



Assessment level and time scales of biodiversity indicators in the scope of the Marine Strategy Framework Directive – A case study for the NE Atlantic

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ABSTRACT

European Union Member States have made an unprecedented effort to implement the Marine Strategy Framework Directive (MSFD). However, the coherent assessment of Europe's marine waters and Good Environmental Status by 2020 has not yet been achieved. This work analysed the implementation level and time scales used to report biodiversity criteria in the 1st MSFD cycle for two Biogeographic Regions: the Celtic Seas and the Bay of Biscay and Iberian Platform. Results were compared across Biogeographic Regions, Marine Sub-units, Criteria, and Biological Groups to assess congruency and integration possibilities. Reporting level was significantly different among Marine Sub-units within the same Biogeographic Region and country. France and Spain showed the highest implementation level and focused on criteria included in Biodiversity (1) and Food-Webs (4) Descriptors, while Ireland mostly reported Commercial Fish and Shellfish (3). Fish, Rocky and Biogenic Reefs and Sedimentary Habitat were the most reported Groups. Heterogeneous data was recorded for temporal scales used to report Groups and Criteria among Marine Sub-units within the same region, showing that each MS is working individually. Average temporal range used for reporting was wider in French Bay of Biscay, particularly for Marine turtles' Group, Food-web Criteria (Descriptor 4), and Ecosystem structure criteria (1.7). Ireland presented consistently shorter temporal data sets focusing on Commercial Fish and Shellfish descriptor (3) and Fish Group. To enable the direct comparisons and integration of MSFD results, the use of historical and opportunistic data should be discouraged, the reporting timeframe of existing monitoring datasets (beginning/end) should be synchronized at regional level, and targeted habitats/species should be decided and prioritized regionally. This work pinpoints MSFD gaps and provides inputs for an improved 2nd implementation cycle, particularly in what concerns temporal scales used for reporting.

1. Introduction

Achieving healthy and sustainable oceans is a major concern for worldwide governments, policy-makers, researchers and Non-Governmental Organizations (NGO) as a consequence of the growing use of ocean space and increasing resources depletion. Anthropogenic impacts are increasing and the marine environment has reached an unprecedented degradation status (e.g. fisheries collapse, pollution, and ocean acidification.) (Borja et al., 2008; European Commission, 2008; UNCLOS, 1982; US Congress, 2002; Valdés et al., 2017). Worldwide organizations, such as the United Nations (UN), have expressed their concern by adopting ocean-related indicators, such as the Sustainable Development Goal (SDG) –GOAL 14: LIFE BELOW WATER –

implemented by the UN global indicator framework (United Nations, 2016). In the past three decades, inter-governmental regional sea conventions (RSCs) (e.g. Oslo and Paris Conventions (OSPAR), Helsinki Convention (HELCOM), Barcelona Convention (UNEP-MAP) and Bucharest Convention (Black Sea Commission)) have played a crucial role in the achievement of ocean sustainability goals. RSCs implemented the first management guidelines and monitoring programs to assess environmental status, proposing common and comparable assessment methods, and defining common targets among geographic regions (Black Sea Commission, 1992; Helsinki Commission, 2010; OSPAR Commission, 1992; UNEP - MAP, 2002; Valdés, 2017). Yet, this task is far from easy because assessment methods must also incorporate a large diversity of ecosystems metrics, and concomitant thresholds, that often

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vary geographically (Borja et al., 2016a; Cavallo et al., 2016). In addition, RSCs are not legally binding and there are no sanctions if MSs do not comply with proposed measures (Cavallo et al., 2018). To address these challenges, in 2000 the European Commission (EC) has approved the Water Framework Directive (WFD) that provides the framework for the assessment and protection of inland surface waters, transitional waters, coastal waters, and groundwaters (European Commission, 2000). Subsequently, the Marine Strategy Framework Directive (MSFD) was approved in 2008 to establish the protection of the marine environment including Member State's Exclusive Economic Zone (EEZ) (European Commission, 2008). The MSFD aims to promote marine conservation and sustainability through an Ecosystem Based Approach (EBA) to achieve the sustainable use of marine goods and services while enabling ecosystems functions and their recovery whenever anthropogenic impacts occur (Borja et al., 2016a; Long et al., 2015). To attain this purpose, Member States (MS) must assess the environmental status to determine whether they are in Good Environmental Status (GES) as defined by the environmental targets established at national level. The assessment is made based on 11 qualitative descriptors: 1 – Biodiversity, 2 – Non-indigenous species, 3 – Commercial fish and shellfish, 4 – Food webs, 5 – Human-induced eutrophication, 6 – Seafloor integrity, 7 – Hydrographical conditions, 8 – Contaminants, 9 – Contaminants in fish and seafood, 10 – Litter, and 11 – Energy and noise (European Commission, 2008). These descriptors assess the environmental status from two perspectives: the state of the marine environment, and human pressures and impacts (European Commission, 2017). The descriptors represent the first EC attempt to implement an ecosystem-based approach to manage the marine environment as a coupled social-ecological system. Biodiversity related descriptors are among the most challenging ones as they include diverse biological or ecological elements (e.g. species, habitats, food webs and ecosystems, etc.) that need to be assessed and integrated (Borja et al., 2016a; Heiskanen et al., 2016) to reflect the global status of an ecosystem. However, the integration of biodiversity's vast set of information poses numerous problems, due to the numerous elements, metrics and units, and to the introduction of novel features such as large-scale environmental assessments (Borja et al., 2008, 2014, 2016a).

Several problems have been identified during the first phase of the MSFD implementation, such as incongruent methodological approaches (Berg et al., 2015; Hummel et al., 2015; Palialexis et al., 2014), redundancy in reporting (Berg et al., 2015), heterogeneous establishment of thresholds within the same region (Cavallo et al., 2016; Hummel et al., 2015; Palialexis et al., 2014; Teixeira et al., 2014), different prioritization of taxa among countries (Cavallo et al., 2016; Peterlin et al., 2015), inconsistent temporal and spatial compartmentation of data (Bergström et al., 2016; Hummel et al., 2015; Patrício et al., 2016), and the lack of large-scale assessment of fluctuations (e.g. climate change) (Bellás, 2014; Cardoso et al., 2010; Santos et al., 2012). The definition of scales is of major importance to assess GES, as the detection of effects may be overlooked if the correct spatial area and/or temporal scope is not outlined. To define the spatial scale to assess GES, it is highly important to know factors, such as the geographical distribution of species/functional group and/or the extension of the habitat/ecosystem. The temporal scale should have into consideration species' biological traits, such as life cycle, growth rate, reproductive cycle, and variability patterns, to ensure that intra- and inter-specific variability is correctly addressed (Teixeira et al., 2014). Scales are critical to understand if any deviations from GES are a consequence of natural variability or of human pressures; they can affect the establishment of reference values and thresholds, and have implications on the detection of environmental recovering trajectories (Bergström et al., 2016; Hummel et al., 2015; Rossberg et al., 2017). Incongruent scales can lead to even wider inconsistencies, such as unbalanced GES classification and the development of inefficient actions and monitoring plans (Berg et al., 2015; Borja et al., 2014; Cavallo et al., 2016). The geographical scales used in the 1st implementation cycle have been

assessed by the EC (Prins et al., 2014), and the the spatial scales that need to be assessed in the 2nd implementation cycle have been defined (European Commission, 2017). However, the temporal spectrum of reporting data is still largely overlooked, even though it is a recognized source of variability in environmental monitoring data that increases uncertainty and decreases the confidence levels of the assessments (Carstensen and Lindegarth, 2016).

