Report on the potential of Argo to help in the MSFD

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EXECUTIVE SUMMARY

This report examines the current and potential contribution of the European Argo Infrastructure to the implementation of European Environmental Policies and specifically to the implementation of the Marine Strategy Framework Directive. The latter is described focusing on its monitoring specifications which are identified by the concept of the description and assessment of the Good Environmental Status (GES). The Argo monitoring activities across the European Seas are presented, with a focus on the Euro-Argo ERIC's efforts to enhance the environmental component of Argo data. The investigation of the existing contribution of Argo to the MSFD's national and regional initiatives is currently restricted to the assessment of a few descriptors such as D7 (hydrographical conditions) and D5 (eutrophication). The ongoing process moreover is characterized by various constraints and weaknesses. Nevertheless, the increased potential of Argo to provide additional valuable information for the GES is also underlined, highlighting the particularly important role of Argo for the MSFD implementation in the near future.

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1 Introduction – General framework

Climate change and anthropogenic pressures on ecosystems have become prior concerns of societies and nations worldwide. Under this context, environmental assessment, protection, and sustainability are amongst the most emerging priorities of nations and global research communities. With regards to the aquatic environments, and especially the marine, such pressures are multiple and diverse. Accordingly, the protection of coastal and open-water environments is a complex and multi-faceted problem that needs to be approached under transnational cooperation. Within the European nations and under the guidance of the European Union (EU) policies, several actions have been either planned, proposed, or are already under implementation regarding these issues. The EU legislation for the protection of the marine environment has been progressively implemented in many relevant areas. Such examples are the regulation of fisheries through the Common Fisheries Policy (CFP) (https://ec.europa.eu/oceans-and-fisheries) and the assessment on the quality of the coastal water environments through the Water Framework Directive (WFD) https://ec.europa.eu/environment/water/water-framework). Following these regulations, and in order to generalize actions towards a more holistic approach, the EU adopted additional instruments during the first decade of the 21st century. These are namely the 2002 EU Recommendation on Integrated Coastal Zone Management (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002H0413) in 2002 and the Marine Strategy Framework Directive (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056) in 2008**,** both forming a more comprehensive and integrated approach to the protection of all European coasts and marine waters under the concept of an Integrated Maritime Policy (IMP) https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy).

With regards to the MSFD, this is a directive (2008/56/EC) of the European Parliament and of the Council that was implied on 17 June 2008 and established a framework for community action in the field of marine environmental policy. The MSFD is based on the concept of the description and achievement of the so-called Good Environmental Status (GES) (https://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm). Being the main goal of the MSFD, the achievement of GES is defined as a sustainable environmental status of the European marine waters where these provide ecologically diverse and dynamic oceans and seas that are clean, healthy and productive and ensure their continuity for future generations. This implies a variety of activities and measures that strongly involve marine monitoring techniques and infrastructures (Fig. 1). The plurality of scientific fields involved along with the wide spatiotemporal scale monitoring, and the diverse assessments and measures that need to be implemented, makes MSFD one of the most challenging missions the European marine research community has to face.

Figure 1. The proposed activity chain to be followed by the EU member-states for the implementation of the MSFD. https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/reports_en.htm.

As MSFD focuses on the offshore areas, it seeks input from datasets that will contribute to the status assessment of the European seas. Under this context, the European marine in-situ monitoring networks and infrastructures are vital components for successful MSFD outcomes and the monitoring array of Argo floats can be a key player amongst its data providers. For more than 20 years, the Argo monitoring array has been providing unprecedented amounts of high-quality and cost-effective data (Riser et al. 2016) and has evolved to the main component of the 3-D global ocean observing system reaching a number of almost 4000 active floats (Fig. 2). Currently, amongst the ongoing activities of the Argo program is the extension into regions that were previously under-sampled such as the ice-covered regions and the marginal seas (Jayne et al., 2017). Such an extension largely relies on the combined efforts of national and international Argo initiatives. Apart from being the major contributor to the physical oceanography basic research in terms of in situ observations, the Argo Program is nowadays essential also for climate assessment studies, and ocean state analysis and forecasting. Furthermore, Argo provides valuable information complementary to the satellite ocean-observing system, and also an important contributor to the MSFD, enhancing long-term reanalyses and predictions of the ocean's state (Le Traon, 2013).

