



Monitoring biodiversity for the EU Marine Strategy Framework Directive: Lessons learnt from evaluating the official reports

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ABSTRACT

Evaluating environmental policies creates opportunities for harmonising and refining their implementation using a heuristic approach, and considering the knowledge gaps in understanding the complex environmental processes. The European Union's (EU) Marine Strategy Framework Directive (MSFD) is an ambitious legislation that brings together state, pressure, and impact Descriptors of the marine environment, and is built on an ecosystem-based approach to management. Ultimately, the Directive aims to achieve Good Environmental Status (GES) and sustainable use of marine resources. The EU Member States' (MS) reporting obligations for biodiversity monitoring were evaluated, to produce the first EU-wide overview of how monitoring programmes across EU waters are organised. Marine biodiversity monitoring is essential for the management of anthropogenic activities that affect the state of marine ecosystems, to support the understanding of complex marine systems, to determine GES, and to evaluate the effectiveness of the established measures. The EU MS put great effort into adapting their established biodiversity monitoring activities for the existing policy requirements, and to plan new monitoring programmes from the emerging needs of this ambitious policy. The monitoring reports provide a unique source of information, and this evaluation could lead to improve MS' reporting, and harmonise implementation of the policy. Moreover, the evaluation provides a basis for sharing good practices, innovative monitoring standards, and developing joint monitoring programmes that could greatly facilitate the establishment of cost-efficient and accurate monitoring. As such, the recommendations from this policy evaluation could be relevant to any environmental management framework worldwide.

1. Introduction

1.1. Policy context

In 2008, the European Union adopted the Marine Strategy Framework Directive (MSFD, [1]), a holistic tool for management of Europe's marine waters, developed to evaluate existing measures, and introduce new ones for achieving or maintaining Good Environmental Status

(GES) of the seas around Europe, while enabling the sustainable use of marine resources. The first cycle of the MSFD began in 2012 with an initial assessment of European waters for the 11 MSFD Descriptors (Annex I in [1]), the determination of GES, and the setting of environmental targets to achieve or maintain GES. In 2014, the European Union (EU) Member States (MS) reported on their established, and new monitoring programmes to meet the MSFD's requirements, and on existing monitoring programmes derived from other legal, national,

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and/or regional obligations and agreements. The monitoring reports, which are updated every 6 years, provide an opportunity for MS to fill in any gaps in knowledge and data that they may have, to determine GES following an ecosystem-based approach, and to provide the data which allows for assessment to classify a marine area as reaching or failing to reach GES [2]. An adequate monitoring approach will determine whether it is possible to assess changes in the state of the environment and if GES is achieved. Ultimately, the monitoring should determine whether management measures have had the desired effects [3].

1.2. Evaluation of the policy implementation

The first evaluation of MS' reporting (2014) resulted in a refined policy implementation following a heuristic approach. The MSFD foresaw immediate refinements both through a revision of Commission Decision [4], which is the backbone of the Directive that provides criteria and methodological standards for policy implementation, and a revision of the Directive's Annex III [1]. To this end, the review and revision of the GES Decision [4], which was completed with the new Commission Decision [5] (hereafter, the 'GES Decision'), was triggered by the in-depth assessment [6,7] of MS' reports for the initial assessment, the GES determination, and the target setting. The new GES Decision incorporates the progress made and lessons learnt in the first cycle of the MSFD implementation. Moreover, the in-depth assessment generated a detailed identification of knowledge gaps in assessments, possible synergies, and good practices with applications across Europe's marine regions or at the EU-wide level. Additionally, it generated an overview of the pressures and impacts on the state of the marine environment, which revealed: (i) the extent of MS' capacity to assess the state of the marine environment in the European seas; (ii) the level of managing anthropogenic activities; and (iii) the capacity of MS to monitor emerging anthropogenic pressures affecting the marine environment. The in-depth evaluation of the MSFD monitoring programmes is expected to be equally important for the policy implementation. According to Nygård et al. [8] efficient monitoring is fundamental for understanding the pressures created by human activities, as well as for improving the quality and reliability of environmental status assessments. Nygård et al. [8] estimated that the value of marine monitoring data is an order of magnitude greater than the resources currently spent on monitoring, and that an improved knowledge base can facilitate the planning of more cost-effective measures.

1.3. Scope of monitoring reports' evaluation for biodiversity

The in-depth evaluation of the MSFD monitoring reports was driven by two factors, the first was the impact that such an evaluation could have on the MSFD's implementation. The second driver was the value of outlining established and new monitoring programmes at the EU-wide level. The scope of this evaluation is to contribute to developing recommendations for the MS, the European Commission and the marine research community, and proposing improved requirements for reporting the 6-year updates of the monitoring programmes, as required under MSFD Article 17. Such recommendations will enhance the required consistency, comparability, and coherence of monitoring and assessing marine biodiversity [2,9]. The new GES Decision [5] for the criteria and methodological standards for determining GES provides the basis for shaping accordingly the recommendations made in this evaluation. For instance, the GES Decision incorporates the application of a risk-based approach in monitoring and assessing the European marine waters, seeking tailor-made monitoring programmes, and setting new priorities compared to those of the first MSFD cycle.

Moreover, this work aims to deliver an overview of the current progress in EU-wide monitoring and policy implementation, focused on the MSFD Descriptor on biodiversity (D1). Several comparisons across EU marine regions explain the similarities and differences observed in the monitoring programmes, and provide a basis for sharing good

practices. Reported separately (i.e. [10]), the technical details from the evaluation of the MS 2014 monitoring reports focused on updating the MSFD reporting guidance for monitoring [11]. It should be noted that the outcome of the analysis reflects the level and consistency of the reported information, which has restricted the development of detailed recommendations on sampling designs and methodological standards. To further improve the coherence and comparability of monitoring outcomes, a deeper analysis of monitoring methods and sampling designs is required, which was only conducted on a case-by-case basis for specific species groups and habitats and marine areas. Furthermore, the joint monitoring projects (BALSAM, IRIS-SES, and JMP NS/CS), that investigated options to combine programmes across policies or ecosystem components and across MS and which are discussed in Section 4.6 revealed that there are also institutional barriers that must be solved, and that a sense of urgency to change the current monitoring programmes is lacking, thus hindering a direct and timely adoption of good practices resulting from the EU-wide evaluation of monitoring programmes.

The MSFD is an ambitious policy that brings together known and emerging anthropogenic activities, pressures and impacts with the state of the marine environment through a holistic marine management framework. This indicator-based framework could be applied to other high-level policies (e.g. Convention on Biological Diversity, or the implementation of United Nations General Assembly sustainable fisheries resolutions [12]) with similar environmental objectives, geographic scales, and multiple contracting parties. The evaluation of the biodiversity monitoring programmes, an integral part of the environmental assessment, could provide good practices, innovative monitoring standards, and a basis for joint, cost-efficient, and accurate monitoring programmes. To this end, the recommendations from the policy evaluation could be relevant to any environmental management framework worldwide.

2. Materials and methods

2.1. Description of reporting process that generated the biodiversity monitoring programmes information

The 23 EU coastal MS, having a legal obligation to implement the MSFD, reported their established and planned monitoring programmes in or after 2014. Several MS missed the 2014 reporting deadline. The European Environment Agency hosts the MS' reports on monitoring programmes [13]. The MSFD Common Implementation Strategy coordinates the policy implementation, and is responsible for guiding, supervising, and evaluating the process. Early in the process, a biodiversity task group [14] proposed the requirements and standards for MSFD monitoring and assessment of marine biodiversity. More specific monitoring guidance documents were produced, with the help of contributions from biodiversity experts from across the MS, to facilitate the first reporting obligation [2,9]. The guidance documents set the overarching principles of monitoring, utilising the state-of-the-art in marine monitoring, and proposed cost-efficient, innovative, and standardised monitoring methods. Following these principles, the MSFD Common Implementation Strategy developed and adopted the reporting guidance [11] to support MS. MS had the option to report in paper format (paper reports, hereafter) or to use standard electronic templates (reporting sheets). However, the two options for reporting complicated the process, leading to some incoherence and inconsistencies. The main reason for the inconsistency was that the structure of the paper reports provided by MS did not strictly follow the guidance documents. These inconsistencies and the limitations that they brought to the analysis are discussed in detail in Section 4.