The present work aims to assess the implementation level and the corresponding temporal data series used to assess environmental status during the 1st MSFD implementation cycle. Particular focus is given to biodiversity descriptors (i.e. #1 – biodiversity; #2 non-indigenous species; #3 – commercial fish and shellfish; #4 – food-webs; #6 – seafloor integrity) implemented in two Biogeographic Regions of the North Eastern Atlantic (Berg et al., 2015; Hummel et al., 2015; Teixeira et al., 2014). This study hypothesizes that reporting level and temporal scales used by MSs in the initial assessment are appropriate, congruent, and comparable, and allow the isolation of natural variability from anthropogenic effects as recommended by the EC. To test this hypothesis, the frequency of reporting and time scales of biodiversity criteria were analysed for the first time, and compared across Biogeographic Regions, MSs, Marine Sub-units, Criteria and Biological elements (taxonomic groups and habitats). Ultimately, this assessment aimed to identify specific urgent actions and to provide novel inputs on how temporal scales can be improved in the 2nd implementation cycle.

2. Methods

2.1. Study area

The study area is located in the North Eastern Atlantic Sea and focus two Biogeographic Regions (the Celtic Seas, and the Bay of Biscay and Iberian Platform), five MSs (UK, Ireland, France, Spain and Portugal), and six Marine Sub-units (UK_Celtic Seas, IR_Celtic Seas, FR_Celtic Seas, FR_Bay of Biscay and Iberian Platform, SP_Bay of Biscay and Iberian Platform and PT_Bay of Biscay and Iberian Platform) (see Fig. 1). The lowest spatial unit used to assess implementation levels and temporal scales was the Marine Sub-unit, which is a sub-division of the MSS

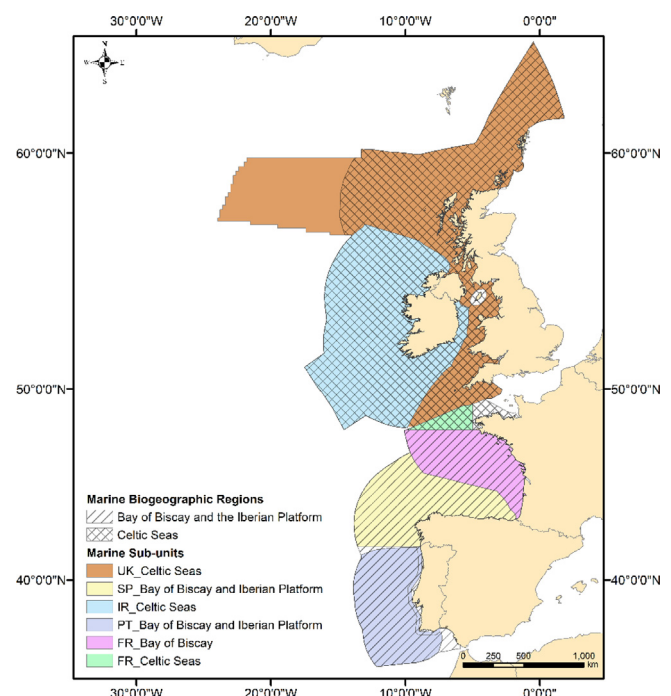


Fig. 1. Study area: Biogeographic regions and Marine Sub-units under study (EIONET Central Data Repository, 2018).

territory according to its corresponding Regional Sea/Biogeographic Region (Peterlin et al., 2015).

2.2. Data collection

MSs reporting level and the corresponding temporal range of biodiversity indicators was assessed by surveying Initial Assessment Reports, GES assessment reports, the European Environment Information and Observation Network (EIONET) factsheets, Task-Group reports and peer reviewed papers (Alemany et al., 2012; Berg et al., 2015; Borja et al., 2011; Cardoso et al., 2010; Cavallo et al., 2018, 2017; DEFRA, 2012; EIONET Central Data Repository, 2018; Hummel et al., 2015; Irish Government, 2013; MAGRAMA et al., 2012; MAMAOT, 2012; Ministère de L'Écologie, du Développement Durable et de L'Énergie, 2012a, 2012b; Norton and Hynes, 2018; Olenin et al., 2010; Piet et al., 2010; Preciado et al., 2012; Punzón et al., 2012; Rice et al., 2010; Stuart Rogers et al., 2010; Sampedro et al., 2012; Teixeira et al., 2016; Velasco et al., 2012). In general, data were collected by crossing and comparing information from the MSs Initial Assessment Reports and reporting factsheets (EIONET Central Data Repository, 2018). Data from Portugal was limited to the information in the national report because this MS did not fill in the corresponding EIONET factsheet. The following biodiversity descriptors were selected: 1 - Biodiversity, 2 - Non-indigenous species (NIS), 3 - Commercial Fish and Shellfish, 4 - Food-webs, and 6 - Seabed Integrity. Although not commonly considered a biodiversity descriptor, Descriptor 3 - Commercial Fish and Shellfish was also analysed as it reflects the environmental status of fish and crustacean biodiversity (Berg et al., 2015) and includes a consistent data series due to the long-term implementation of the Common Fisheries Policy (CFP) in Europe (European Commission, 2015). To assess reporting level, the number of indicators used to report was accounted and to assess time scale, the temporal range of each indicator was identified. Both variables were assessed for each Biogeographic Region, MS, Marine Sub-unit, Descriptor, Criteria, and for all reported biodiversity components. The assembled database included the following items: Biogeographic Region, MS, Marine Sub-unit, Descriptor, Criteria, Indicator, Group, Specific taxa, Initial year of reporting/Start year (initial year for which data are available) and Time range (number of years for which data are available, e.g., time series from 1992 to 2011 has a Time range of 19 years). Biodiversity components were merged into larger functional groups (hereafter designated by Groups) since MSs used different terminology across the same components (Peterlin et al., 2015). This standardization aimed to enable direct comparisons across defined Groups: Benthic habitats, Benthic species, Fish, Food-web, Marine mammals, Marine turtles, Plankton, Pelagic habitats, Rock & Biogenic Reef, Seabirds and Sedimentary habitat. A total number of 5 descriptors, 17 criteria, 35 indicators, and 11 functional groups/habitats were addressed (see Table 1). The data set was standardized to criteria level since not all MS reported up to the indicator level. To tackle differences in reporting level due to the unbalanced number of Indicators per Criteria (see Table 1), the average reporting level was calculated by summing all reported data in that particular Criteria, and by dividing it by the number of Indicators included in that Criteria - generating an average reporting level (e.g., Criteria 3.1 includes Indicators 3.1.1, 3.1.2, therefore all data reported in 3.1 was summarized and divided by the number of existing Indicators, “2”).

2.3. Statistical analysis

To test differences in MSFD reporting level, the number of criteria used to report each Biogeographic Region, Marine Sub-unit, Criteria, and Group as well as their interaction were tested using Generalized Linear Models (GLMs). The Poisson distribution was chosen since it is typically used for count data (Warton et al., 2016; Zeileis et al., 2008). In this analysis, a nested design was prepared considering that each

Marine Sub-unit was grouped within their corresponding Biogeographic Region. Descriptor showed a strong collinearity with Criteria, and therefore it was not considered in the analysis. All factors were considered fixed (Underwood, 1997). To further disentangle variability patterns, a non-parametric multivariate analysis for categorical variables - Multiple Correspondence Analysis (MCA) - was used to understand how different variables explained the heterogeneity of reporting level. Similarly, the variables selected to perform the MCA analysis of reporting level were Biogeographic Region, Marine Sub-unit, Descriptor, Criteria, and Group.

