member States, including MS nominated experts and Regional Sea Conventions (e.g. HELCOM, OSPAR) representatives.

A Microsoft Team called "GRP-MSFD Pelagic Habitats D1C6 assessment" was created on purpose to share the workshop material and foster a collaborative approach. Four channels were created to allow participants working in sub-groups.

Table A1. Workshop's agenda.

Tuesday 9th March 2021	
09:30-09:35	Welcome participants (JRC)
09:35-09:50	MSFD policy requirements (JRC)
09:50-10:10	Member States' reports on D1C6 (Arts. 8, 9, 10): gaps and priorities (JRC)
10:10-10.25	Presentation of the Objectives and Agenda (JRC)
10:25-10:40	Presentation of Objective 1 (JRC): To define pelagic habitats and adapt the criteria elements to the scale-specific processes.
10:40-10:55	Discussion on Objective 1 (All, plenary)
10:55-11:15 Break	
11:15-11:20	Presentation of Objectives 2 and 3 (JRC): Objective 2: To identify the pelagic habitats' direct and indirect pressures, i.e., the physical/chemical characteristics and biological responses. Objective 3: To determine the appropriate spatial and temporal scales of main anthropogenic pressures within and across marine regions. To prepare recommendations on data gaps (day 2).
11:20-12:00	SUB-GROUPS: discussion on Objectives 2 and 3 (groups)
12:00-12:30	Summary of sub-groups results (All, plenary)
12:30-13:30 Lunch break	
13:35-13:45	Presentation of Objective 4 (JRC): To select the a priori indicators, evaluate their applicability across marine regions (regional and EU-wide) and describe how they can ensure consistency of GES assessment (MSFD Art. 8) (relevance and feasibility). To suggest paths for finding relationships between environmental variables & indicators.
13:45-14:30	SUB-GROUPS: discussion on Objective 4 (groups)
14:30-14:50 Break	
14:50-15:20	Summary of sub-groups results (All, plenary)
15:20-16:00 Questions and End of Day 1	
Wednesday10th March 2021	

09:30-10:00	Summary and questions on 1st day meeting (JRC)
10:00-10:15	Presentation of Objective 5 (JRC): brainstorming session first by sub-groups
10:15-11:15	SUB-GROUPS: discussion on Objective 5 (groups)
11:15-11:35 Break	
11:35-12:00	Summary of sub-groups results (All, plenary)
12:00-13:00	Presentation recommendation on Objective 5 (All, plenary)
13:00-14:00 Lunch Break	
14:00-15:50	SUB-GROUPS: recommendation (groups)
15:50- 16:00 Follow-up and end of workshop	

Figure A1. Assessment flow for Descriptor 1, pelagic habitats in Magliozzi et al., 2021b.

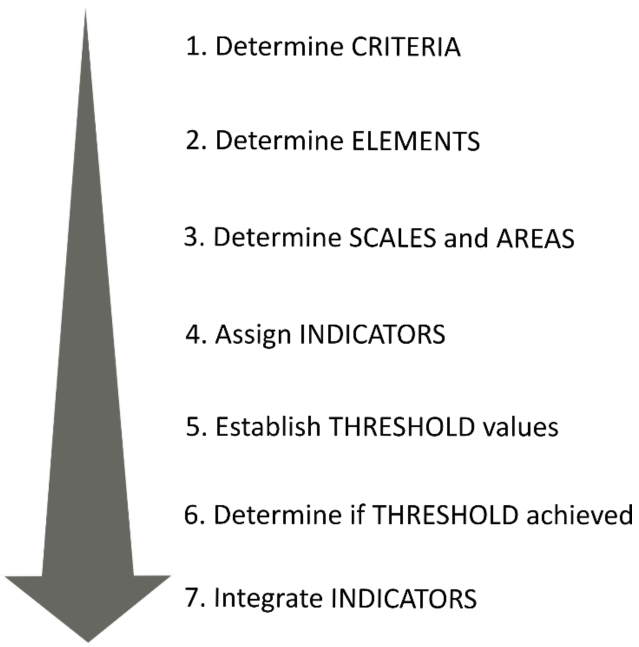


Figure A2. Vertical limits of pelagic habitats: (a) marine regions with seasonal thermoclines (e.g. Mediterranean Sea), (b) marine regions with permanent halocline (e.g. Baltic Sea) (from Magliozzi et al., 2021b).