The electronic reporting sheets were organised at three levels:

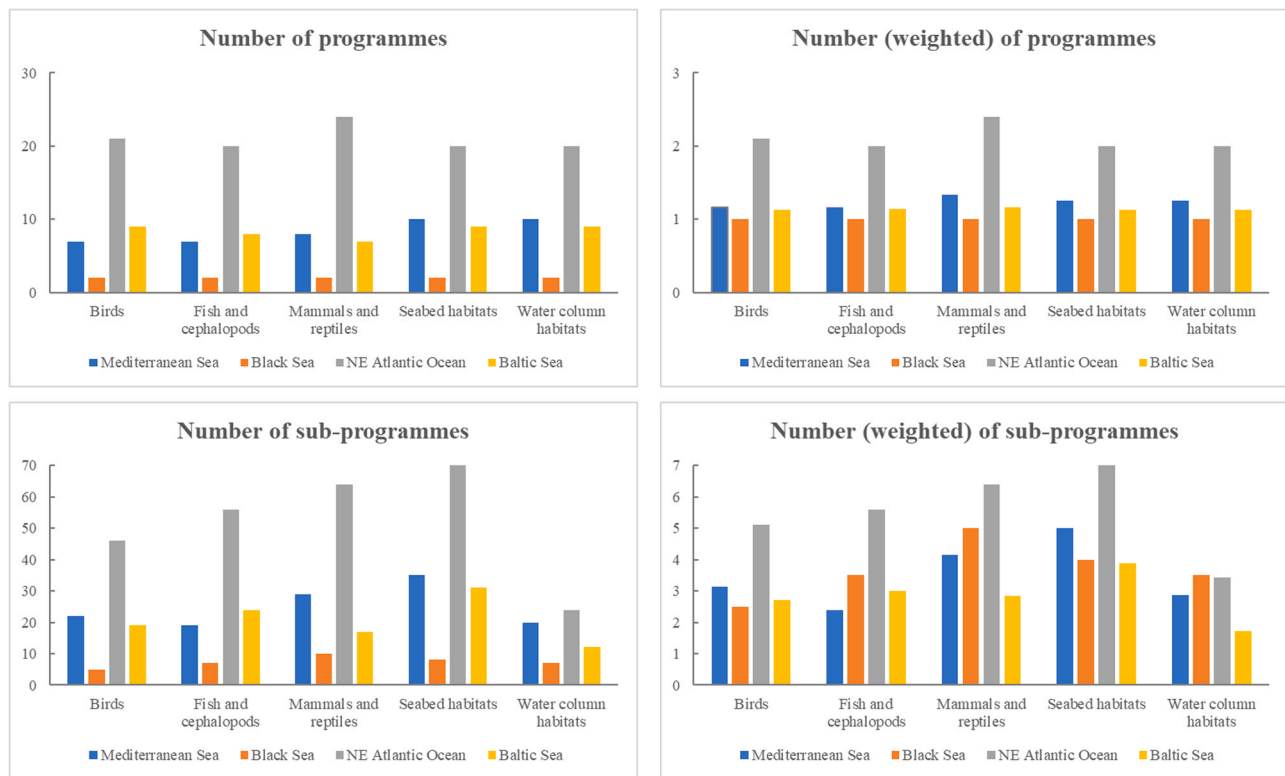


Fig. 1. Number of monitoring programmes and sub programmes reported for the MSFD Biodiversity Descriptor (D1) per ecosystem component and region (left: absolute numbers; right: weighted by the number of Member States (MS) per region).

- I. General information, where MS provided broad information for the MSFD Descriptors as a whole and their monitoring programmes;
- II. Monitoring programmes, where MS organised their existing or new monitoring programmes according to the assessment needs for each of the MSFD Descriptors (i.e. each ecosystem component - marine mammals, sea birds, etc); and
- III. Monitoring sub programmes, where the monitoring programmes were split into sub programmes to cover more detailed technical information, which was organised according to the reporting guidance document [11].

2.2. Compilation of the reported monitoring information for the analysis

Three datasets were compiled corresponding to the general monitoring information, monitoring programmes and monitoring sub programmes, by collating the reporting information from all available sources (in some cases, MS submitted both reporting sheets and paper reports). In total, 199 monitoring programmes and 525 monitoring subprogrammes were reported for MSFD biodiversity Descriptor 1 by the 23 MS. All of them were revised and collated in a harmonised way. Then, they were analysed according to the reported qualitative and quantitative monitoring characteristics, including area, ecosystem component (species and habitats), duration, frequency, MSFD requirements (e.g. Descriptor, criterion, indicator, relevance with other policies) and methodological characteristics. The analysis was made at regional and EU-wide level for each ecosystem component. More details on the organisation of the biodiversity monitoring programmes and subprogrammes are provided in Section 3.1, which gives an EU overview.

2.3. Description of the analytical approach

The analysis evaluated the level of consistency and coherence of the monitoring programmes for all ecosystem components (i.e. the species groups birds, mammals, reptiles, fish and cephalopods, and for pelagic and benthic habitats) and their characteristics, which were reported for the MSFD Biodiversity Descriptor (D1) in the European waters. More specifically, it was analysed how each ecosystem component is monitored in each region, and whether the national monitoring programmes are in line with regional programmes, or with other legal obligations. The analysis then focused on the MSFD's main objectives: how well monitoring programmes can generate information to assess progress towards achieving GES, per ecosystem component in each region or sub region (Article 4 of the MSFD; layers in [15]). Moreover, the duration of the monitoring programmes per ecosystem component and region was analysed.

The analysis was structured with the aim of providing input for the following three activities, and their respective objectives:

- a) Reporting monitoring programmes. Reporting can be improved by increasing the consistency and comparability of the reported information, building on the lessons learnt from this evaluation;
- b) Monitoring strategies. The good monitoring practices identified at regional or at ecosystem component level can harmonise and improve monitoring approaches; and
- c) Implementing the MSFD. Evaluating consistency and compliance with the MSFD requirements and other policies can improve the MSFD's second-cycle implementation.

Additionally, with the aim of maximising the impact on the above activities, we analysed and evaluated the monitoring reports from three different perspectives:

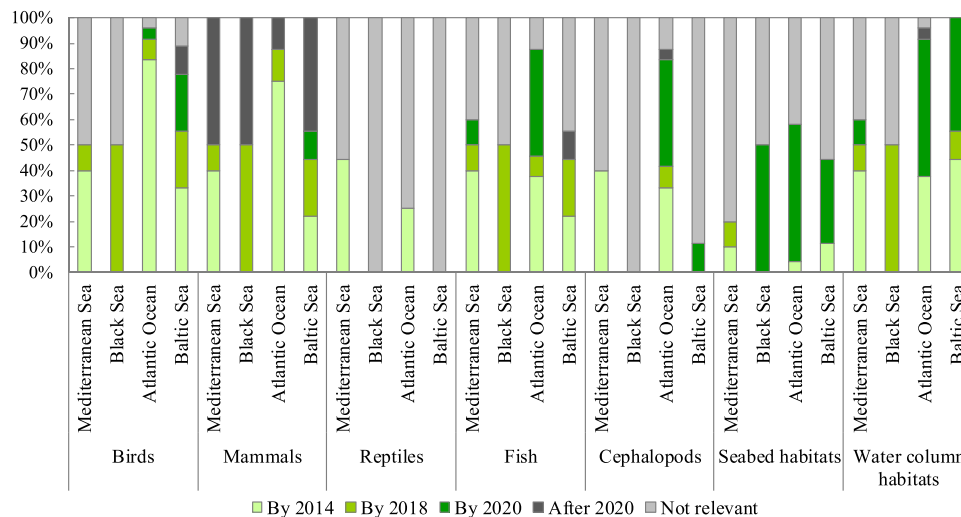


Fig. 2. Distribution of the dates (by percentage % of total number of programmes reported) by when MS reported that their biodiversity Descriptor 1 monitoring programmes would be fully in place for each ecosystem component and region.

- The perspective of MS. Aiming to spot good practices from neighbouring MS to increase methodological harmonisation;
- The regional perspective. Aiming to uncover whether there was potential for joint monitoring efforts, especially for monitoring highly mobile species whose distribution goes beyond the national waters; and
- The European Commission perspective. Aiming to identify any gaps and drawbacks in implementation, to prioritise the support to MS in the second MSFD cycle.

Inevitably, some parts of the reported information were not possible to quantify or compare across MS, given the reporting inconsistencies. To this end, we limited the results to the most informative outcomes at either the regional or EU-wide level.

3. Results

3.1. Overview of programmes and sub programmes reported for the biodiversity monitoring programmes on an EU-wide scale

It is essential that all MS have a common understanding of the reporting levels of 'programme' and 'sub programme', since this influences the consistency of reporting, and determines the level of detail reported under each section of the reporting sheet. Programmes are structured according to the MSFD Descriptors, reflecting the different aspects of GES that need to be monitored, and therefore which have data generated on. Each programme contains one or more sub programmes. Sub programmes are structured around the operation of monitoring, reflecting different data types and data collection methodologies. The number of sub programmes varies depending on the complexity of the Descriptor, the extent of GES achievement, the area extent of MS marine waters, the variety of associated activities, the pressures and measures, and the number of environmental targets reported.

The sub programmes aim to address at least one of the following topics:

- The state of the ecosystem (e.g. to address if GES has been met, and whether the environmental state is changing);
- The pressures acting on the ecosystem which could impact the state of the environment (e.g. to assess if environmental targets are being met);

- Anthropogenic activities, and how the marine environment is used, which may be giving rise to pressures; and/or
- The measures in place to address the pressures and impacts on the marine environment (e.g. to assess whether the measures are effective at managing anthropogenic activities).