On a second stage, the Time range used to report each biodiversity indicator was compared using a GLM with Gamma distribution, following data normality and homoscedasticity assessment procedures. This analysis considered the following factors: Biogeographic Region, Marine Sub-unit (nested within Biogeographic Region), Criteria and Group. All factors were considered fixed. Similarly to the previous analysis, Descriptor exhibited a strong collinearity with Criteria, and therefore it was not considered in the analysis. Heterogeneity patterns among reporting Time range were analysed using Factor Analysis of Mixed Data (FAMD). This method is a mixture of two popular methods: Principal Component Analysis (PCA) which allows the ordination of quantitative datasets, and MCA which is suitable for exploring qualitative variables (Pagès, 2004). FAMD provides the classical results of a factorial analysis, such as ordination diagrams that assess the patterns of observations and allows to evaluate its relationships with the considered variables. The variables selected for the Time range FAMD analysis were: Biogeographic Region, Marine Sub-unit, Criteria, Group, Initial reporting year, and Time range. Cluster Analysis was applied to both non-parametric analyses using a probability of 0.05, creating an automatic similarity threshold to understand if reporting level and time scales show any patterns across the study area. All the analysis were performed using R software (R Core Team, 2014).

3. Results

3.1. Reporting variability

Reporting level was highly heterogeneous among Biogeographic Regions, MSs, Marine Sub-units, Descriptors, Criteria, and Groups. The Bay of Biscay and the Iberian Platform was the most reported region ($n = 1553$), France was the country with the highest reporting level ($n = 1555$), and French Bay of Biscay was the most reported Sub-unit ($n = 716$). The most reported descriptor was 1 - Biodiversity ($n = 2013$), which notably contrasted with Descriptor 2 - NIS ($n = 139$; Fig. S1). Criteria and Group implementation was highly heterogeneous across MSs (Fig. 2A and B, respectively). France, Portugal and UK highly reported Criteria 1.6 *Habitat Condition*, while Ireland focused on Criteria 3.3 *Population age and distribution*. Spain mostly reported Criteria 1.1 *Species distribution* (Fig. 2A). The number of Groups reported per MS was the highest in the UK ($n = 9$) and lowest in Ireland ($n = 6$); this latter MS reported a large number of Criteria but concerning the same Group, i.e. Fish within the descriptor 3 - Commercial fish and shellfish. Fish was the most frequently reported Group for most MS except for France and UK that reported more often Rock & Biogenic Reef and Marine Mammals (Fig. 2B).

Marine Sub-units, within each Biogeographic Region, had a low contribution to explain reporting variability (2.62% of deviance explained; $p = 0.000$). Nevertheless, post-hoc tests confirmed that the Bay of Biscay and Iberian Platform reporting level was significantly higher in French Bay of Biscay in comparison to Spanish Bay of Biscay (with 3.3 and 1.6 average number of criteria, respectively), but similar to the Portuguese Sub-unit (with 2.0 average reporting number). In the Celtic Seas, the three Sub-units were significantly different but presented a smaller amplitude of variation (ranging from 2.6 in Ireland to 1.3 in the UK unit). The most important explanatory variables were Group, the interaction between Marine Sub-unit and Criteria and Criteria. Group

Table 1
List of Descriptors, Criteria, Indicators and Groups assed for the case study region.

Descriptor	Criteria	Indicator	Group/Habitat
1 - Biodiversity	1.1 Species distribution	1.1.1	Fish; Marine mammals; Marine turtles; Pelagic habitats; Seabirds; Sedimentary habitat
		1.1.2	Fish; Marine mammals; Marine turtles; Pelagic habitats; Seabirds
		1.1.3	Benthic habitats
	1.2 Population size	1.2.1	Fish; Marine mammals; Marine turtles; Pelagic habitats; Seabirds
	1.3 Population condition	1.3.1	Fish; Marine mammals; Marine turtles; Pelagic habitats; Seabirds
		1.3.2	Fish; Marine mammals
	1.4 Habitat distribution	1.4.1	Benthic habitats; Fish; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
		1.4.2	Benthic habitats; Fish; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
		1.4.3	Sedimentary habitat
	1.5 Habitat extent	1.5.1	Benthic habitats; Fish; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
		1.5.2	Benthic habitats; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
		1.5.3	Benthic habitats
	1.6 Habitat condition	1.6.1	Benthic habitats; Fish; Marine mammals; Marine turtles; Pelagic habitats; Rock & Biogenic Reef; Seabirds; Sedimentary habitat
		1.6.2	Benthic habitats; Fish; Marine mammals; Marine turtles; Pelagic habitats Rock & Biogenic Reef; Seabirds; Sedimentary habitat
		1.6.3	Benthic habitats; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
		1.7.1	Fish; Pelagic habitats; Seabirds
2 – Non- Indigenous Species (NIS)	2.1 Abundance of NIS	2.11	Benthic species; Rock & Biogenic Reef; Pelagic habitats
	2.2 Environmental impact of NIS	2.2.1	Benthic species; Rock & Biogenic Reef
		2.2.2	Benthic species; Rock & Biogenic Reef
3 - Commercial fish and shellfish	3.1 Fishing activity pressure	3.1.1	Fish; Marine mammals; Marine turtles
		3.1.2	Fish; Marine mammals; Marine turtles
	3.2 Reproductive capacity	3.2.1	Fish
		3.2.2	Fish
	3.3 Population age and size distribution	3.3.1	Fish
		3.3.2	Fish
		3.3.3	Fish
4 - Food-webs	4.1 Biomass of key species/ trophic groups	4.1.1	Benthic habitats; Fish; Marine mammals; Marine turtles; Seabirds
		4.1.3	Fish
	4.2 Proportion of species at the top of food webs	4.2.1	Benthic habitats; Fish; Food-web; Seabirds
	4.3 Abundance of key trophic groups/ species	4.3.1	Benthic habitats; Benthic species; Fish; Food-web; Marine mammals; Marine turtles; Plankton, Pelagic habitats; Rock & Biogenic Reef; Seabirds; Sedimentary habitat
		4.3.1	Benthic habitats; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
6 - Seafloor Integrity	6.1 Substrate physical damage	6.1.1	Benthic habitats; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
		6.1.2	Benthic habitats; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
	6.2 Condition of benthic community	6.2.1	Benthic habitats; Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
		6.2.2	Pelagic habitats; Rock & Biogenic Reef; Sedimentary habitat
5	17	35	124

explained 23.3% of the existing variance and Rock & Biogenic Reefs and Fish Groups were significantly more reported than the overall Groups (with 5.6 and 4.9 average number of criteria) (Table 2). Benthic habitats, Pelagic Habitats, Food-webs and Benthic species were the least reported Group (with 0.7, 0.3, 0.2 and 0.1 average number of criteria). The interaction between Marine Sub-units (nested in Biogeographic Region) and Criteria explained 19.55% of variance ($p = 0.000$; Table 2). Post-hoc tests showed that Ireland implementation of 3.3 *Population age and distribution* and 3.2 *Reproductive capacity of the stock* were highest than the overall interactions (36.0 and 26.0 mean reporting number per Criteria/Sub-unit, respectively). Portugal also exhibited high implementation rates of the same descriptors (with 9.3 and 18.0 mean reporting number). By the contrary, French Bay of Biscay and Celtic Seas Sub-units highest reporting rates were 6.1 *Substrate physical damage* (mean of 11.0 and 5.8 mean reporting number per Criteria/Sub-unit, respectively). Spain focused on 3.2 *Reproductive capacity of the stock* and 6.1 *Substrate physical damage* (8.0 and 7.0 mean reporting number per Criteria/Sub-unit, respectively) and the UK addressed 4.3 *Abundance of key trophic groups* and 1 *Habitat Condition* (with 4.4 and 3.1 mean reporting number of Criteria/Sub-unit) (Figs. 4 and 3A). Criteria explained 12.9% of the existing variance and Criteria 3.1 and 3.3 were significantly more reported than the overall Criteria (with 9.8 and 9.1 average reporting number per Criteria). Although in a lesser extent, Marine Sub-unit and Group interaction was also significant and explained as much as 10.8% of the variance ($p = 0.000$; Table 2). Post hoc tests showed highest implementation rates for Rock & Biogenic Reefs and Sedimentary habitats by the French Bay of Biscay (7.4 and

3.3 mean reporting number per Group/Sub-unit) and Fish by Ireland and Portugal Sub-units (10.6 and 6.7 mean criteria Group/Sub-unit). High reporting rates were also registered for French Celtic Seas and Rock & Biogenic Habitats (7.4 mean reporting number) (Fig. 3). The analysis of Criteria and Group interaction was redundant, since the MSFD conceptual design implies that specific descriptors are focused on particular groups (e.g. Descriptor 3 focus on Fish group, 1.6 Criteria focusing on Benthic habitats, etc., see Table 1).