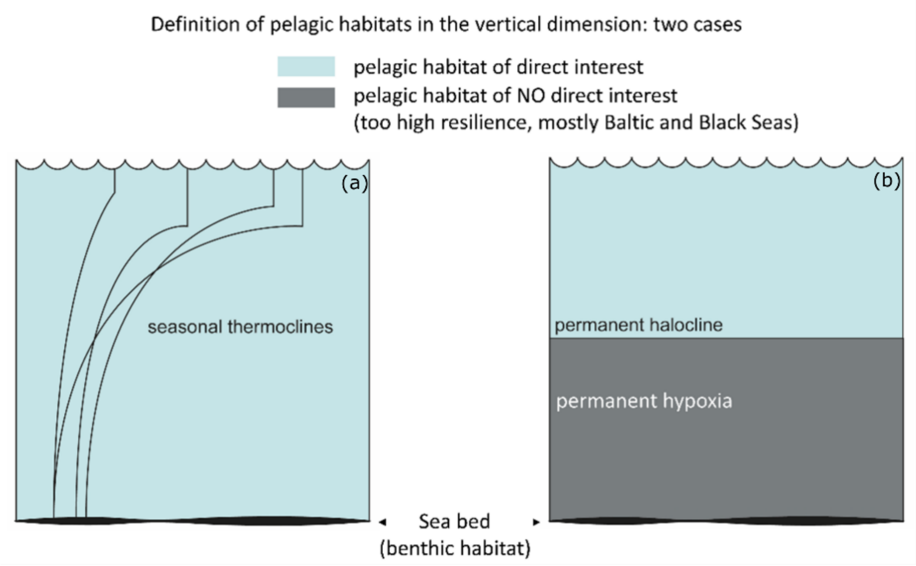
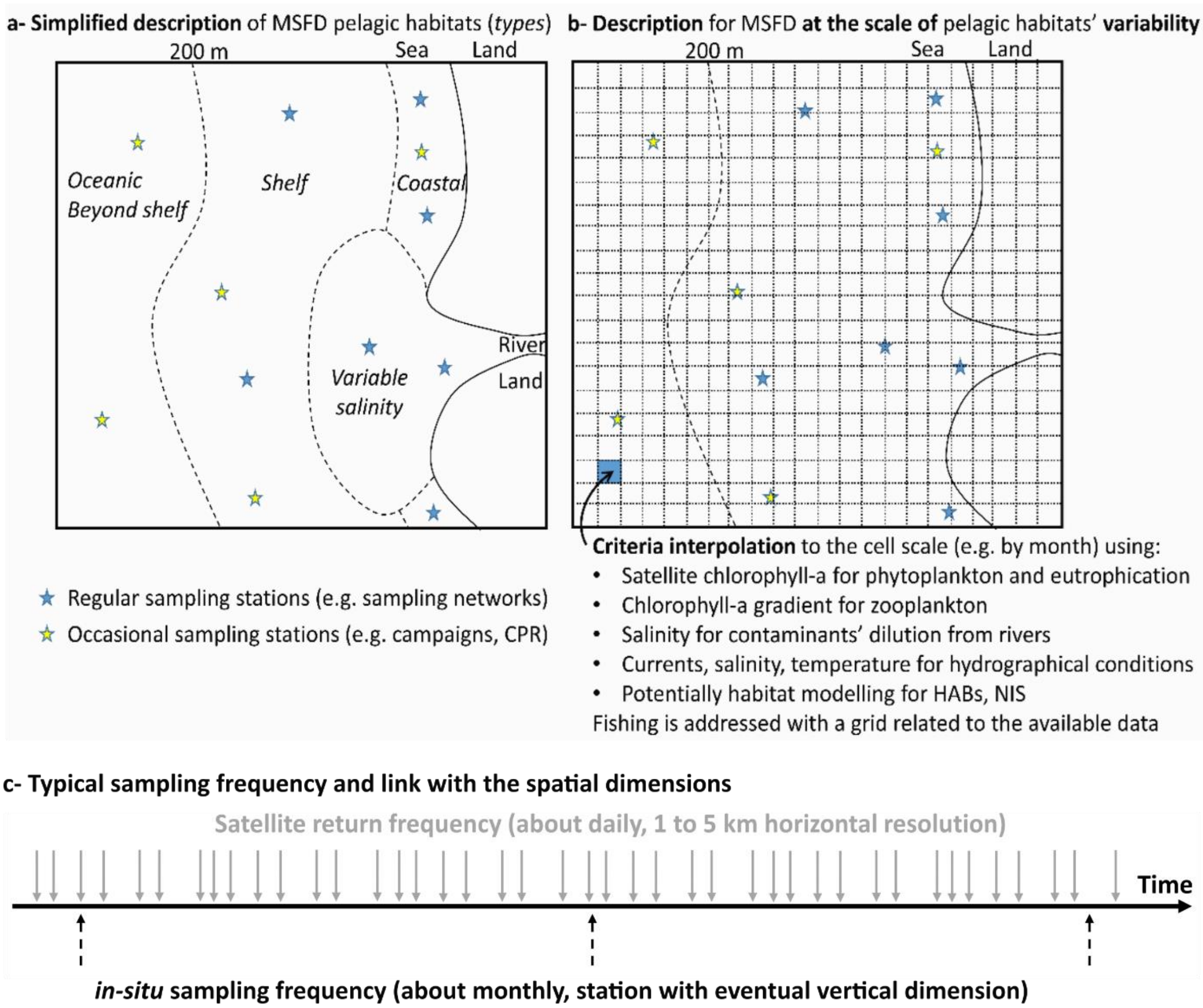