However, the new measures put forward by MS under MSFD Article 13 in 2016 were not reflected, as the process of identifying measures relevant to MSFD implementation was still under way at the time of the 2014 reporting on monitoring programmes [11].

In total, 199 programmes were reported for D1 at the EU level, equally distributed (approximately 20% each) across the different ecosystem components (birds, fish and cephalopods, mammals and reptiles, seabed habitats, and water column habitats) for each region (Baltic Sea, North-East (NE) Atlantic, Mediterranean Sea and Black Sea) (Fig. 1). This indicates that similar attention is given to the monitoring of each ecosystem components across the four regions and that these components are sufficiently high level that they occur in every region/MS. In total 144, out of 525 sub programmes reported, addressed seabed habitats, outnumbering the sub programmes reported across the other ecosystem components: 63 sub programmes for water column habitats, 92 for birds, 106 for fish and cephalopods, and 120 for mammals and reptiles. Most of the programmes and sub programmes reported were recorded in the NE Atlantic, either as an absolute number, or as a weighted number, per MS in each region (Fig. 1).

3.2. Temporal GES achievement from existing and planned monitoring programmes

Overall, the monitoring programmes were considered by the MS adequate to provide appropriate types of data for assessing progress towards GES, though there were a few exceptions (Fig. 2). In this analysis, 'adequacy' is discussed in relation to ecosystem components (species and habitats), for which a provisional GES achievement was reported. MS had to select from the four options shown in the legend of Fig. 2 for the date by which the monitoring programmes were expected to be fully in place for the purposes of assessing progress towards GES for species and habitats. The "not relevant" option in the reporting (see Fig. 2) was interpreted in two ways by MS. In some cases, MS chose this option to refer to regions where a particular species groups was not present, and consequently the reporting entry was not relevant (i.e. reptiles and cephalopods in the Baltic Sea, or reptiles in the Black Sea).

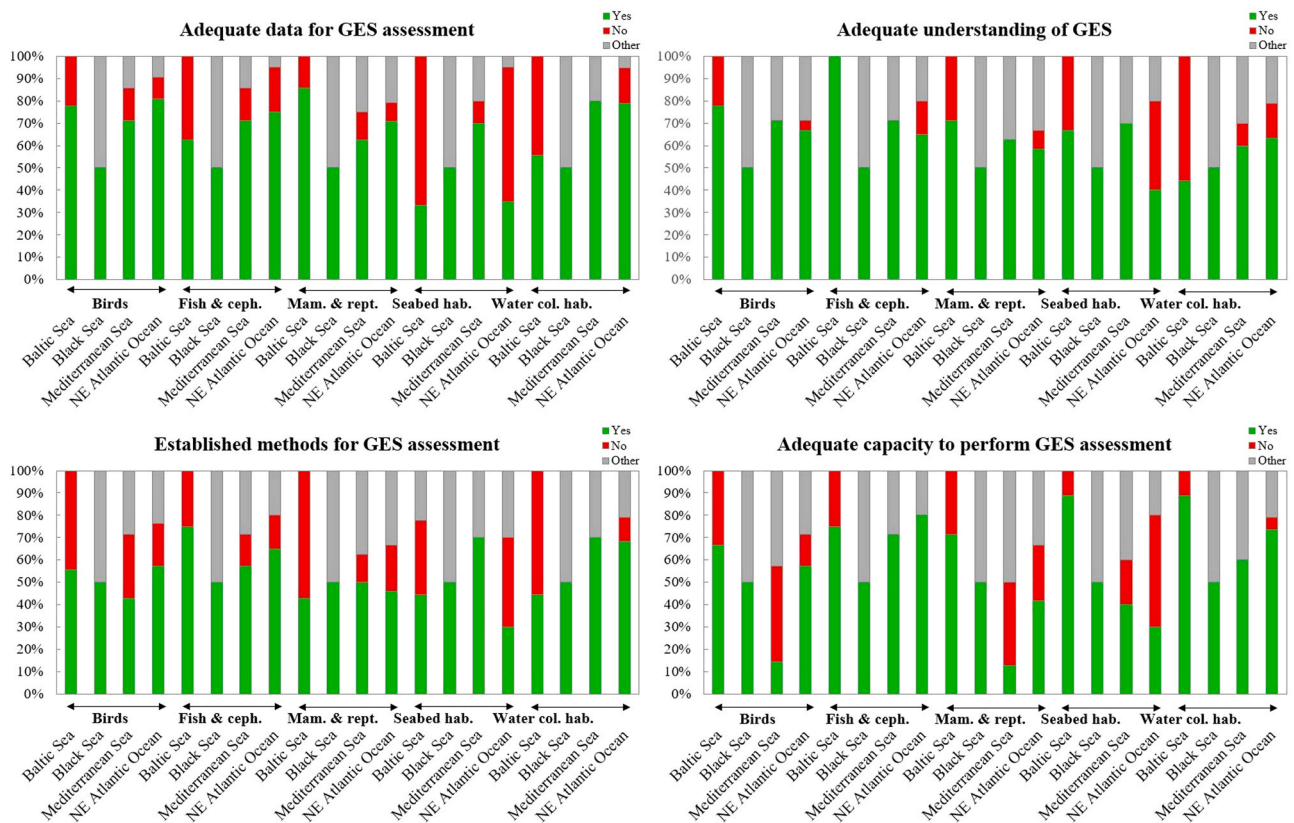


Fig. 3. Levels of data adequacy to assess GES, adequate understanding of GES, established methods to assess GES, and adequate capacity to perform GES assessments per ecosystem component and region. These levels are as reported by MS across their D1 biodiversity monitoring programmes. ‘Other’ refers to entries which were not reported, and to unavailable information.

In other cases, MS used the “not relevant” option to report gaps in their plans to cover GES achievement by a certain date. This distinction should be considered when interpreting the reporting information, as it may refer to either information that is indeed not relevant, or to monitoring gaps. For at least half of all the monitoring programmes reported MS did not provide a provisional date by when the monitoring for GES assessment would be in place.

In the Mediterranean Sea, the 2014 monitoring programmes assessed by the MS, revealed that the majority do not adequately cover the biodiversity GES criteria (as MS reported under Article 9). In the Black Sea, MS reported that half of the programmes will cover the GES criteria for birds, fish, and water column habitats by 2018, and for seabed habitats by 2020. In the NE Atlantic, most monitoring programmes for birds and mammals adequately covered the GES criteria at the time of reporting in 2014. However, the NE Atlantic monitoring programmes for fish, cephalopods, seabed habitats, and water column habitats will only cover the GES criteria by 2020. No information was provided on the temporal coverage of the GES criteria for most of the marine reptile monitoring programmes. Finally, in the Baltic Sea, most monitoring programmes for birds and mammals, and all monitoring programmes for water column habitats, will cover the GES criteria by 2020. There was no relevant information reported for most of the seabed habitats programmes, indicating a gap in the provisional GES achievement dates across the EU seas.

3.3. Monitoring programmes and adequacy for GES assessments

The main purpose of the monitoring programmes is to provide data to enable a systematic assessment of the environmental status in relation to the GES determination, and to assess the distance from GES

achievement. Each monitoring programme is therefore assigned to a MSFD Descriptor (though biodiversity topics are assigned to several MSFD Descriptors), and potentially to specific criteria and/or GES characteristics. It is essential for the MSFD to link the monitoring programmes to ecosystem components (e.g. birds, mammals, reptiles, benthic habitats) and/or to relevant pressures [11]. MS evaluated and reported the adequacy of their monitoring programmes for the GES assessment (pursuant to MSFD Articles 8 and 9), per ecosystem component and region. The level of adequacy was reported for the following four categories:

- Data adequacy for GES assessment (this refers to the information needed to assess whether GES has been achieved, and if it has not been achieved, the distance to GES);
- Established methods for GES assessment (this refers to methodological standards, including indicators to assess criteria, agreed integration rules, and agreed threshold values for GES);
- Adequate understanding of GES (this refers to adequate scientific knowledge to discriminate between good and bad status, at the species and species groups level); and
- Adequate capacity to perform the GES assessment (“capacity” refers to the required expertise and resources to perform GES assessments) [11].

The reported information was quantified per ecosystem component and region, and an overview is presented in Fig. 3. The four categories were self-assessed by MS, which could lead to potential inconsistencies in how the categories were interpreted, and consequently to incomparable outcomes.