MCA analysis explained 16% of the heterogeneity among reporting levels. A similarity threshold was automatically defined by a Cluster Analysis with a statistical probability of 0.05, creating five clusters with a similarity threshold of 3%. Clusters' similarity was based on Descriptor/Criteria, Group and, in a less extent, Marine Sub-unit. Descriptor 6 - Seabed Integrity and its corresponding criteria were associated with all benthic habitats and all Bay of Biscay Sub-units (Cluster 1). Cluster 2 included all Descriptor 1 criteria, Plankton Group and UK Sub-unit, while Cluster 3 included Descriptor 4 criteria and was associated to Marine mammals, Seabirds, Marine turtles and French Celtic Seas (Cluster 3). Descriptor 2 - NIS reporting and corresponding Criteria are associated with the Irish Sub-unit and Rock and Biogenic Reefs (Cluster 4). The Irish Sub-unit was partitioned in a second cluster (Cluster 5) together with Fish group and Criteria from Descriptor 3 - Commercial fish and shellfish and the Portuguese Sub-unit (see Table 3 and Fig. S2).

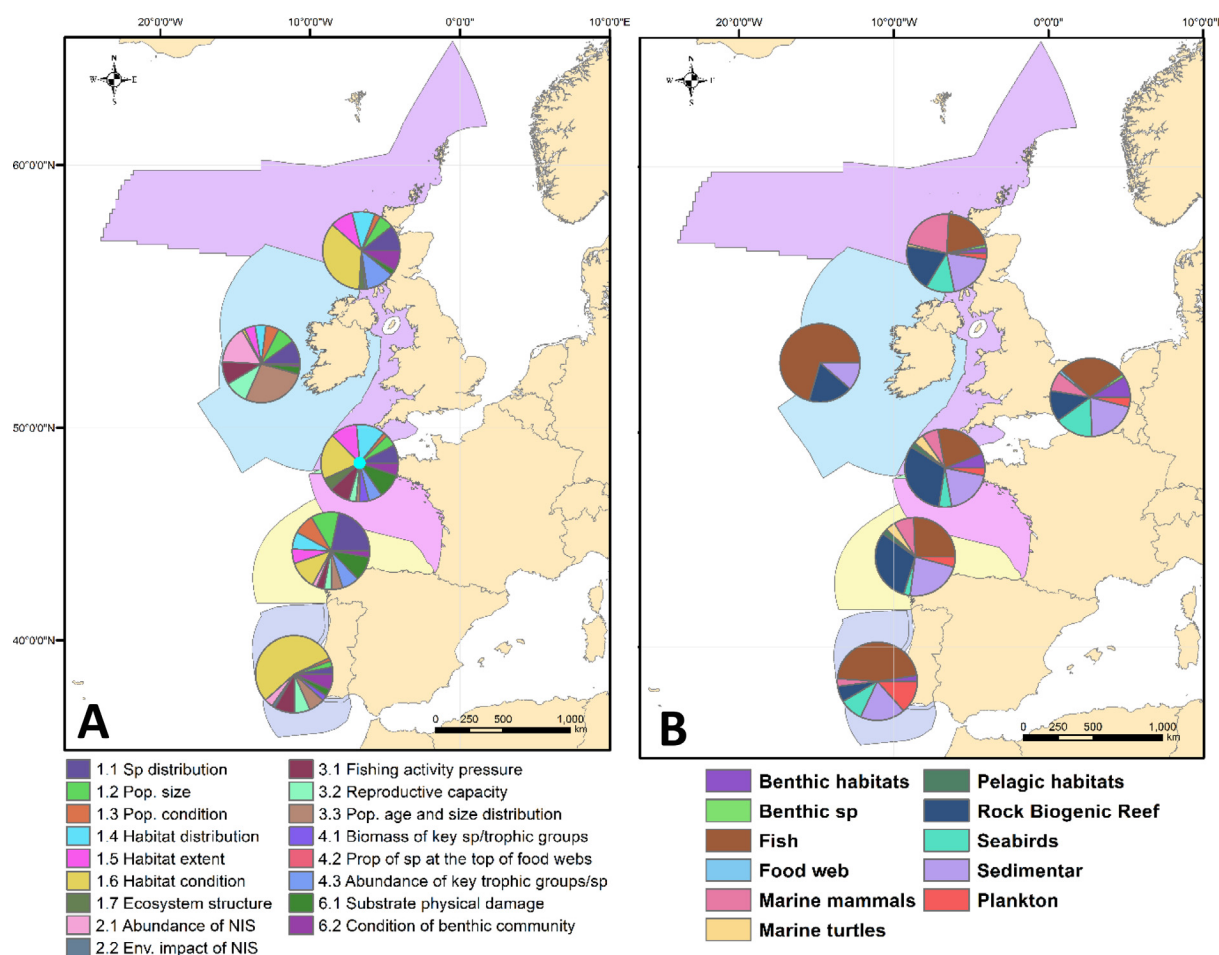


Fig. 2. A: Frequency distribution (%) of reporting per each Criteria and Member State; B: Frequency distribution (%) of reporting per Groups and Member State (see Table 1 for codes on Criteria and Groups).

Table 2

Goodness-of-fit statistics for the Generalized linear models (GLMs) with Poisson distribution applied to the average number of criteria reported (i.e., reporting level) per Biogeographic Region, Marine Sub-unit, Criteria, Group and their corresponding interaction.

Model	Residual	Deviance	% Expl	p-value
Biogeographic Region	4285.9	5.3	0.124	0.0213
Biogeographic Region (Marine Sub-unit)	4173.3	117.9	2.624	0.000
Criteria	3620.8	670.4	12.875	0.000
Group	2619.4	1671.8	23.336	0.000
Biogeographic Region (Marine Sub-unit): Group	2155.6	2135.6	10.808	0.000
Biogeographic Region (Marine Sub-unit): Criteria	1316.5	2974.7	19.554	0.000
Total explained			69.321	

3.2. Time range variability

Temporal scales varied largely across all factors under study: Biogeographic Region, MS, Marine Sub-unit, Descriptor, Criteria, and Group (Fig. 4). Average Time range was wider for Bay of Biscay and Iberian Peninsula and for France and Spain. As for Marine Sub-units, French Bay of Biscay reported the widest ranges (average range of 28.4 years). Descriptor 4 – Food-webs and 2 – Non-Indigenous species presented the largest time scales (with an average range of 25.3 and 20.8 years, respectively) and were represented by Criteria 4.1 *Productivity of key species/trophic groups*, 4.3 *Abundance of key trophic groups/species*, and 2.1 *Abundance of NIS*. Marine Turtles presented the

widest time scales followed by the Benthic Species Seabirds group (51.5, 21.9 and 21.6 average temporal range) (Fig. 4).