Figure A3. Horizontal delineation of pelagic habitats: (a) pelagic habitats as described in the MSFD (four habitat types: variable salinity, coastal, shelf and oceanic and beyond shelf) (b) description at the scale of variability of the coastal and oceanic processes (continuous grid of few km) interpolating most i*n-situ*-based criteria using environmental and operational model data such as satellite chlorophyll-a and the Marine Copernicus operational physical models (CMEMS5). [CPR: Continuous Plankton Recorder; HAB: Harmful Algal Blooms; NIS: Non-Indigenous Species]. (c) sampling frequency of *in-situ* and satellite/operational model data. Dashed arrows relate to spatiotemporal discontinuity and grey colour depicts lower absolute precision (from Magliozzi et al., 2021b).



[5] https://marine.copernicus.eu/

Annex 2. Pelagic habitats' direct and indirect pressures.

Table A2. Pelagic habitats' direct and indirect pressures by marine region. The confidence score is provided when the indicators is applicable to the marine region or it is under development.

pressure	MSFD descriptor and criterion	MSFD unit	indicators pre(operational)	confidence of pressure-indicator relationship (1 to 5, 1 is low)				reference
				MED	BAL	NEA	BLK	
Non-Indigenous Species	D2C3- Adverse effects of Non-Indigenous Species	extent (km^2)	*Mnemiopsis leidyi* biomass	5 (relevant in the Adriatic Sea)			5	BSIMAP 2017
Eutrophication	D5C2- Chlorophyll a concentration;	ug/l	Chlorophyll-a (Chl-a)	5	5		5	Commission Decision (EU) 2018/229
	D5C3- Harmful algal blooms;	no. events, duration (days), extent (km2) per year	Chlorophyll-a (Chl-a)	5	5		5	HELCOM, 2018a
			Cyanobacterial Bloom Index	1 (not relevant)	5			HELCOM, 2018b
			Microbial species indicator	potentially relevant for NW				Ferrera et al., 2020
	D5C4- Photic limit	m	Diatom/Dinoflagellate Index	1 (not accurate when heterotrophic dinoflagellates are dominant)				HELCOM, 2018c
			Phytoplankton abundance	3 (it gives us the same information as Chlorophyll)			3	BSIMAP, 2017
			Phytoplankton biomass	not used			3	BSIMAP, 2017
			Seasonal succession of Dominating Phytoplankton group	it does not reflect pressure unless you have a time series long enough to understand the ecological mechanisms behind	3			HELCOM, 2018d
			PH1/FW5: Changes in Phytoplankton and Zooplankton Communities	2 under development		2		OSPAR, 2018
			PH2: Changes in Phytoplankton Biomass and Zooplankton Abundance	2 under development		3		OSPAR, 2019a
			PH3: Changes in Plankton Diversity	1 under development		1	1	OSPAR, 2019b

pressure	MSFD descriptor and criterion	MSFD unit	indicators pre(operational)	confidence of pressure-indicator relationship (1 to 5, 1 is low)				reference
				MED	BAL	NEA	BLK	
			Zooplankton H-Shannon	2 under development			1 under development	BSIMAP, 2017
			Zooplankton abundance	4 under development			4	BSIMAP, 2017
			Zooplankton biomass	4 under development			4	BSIMAP, 2017
			Copepoda biomass	4 under development			4	BSIMAP, 2017
			Noctiluca scintillans biomass	1 (maybe relevant for coastal areas in Eastern Med)			3	BSIMAP, 2017
			Zooplankton Mean Size and Total Stock	2 under development	3			HELCOM, 2018e
Overfishing	D3		Fishing Mortality	5				Stock assessments (e.g. GFCM)
			CPUE of pelagic fish species	3				Stock assessments (e.g. GFCM)
			Copepod Mean Size and Total Abundance	3 (potentially relevant in the NW)				Pitois et al., 2021
			Zooplankton Mean Size and Total Stock	2 under development	3			
			OPFish/OPHarvest	4 under development				Druon et al. (under review)
Climate change	?		Fishing effort / Fishing effort fleets overlap					Stock assessments (e.g. GFCM)
			Distribution change					Pennino et al., 2020
			Climate refugia					Pennino et al. 2020
			PH1/FW5: Changes in Phytoplankton and Zooplankton Communities	2 under development		5		OSPAR, 2018