More than half of the monitoring programmes were reported to

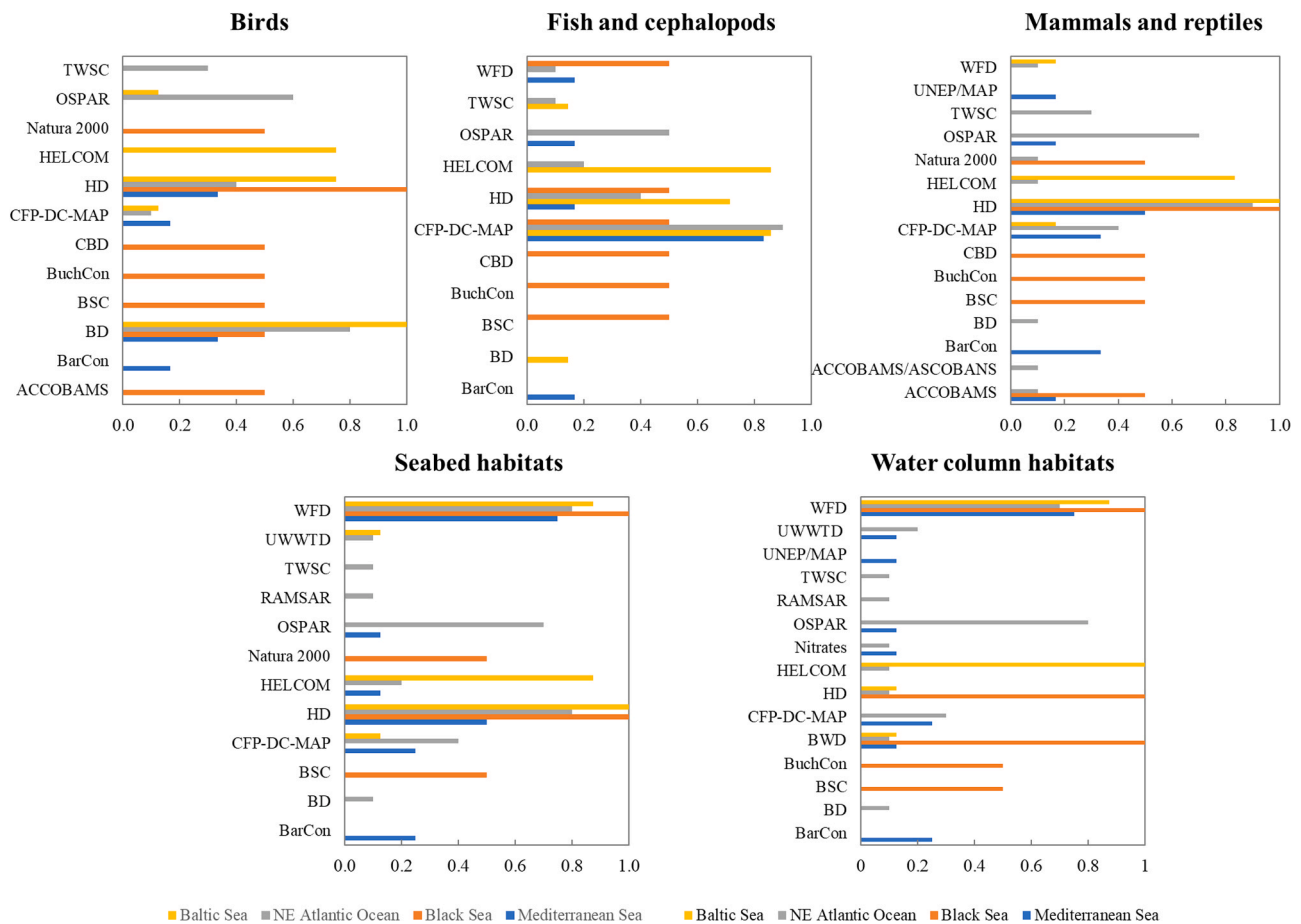


Fig. 4. Overview of the proportion of MS that referred to monitoring programmes established by EU, RSC and other policies and agreements, per region and ecosystem component. The abbreviations are explained in Appendix A.

generate adequate data for GES assessment per ecosystem component and region, apart from the seabed habitats in the Baltic Sea and NE Atlantic (Fig. 3, upper left). The highest percentages of established methods for GES assessment in the reported monitoring programmes (Fig. 3, lower left) were for: (a) seabirds in the NE Atlantic (57.1%), (b) fish and cephalopods in the Baltic Sea (75.0%), (c) seabed habitats in the Black Sea (70.0%), and (d) water column habitats in the Mediterranean Sea (70.0%). In the remaining cases, there were significant gaps in the established methods for GES assessment. It is notable that 70% of the monitoring programmes related to seabed habitats in the NE Atlantic do not have established methods for GES assessment.

Most MS reported that the monitoring programmes provide adequate information to allow MS to discriminate between good or poor environmental status per species and species group. This information could support a harmonised GES determination. Fig. 3 (upper right) summarises the results of GES understanding for the groups of species, which range:

- For birds, from 66.7% in the NE Atlantic Ocean, to 77.8% in the Baltic Sea;
- For fish and cephalopods, from 65.0% in the NE Atlantic Ocean, to 100% in the Baltic Sea; and
- For marine mammals and reptiles, from 58.3% in the NE Atlantic, to 71.4% in the Baltic Sea.

In contrast, for an adequate understanding of GES, MS reported lower levels for habitats ranging:

- For seabed habitats, from 40% in the NE Atlantic, to 66.7% in the Baltic Sea; and
- For water column habitats, from 44.4% in the Baltic Sea, to 63.2% in the NE Atlantic.

The Baltic Sea was the only region where MS reported that they have an adequate capacity to perform GES assessment (Fig. 3, lower right) in the majority of programmes for birds (66.7%), fish and cephalopods (75.0%), mammals and reptiles (71.4%), seabed habitats (88.9%), and water column habitats (88.9%). All other regions reported significant gaps in expertise and resources for conducting GES assessments. In the Mediterranean Sea, 85.7% of the monitoring programmes for birds, and 87.5% of the monitoring programmes for mammals and reptiles do not have an adequate capacity for performing GES assessments. Similar gaps were reported for 70% of the seabed habitat programmes in the NE Atlantic Ocean.

3.4. Monitoring programmes linked to other policies and agreements

One of the benefits of the MSFD as an inclusive policy for reaching good environmental status in European seas is that it brings together a variety of other environmental policies and agreements into a single framework for implementation. Existing monitoring programmes, established by MS for other policies, could be utilised for MSFD purposes to ensure the optimal use of resources, and to avoid duplications. To this end, the extent to which the reported MSFD monitoring programmes were derived from other policies was quantified according to the number of links with established biodiversity monitoring programmes from

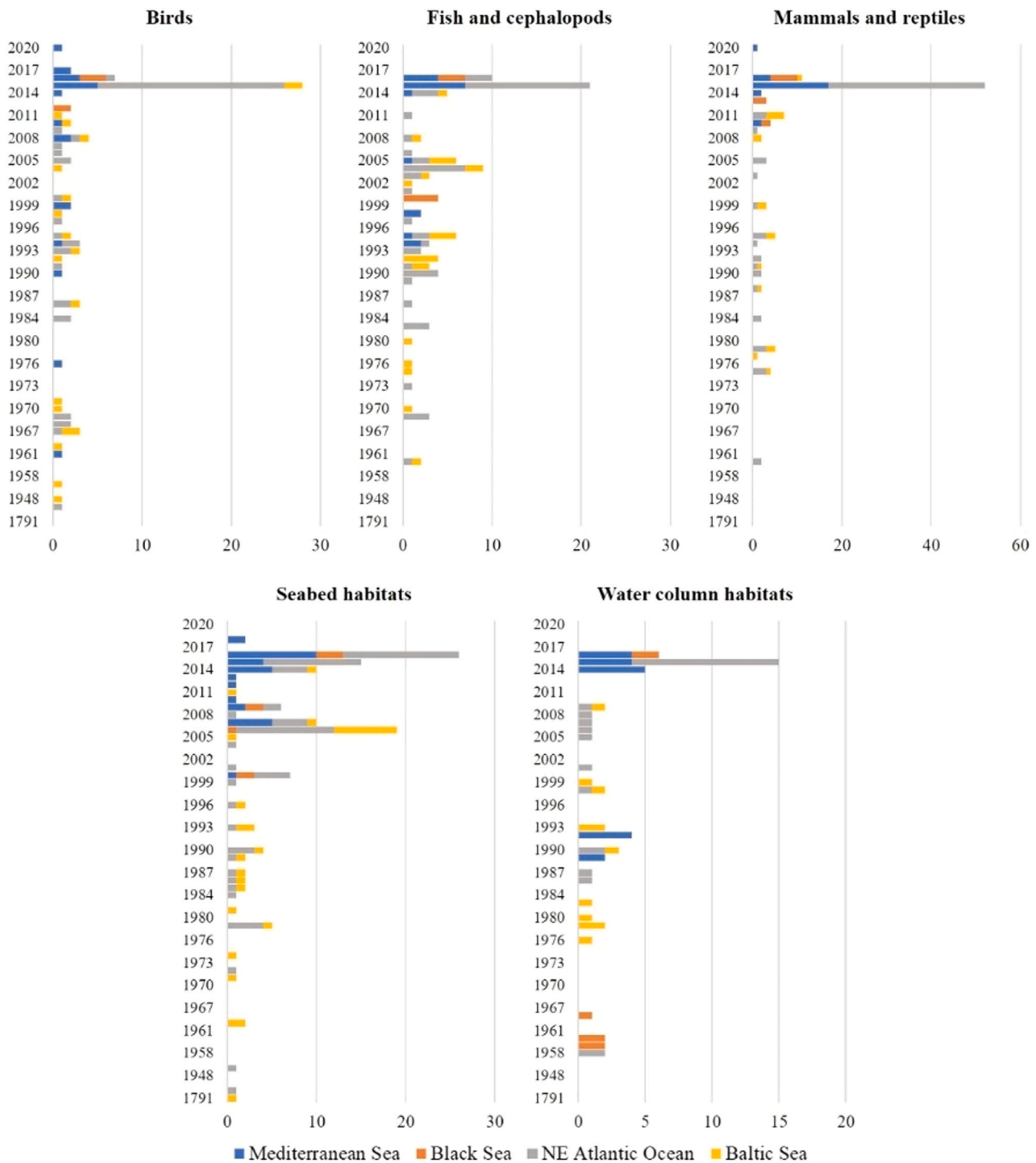


Fig. 5. Starting date of sub programmes per ecosystem component and region. X-axis shows the number of reported monitoring sub programmes that started each year.