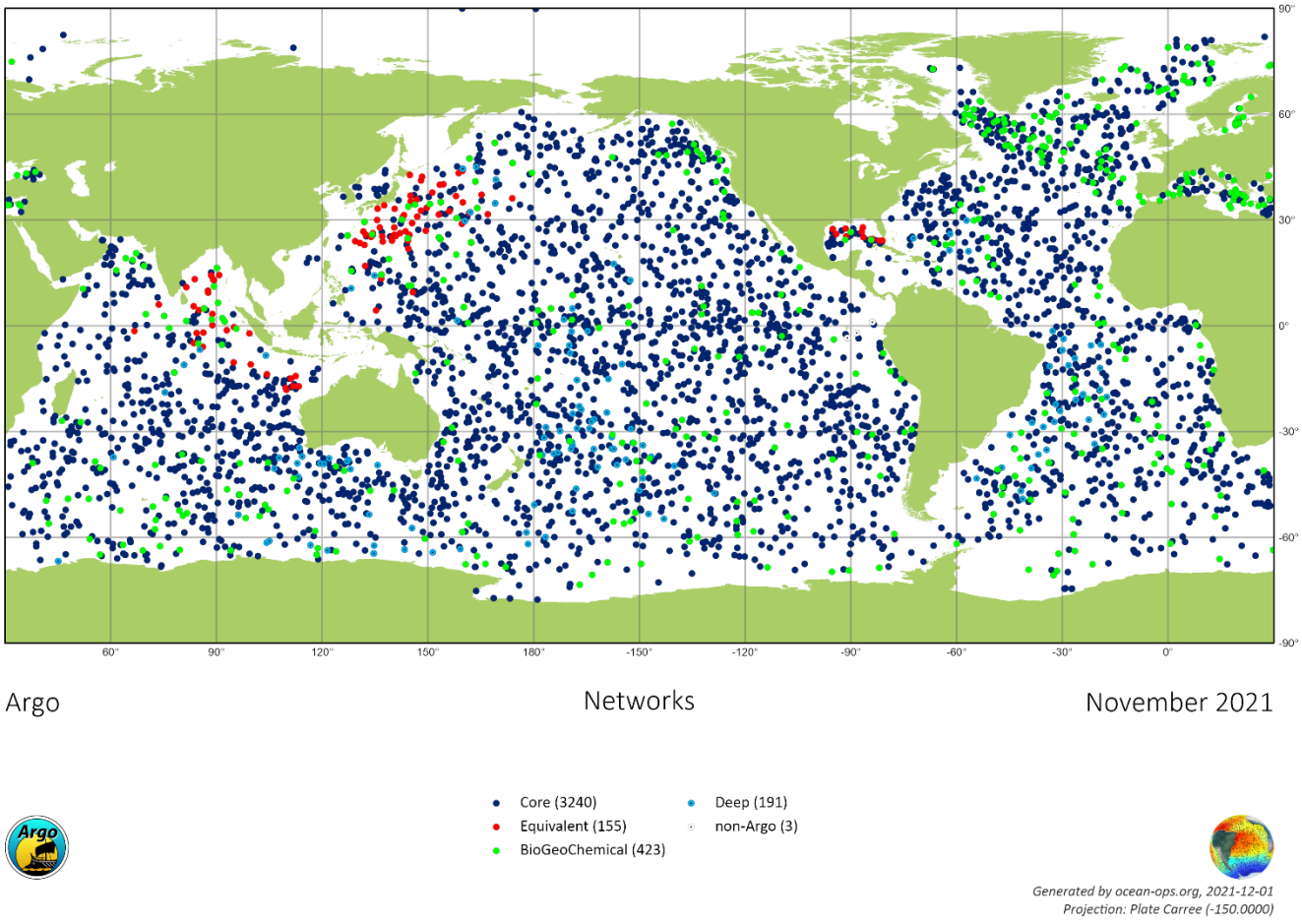

Figure 2. The status of the global active Argo network as of November 2021 (https://www.ocean-ops.org)

The contribution of Argo to the MSFD is also strongly related to the subset of Argo data that refer to the European Marginal Seas. Under this aspect, Euro-Argo European Research Infrastructure Consortium (ERIC) became the primary speaker with the MSFD community. Euro-Argo has timely adopted a plan for better coverage of the European Marginal Seas (Euro-Argo ERIC, 2017). Furthermore, it provides open, free, and quality checked, both in real-time and in delayed mode, ocean data, thus, the potential to contribute to the description of GES is big. Currently, the European Argo contribution counts more than 800 active platforms with a big percentage of these operating across the European Seas (Fig. 3) and thus, within the interests of MSFD. Additionally, the development of extensions towards high latitudes and biogeochemistry gives access to new types of data particularly valuable for MSFD which in turn can become Euro-Argo's new strategic driver.

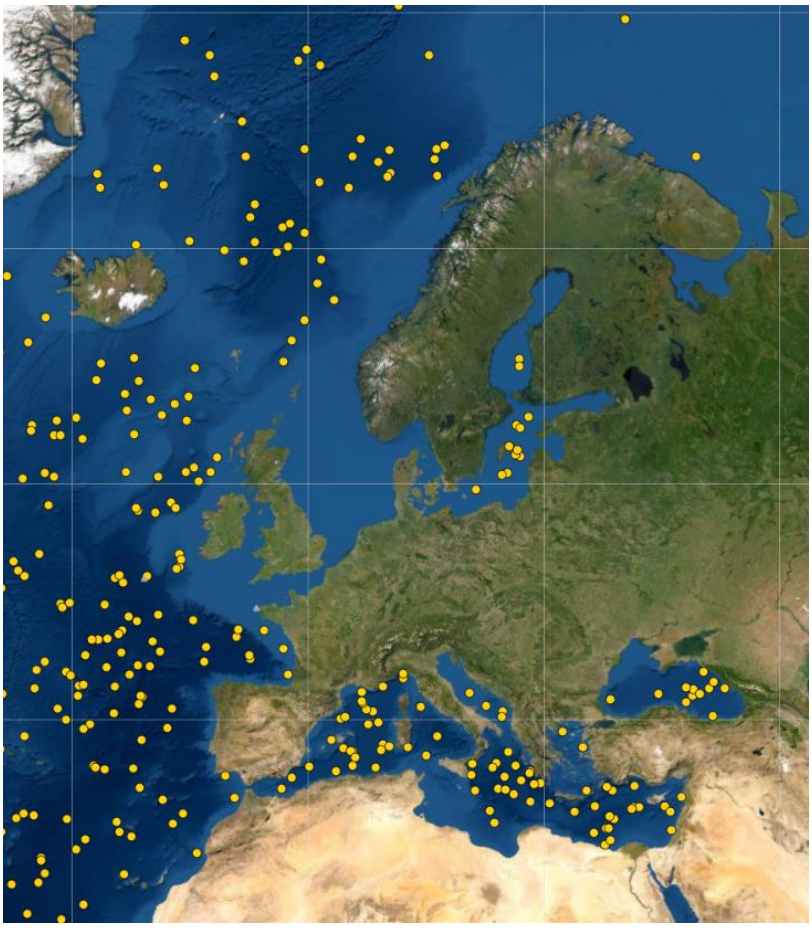

Figure 3. The status of the active European Argo network array across the European Continent in December 2021 (https://fleetmonitoring.euro-argo.eu)

In the following chapters, this report provides further information on the requirements of MSFD implementation in relation to the Argo potential in the European Seas. The current status is investigated for several national activities, and at a regional and pan-European level. Future steps and recommendations are further discussed in an attempt to identify gaps and weaknesses, but also highlight the continuously increasing potential of Argo to become a strategic contributor not only for the MSFD but for the European environmental policy in general. More specifically, in chapter 2, the European marine environmental framework is presented, focusing on the GES description and MSFD implementation requirements. In chapter 3 the Argo infrastructure is presented in relation to environmental monitoring and climate change. Chapter 4 presents the current and potential links between MSFD activities and Argo infrastructure in conjunction with other European and international initiatives. Finally, in chapter 5, specific reported activities and progress are listed whilst future planning and recommendations are summarized.