pressure	MSFD descriptor and criterion	MSFD unit	indicators pre(operational)	confidence of pressure-indicator relationship (1 to 5, 1 is low)				reference
				MED	BAL	NEA	BLK	
			PH2: Changes in Phytoplankton Biomass and Zooplankton Abundance	2 under development		4		OSPAR, 2019a
			PH3: Changes in Plankton Diversity	2 under development		2		OSPAR, 2019b; Villarino et al. 2020
Cumulative impacts (areas under various pressures), e.g. eutrophication/ overfishing/climate change	Linked with several descriptors		Surface of persistent optimal environmental areas					Ramirez et al. 2021
			Surface of safe operational space					Ramirez et al. 2021
			Combination of multiple biodiversity and evenness indices (Shannon-Wiener's index, Simpson's index, Berger-Parker's index, McNaughton's index)	2 under development (see comment)				Ferrera et al., 2020, Varkitzi et al., 2018, Cozzoli et al., 2017, Francé et al., 2021.
			anomalous jelly fish blooms	3 (species-specific to subregions)				

Table A3. Indicators' temporal and spatial sampling (e.g. frequency and duration, sampling coverage) by pressure and marine region.

pressure	indicator	data type	indicator temporal and spatial sampling (frequency and duration, sampling coverage)			
			MED	**BAL**	**NEA**	**BLK**
Eutrophication	Chlorophyll-a (Chl-a)	*in-situ*	Italy: monthly transects in eutrophicated area / bi-monthly in less eutrophicated area with fixed (54 transects). Slovenia: monthly at sampling stations representative for water bodies. France: monthly at coastal sampling stations, monthly to seasonally in	bi-weekly to monthly, good to complement with CPR data		warm season (May-September)

pressure	indicator	data type	indicator temporal and spatial sampling (frequency and duration, sampling coverage)			
			MED	**BAL**	**NEA**	**BLK**
			offshore water. Greece: monthly to seasonal sampling in coastal waters, seasonal sampling in offshore waters (fixed point stations).			
Eutrophication	Chlorophyll-a (Chl-a)	*in-situ*, satellite	Relative variation respect to 2012-2017 vs 2004-2010 Chlorophyll a data in Italy			NO use of satellite data - under development
Eutrophication	Cyanobacterial Bloom Index	*in-situ*, satellite	not relevant			
Eutrophication	Diatom/Dinoflagellate Index	*in-situ*	under development			under development
Eutrophication	Phytoplankton abundance	*in-situ*	Italy: transects monthly in eutrophicated area / bi-monthly in less eutrophicated area (54 transects), with fixed sampling stations with two sampling points: surface layer and DCM. Two size classes. Greece: monthly to seasonal sampling in selected coastal areas, seasonal sampling in offshore waters (fixed point stations). Slovenia: monthly at one LTER station.			warm season (May-September)
Eutrophication	Phytoplankton biomass	*in-situ*	not used			warm season (May-September)
Eutrophication	Seasonal Succession of Dominating Phytoplankton group		under development			

pressure	indicator	data type	indicator temporal and spatial sampling (frequency and duration, sampling coverage)			
			MED	**BAL**	**NEA**	**BLK**
Eutrophication /climate change	PH1/FW5: Changes in Phytoplankton and Zooplankton Communities	*in-situ*	under development	Samples from 1958 - present for CPR but shorter for fixed point t-s. A combination of CPR and fixed-point stations. Monthly data required for indicator.	Samples from 1958 - present for CPR but shorter for fixed point t-s (though may be more frequent). A combination of CPR and fixed-point stations used. Monthly data required for indicator.	
Eeutrophication /physical hydro-climatic changes/climate change	PH2: Changes in Phytoplankton Biomass and Zooplankton Abundance	*in-situ*, satellite (phytoplankton)	under development	Samples from 1958 - present for CPR but shorter for fixed point t-s. A combination of CPR and fixed- point stations. Monthly data required for indicator.	Samples from 1958 - present for CPR but shorter for fixed point t-s (though may be more frequent). A combination of CPR and fixed- point stations used. Monthly data required for indicator. Remote sensing data useful for phytobiomass, increasing spatial coverage.	
Eutrophication /physical hydro-climatic changes/climate change	PH3: Changes in Plankton Diversity	*in-situ*	under development	Samples from 1958 - present for CPR but shorter for fixed point t-s. A combination of CPR and fixed- point stations. Monthly data required for indicator.	Samples from 1958 - present for CPR but shorter for fixed point t-s (though may be more frequent). A combination of CPR and fixed- point stations used. Monthly data required for indicator.	