existing relevant European legislation, or other international agreements. The relevant European Union legislation includes Directives and Regulations, such as the Water Framework Directive (WFD [16]), the Bathing Water Directive [17], the Habitats Directive (HD [18]), the Birds Directive (BD [19]), and the Data Collection Framework Regulation for the Common Fisheries Policy (DC-MAP [20], CFP [21]). International agreements refer to monitoring programmes established by the four Regional Sea Conventions (RSC): Barcelona (UNEP/MAP) [22],

Helsinki (HELCOM) [23], Oslo-Paris (OSPAR) [24] and Bucharest Conventions (BSC) [25] or other international agreements (e.g. ASCOBANS [26], ACCOBAMS [27]).

Appendix A summarises the 19 possible monitoring sources that were linked to the reported MSFD Biodiversity monitoring programmes. The BD has established monitoring programmes for seabirds in all MSFD regions. The DC-MAP of the CFP put in force monitoring programmes for fish and cephalopods. The HD mostly monitors marine mammals and

Table 1
Mean duration (in years) of monitoring programmes since their starting date per ecosystem component and region.

Region	Ecosystem component				
	Birds	Fish and cephalopods	Mammals and reptiles	Seabed habitats	Water column habitats
Mediterranean Sea	23	16	4	6	24
Black Sea	2	14	3	9	52
NE Atlantic Ocean	25	22	22	26	18
Baltic Sea	28	25	23	37	24

reptiles, some fish species and selected habitats. Significant regional alignment was observed with the fish, cephalopods, and marine mammals’ monitoring programmes that were established by the CFP and ACCOBAMS in the Mediterranean and the Black Seas. All monitoring programmes for seabed habitats were linked to the HD and WFD. Finally, monitoring programmes for water column habitats were linked to the WFD, BSC (Black Sea), HELCOM (Baltic Sea), and OSPAR (NE Atlantic Ocean), showing strong regional coordination. Fig. 4 provides an overview of the percentage of MS that referred to established monitoring programmes from other policies and agreements, per region and ecosystem component. Methodological standards developed by North European MS were also reported by South European MS, indicating good collaboration across regions, and efficient flow of information and good practises. For instance, HELCOM’s monitoring protocols were reported in the Mediterranean and Black Seas for seabed habitats, and OSPAR’s monitoring protocols were reported in the Mediterranean Sea for marine mammals, reptiles, and all habitat types (Fig. 4), from at least one MS.

3.5. Overview of the duration of existing monitoring sub programmes for biodiversity across the EU

The reported length of time of operational sub programmes per ecosystem component and region is presented in Fig. 5. The most long-term monitoring undertaken thus far has focused on seabirds and seabed habitats in the NE Atlantic and Baltic Sea. In the same regions, fish and cephalopods, marine mammals, reptiles, and water column habitats have been monitored for several decades (water column physical characteristics – ice monitoring reported to be started in 1791). In the Mediterranean Sea, birds have been monitored from the 1960s, and fish and cephalopods from the early 1990s, however with significant gaps in the number of species monitored. The rest of the ecosystem components have sporadic monitoring programmes with shorter durations. Table 1 presents the mean duration of the reported monitoring sub programmes in years, from their starting date, per ecosystem component and region.

Fig. 6 shows the percentage of sub programmes which started before 2014, and those that MS reported would be in place after 2014, per ecosystem component and region. The new sub programmes would cover the gaps in data need for particular ecosystem components. The actual date of establishment is due to be reported in 2020 for MSFD Article 17 updates. Progressively, from the Baltic Sea and the NE Atlantic, to the Mediterranean Sea and Black Sea, additional monitoring sub programmes are needed to cover the gaps in monitoring for biodiversity ecosystem components that MS had at the time of their 2014 Article 11 reporting. This pattern is observed in all components except for the water column habitats, where monitoring coverage in the Mediterranean and Black Seas was already better established (Fig. 6).

4. Discussion

Evaluating marine biodiversity monitoring programmes reported for the MSFD has provided an overview of existing and planned monitoring across the EU. Such an overview fosters the identification of good

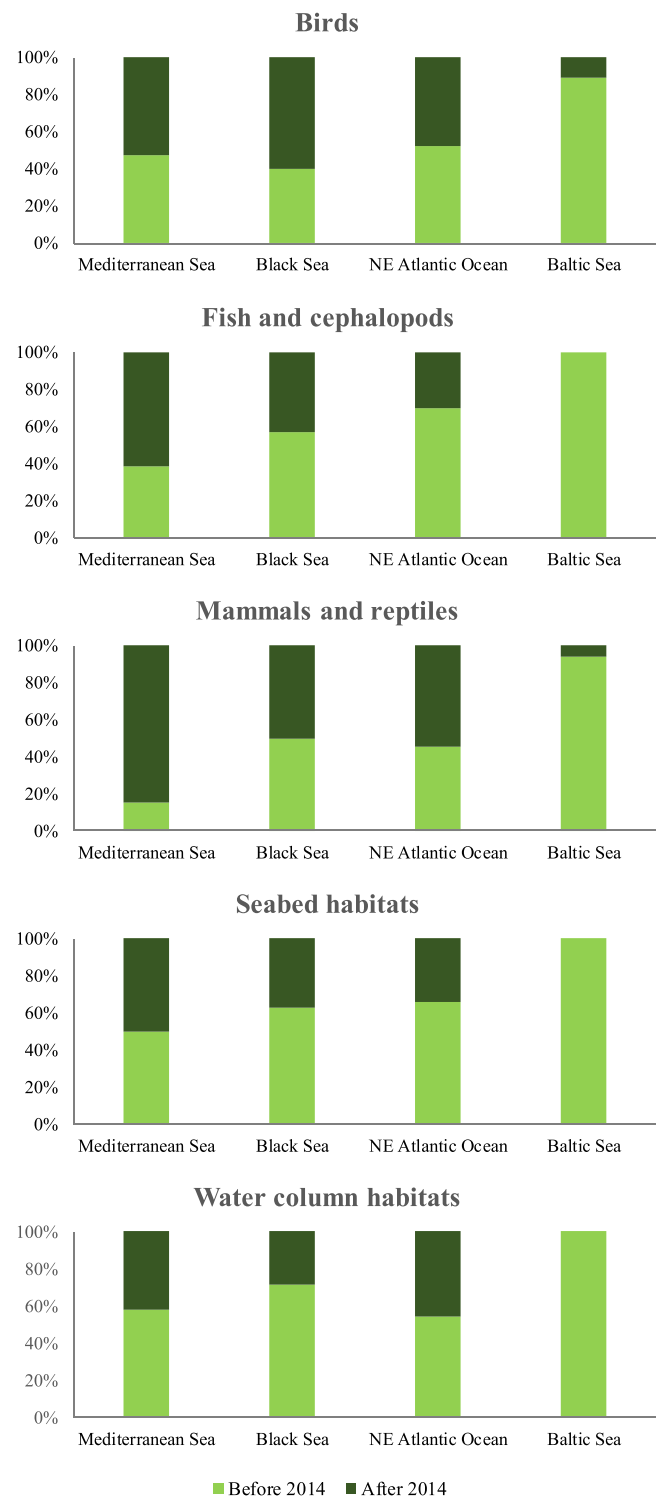


Fig. 6. Percentage (%) of sub programmes where monitoring started before 2014 (light green), or was due to start after 2014 (dark green), per ecosystem component and region. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

practices and gaps in marine biodiversity monitoring across the European waters. A key outcome from the evaluation is that most MS already invested great effort in collecting data, and reporting for the biodiversity monitoring programmes, but there was still room from improvement [28] at the time they reported (2014). However, the lack of consistency and coordination in the reported detail and quality jeopardises a

harmonised and comprehensive synopsis of the biodiversity monitoring programmes at the regional and EU-wide level. For instance, the inconsistency in allocating species and habitats to monitoring programmes hampered the formation of species and habitats reference lists that could support a harmonised regional monitoring. This was caused by ambiguous reporting entries, which meant that various MS interpreted what was being asked of them in different ways, and by the different national data structures that were adapted to fit the reporting requirements. The outcomes of this evaluation and of similar technical evaluations (e.g. [10]) will contribute to improving consistency in reporting, and will build a common understanding of monitoring across MS.