2 Marine Environmental Policy for the European Seas

2.1 The Marine Strategy Framework Directive

The environmental strategy of Europe largely lies at the heart of the EU policy agenda. Being a maritime continent with an extensive coastline, oceans and seas, Europe focuses on marine protection and sustainability. This is expressed within various EU plans, policies, and directives. The Integrated Maritime Policy (IMP) is one example aiming to promote the sustainable growth of the maritime economy and the coastal regions. This will rely on the coordination between the different sectoral policies and on the development of cross-cutting tools to respond to maritime challenges. Under IMP, national, pan-European, and international cooperation play an important role since marine ecosystems transcend national boundaries and borders. Thus, for the preservation of Europe's seas, oceans, and marine environment and in order to address future challenges, an integrated approach is needed that requires international cooperation. Similarly, under the European Green Deal, an integrated approach is followed including several priorities for marine environment preservation such as the protection of biodiversity, the reduction of pollution, the strengthening of circular economies, the improvement of waste management, and the achievement of a sustainable blue economy.

The MSFD is following similar approaches, however under a more focused target on the protection and preservation of the marine environment, which is adversely affected by human activities. Imposed in 2008, MSFD emerged from the need of Member States to ensure that the anthropogenic impacts on the marine biodiversity and marine ecosystems are insignificant (https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive). Thus, according to the Directive, each Member State must implement a marine strategy, which will be renewed every 6 years, for its marine waters, in cooperation with neighbouring Member States. Under the MSFD, a general strategy is proposed for each Member State that comprises 5 steps: a) an initial assessment of their marine waters, b) the determination of the good environmental status of their marine waters, c) the setting of environmental targets, d) the establishment and implementation of coordinated monitoring programmes, and e) the identification of measures or actions that need to be taken in order to achieve or maintain good environmental status.

An important step for the achievement of MFSD's goal is the establishment of well-defined European marine regions and sub-regions on the basis of both geographical and environmental criteria. For this scope, four main European marine regions, located within the geographical boundaries of the existing Regional Sea Conventions cooperation between the Member States, are described under the Directive namely: a) the North-east Atlantic Ocean, b) the Baltic Sea, c) the Mediterranean Sea and, d) the Black Sea (Fig. 4). A further division into sub-regions has been also implied on the North-east Atlantic Ocean and the Mediterranean Sea which are divided into four sub-areas each forming: a1) the Greater North Sea (including the Kattegat and the English Channel), a2) the Celtic Seas, a3) the Bay of Biscay and the Iberian Coast, a4) the Macaronesia, c1) the Western Mediterranean Sea, c2) the Adriatic Sea, c3) the Ionian Sea and the Central Mediterranean Sea, and c4) the Aegean-Levantine Sea (Fig. 4).

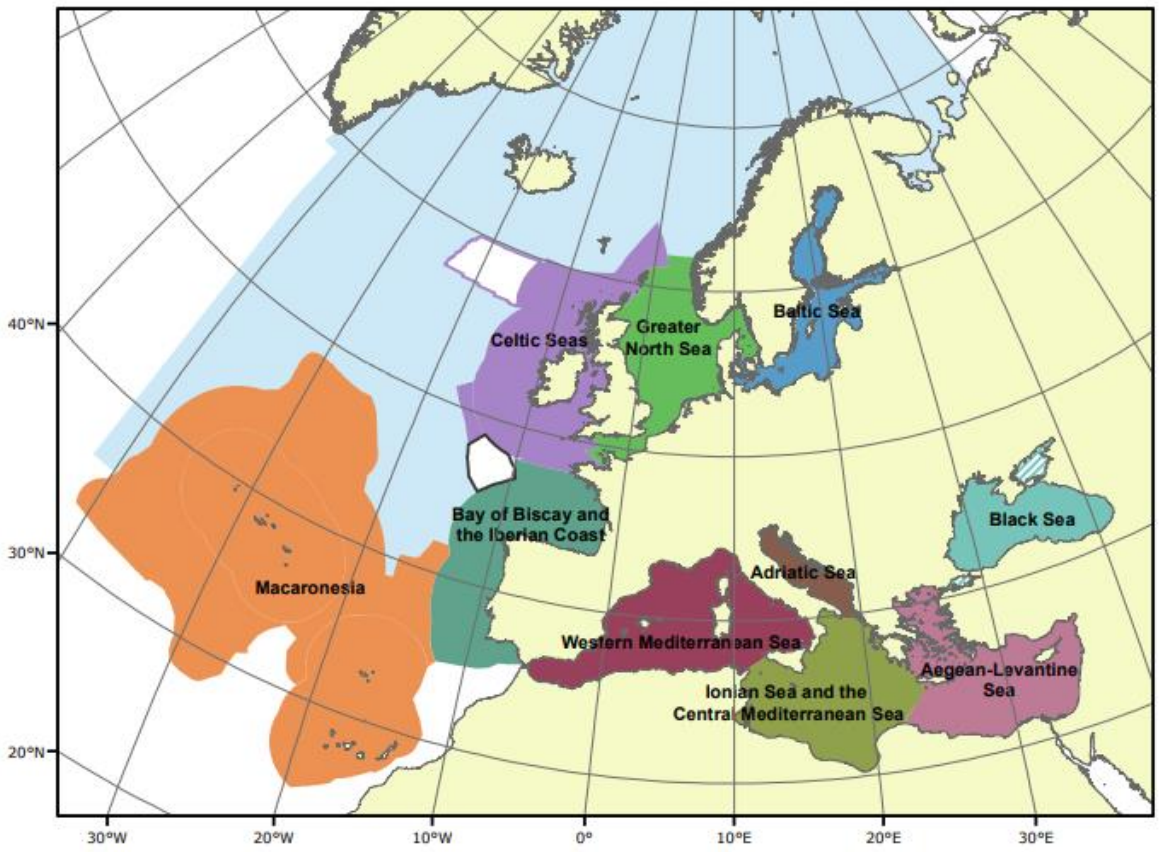

Figure 4. Representation of the marine regions and sub-regions of MSFD Article 4. https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions Disclaimer: *"This map serves as a working tool only and shall not be considered as an official or legally-binding map representing marine borders in accordance with international law. This map shall be used without prejudice to the agreements that will be concluded between Member States or between Member States and non-EU states in respect of their marine borders."*.

In relevance to the main regions described in the MSFD monitoring plan, the Directive remains in close collaboration and in line with the action plan of regional conventions that were adopted several years before. These are:

1. The Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean adopted in 1995
2. The Bucharest Convention on the Protection of the Black Sea against Pollution adopted in 1992
3. The Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area adopted in 1992
4. The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic 1992

The environmental action plan, identified within these intergovernmental initiatives, has also adopted parts of the MSFD strategy and the concept of the Good Environmental Status. The latter is proposed in the Directive in order for each Member State to be able to assess in both qualified and quantified manner the status of their waters. Under this context, several MSFD descriptors were defined and the national programmes should address each of these descriptors according to several criteria that each

descriptor has. The first stage of the assessment reporting was finalized in 2014 (Fig. 5) when the directive was updated and specifications were given for measures that should as a whole aim to ensure that environmental targets are addressed and good environmental status (GES) is achieved or maintained by 2020.