pressure	indicator	data type	indicator temporal and spatial sampling (frequency and duration, sampling coverage)			
			MED	**BAL**	**NEA**	**BLK**
Eeutrophication	Zooplankton H-Shannon	*in-situ*	under development			There are data, under testing, threshold values to be established
Eutrophication	Zooplankton abundance	*in-situ*	Italy: seasonal (not linked to eutrophication-(54 transects); 3 size class.			
Eutrophication	Zooplankton biomass	*in-situ*	Monitoring starting in 2021			warm and cold season
Eutrophication	Copepoda biomass	*in-situ*	under development			warm and cold season
Eutrophication	*Noctiluca scintillans* biomass	*in-situ*	abundance - transects monthly in eutrophicated area / bi-monthly in less eutrophicated area (54 transects)			warm and cold season
Overfishing, eutrophication	Zooplankton Mean Size and Total Stock	*in-situ*	seasonal samples, under development			
Non-Indigenous Species	*Mnemiopsis leidyi* biomass	*in-situ*	abundance – spp. sampled, but not indicators developed			warm and cold season

Table A4. Pressures' temporal and spatial sampling (e.g. range m to km, days, weeks, months) by marine region.

pressure	indicator	pressure temporal and spatial scale of variability (range m to km, days, weeks, months)			
		MED	**BAL**	**NEA**	**BLK**
Eutrophication	Chlorophyll-a (Chl-a)	3, 6, 12 miles from the coast (MSFD) data integrated with WFD/ 200 M - 1 NM - monitoring programmes under WFD, (also hydrographical and chemical parameters are monitored in Greece and in Italy).			coastal, variable salinity and shelf waters (0-200m isobath)

pressure	indicator	pressure temporal and spatial scale of variability (range m to km, days, weeks, months)			
		MED	**BAL**	**NEA**	**BLK**
		Physico-chemical parameters are sampled along with Chl-a (Slovenia)			
Eutrophication	Chlorophyll-a (Chl-a)	Relative variation respect to 2012-2017 vs 2004-2010 Chlorophyll a data in Italy			NO use of satellite data - under development
Eutrophication	Cyanobacterial Bloom Index	not relevant in MED			not relevant in BLK
Eutrophication	Diatom/Dinoflagellate Index	under development			under development
Eutrophication	Phytoplankton abundance	3, 6, 12 miles from the coast (MSFD) data integrated with WFD/ 200 M - 1 NM - monitoring programmes under WFD (also hydrographical and chemical parameters are monitored in Greece) Physico-chemical parameters are sampled along with phytoplankton abundance (Slovenia)			coastal, variable salinity and shelf waters (0-200m isobath)
Eutrophication	Phytoplankton biomass	not used			warm season (May-September)

pressure	indicator	pressure temporal and spatial scale of variability (range m to km, days, weeks, months)			
		MED	**BAL**	**NEA**	**BLK**
Eutrophication	Seasonal Succession of Dominating Phytoplankton group	under development			
Eutrophication /climate change	PH1/FW5: Changes in Phytoplankton and Zooplankton Communities	under development	Climate data at regional scale. Nutrient data shorter time-series and more spatially constricted, but often coinciding with fixed-point stations	Climate data at regional scale (multidecadal). Nutrient data shorter time-series (<20 years) and more spatially constricted than climate, but often coinciding with fixed-point stations.	
Eutrophication /physical hydro-climatic changes/climate change	PH2: Changes in Phytoplankton Biomass and Zooplankton Abundance	under development Physico-chemical parameters sampled along with phytoplankton community composition (Slovenia)	Climate data at regional scale. Nutrient data shorter time-series and more spatially constricted, but often coinciding with fixed-point stations	Climate data at regional scale (multidecadal). Nutrient data shorter time-series (<20 years) and more spatially constricted than climate, but often coinciding with fixed-point stations.	