The evaluation of MS' reports will benefit the official reporting process of MS, by highlighting areas for improvement in the updated reporting guidance documents in the future. The updated reporting guidance should encompass the monitoring requirements derived from the new GES Decision [5], which provides revised and updated monitoring guidelines compared to the repealed GES Decision [4]. These guidelines can help provide an improved and concise structure in the updated reporting of the monitoring programmes for the MSFD, which were due to be reported by October 2020. Moreover, MS should link the monitoring programmes with the 2018 reported updates for GES determination (MSFD Article 9) and environmental targets (MSFD Article 10) (pursuant to MSFD Article 17), as well as with the 2016 reported Programmes of Measures (MSFD Article 13) and 2018 reported progress of Measures (MSFD Article 18). At the level of MSFD Descriptors, criteria, and ecosystems components, the evaluation provides several good practices and opportunities for synergies at the regional level. Species and habitats with a wide distribution spread across several MS should be prioritised for developing joint and harmonised regional monitoring programmes. The RSC should play a key role in coordinating monitoring programmes through their monitoring plans (e.g. OSPAR Joint Assessment and Monitoring Programme, HELCOM monitoring and assessment strategy, and UNEP/MAP's Integrated Monitoring and Assessment Programme).

4.1. Overview of programmes and sub programmes and the reporting structure

A key finding of the evaluation of reported monitoring programmes and sub programmes was their deviation from the proposed structure in the reporting guidance document [11]. This was caused by different interpretations of the guidelines, and by the way MS allocated species and habitats to each sub programme. Fig. 1 presents the regional perspective of species and habitats allocation to sub programmes, aggregating the national data. Moreover, MS largely reported on what monitoring programmes they had in place rather than on what was required of them [29], showing that the information reported was not tailor-made for the MSFD biodiversity monitoring, as it was expected to be. For instance, the species grouping and indicators in MS' established monitoring programmes did not consistently follow the MSFD requirements [4]. The absolute number of monitoring programmes and sub programmes reported per MS indicates the need for harmonisation at the regional level, at least in terms of their structure and organisation. In principle, the reporting guidance [11] did not allow for significant deviation in the number of monitoring programmes, which were similarly structured to the later published GES Decision's ecosystem components [5]. On the contrary, reporting on monitoring sub programmes was more varied, as it was structured around each MS' monitoring design, and reflected the number of species and habitats being assessed by the MS, their internal institutional structures and delivery of existing policies. The high number of programmes and sub programmes in the NE Atlantic, both in absolute and weighted values (Fig. 1), is a reflection of the number of MS, the higher number of species and habitats that are relevant for the MSFD in this region, institutional diversity, greater funding, and for some species groups (e.g. marine mammals) longer

history of monitoring, compared with the other three regions. Additionally, the NE Atlantic has a high proportion of MS with monitoring programmes in more than one region (i.e. France, Spain, Germany, Sweden, Denmark), with different species composition, environmental conditions, and anthropogenic pressures.

The weighted number of monitoring sub programmes reflects the number of species and habitats monitored per MS in a more comprehensive way than the counting at monitoring programme level. For instance, we anticipated that there would be more bird species in the NE Atlantic Ocean than in the Mediterranean Sea, and it is indeed the case that there are less seabirds reported for assessment and monitoring in the Mediterranean than there are in the NE Atlantic [30]. However, in other cases, such as mammals in the Black Sea, each MS reported dedicated monitoring sub programmes for each of the three species reported there. In contrast, Mediterranean MS have grouped several of the 12 highly prioritised marine mammal species [31,32] within a single sub programme. Practically speaking, harmonising the structure, and reporting of monitoring sub programmes will facilitate a consistent large-scale mapping of established monitoring designs and overview of their characteristics, such as temporal and spatial resolution, and quality control of the data monitored.

4.2. Temporal achievement of GES, and the gaps in monitoring programmes

MS reported the date by which they considered their monitoring programmes (established and new) would cover all GES criteria, species, and habitats needed to complete the GES assessment for biodiversity Descriptor 1. Generally, major gaps were observed in data availability, both at spatial and ecosystem component levels. It should be noted, however, that the GES determination reported in 2012 was not consistent across MS or across ecosystem components [7]. GES was determined at different levels (Descriptor, criterion, and indicator) and in many cases in a qualitative manner, revealing gaps in knowledge and data. These gaps were also confirmed by the analysis of the MS' monitoring programmes. Consequently, the monitoring requirements in relation to the GES determination refer to different or inconsistent levels across MS, as well, since the monitoring reports are linked with the GES determination of the 2012 reporting obligation.

Despite the obvious data gaps shown in Fig. 2 (only a few MS reported that they had sufficient monitoring for GES assessment in place by 2014), MS planned to fill in these gaps in the subsequent years after the 2014 reporting. The delays in establishing the planned monitoring programmes until beyond 2018 are likely to put at risk the availability of sufficient data needed to assess whether GES has been achieved or not. It should be acknowledged, however, that several years of monitoring are required to guarantee an ecologically relevant and robust assessment, and to enable measures enforcement, in data poor or no-data cases. Thus, assessment of the extent to which GES has been achieved is only feasible for criteria with adequate data to assess pressures and impacts on the state of the ecosystem components, where measures have already been applied and have an effective response. An exception could be made in cases where a precautionary approach is applied for the GES determination, to cover any potential data gaps.

Regarding species and habitats, it was expected for MS to have adequate monitoring programmes in place for specific seabed habitats that are included in the HD, given that this policy has been in place since 1992. However, as shown in Fig. 2, there are only a few cases where GES assessments for seabed habitats were reported as adequately covered by monitoring before 2014. Possible explanations for this inconsistency might be that MS have included habitats which are not covered by the HD in their monitoring programmes, or that the HD monitoring programmes are not yet well exploited for the MSFD requirements. The MSFD includes a number of benthic broad habitat types [4] which are not covered by the HD monitoring to the scale and extent that the MSFD requires. Nevertheless, the HD partially covers the MSFD requirements

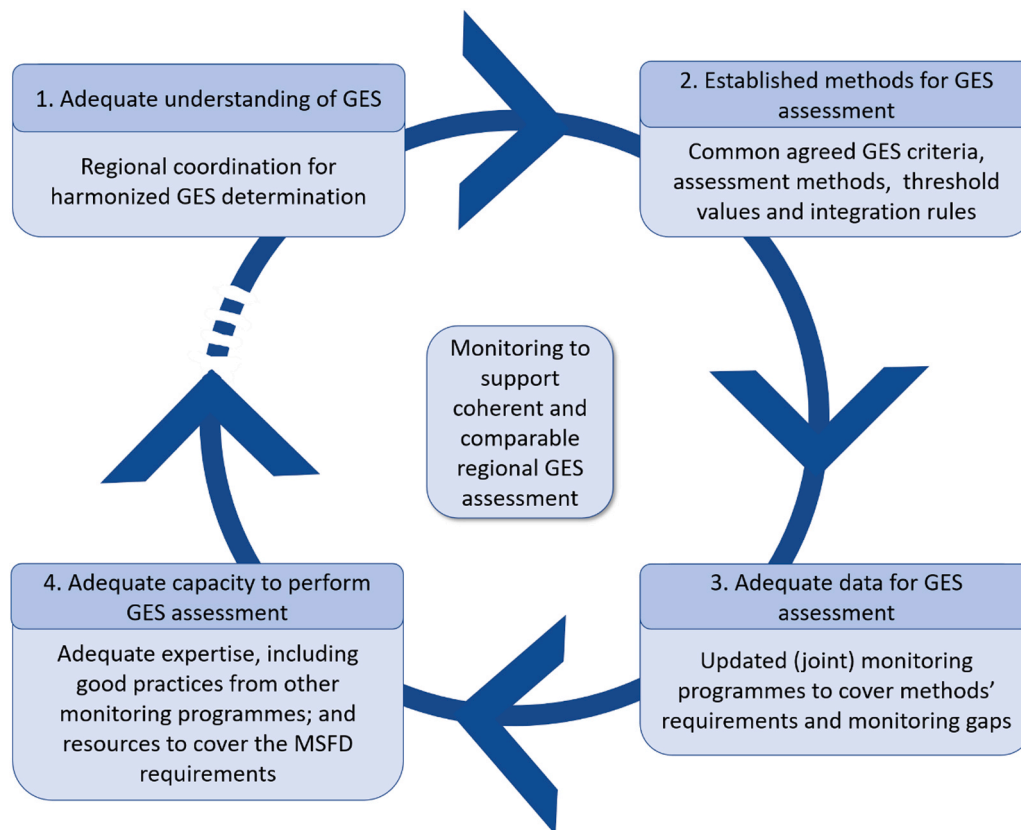


Fig. 7. Evaluation cycle for monitoring to support coherent and comparable regional GES assessment, through an evaluation of GES understanding, methods, data, and capacity to perform GES assessments.

in terms of criteria assessment. There is ongoing work to align the MSFD and HD marine assessment and reporting requirements, which could improve the development of common monitoring programmes, to serve both reporting obligations.