GLMs showed that all tested factors influenced mean Time range of reporting (Table 4). The GLM model that most influenced mean Time range was the interaction of Marine Sub-units (nested in Biogeographic Region) and Group (15.88% of deviance explained; $p = 0.000$). The interaction between nested Marine Sub-unit and Group showed that the widest Time ranges were used to report Marine Turtles by French Celtic Seas and French Bay of Biscay (with 102.0 and 58.3 years in average); Plankton and Food-webs in Spain (20.5 and 20.0 average years); Seabirds in the UK (27.0 average years) and Fish in Portugal (with 16.5 average years) (Fig. 5A). Criteria explained 14.58% of the variance and, when in interaction with Marine Sub-unit (nested within Biogeographic Region), explained as much as 12.01% (Table 4; Fig. 5B). Marine Sub-unit/Criteria interaction showed that 3.1 *Fishing activity pressure* and 4.1 *Biomass of key species/ trophic group* were highest for French Celtic Seas (with 29.9 and 28.9 years in average) followed by 4.3 *Abundance of key trophic groups/specie* and 4.1 *Biomass of key species/ trophic group* for French Bay of Biscay (with 26.6 and 26.1 years in average). Criteria 4.1 *Biomass of key species/ trophic group* was widest in the Portuguese Sub-unit and 1.3 *Population condition* in Spain (21.30 and 20.8 average years). On the other hand, mean Time range for Descriptor 2 – NIS was very low for all Sub-units except for the UK, Ireland and Spain that presented historical data on NIS (Fig. 5B). Marine Sub-unit nested within Biogeographic Region explained 13.32% of deviance ($p = 0.000$); French Bay of Biscay and Spanish Bay of Biscay presented the widest time-scales (average Time range of 18.6 and 16.0 years) and were significantly higher than the corresponding Portuguese unit.

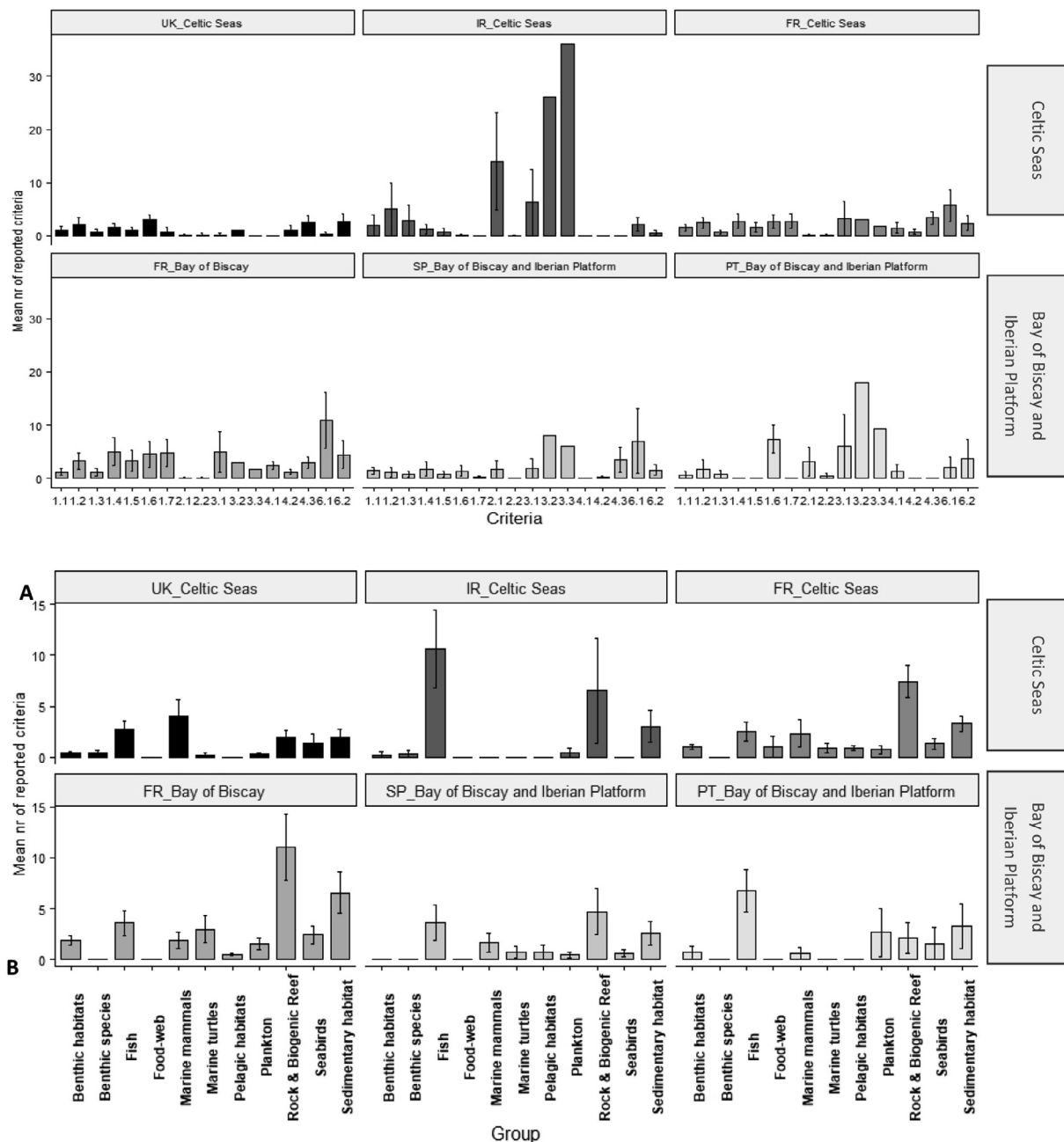


Fig. 3. Average reporting number of criteria (lines above bars represent \pm SE) per Criteria, Marine Sub-unit and Biogeographic Region (A) and average number of criteria (lines above bars represent \pm SE) reported per Group, Marine Sub-unit and Biogeographic Region (B) (see Table 1 for codes on Criteria and Groups).

French Celtic Seas and Ireland presented the lowest average reporting time (average Time range of 10.5 and 7.8 years).

The first two dimension of the FAMC explained 16% of the variability. Geographically related variables were the most relevant for Dimension 1 (e.g. Marine sub-unit and Biogeographic Region), while Dimension 2 was mostly explained by Criteria and Group (Fig. 6B). Although in a less extent, Time range, and Initial year of reporting also contributed to explain variability (Fig. 6A). Using a statistical probability of 0.05, a similarity threshold was automatically defined by a Cluster Analysis that resulted in four clusters. Clusters showed that time scales were highly related with Criteria, Marine sub-unit and Group (Figs. 6B; S3 and Table S1), suggesting that Time range used to report followed distinct patterns in accordance with these variables. Portuguese and Spanish Bay of Biscay and Iberian Platform data exhibited a similar intermediary Time range and Initial year of reporting. Both Sub-

units were included in the same cluster with Criteria 2.2 *Environmental impacts of NIS* and 1.6 *Habitat Condition* and Groups such as Benthic species, Rock & Biogenic Reef and Fish (Cluster 1). The categories most influenced by high Initial year of reporting and low Time range were Irish Celtic Seas, associated with Criteria 3.3 *Population age and size distribution*, 3.1 *Fishing activity pressure*, and Groups as Fish (Cluster 2). Although in a lesser extent, the third Cluster was also associated with short Time range, including Rock & Biogenic Reef, Sedimentary habitat, and Criteria such as 1.4 *Habitat distribution*, 1.5 *Habitat extent* and 6.2 *Condition of benthic community* together with Celtic Seas units (French and UK Celtic Seas; Cluster 3). A fourth cluster included Marine Turtles, Seabirds and Food-web data together with 1.7 *Ecosystem structure*, 4.1 *Biomass of key species/ trophic group*, and 4.3 *Abundance of key species*. This group was associated to the French Bay of Biscay region, high Time range and low Initial year of reporting (Cluster 4) (Fig. 6B).

Table 3
Cluster outputs obtained by the MCA analysis on reporting level (similarity level was established with a probability of 0.05).