pressure	indicator	pressure temporal and spatial scale of variability (range m to km, days, weeks, months)			
		MED	**BAL**	**NEA**	**BLK**
Eutrophication /physical hydro-climatic changes/climate change	PH3: Changes in Plankton Diversity	under development (also hydrographical and chemical parameters are monitored in Greece)	Climate data at regional scale. Nutrient data shorter time-series and more spatially constricted, but often coinciding with fixed-point stations	Climate data at regional scale (multidecadal). Nutrient data shorter time-series (<20 years) and more spatially constricted than climate, but often coinciding with fixed-point stations.	
Eutrophication	Zooplankton H-Shannon	under development			coastal, variable salinity and shelf waters (0-200m isobath)
Eutrophication	Zooplankton abundance	3, 6, 12 miles from the coast (MSFD)			
Eutrophication	Zooplankton biomass	Monitoring starting in 2021			coastal, variable salinity and shelf waters (0-200m isobath)
Eutrophication	Copepoda biomass	under development			coastal, variable salinity and shelf waters (0-200m isobath)
Eutrophication	*Noctiluca scintillans* biomass	3, 6, 12 miles from the coast (MSFD) data integrated with WFD/ 200 M - 1 NM - monitoring programmes under WFD			coastal, variable salinity and shelf waters (0-200m isobath)
Overfishing, eutrophication	Zooplankton Mean Size and Total Stock	under development			
Non-Indigenous Species	*Mnemiopsis leidyi* biomass	abundance -sampled, but not indicators developed			coastal, variable salinity and shelf waters (0-200m isobath)

Table A5. Pressures' temporal and spatial sampling (e.g. range m to km, days, weeks, months) by marine region.

pressure	indicator	comments on current data gaps			
		MED	BAL	NEA	BLK
Eutrophication	Chlorophyll-a (Chl-a) -in situ	coverage depends on the MS			
Eutrophication	Cyanobacterial Bloom Index	not relevant			
Eutrophication	Diatom/Dinoflagellate Index	not promising results so far			
Eutrophication	Phytoplankton abundance	2-6 times per year depending on the area			
Eutrophication	Phytoplankton biomass	not used			
Eutrophication	Seasonal Succession of Dominating Phytoplankton group	2-6 times per year depending on the area			
Eutrophication /climate change	PH1/FW5: Changes in Phytoplankton and Zooplankton Communities	2-6 times per year depending on the area		Spatial gaps, not all time-series capture all lifeforms, time-series are different lengths, small phytoplankton are not well sampled, few zooplankton time-series, pico-nano component not often sampled (and lifeforms not developed). *** The priority is preserving existing time-series over starting new ones***	
Eutrophication /physical hydro-climatic changes/climate change	PH2: Changes in Phytoplankton Biomass and Zooplankton Abundance	2-6 times per year depending on the area		Spatial gaps, time-series are different lengths, few zooplankton time-series. *** The priority is preserving existing time-series over starting new ones***	

pressure	indicator	comments on current data gaps			
		MED	BAL	NEA	BLK
Eutrophication /physical hydro-climatic changes/climate change	PH3: Changes in Plankton Diversity	2-6 times per year depending on the area		Spatial gaps, not all time-series go to genus level, time-series are different lengths, small phytoplankton are not well sampled, few zooplankton time-series, pico-nano component not often sampled. *** The priority is preserving existing time-series over starting new ones***	
Eutrophication	Zooplankton H-Shannon	Slovenia: no on-going monitoring for zooplankton			
Eutrophication	Zooplankton abundance	Slovenia: no on-going monitoring for zooplankton			
Eutrophication	Zooplankton biomass	Slovenia: no on-going monitoring for zooplankton			
Eutrophication	Copepoda biomass	Slovenia: no on-going monitoring for zooplankton			
Eutrophication	*Noctiluca scintillans* biomass				
Overfishing, eutrophication	Zooplankton Mean Size and Total Stock	Slovenia: no on-going monitoring for zooplankton			
Non-Indigenous Species	*Mnemiopsis leidyi* biomass				

Annex 3. Indicators' selection at regional and EU-wide scales.

Table A6. Indicators' applicability across marine regions and linkages with environmental variables.

indicator	region	scale of application	threshold scale	methods for threshold	ecological and environmental variables (biotic and abiotic)			
					MED	**BAL**	**NEA**	**BLK**
Chlorophyll-a (Chl-a)	MED	EU	REGIONAL	Deviation from baseline	daily satellite Chl-a, SST, nutrients, salinity, oxygen (when available), Secchi disk depth			daily satellite Chl-a
Chlorophyll-a (Chl-a)	BAL	EU	REGIONAL	Deviation from baseline	daily satellite Chl-a			daily satellite Chl-a
Cyanobacterial Bloom Index	BAL	EU	REGIONAL	Deviation from baseline		Zooplankton, Wind speed/weather conditions?, SST, salinity?, Phosphorus pool, summer and/or winter?		
Diatom/Dinoflagellate Index	BAL	EU	REGIONAL	Deviation from baseline	satellite Chl-a, SST	satellite Chl-a, SST, Silica concentration?, winter SST? Salinity?, N/P ratio?		satellite Chl-a, SST
Phytoplankton abundance	BLK	EU	REGIONAL	Deviation from baseline	satellite Chl-a, SST, nutrients			satellite Chl-a
Phytoplankton biomass	BLK	EU	REGIONAL	Deviation from baseline				
Seasonal Succession of Dominating Phytoplankton group	BAL	EU	REGIONAL	Deviation from baseline	satellite Chl-a, SST, nutrients	satellite Chl-a, SST, salinity?, Nutrients?		satellite Chl-a, SST