Marine mammals, being long-lived species, require long-term monitoring programmes to generate sufficient data for GES assessment. As such, unlike other species groups, GES determination was reported to be sufficiently covered beyond 2020. Moreover, marine mammals with wide spatial distribution beyond the national waters (assessment areas for HD) require input from dedicated, wide scale, coordinated monitoring programmes to enable GES assessment. A good practice, which achieves wide-scale coordination, comes from the NE Atlantic, where the SCANS monitoring project has generated data for marine mammals for over 30 years. The SCANS surveys were conducted in 1994, 2005, and 2016 [33–35]. Consequently, these were consistently reported by MS in the NE Atlantic.

The HD, BD, and the CFP provide data for mammals, birds, cephalopods and fish, however without fully covering all the MSFD assessment requirements for these species groups and GES criteria. These sources of information were consistently reported, and are discussed below in detail, demonstrating the ability of the MSFD implementation process to compile and integrate inputs from other relevant environmental legislation and international agreements.

4.3. Monitoring programmes and GES achievement

The analysis of monitoring reports for the coverage of GES assessment revealed that MS interpreted the four reporting categories differently, despite the clarifications in the monitoring guidance document [11]. The differences in MS' approaches to GES were caused, at least

partially, by the inconsistency in the GES determination by MS in the first reporting obligation (2012) [7]. The level of GES determination varied for each ecosystem component, from Descriptor level to criteria or indicator level. The first MSFD cycle, including the reporting of monitoring programmes in 2014, was based on the repealed GES Decision [4]. The new GES Decision [5] clarifies the GES determination, and provides detailed guidelines for the GES assessment, which will potentially facilitate a common interpretation of the four reported GES categories in the coming monitoring updates for the MSFD.

The misinterpretation of the four GES categories led to inconsistent or misleading outcomes. For instance, for seabed habitats, only half of the Baltic Sea MS reported adequate data, understanding and established methods for GES; however, almost all of them reported adequate capacity to perform GES assessments. In other cases, the outcomes were more consistent, providing a good overview of the state-of-play. For instance, for fish, most MS reported a good understanding and capacity to assess GES, but not enough data. In contrast, for marine mammals, the established monitoring programmes generate adequate data, and the MS reported a good understanding of GES, but MS lack established methods to assess GES. Eventually, the progress made from the 2014 reporting of the MSFD monitoring programmes, and onwards in the development and harmonisation of assessment methods for the marine mammal species [36,37], will be reflected in the coming updates of the monitoring programmes.

To facilitate a harmonised understanding across MS of the four GES categories, we propose the step-wise approach in Fig. 7, which sets out the reported requests for monitoring GES in a structured order, aligned with the requirements of the new GES Decision [5].

The development of coherent monitoring and assessment approaches requires extensive coordination across marine regions. Optimally, a

common GES determination should first be established, then existing monitoring programmes should be adjusted according to the GES Decision, and new programmes should cover potential gaps. Current indicators have often been selected based on existing monitoring programmes (e.g. [23]), and restricted MS resources often limit the possibilities for revising or establishing new programmes. Nevertheless, we propose that the steps in Fig. 7 could establish coordinated monitoring programmes to support coherent and comparable GES assessments, concurrently the four categories for GES adequacy in reporting:

- Adequate GES understanding requires sufficient scientific knowledge to discriminate good from poor environmental status, and MS should build on regional coordination for a harmonised GES determination (a legal requirement derived from MSFD Article 3(5)), for all relevant ecosystem components, pressures, and impacts.
- The established methods for GES assessment require adequate indicators to assess the GES criteria, agreed integration rules, and threshold values. MS should evaluate the coverage of the required methods from existing monitoring programmes, and update them accordingly. Common agreed methods to set threshold values [38], common integration rules [39], and regional coordination for developing new indicators should be prioritised. While species-specific indicators can differ within a marine region based on biogeographic differences, the principles for the selection of indicators, and the threshold setting methods need to be agreed jointly within and across a region to ensure comparability of results. Once the indicators and desired precision of assessment results have been agreed, the spatiotemporal design of monitoring programmes can be optimally defined.
- Data adequacy, and consequently data management, should acquire the required data from the methods in the previous step. In this step, MS should evaluate data gaps related to indicators for the GES criteria, sampling design in space and time, and data collection methods. Common monitoring methods are essential for producing comparable data that can be pooled to support regional assessments. This includes the collection of samples in the field, including gears and sampling strategies, such as depths and time of day, the storage of samples, analyses of samples in the laboratory, and statistical processing of metrics to prepare indicator assessments. In cases where existing monitoring programmes are used to support common regional indicators, the guidelines should be reviewed and updated to meet regional assessment needs. Moreover, coordinated data management should include specified data standards which enable aggregation of data across MS and joint databases for regional assessments. As a minimum, metadata and common quality assurance protocols are needed, as well as agreed processing of data for indicator assessments.
- For a MS to have adequate capacity to perform GES assessments requires sufficient expertise in all relevant ecosystem components and resources. MS need to assess potential gaps in expertise and resources to set up new monitoring programmes for the MSFD, as well as to exploit good practices and expertise available at the regional level.

The cycle in Fig. 7 can be evaluated periodically following the MSFD 6-year cycle incorporating the developments throughout the implementation. Revising existing monitoring programmes is often a sensitive issue since it may disrupt long-term national monitoring strategies. However, it should be recognised that assessments from a regional perspective, often area-based as requested by the MSFD, are not necessarily best met by current national monitoring programmes.

4.4. Monitoring programmes and existing legislations or agreements

MS reported for the MSFD their established monitoring programmes

from other EU legislation or international agreements. This is an important step to achieve harmonisation and consistency for the GES assessment at a regional and European scale. The MSFD came into force in 2008 to provide a mechanism for integrated assessment of the marine environment, bringing together all of the relevant marine information generated by previous EU policies. In this first evaluation of the MS monitoring programmes for the MSFD, we verified that most of the monitoring programmes already established under other relevant policies were incorporated into the MSFD monitoring programmes, thereby avoiding potential duplication of effort. However, there is still room for improvement, considering the progress of the RSC monitoring programmes and their alignment with MSFD requirements in line with the new GES Decision requirements [5].

Ultimately, the alignment of the EU environmental policies aims to achieve a single monitoring and assessment process which serves all reporting requirements for a given species, species group or habitat. To this end, MS should ensure that established or future monitoring programmes will cover the needs of all policies. On the other hand, the European Commission should prioritise aligning policies with overlapping objectives, such as the monitoring and assessment of marine mammals under both the MSFD and the HD. The RSC lead the coordination for joint and efficient monitoring programmes, especially for biodiversity, where species and habitats have natural distributions beyond the MS' national waters.

4.5. Duration and establishment of monitoring sub programmes

Two key findings were derived from evaluating the starting point of the reported monitoring sub programmes. Firstly, most of them were established for or adapted to the MSFD, rather than for other obligations. All groups in Fig. 5 peak at the point that the MSFD went into force. Existing monitoring programmes for other obligations were modified to fit the MSFD requirements and consequently their origin was hidden in the reporting, however references were made as shown in Section 3.4. Secondly, earlier monitoring sub programmes generally corresponded to the enforcement of other ecologically relevant Directives or policies (HD, BD, CFP), or to EU enlargement periods, when new MS had to comply with the existing EU legislation. In all groups, the onset of reported monitoring sub programmes is spread over time, with significant differences across regions.

An overview of the starting point of monitoring programmes indicates the need for an extended period of monitoring of each species group and habitats, to ensure a robust GES determination and assessment. Moreover, it indicates the gaps and a lack of long data-series for each group or region, which jeopardises the effort to harmonise methodological standards and threshold values for GES. For instance, marine mammals monitoring programmes in the Baltic Sea generated more than two centuries of data, while in the Black Sea and the Mediterranean Sea, data generation has taken place for less than a decade. Generally, the Mediterranean and Black Seas have more recent monitoring programmes, compared to the NE Atlantic and the Baltic Sea, partially due to MS that joined the EU at later stages (e.g. Bulgaria and Romania in 2007; Cyprus, Malta and Slovenia in 2004). Patrício et al. [3] noticed that the northern RSCs (HELCOM, OSPAR) have a longer period of experience in coordinated monitoring than the southern RSCs (UNEP/MAP, BSC), and that western MS have a longer history of compliance with EU environmental Directives, compared with the eastern MS.