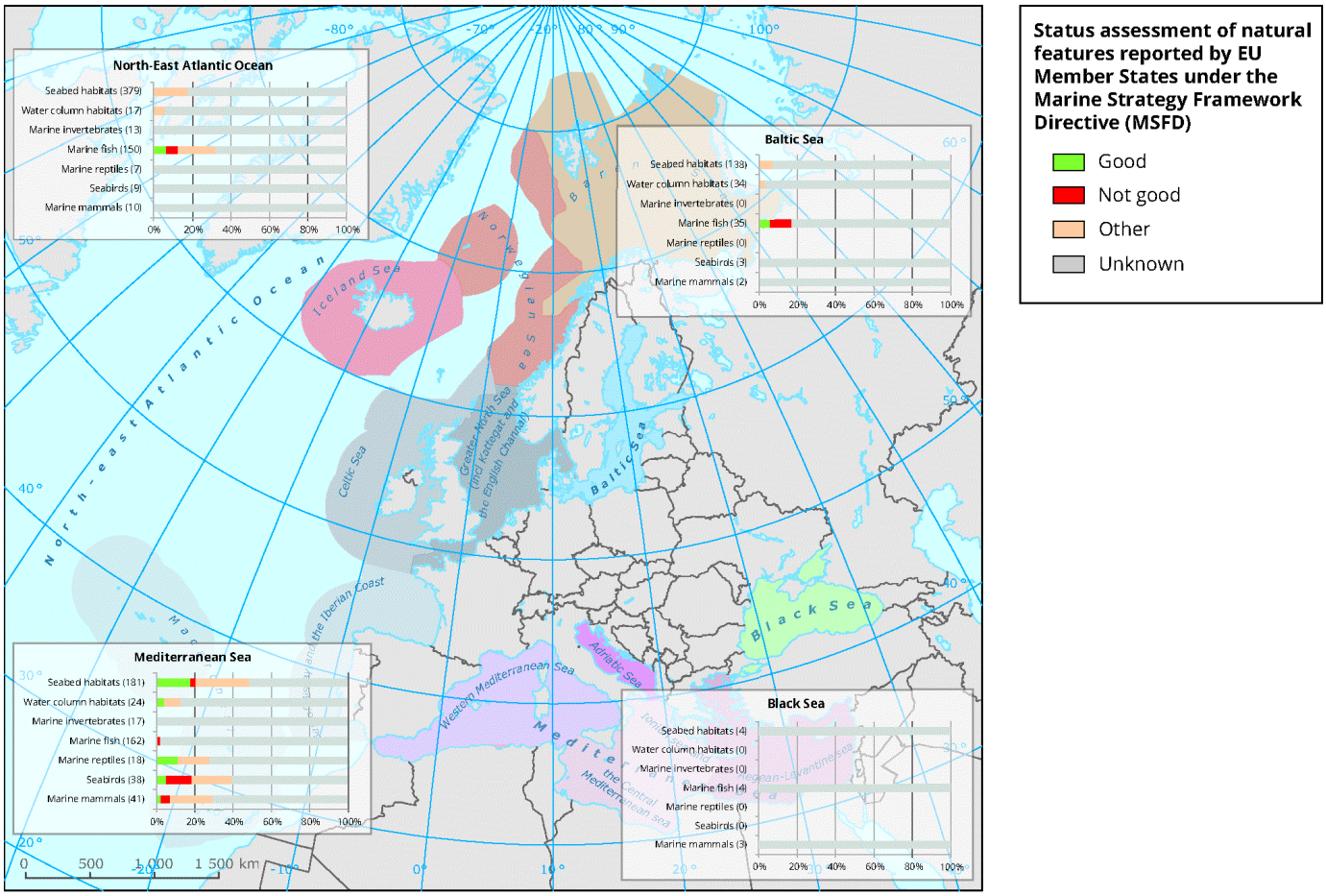

Figure 5. Integrated results per region from the 2012 MSFD reported status assessment (https://www.eea.europa.eu/data-and-maps/figures/status-assessment-of-natural-features-1)

In 2017, the European Commission (COMMISSION DECISION (EU) 2017/848 of 17 May 2017) has laid down updated criteria and methodological standards for the GES along with specifications and standardised methods for monitoring and assessment of marine waters (repealing Decision 2010/477/EU of marine waters). On 31 July 2018, the Commission adopted the assessment report of national programmes, identifying whether they constitute an appropriate framework within the requirements of the MSFD and whether they address the pressures that the EU seas and oceans are facing. The Commission's conclusion was that although considerable efforts have been made by Member States, not all pressures are covered properly by the measures. The Commission, therefore, provides recommendations to the Member States to guide them in accordance with Article 16 of the Directive.

2.2 The GES description

The concept of the Good Environmental Status for the European Seas is based on several general principles that can be summarized under the sustainability of the oceanic environmental status and the health of the marine ecosystems. These principles include a variety of definitions regarding environmental functioning and resilience to human-induced pressures. These include, amongst others, the ecosystem hydro-morphology, its structure and evolution, the physical and biogeochemical conditions, the status and protection of biodiversity, and the introduction of substances and energy into the marine environment by human activities. The monitoring and assessment of all these topics is a very complicated task and thus, MSFD, in order to assist the Member States to interpret GES, has defined eleven qualitative descriptors describing the desirable environmental status after the GES achievement (Fig. 6).

Figure 6. The eleven descriptors described in the GES

These descriptors are related to specific topics that are applied in multi-scientific fields and are related to ecosystem health and functioning (Table 1). Each Descriptor is further divided into two or more Criteria that describe specific parameters to be addressed. In 2017, the updated Commission decision proposed an improved way of determining GES. It contains a number of new criteria and methodological standards, in relation to the 11 Descriptors of GES that were laid down in Annex I of the Directive. Apart from criteria and standards, the Decision also contains specifications and standardised methods for monitoring and assessing marine waters. The Decision is a major stepping stone to establish precise objectives for the achievement of GES within the implementation of the MSFD, thereby providing a picture of the extent to which good environmental status is achieved in the European seas and oceans. More specifically, this new framework tries to create more comparability and consistency for the outcomes across the Member States, focusing on the extent to which GES is. This requires the setting of "threshold values", thereby contributing to an improved and clearer way to achieving environmental objectives. Additionally, under the new framework, more flexibility is given to the Member States in order to focus their efforts on the main problems for their marine waters. Thus, each Member can extract criteria that are not relevant for their monitored areas, or apply a risk-based approach to the implementation of their marine strategies. Finally, the new framework

promotes cooperation and synergies of Member States in a regional or sub-regional context, often through the work developed by the Member States in Regional Sea Conventions.