indicator	region	scale of application	threshold scale	methods for threshold	ecological and environmental variables (biotic and abiotic)			
					MED	**BAL**	**NEA**	**BLK**
PH1/FW5: Changes in Phytoplankton and Zooplankton Communities	NEA	EU	REGIONAL	No thresholds yet, new project (NEA PANACEA) to explore if we will set them and how. Identifying drivers of change is important. A t-s can be in GES if changes are because of natural variability, but not because of anthropogenic pressure. Velocity of change should also be investigated. This can also reveal synchrony.	satellite Chl-a, Chl-a horizontal gradient, SST, nutrients		SST, oscillations (eg NAO), pH change, nutrients	satellite Chl-a, Chl-a horizontal gradient
PH2: Changes in Phytoplankton Biomass and Zooplankton Abundance (Copepod abundance)	NEA	EU	REGIONAL	see above	satellite Chl-a, Chl-a horizontal gradient, SST,nutrients		see above	satellite Chl-a, Chl-a horizontal gradient
PH3: Changes in Plankton Diversity	NEA	EU	REGIONAL	see above	satellite Chl-a, Chl-a horizontal gradient		see above	satellite Chl-a, Chl-a horizontal gradient
Zooplankton H-Shannon	BLK	EU	REGIONAL	Deviation from baseline	satellite Chl-a, Chl-a horizontal gradient			satellite Chl-a, Chl-a horizontal gradient
Zooplankton abundance	BLK	EU	REGIONAL	Deviation from baseline	satellite Chl-a, Chl-a horizontal gradient			satellite Chl-a, Chl-a horizontal gradient
Zooplankton biomass	BLK	EU	REGIONAL	Deviation from baseline	satellite Chl-a, Chl-a horizontal gradient			satellite Chl-a, Chl-a horizontal gradient

indicator	region	scale of application	threshold scale	methods for threshold	ecological and environmental variables (biotic and abiotic)			
					MED	BAL	NEA	BLK
Copepoda biomass	BLK	EU	REGIONAL	Deviation from baseline	satellite Chl-a, Chl-a horizontal gradient			satellite Chl-a, Chl-a horizontal gradient
Zooplankton Mean Size and Total Stock	BAL	EU	REGIONAL	Deviation from baseline	satellite Chl-a, Chl-a horizontal gradient	satellite Chl-a, SST, salinity, size of hypoxic layer?		satellite Chl-a, Chl-a horizontal gradient
Noctiluca scintillans biomass	BLK	REGIONAL	REGIONAL	Deviation from baseline and expert judgement	satellite Chl-a, SST (operational and high)			satellite Chl-a, SST (operational and high)
Mnemiopsis leidyi biomass	BLK	REGIONAL	REGIONAL	Literature	SST			SST
Mnemiopsis leidyi biomass	MED	REGIONAL	REGIONAL	trends (timeseries length to be discussed)	SST, satellite Chl-a, increasing trophic potential for zooplankton)			
Anomalous jelly fish blooms (species-specific to subregions	MED	SUB-REGIONAL	SUB-REGIONAL	trends (timeseries length to be discussed)	SST, satellite Chl-a, zooplankton biomass			
Microbial species indicator (pico-nano plankton diversity)	MED	SUB-REGIONAL	can be SUB-REGIONAL	not set yet (to be discussed)	temperature, salinity, nutrients (gradient from coast to open ocean)			
Ratio of microbial biomass	MED	SUB-REGIONAL	can be SUB-REGIONAL	not set yet (to be discussed)	temperature, salinity, nutrients (gradient from coast to open ocean)			
CPUE of pelagic fish species	MED							
Fishing Mortality	MED							
Fishing effort / Fishing effort fleets overlap	MED							
Distribution change	MED							

indicator	region	scale of application	threshold scale	methods for threshold	ecological and environmental variables (biotic and abiotic)			
					MED	BAL	NEA	BLK
Climate refugia	MED							
Surface of persistent optimal environmental areas	MED							
Surface of safe operational space	MED							
Combination of multiple biodiversity and evenness indices (Shannon-Wiener's index, Simpson's index, Berger-Parker's index, McNaughton's index)	MED	SUB-REGIONAL	SUB-REGIONAL (AT LEAST)	deviation from baseline	satellite Chl-a, SST, nutrients, salinity, oxygen (when available), Secchi disk depth			

Table A7. Methods for linking the indicator with spatio-temporal env. variable(s) (e.g. strengths and significance of relationships, spatial clustering, geostatistical analysis etc.)