The mean duration of established monitoring programmes per region and ecosystem component (Table 1) gives another perspective on the differences in data availability, and in the length of time-series datasets. These differences jeopardise the harmonisation of methods to set threshold values, to determine GES (as was also evident in Fig. 2), and to assess GES. To exemplify this outcome, in the Baltic Sea and the NE Atlantic, there are well developed and tested methods for assessing species distribution and abundance of marine mammals [40–42], as summarised in Palialexis et al. [38], which cannot be applied in the

Mediterranean and the Black Seas, due to their short time-series. Especially for marine mammals and other long-lived species, the duration of the available data is essential for showing changes in population dynamics and characteristics (as required by the GES criteria). Similarly, Nygård et al. [8] linked the monitoring effort and cost with the distance from GES. If the current environmental status is far from the GES threshold value (the environmental status is either poor or excellent), this can usually be verified with less monitoring effort (e.g., with less frequent monitoring). As the status moves closer to the GES threshold value (towards achieving GES or deteriorating from GES and risking becoming in poor status), higher monitoring effort is required to attain a more precise estimate of the status.

At the ecosystem component level, both Table 1 and Fig. 5 indicate areas where the MSFD boosted the generation of new monitoring programmes and sub programmes for species group, with no dedicated programmes from other in-force policy obligations or agreements. Such programmes include those which monitor several marine birds in the NE Atlantic, seabed habitats in the Mediterranean Sea, and marine mammals in the Baltic Sea.

The monitoring sub programmes are more detailed and usually species specific, compared with the more generalised monitoring programmes. Fig. 6 summarises the amount of monitoring sub programmes that were established for the MSFD requirements (those that started after 2014). The MSFD initial assessment in 2012 (Article 8) identified gaps in data and methods, and MS had the opportunity to cover those gaps with new monitoring sub programmes when they reported in 2014. Eventually, the updated monitoring programmes, due to be reported by October 2020, should have fewer new sub programmes compared to the 2014 reporting, where all established monitoring programmes were adapted to the MSFD reporting obligation for monitoring. In the Baltic Sea, most of the sub programmes were in place at the beginning of the MSFD or earlier, because of high-level regional coordination (through HELCOM) or other monitoring obligations. In the Mediterranean Sea, however, more than half of the monitoring sub programmes were established after the 2012 initial assessment to cover identified data gaps.

4.6. Building on the progress from the first MSFD implementation cycle, and preparing the updated monitoring programmes

Among the achievements of the MSFD first cycle of implementation is that it brought together experts across Europe and beyond, covering almost all aspects of environmental assessment, monitoring, and management of the marine environment. Moreover, the MSFD aimed to either attract or create funding opportunities to support the new policy requirements for data, methodological standards, monitoring programmes, and measures derived from this ambitious legislation. Multi-disciplinary groups of experts, managers, and policymakers worked together to assess and ensure the sustainable use of marine resources, in line with global policies, such as the Convention of Biological Diversity. These efforts provided fundamental input to the MSFD monitoring methods and programmes during the first MSFD cycle.

The MSFD biodiversity concepts were established with the Task Group 1 report [14] (a series of ten reports for each of MSFD Descriptors, prepared by groups of independent experts, that led to the development of the 2010 GES Decision [4]). Before the monitoring reporting obligation of 2014, the European Commission, and experts from MS collectively created the general MSFD monitoring guidance [9], which was further refined by the MSFD biodiversity expert network during the process to review the 2010 GES Decision. In parallel, scientific consortia were working on EU-funded projects to provide scientific support for policy implementation, such as the DEVOTES [43], PERSEUS [44], and STAGES [45] projects. One of the priorities was to support the monitoring programmes and data generation in regions with identified gaps (e.g. regional coordination of monitoring in the Mediterranean Sea, with the participation of EU and non-EU countries within the PERSEUS

project). More dedicated funding opportunities (EU Directorate-General for Environment) gave way for the three joint monitoring pilot projects BALSAM (Baltic Sea, [46]), IRIS-SES (Mediterranean and Black Seas, [47]) and JMP NS/CS (North Sea and Celtic Seas, which are sub-divisions of the NE Atlantic Ocean [48]).

Those projects developed new concepts and decision-making tools for MSFD implementation, and integrated monitoring strategies based on existing sampling programmes. They developed pilot studies and frameworks for joint monitoring programmes within and between MS. The projects ultimately built on the state-of-the-art monitoring practices and adjusted them to meet the MSFD requirements. These projects influenced parts of the RSC monitoring programmes and guidance documents, some of which are under development, pending finalisation of the work on indicators and threshold values. Obviously, it takes time for the MS to adopt and apply the monitoring practices and recommendations and the project's results were not yet visible in the monitoring reports of the MS. Furthermore, institutional barriers hamper joint monitoring and the MSFD lacks a dedicated financing instrument (such as for the European Common Fisheries Policy Data Collection Framework) that promotes collaboration between MS and could trigger the monitoring planning from national to regional level. Nevertheless, the cumulative effort and outcomes of those projects created a substantial monitoring inventory, which MS should exploit in the following MSFD monitoring updates. Collaboration within the RSC for the development of common guidance and common platforms for data sharing will increase the coherence and comparability of GES assessments [3,5]. Consistency across monitoring programmes, and consequently in reporting, can be further achieved through joint monitoring programmes, and better use of already established ones. Cost effective, innovative, and standardised monitoring methods (e.g. in [49] and in [9]), and good practises which are identified can generate the required data in an efficient way. These methods should be developed collectively by MS covering all relevant EU, regional, and national obligations [3].

5. Conclusion

Several stages, from collection of data through monitoring programmes to achieving consistent GES assessments, require coordination, beyond measuring the same parameters. These stages include common guidance for sampling techniques, spatio-temporal sampling strategies, sample analyses, data handling, common agreement on indicators and threshold values, platforms for pooling data, common methods for determination and assessment of GES. MS and the European Commission are responsible for the MSFD implementation, and so they face the challenge of channelling the concepts, methods, and tools developed for the MSFD over the last decade, and the outcomes from this work, into updating their biodiversity monitoring programmes every 6 years. Outcomes of the analysis, good practices and gaps derived from a European-wide perspective could influence and guide any complex monitoring system to contribute to an efficient and harmonised environmental management framework.

The outcomes from the first EU-wide analysis of the MS biodiversity monitoring reports for the MSFD demonstrated that the MS put great effort to accomplish the ambitious MSFD objectives for reporting and consequently assessing marine biodiversity. Regional coordination and alignment of EU-relevant policies (Habitats and Birds Directives, Common Fisheries Policy, Water Framework Directive) can contribute to harmonise marine biodiversity monitoring. Joint monitoring programmes can achieve consistent reporting and monitoring at regional scale, notably for highly mobile species, however institutional barriers still need to be overcome. The MSFD provides sound legal framework to harmonise biodiversity monitoring, which will support a harmonised and comparable GES determination and assessment. Only then can we achieve a robust and ecologically unequivocal Good Environmental Status for the EU marine biodiversity.

CRedit authorship contribution statement

Andreas Palialexis: Funding acquisition, Conceptualization, Investigation, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **Vasiliki Kousteni:** Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Laura Boicenco:** Conceptualization, Validation, Writing - review & editing. **Lisette Enserink:** Conceptualization, Validation, Writing - review & editing. **Kalliopi Pagou:** Conceptualization, Validation, Writing - review & editing. **Ulla Li Zweifel:** Conceptualization, Validation, Writing - review & editing. **Francesca Somma:** Funding acquisition, Supervision, Writing - review & editing. **Anna Cheilari:** Methodology, Validation, Writing - review & editing. **David Connor:** Methodology, Validation, Writing - review & editing.

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Appendix A

See [Table A1](#).

Table A1

List of Directives, other EU policies and Conventions which are relevant to monitoring for MSFD Descriptor 1.

Abbreviation	Description
ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
BarCon	Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean of 1995
BD	Birds Directive
BSC	Black Sea Commission
BuchCon	Bucharest Convention on the Protection of the Black Sea Against Pollution of 1992
BWD	Bathing Water Directive
CBD	Convention on Biological Diversity of 1993
CFP-DC-MAP	Common Fisheries Policy-Data Collection-Multi-Annual Programme
HD	Habitats Directive
HELCOM	Baltic Marine Environment Protection Commission
Helsinki convention	Convention on the Protection of the Marine Environment of the Baltic Sea Area of 1992
Natura 2000	Network of nature protection areas in the territory of the European Union
Nitrates	Nitrates Directive
OSPAR	Convention for the Protection of the Marine Environment in the North-East Atlantic of 1992
RAMSAR	Convention on Wetlands of International Importance especially as Waterfowl Habitat of 1994
TWSC	Trilateral Wadden Sea Cooperation
UNEP/MAP	United Nations Environment Programme/Mediterranean Action Plan
UWWTD	Urban Waste Water Treatment Directive
WFD	Water Framework Directive

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