Table 1. Targets of the GES Descriptors and main effects and pressures associated with them

Descriptor	Descriptor's target	Main pressures and effects
1	Biodiversity is maintained	Fisheries, shipping, sea warming, ocean acidification, T/S alternations
2	Non-indigenous species do not adversely alter the ecosystem	Ballast water, ship fouling, sea warming, T/S alternations
3	The population of commercial fish species is healthy	Overfishing, environmental changes
4	Elements of food webs ensure long-term abundance and reproduction	Overfishing, deterioration of habitats, environmental and climate variability, marine pollution
5	Eutrophication is minimised	Nitrates increase, oxygen depletion, algae blooms, biodiversity shift and ecosystem imbalance
6	The sea floor integrity ensures functioning of the ecosystem	Human infrastructures and activities, bad fishing practices, marine pollution, changes in the hydrological balance
7	Permanent alteration of hydrographical conditions does not adversely affect the ecosystem	Human infrastructures, offshore installations, sediment remobilization, dredging, mining, desalination, hydrological imbalance
8	Concentrations of contaminants give no effects	Industrial activity, ship pollution, atmospheric deposition, oil, gas and mineral exploration and exploitation
9	Contaminants in seafood are below safe levels	Oil spills, aquaculture and shipping, land-based activities and water discharge from urban areas, toxin bioaccumulation
10	Marine litter does not cause harm	Littering of coastal areas, industrial emissions, municipal sewerage, fishing and aquaculture, sea dumbing from shipping, offshore mining and extraction
11	Introduction of energy (including underwater noise) does not adversely affect the ecosystem	Transport, mining, fishing, construction, sonars and military activities

3 Argo for environmental monitoring

3.1 The role of Argo array

The Argo program has evolved in the past 20 years and presently consists of three basic elements: Core, Deep, and Biogeochemical (BGC) (Roemmich et al., 2019), and has become the major and only systematic source of physical and biogeochemical data over the oceans interior. In terms of coverage, the Argo network has been continuously expanding in the world's oceans and seas during the last two decades (Fig. 2). For the European Seas, this expansion has been boosted through the combined efforts of European countries under the coordination and planning of Euro-Argo ERIC that was officially formed in 2014. Euro-Argo has timely included in its strategic targets (Euro-Argo ERIC, 2017) the aim to provide high quality *in-situ* datasets in the European Marginal Seas (EMS). This has resulted in an increasing number of operating floats in the Nordic, Baltic, Mediterranean, and Black, Seas that has significantly enhanced oceanographic monitoring.

In the Mediterranean Sea, the systematic use of Argo for more than a decade has initiated a new era of oceanographic monitoring (Kassis and Korres, 2020). Similarly, such expansion has lately taken place even in especially shallow areas such as the Baltic Sea (Siiriä et al., 2019) and in previously under-sampled enclosed sea regions such as the Black Sea (Grayek et al., 2015). This evolution, in combination with the technological advancements of the floats to host additional sensors and to sample in shallow coastal areas (Euro-Argo RISE D6.1), creates a two-dimensional expansion of the European Argo fleet. An expansion capable of putting Argo in the top list of data contributors to the European environmental monitoring efforts. Such an example is the EU Green Deal action plan that aims the monitoring and assessment of the marine environment status and functioning in relation to climate change.

With regards to environmental preservation, Green Deal's priorities such as the protection of ecosystems and biodiversity, and the sustainability of the blue economy, are related to Euro-Argo ERIC's activities through the latter's contribution to EU environmental policies. The contribution of Argo to the description of the GES under the MSFD framework is such an example. More specifically, the capability of the Argo network to provide high-quality datasets and describe the hydrographical conditions that are characterized by the physical parameters of seawater is important for the description of the dynamics of marine ecosystems. Moreover, the emerging BGC Argo component in the EMS provides a new set of parameters such as nitrates, phosphate, O_2, and bio-optics which, together with the Argo's data of the background physical conditions, provides particularly valuable information for the existence, survival, and reproduction of threatened marine organisms.

3.2 The BGC Argo

The biogeochemical Argo (BGC-Argo) component is an expansion of the Core-Argo programme which is based on integrating new sensors onto standard float platforms to measure six biogeochemical ocean variables: chlorophyll fluorescence, particle backscatter, dissolved oxygen, nitrate, pH, and irradiance. The European contribution to the BGC-Argo array has been enhanced through the efforts of Euro-Argo (Fig. 7), which aims for a continuous and sustainable contribution of approximately 50 BGC floats annually (Euro-Argo ERIC, 2017). The identified areas of deployment are mainly the EMS. This fact creates a great new potential for Argo to contribute to the European environmental monitoring initiatives. The example of the Mediterranean Sea (Fig. 8) shows that an increased BGC floats density in Marginal Seas is achievable and can provide extremely useful datasets whilst in parallel

can serve as a test-case for the global BGC-Argo implementation plan (D'Ortenzio et al., 2020). Furthermore, the use of biogeochemical sensors on Argo floats will largely contribute to the assessment of both physical and biogeochemical forecasting and re-analysis models, and to our understanding of the coupling between ocean physics and biology (Claustre et al., 2010). An important contribution of BGC-Argo is also reported for the assessment of remote-sensing products. Such an example is their substantial potential to improve regional validation of satellite ocean colour products (Wojtasiewicz et al., 2018). Additionally, biogeochemical variables are useful for the identification of climatic trends and human pressures since the expected technological advancements on sensors and floats can also add new parameters to the list of parameters measured by Argo. These are for example CO_2, or underwater sound. Such evolution will make the BGC-Argo component more appealing for the environmental monitoring policies such as the Green Deal, and the MSFD.