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
6 – Seabed Integrity 6.1 Substrate physical damage 6.2 Condition of benthic community Rock & Biogenic Reef Sedimentary habitat Benthic habitats Bay of Biscay and Iberian Platform FR_Bay of Biscay and Iberian Platform SP_Bay of Biscay and Iberian Platform PT_Bay of Biscay and Iberian Platform Marine Turtles	1 – Biodiversity 1.6 Habitat Condition 1.5 Habitat extent 1.4 Habitat distribution 1.1 Species distribution 1.2 Population size 1.7 Ecosystem structure 1.3 Population condition Plankton Sedimentary habitats UK_Celtic Seas	4 – Food-webs 4.3 Abundance of key trophic groups 4.1 Biomass of key species/ trophic group Marine mammals 4.2 Proportion of species at the top of food webs Seabirds Marine Turtles FR_Celtic Seas Pelagic habitats SP_Bay of Biscay and Iberian Platform UK_Celtic Seas	2 – NIS 2.1 Abundance of NIS IR_Celtic Seas Rock & Biogenic Reef 2.2 Environmental impact of NIS Benthic species Celtic Seas 4.1 Biomass of key species/ trophic group 1.3 Population condition 1.7 Ecosystem structure 3.2 Stock reproductive capacity	3 – Commercial fish and shellfish Fish 3.3 Population size/age distribution 3.1 Fishing activity pressure 3.2 Stock reproductive capacity IR_Celtic Seas Celtic Seas PT_Bay of Biscay and Iberian Platform 2.2 Environmental impact of NIS Marine Turtles Pelagic habitats

4. Discussion

MSFD implementation involved a great effort from MSs in searching, compiling, analysing, and reporting marine environment data. This unprecedented effort allowed MSs to achieve a high-level overview of existing information while concomitantly exposing existing problems. Analyses of the 1st implementation cycle, such as [Hummel et al. \(2015\)](#) and [Palialexis et al. \(2014\)](#), provided an holistic view of the MSFD implementation. These authors highlighted how differently each MS reported. However, their scope was limited to the evaluation of implementation of Descriptor 1 ([Hummel et al., 2015](#)) or Descriptors 1, 2, 4 and 6 ([Palialexis et al., 2014](#)). Consequently, and due to the overarching aim of the MSFD, several critical aspects are yet to be addressed. By looking into the specific case study of two Biogeographic Regions, the present work showed how MSFD reporting level and, for the first time, temporal scales varied among sub-units and MSs within the same regional seas and RSC – i.e., OSPAR ([OSPAR Commission, 1992](#)).

Overall, different MSs sharing the same region reported differently, which highlights the need for further synchronization across neighbouring MS and Marine Sub-units. French Sub-units presented higher implementation rates and Ireland showed a different strategy from the additional Celtic Seas Marine Sub-units. Ireland reported a large number of indicators, but focused on Fish Group and Criteria from Descriptor 3 – Commercial Fish & Shellfish and Descriptor 2 – NIS and Benthic species, thereby unbalancing MSFD implementation in the Celtic Sea region. This strategy is likely a result of a larger investment made by Ireland in obtaining data on commercial stocks. Due to their economic value and consequent commercial exploitation, fish populations have received a greater attention by the EU. The implementation of the CFP has obliged MSs to perform annual stock assessment and created a vast monitoring network ([European Commission, 2015](#)). Nevertheless, within each Biogeographic Region, countries should agree on what fish species need to be reported in order to guarantee congruency and Fish Criteria is not over/under-estimate in the same region. On the other hand, Irish results can also evidence different reporting strategies and/or commitment by different institutions; thereby, affecting reporting level and quality of information across descriptors. The distinctive implementation and lack of coordination between national institutions was already pointed out by [Cavallo et al. \(2017\)](#). However, this question can only be addressed by a dedicated study, focused on implementation differences driven by reporting institution. Criteria and Groups from Descriptor 4 – Food-webs and Descriptor 2 – NIS were significantly underreported when compared to criteria from Descriptors 1 – Biodiversity and 3 – Commercial Fish and Shellfish. Although related to the MSFD design, these outputs can also be associated with methodological weaknesses and the lack of fully operational indicators and data concerning these Descriptors ([ICES, 2015](#); [Lehtinen et al., 2016](#); [Palialexis et al., 2014](#); [Rombouts et al., 2013](#)). Descriptor 4 – Food-webs requires the establishment of relations between trophic levels and relies on long term datasets for implementation, but data gaps and incongruences within and across MSs are hindering its efficient application. Nonetheless, the development of new metrics, methodologies, and modelling tools are expected to increase Descriptor 4 -Food-webs assessment and reporting ([Borja et al., 2016b](#); [Heiskanen et al., 2016](#)). Descriptor 2 – NIS was also significantly underreported, which is driven by NIS impacts on ecosystems being a relatively recent problem when compared to other, well studied, human impacts (e.g. fisheries, etc.) ([Heiskanen et al., 2016](#)). Information from previously implemented directives (e.g. WFD, Birds and Habitats Directives and Common Fisheries Policy (CFP)) was often used in the MSFD reporting. This resulted in high reporting level of Descriptors 1 – Biodiversity and 3 – Commercial Fish and Shellfish and functional groups such as Fish, Birds, and Rocky & Biogenic Reefs. The use of data from previous Directives is highly recommended in order to concentrate efforts, avoid duplication of work, and stick to the very ambitious time frame of the