indicator	region	scale of application	threshold scale	methods for threshold	methods for linking the indicator with spatio-temporal env. variable(s) (e.g. strength and significance of relationships, spatial clustering, geostatistical analysis etc.)			
					MED	**BAL**	**NEA**	**BLK**
Chlorophyll-a (Chl-a)	MED	EU	SUB-REGIONAL	Relation to pressures (outcome of MEDGIG)	Strong relation to nitrogen and phosphorus in Aegean coastal waters (Greece). Adriatic Sea: good correlation between Chl-a and Total Phosphorus	provided a good intercalibration between the *in-situ* Chl-a and satellite data, medium to strong correlation is expected		
Chlorophyll-a (Chl-a)	BAL	EU	REGIONAL	Deviation from baseline				
Cyanobacterial Bloom Index	BAL	EU	REGIONAL	Deviation from baseline		medium-to-low, potential correlations -> need evaluation		
Diatom/Dinoflagellate Index	BAL	EU	REGIONAL	Deviation from baseline		potential correlations -> need evaluation		Diatom/Dinofl. in relation to salinity gradient
Phytoplankton abundance	BLK	EU	REGIONAL	Deviation from baseline				
Phytoplankton biomass	BLK	EU	REGIONAL	Deviation from baseline				
Seasonal Succession of Dominating Phytoplankton group	BAL	EU	REGIONAL	Deviation from baseline		low		

indicator	region	scale of application	threshold scale	methods for threshold	methods for linking the indicator with spatio-temporal env. variable(s) (e.g. strength and significance of relationships, spatial clustering, geostatistical analysis etc.)			
					MED	**BAL**	**NEA**	**BLK**
PH1/FW5: Changes in Phytoplankton and Zooplankton Communities	NEA	EU	REGIONAL	No thresholds yet, new project (NEA PANACEA) to explore if we will set them and how. Identifying drivers of change is important. A t-s can be in GES if changes are because of natural variability, but not because of anthropogenic pressure. Velocity of change should also be investigated. This can also reveal synchrony.			testing sensitivity and using all t-s together by selecting current assessment period as reference period and looking backwards	
PH2: Changes in Phytoplankton Biomass and Zooplankton Abundance (Copepod abundance)	NEA	EU	REGIONAL	see above			see above	
PH3: Changes in Plankton Diversity	NEA	EU	REGIONAL	see above			see above	
Zooplankton H-Shannon	BLK	EU	REGIONAL	Deviation from baseline				
Zooplankton abundance	BLK	EU	REGIONAL	Deviation from baseline				
Zooplankton biomass	BLK	EU	REGIONAL	Deviation from baseline				
Copepoda biomass	BLK	EU	REGIONAL	Deviation from baseline				
Zooplankton Mean Size and Total Stock	BAL	EU	REGIONAL	Deviation from baseline		low, need testing		
Noctiluca scintillans biomass	BLK	REGIONAL	REGIONAL	Deviation from baseline and expert judgement				

indicator	region	scale of application	threshold scale	methods for threshold	methods for linking the indicator with spatio-temporal env. variable(s) (e.g. strength and significance of relationships, spatial clustering, geostatistical analysis etc.)			
					MED	**BAL**	**NEA**	**BLK**
Mnemiopsis leidyi biomass	BLK	REGIONAL	REGIONAL	Literature				
Mnemiopsis leidyi biomass	MED	REGIONAL	REGIONAL	trends (timeseries length to be discussed)				
anomalous jelly fish blooms (species-specific to subregions	MED	SUB-REGIONAL	SUB-REGIONAL	trends (timeseries length to be discussed)				
Microbial species indicator (pico-nano plankton diversity)	MED	SUB-REGIONAL	can be SUB-REGIONAL	not set yet (to be discussed)				
Ratio of microbial biomass	MED	SUB-REGIONAL	can be SUB-REGIONAL	not set yet (to be discussed)				
CPUE of pelagic fish species	MED							
Fishing Mortality	MED							
Fishing effort / Fishing effort fleets overlap	MED							
Distribution change	MED							
Climate refugia	MED							
Surface of persistent optimal environmental areas	MED							
Surface of safe operational space	MED							
Combination of multiple biodiversity and evenness indices (Shannon-Wiener's index, Simpson's	MED	SUB-REGIONAL	SUB-REGIONAL (AT LEAST)	deviation from baseline	Non-linear relationship between indices and pressure categories			

indicator	region	scale of application	threshold scale	methods for threshold	methods for linking the indicator with spatio-temporal env. variable(s) (e.g. strength and significance of relationships, spatial clustering, geostatistical analysis etc.)			
					MED	BAL	NEA	BLK
index, Berger-Parker's index, McNaughton's index)								

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