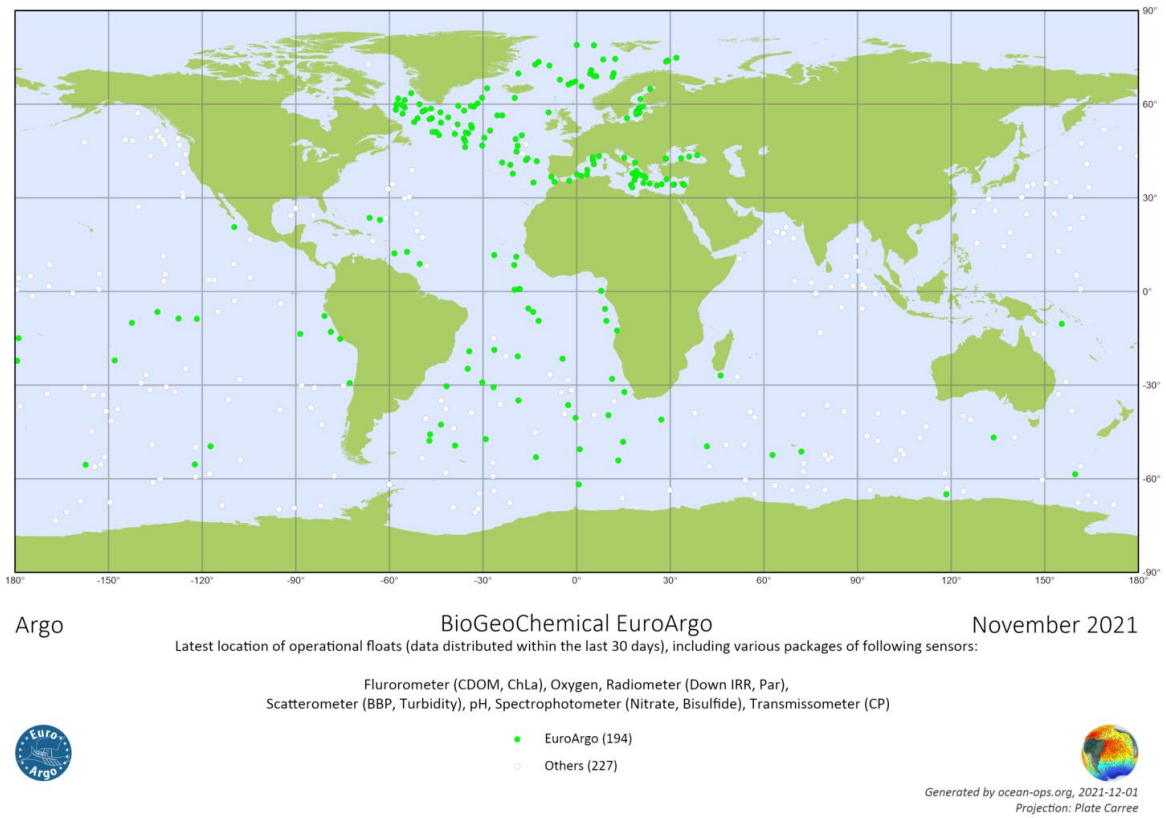

Figure 7. The Euro-Argo BGC Argo network as for November 2021 (https://www.ocean-ops.org)

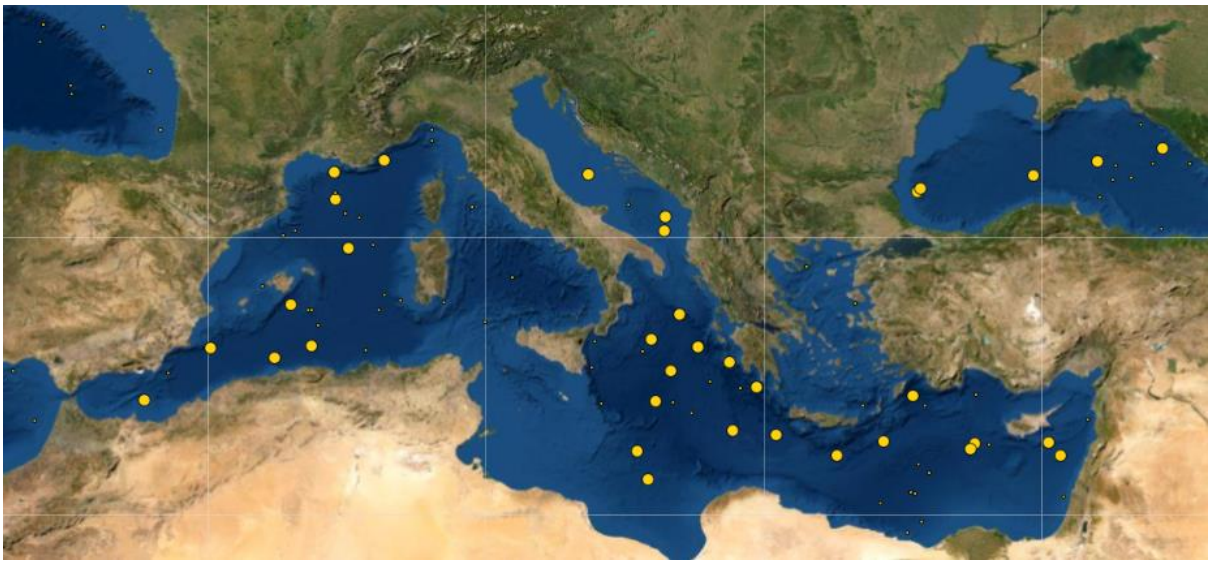

Figure 8. BGC Argo distribution of active floats in the Mediterranean and the Black Sea in December 2021 (https://fleetmonitoring.euro-argo.eu)

3.3 Argo contribution to climate change monitoring

Climate change and especially the pressures and effects associated with the climatic variability and the marine environment, is a major topic of the Green Deal but also concerns MSFD since it is strongly related to GES implementation upon its several descriptors (Fig. 9). In parallel, climate change related to the oceans is a key objective of Argo. Argo data is the main contributor associated with the observation of ocean signals related to climate change and its assessment. This may include regional and global changes in ocean temperature and salinity and heat/salt content (Fig. 10), the steric height of the sea surface in relation to total sea level, large-scale ocean circulation, and associated long-term forecast studies. During the last decade, numerous studies based on Argo data have highlighted the role of the oceans in the global warming, the sea level and temperature rise, and other processes related to ocean climate (salinification, acidification, etc.) (e.g. Riser et al., 2016; Cazenave et al. 2019; Claustre et al. 2020). However, straightforward synergetic activities between Argo and MFSD have not been established yet since, under the framework of MSFD, climate change is mainly assessed under an ecosystem and habitat approach.