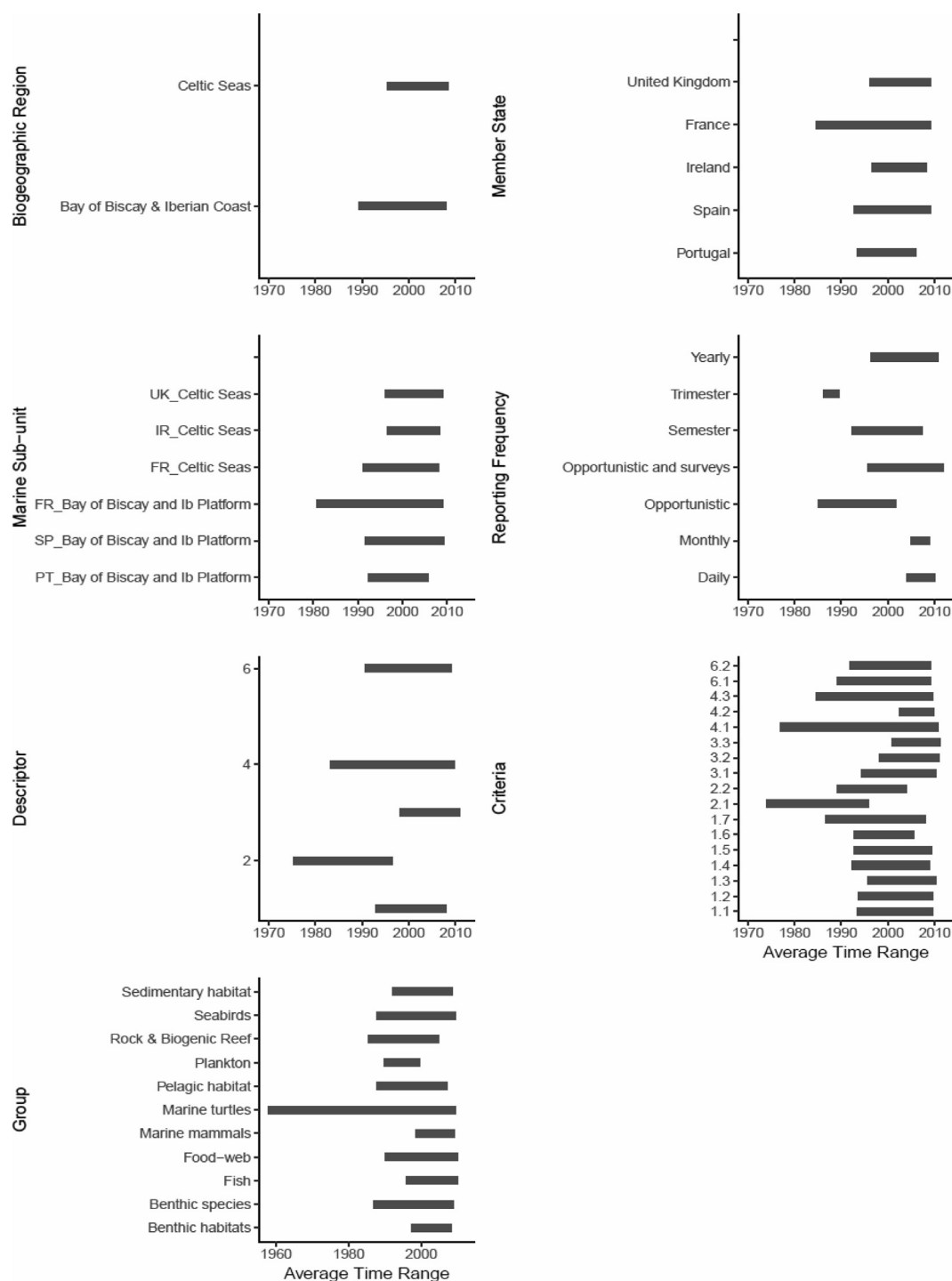


Fig. 4. Average initial and final reporting date per Member State, Marine Sub-unit, Biogeographic Region, Descriptor, Criteria and Group (see Table 1 for codes on Descriptors, Criteria and Groups).

MSFD. Inclusively, high level assessments of the 1st implementation cycle have concluded that MSs should go even farther in what regards using data from earlier policies (Bigagli, 2017; Palialexis et al., 2014). However, data from previous Directives should be carefully selected and standardized as it was partially collected during national monitoring programmes that sometimes failed to focus in regional features, do not consider an inter-sectorial approach and therefore do not support an integrative EBA.

Temporal scales' variability was mostly explained by different Groups across each Marine Sub-unit (Fig. 6). Bay of Biscay presented superior implementation rate and reporting time scales, suggesting that

data sets in the region are consistent and lengthier. French units and Spanish Bay of Biscay used a wide temporal window to assess Marine Turtles and Food-webs criteria (e.g. 4.1 and 4.3), employing historic stranding data to report biological groups such as Marine Turtles and Marine mammals'. These data sets reached as far as 100 years' time span and were not reported congruently across MSs. Depending on the MS, these data sets were used to assess tendencies and/or to establish historical references, but their use should be restricted to the establishment of baselines/references, since stranding data can lack representability and statistical credibility (Peltier et al., 2014). On the contrary, Groups from Descriptor 2 - NIS were reported using the lowest

Table 4

Goodness-of-fit statistics for the Generalized Linear Models (GLM) with Gaussian distribution applied to the Time Range (years) used to report under the MSFD.

Model	Residual	Deviance	% Expl	p-value
Biogeographic Region	1429.90	112.10	7.27	0.000
Biogeographic Region (Marine Sub-unit)	1224.50	317.50	13.32	0.000
Criteria	999.61	542.39	14.58	0.000
Group	841.09	700.91	10.28	0.000
Biogeographic Region (Marine Sub-unit) * Criteria	655.92	886.08	12.01	0.000
Biogeographic Region (Marine Sub-unit) * Group	411.06	1130.94	15.88	0.000
Biogeographic Region (Marine Sub-unit) * Criteria * Group	374.03	1167.97	2.40	0.000
Total explained			5.74	

Time range. Both descriptors were strongly influenced by the use of historic monitoring networks (Descriptor 4– Food-webs) and sporadic research studies (Descriptor 2 - NIS) (e.g. historical marine turtles stranding networks, recent NIS monitoring programs) (Heiskanen et al., 2016), that increase incoherence. These datasets also have shortcomings, such as distinct methodologies and/or sampling designs and are not directly comparable between Marine Sub-units from the same

regional sea or even from the same MS (Palialexis et al., 2014). Overall, for contemporary comparison between territories, the use of historical and opportunistic data for assessment should be discouraged. For this purpose, data should be obtained through integrated and harmonised tools and indicators should be measured in the same timeframe. Other Marine Sub-units, such as the UK and Ireland, have founded their reporting in consistent medium- (the UK) to short-term (Ireland) monitoring programmes (Patrício et al., 2016), but lack synchronized initial/end time of reporting. As a result, data sets and their corresponding temporal scales are not comparable and require further harmonization. Although included in distinct Biogeographic Regions, Portugal and the UK used a similar mean Time range but focused on different ecosystem features and Criteria type. Portugal mostly reported Fish Group, while the UK Celtic Seas focused on Seabirds and 4.3 Abundance of key trophic groups criteria, somewhat similarly to the Irish Celtic Seas but different to French Celtic Seas. Irish data consistently exhibited a low Time range of reporting, and high (recent) Initial report date (i.e. 1997) (Fig. 6). Descriptors 1 - Biodiversity and 3 – Commercial Fish and Shellfish exhibited a similar mean Time range, reflecting the use of data from previously implemented Directives. However the average initial/end time for each Descriptor was not synchronized across Marine Sub-units and, therefore, GES was assessed with data from distinct temporal windows at the sub-regional and regional level.