Within the different regions of MSFD monitoring, climate change is identified as a threat in the context of producing and multiplying pressures in marine biotic communities. For the case of the Baltic Sea, an associated report published by HELCOM, highlights climate variability as being amongst the main factors that add more pressure to the already affected by a wide variety of anthropogenic impacts, Baltic's fragile ecosystem (Strempel, 2019, HELCOM, 2013). In the report, the Baltic Sea Action Plan is described. The report also highlights the increasing need of addressing relevant challenges after an in-depth assessment of climate change in the area. This fact creates the conditions for the Argo community to provide data relevant to MSFD since under the coordination of Euro-Argo, the float deployments in the Baltic have been lately accentuated. This is the result of joint national efforts (Finland, Poland, Germany, and other countries), along with activities undertaken under several Argo projects like the Euro-Argo RISE H2020 project (see for example Euro-Argo RISE D6.4 "Preliminary results of shallow coastal float operations in the Baltic Sea").

Another important topic, relevant to the context of MSFD, is the monitoring of the sea ice extent which is particularly important for the high-latitude regions. According to the European Environmental Agency (EEA), there was a decrease of 42000 km^2 of the winter sea ice extent in the Arctic which almost doubled in the summer during the period 1979-2019 (EEA, 2019). The summer decrease corresponds to an unprecedented percentage that exceeds 10 % decrease per decade (Halfar et al., 2013). Similar losses of sea ice, driven by a combination of warmer atmosphere and ocean waters (Swart et al., 2015; EEA, 2019) have been also observed for the Baltic where the number of "mild ice winters" increased since the 80's, followed by a decrease of "severe ice winters" from six to one during the same periods (EEA, 2019). However, for the Baltic Sea, the statistical significance is difficult to be calculated due to the large interannual variability (Haapala et al., 2015). Due to the new float generation which can sample under ice (Rizer et al., 2018), the Argo programme can again be proved a very valuable tool for the monitoring of high-latitude sea regions and even ice-covered sea areas. Additionally, BGC Argo can provide valuable data for the MSFD assessment of active phytoplankton population or blooms observed in the wake of the receding ice edge. Furthermore, the use of Argo in-situ measurements helps to assess the satellite observations and their combination can lead to significant improvement of the numerical models in the Arctic (Olmedo et al., 2018).

For the high-latitude regions the climate change induces additional pressures and threats identified under MSFD. Such a case is the variability in the fish distribution of the North-East Atlantic Ocean over the last decades. Nevertheless, for such changes the climate change might not be the only important factor. Since other environmental and biotic factors can influence species distributions, a multi-sensor monitoring similar to the BGC-Argo component is needed. For MSFD the combined effects of climate change with the increasing impacts of multiple anthropogenic activities is particularly important, however they are still poorly understood and are expected to escalate in the future (Hoegh-Guldberg and Bruno, 2010).

Similarly, in the North-East Atlantic, the Argo array is widely used as a tool to assess changes in oceanographic conditions related to climate. Such an example is the Marine Climate Change (MCC) programme in the Marine Institute where the floats are providing valuable time series data to assess spatial and temporal variations in the mixed layer depth and Temperature-Salinity profiles in the North East Atlantic. (https://www.euro-argo.eu/Activities/Data-Use-and-Applications/Operational-Systems/Validation-of-NorthEast-Atlantic-Regional-Model-2012).

Climate change is also recognised as an important pressure in the Black Sea basin and it is accordingly addressed in the State of the Environment of the Black Sea (2009-2014/5) (BSC, 2019). For the MSFD, climate change is adding another threat to current multiple pressures in the area related to temperature rise that causes reduction of the ventilation mechanisms and the solubility of oxygen. In such monitoring, Argo can be a valuable contributor by providing temperature profile records but also information on hypoxia levels in relation to the warming of the climate (BSC, 2019). Similarly, the temperature rise in the Mediterranean affects several fish species, such as sardine, bouge and wrasse, which have started to migrate into the Black Sea in recent years (BSC, 2019).

For the Mediterranean Sea, climate change is considered to be a very important pressure since the region was recognised as one of the most responsive regions to climatic variability (UNEP MAP, 2015; UNEP MAP, 2017). According to the UNEP MAP Mid-Term Strategy for the period 2016-2021 (UNEP MAP MTS), two Strategic Objectives are identified: a) the strengthening of the resilience of the Mediterranean natural and socioeconomic systems to climate change, and b) The reduction of human pressures on coastal and marine environments. Under this aspect, MedArgo has an important role to play by providing high quality and spatiotemporally dense physical and biogeochemical datasets.

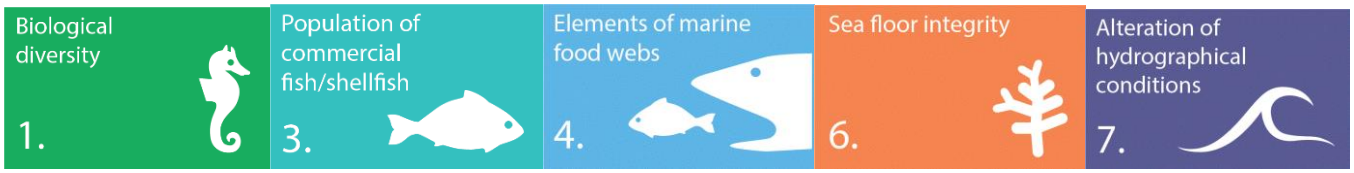

Figure 9. Most relevant MSFD descriptors associated with climate change pressures