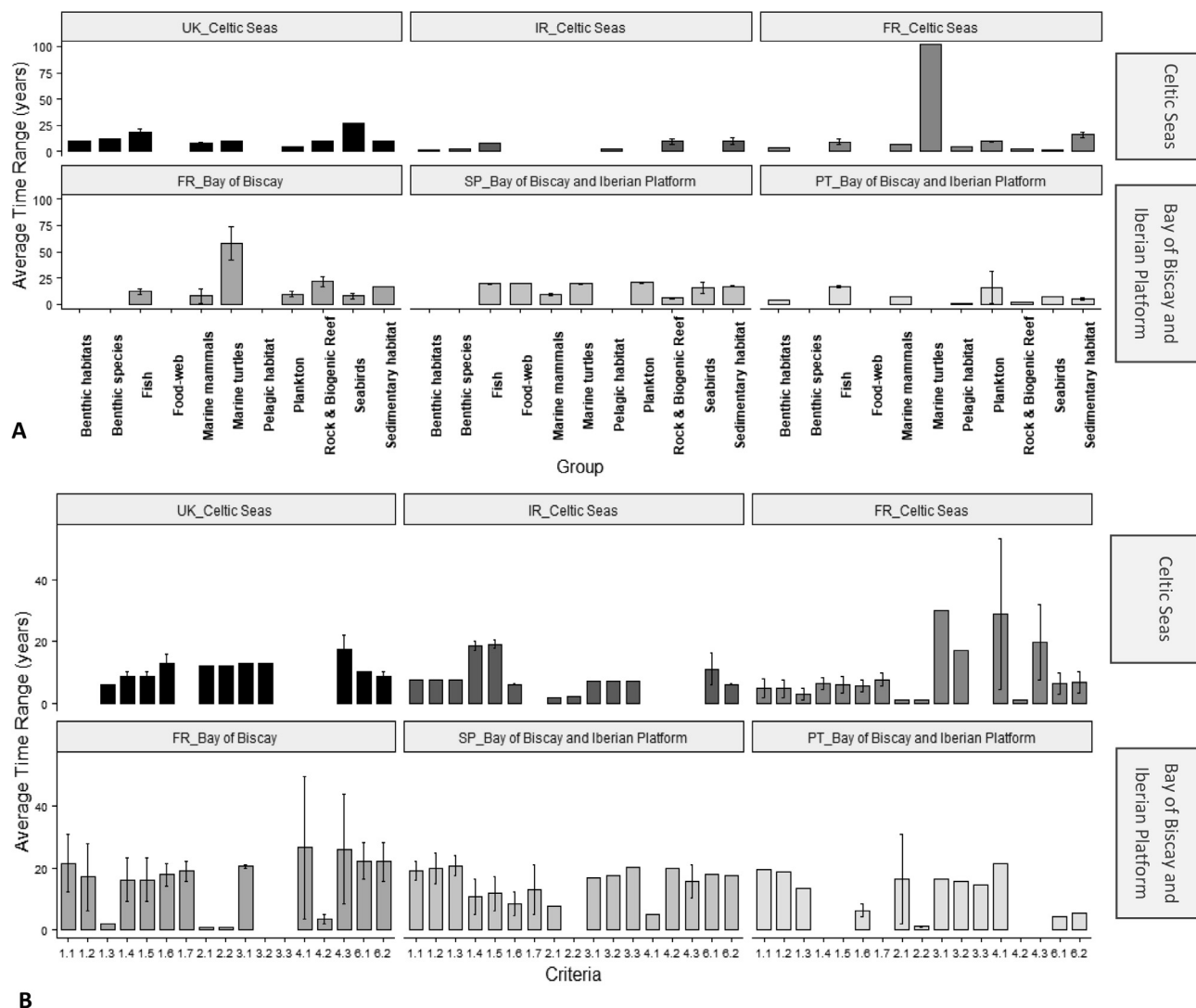


Fig. 5. Average time-range (lines on bars represent \pm SE) per Group, Marine Sub-unit and Biogeographic Region (A); average time-range (lines on bars represent \pm SE) per Criteria, Marine Sub-unit and Biogeographic Region (B), (see Table 1 for codes on Criteria and Groups).

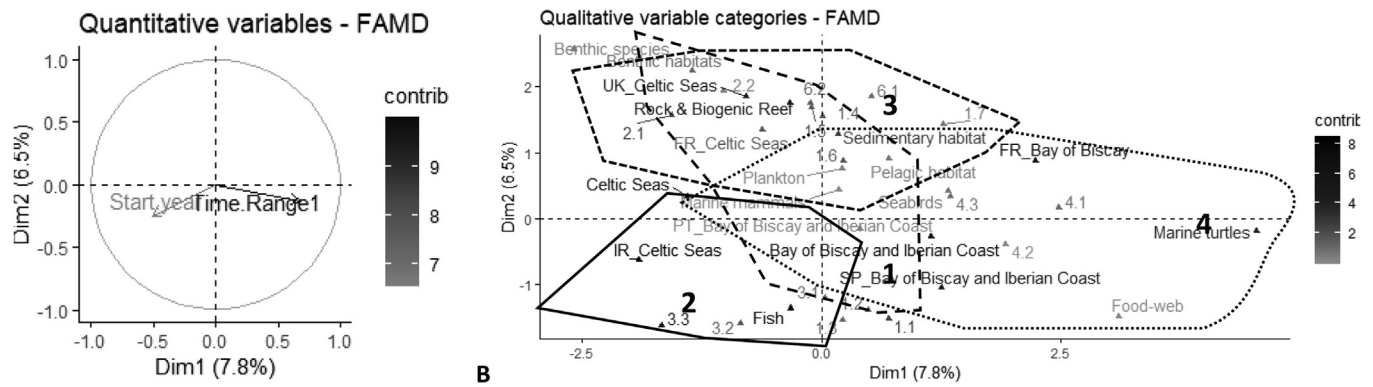


Fig. 6. FAMD results showing the contribution of A) - quantitative variables: Time range and Start year/Initial year of reporting and B) qualitative variables: Biogeographic Region, Member State, Marine Sub-unit, Criteria and Group; numbers indicate Clusters and [Table 1](#) indicates codes for Criteria and Groups.

Nevertheless, the initial reporting date occurred in the previous three decades, matching the results pertinently obtained by [Patrício et al. \(2016\)](#) when assessing MSFD monitoring programmes.

The present study suggests that, for the 1st MSFD cycle, any integration method to combine data across Marine Sub-units, Criteria, and Group should be hindered since temporal scales varied significantly, and the associated uncertainty was not estimated. Furthermore, any management decision that is based on MSFD outputs should be made carefully. To improve MSFD congruency and to increase coordination mechanisms for Marine Sub-units of the same region, several measures need to be put in place. Marine sub-units should agree on the scales to be used in regional monitoring programs, while considering the specificities of the regional environment. More focus should be given to Descriptors 2 – NIS, 4 – Food-webs and 6 – Seafloor Integrity monitoring programs to increase reporting confidence of these descriptors. Further work should be developed concerning Descriptors 1 – Biodiversity and 3 – Commercially exploited Fish and Shellfish, since the time length is similar across Criteria/Groups, but it is not synchronized; the initial and final date of reporting should be decided at a regional level. Establishing an initial time point for reporting would improve commonalities among data sets and enable comparison and integration at a regional level. Congruency should be promoted in the selection and prioritization of targeted habitats and species that have been properly characterized by baseline studies at a regional level, following the recommendation of the Commission Decision 2017/848/EU ([European Commission, 2017](#)). This task has already been partially initiated for Descriptors 1 and 6 ([Palialexis et al., 2018](#)) but should be extended to all Biodiversity Descriptors. Lastly, reporting of opportunistic and historical data sets by MSs should be monitored and restricted to the establishment of reference values – more focus should be given to monitoring programmes that address regional seas or Biogeographic Region as a whole. This could be achieved by the development of guidelines at Biogeographic level, that address scales, targets, maximum uncertainty levels, and establishes thresholds, etc., together with a deeper calibration analysis to select inter-MS data to be considered in the regional assessment. Intercalibration, such as the one made for WFD, and uncertainty estimations can provide some perspectives on how to achieve further congruency. However, even though the MSFD and WFD overlap in some extent, the MSFD poses additional challenges, by targeting a much wider number of functional elements and a very wide-ranging criteria/indicators. To accomplish such measures and therefore improve regional coordination, the EC should develop policy instruments and focus in harmonizing methods, scales, and thresholds. Furthermore, Regional implementation could be enhanced by creating scientific institutions in each Biogeographic Region, that focus in the intercalibration and establishment of the regional goals previously suggested. Although very helpful, RSC consider highly diverse regions, their recommendations are not legally binding, and MS

have some freedom to implement the Directive ([Cavallo et al., 2018](#)). Consequently, MS are interpreting and implementing MSFD differently, in accordance with national data and without a regional/sub-regional perspective.

This political de-synchronization in MSFD implementation contrasts with EBA concept, since the assessment of ecosystems status and anthropogenic pressures should be detached from political borders and should rely in cooperation within RSC and Biogeographic Region. Even though factors behind reporting differences have been widely identified (e.g. MSs politics, policies, funding and even the distinct usage of maritime space ([Cavallo et al., 2017](#))), the present work discloses the factors behind temporal patterns and highlights aspects that need to be addressed to improve MSFD reporting: 1) unbalanced reporting – each Marine sub-unit is working separately; 2) temporal incongruence due to the use of historical and opportunistic data, and 3) unsynchronized time spans even if using similar data from identical monitoring programs established by previous directives (e.g. CFP, Habitats Directive, etc.). In conclusion, reporting level and time scales used to report biodiversity descriptors in the NE Atlantic Ocean indicate low cooperation and integration of MSs data within Biogeographic Regions, not only in terms of implementation but also in terms of monitoring networks and selection of datasets to assess GES. If no changes are made to the action plan, the main purposes of the MSFD – conservation and sustainability through and integrative ecosystem approach – is very likely compromised.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecolind.2019.05.067>.

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