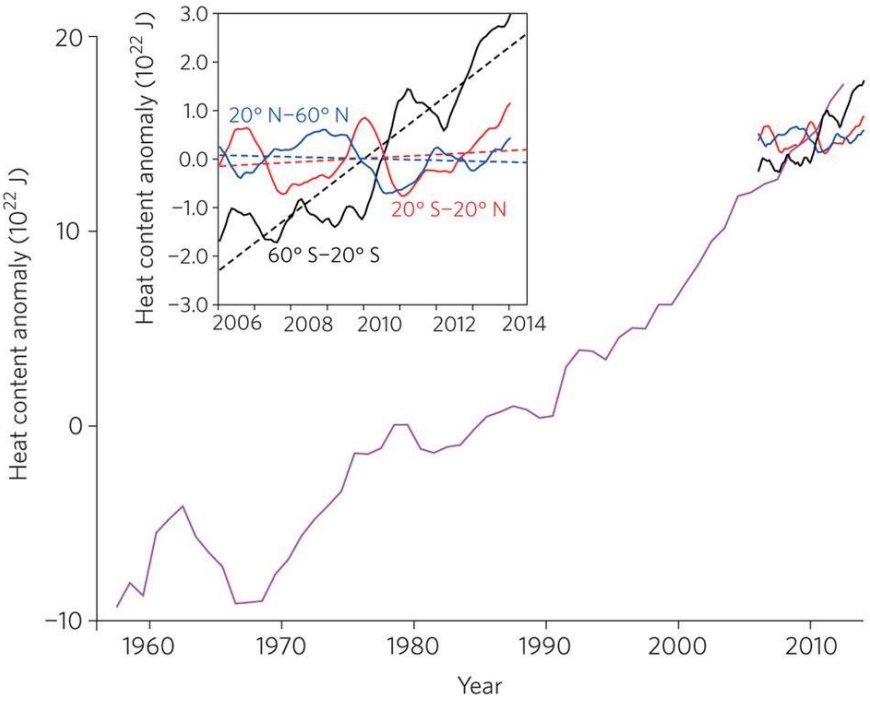

Figure 10. Estimates of the heat content anomaly for 60°s – 20°s (black), 20°s – 20° n (red) and 20°n – 60°n (blue), and a global estimate (purple). Regression lines (dashed) are shown in the inset. (from Riser, S.C., H.J. Freeland, D. Roemmich, et al, 2016: Fifteen years of ocean observations with the global argo array. Nature Clim. Change, 6, 145-153, http://dx.doi.org/10.1038/nclimate2872)

4 Establishing links between Argo and MSFD

4.1 The current status

As previously shown, Argo data is either directly, or indirectly related to the monitoring needs of environmental policies. Regarding the MSFD, EMS Argo data are not currently reported in an individual and autonomous manner. In fact, several national initiatives have been already utilizing Argo data from the beginning of their ongoing GES assessment. These data were however hidden in integrated products or were reported in integrated datasets of "in-situ" datasets. Thus, the official contribution of Argo to initiatives like the MSFD seems to be not an easy and straightforward process. It implies the establishment of links with scientific communities across Europe and the forming of new coordinating bodies that will regulate monitoring efforts, sampling strategy and data streams. On the contrary, with regards to climate action under the Green Deal, the Argo contribution seems more direct. This is mainly because of two reasons: a) the direct interest of Green Deal for climate data and the capacity of Argo network to provide them since it is the most efficient tool for the assessment of the stored heat and salt into the deep oceans, and b) the implementation of the MSFD is often coordinated by ministerial bodies that follow national legislation which induce several bureaucratic procedures.

4.1.1 Euro-Argo RISE efforts

Euro-Argo has identified the need for the establishment of links with the MSFD and become, either through a central, or through a distributed way amongst its members, a systematic source of data for the GES assessment. In order to overcome the aforementioned constraints, Euro-Argo undertakes efforts to approach national and intergovernmental bodies and research communities that are related with MSFD monitoring and reporting. This aim is included in the scopes of Euro-Argo RISE project which has dedicated specific activities towards this under WP7's subtask 7.2.4 which states: "*HCMR will underline the important role of Argo for the MSFD (Marine Strategy Framework Directive) and description of Global Environment Status (descriptors such as hydrographical conditions and eutrophication)*" (Euro-Argo RISE DOW pp. 44). According to this, HCMR has undertaken specific activities starting with the Greek MSFD implementation. The Greek MSFD is coordinated by the Greek Ministry of Environment and assigned to HCMR for the monitoring, reporting, and assessment of GES for the Greek Seas. The activities undertaken by HCMR under Euro-Argo RISE focused on four separate topics: a) evaluate the current legislation and propose an amendment for the Greek MSFD monitoring programme in which Argo data will be specifically mentioned in the contributing datasets, b) integrate and reference Argo data in the Greek MSFD reporting, c) promote Euro-Argo position on targeted intergovernmental bodies, regional conventions, and organizations related to the MSFD such as UNEP-MAP, CMEMS, and EMODNet, and d) assess the current status of the relation of Argo and national MSFDs in countries that are members of the Euro-Argo ERIC.

Additional activities include the creation of links between Argo and MSFD. Such links were discussed and promoted to a wide Mediterranean and Black Sea research community during the Euro-Argo RISE Mediterranean and Black Seas Argo Workshop (Euro-Argo RISE D6.5) that was organized by HCMR with the contribution of OGS, IO-BAS and the Euro-Argo Office, in April 2021 (https://www.euro-argo.eu/News-Meetings/Meetings/Others/Mediterranean-and-Black-Seas-workshop). During the workshop, a presentation made by Dr. Kalliopi Pagou (The PI of the Greek MSFD programme) entitled: "Argo for Environment and Marine Strategy Aspects" highlighted the Argo potential to contribute to MSFD and for the most important elements for the Directive that are potentially related to Argo Data.

These are several sea water parameters like temperature, salinity, currents, light, pCO2, pH, DO, Chl-a, other pigments, nutrients, pollutants, litter, and noise. Furthermore, the importance of the Argo platform for MSFD was highlighted due to the need of the latter for extension of the assessment area in offshore basins and within the water-column. Finally the cost-effectiveness of the Argo platform was mentioned as an important asset.

4.1.2 Other related efforts

Several projects in the past, such as PERSEUS FP7 project, focused on similar issues highlighting the need for planning and implementation of new platform deployments including new biogeochemical sensors on Argo floats to complement the existing open-sea multi-parametric moorings and coastal stations that are located within key zones of the Southern European Seas (Kassis et al., 2013). The aim was to integrate the requirements of EU environmental policies, directives, and recommendations to new observing platforms, strengthen monitoring infrastructures, promote their capacity on delivering data relevant to marine environmental monitoring, and assess gaps in our knowledge by providing enhanced information on the ecosystem dynamics (Fig. 11). PERSEUS project made an effort to put in practice this vision, focusing on the robustness of inferred links between pressures (perturbations), which are easier to quantify, once selected, and the impacts, i.e. changes in the state of the ecosystem (Crise et al., 2015). A Diagnostic Report of the project provided important recommendations that have been taken into consideration, such as a) need for spatial expanding of the monitoring programmes towards the open sea, and b) revision of the existing monitoring programmes to include new parameters and frequencies of observation according to all relevant Directives and especially to MSFD. Another issue tackled within this gap-analysis was the assessment of the opportunities to use the monitoring infrastructure including platforms, buoys, remote sensing tools etc., for smart monitoring for the needs of the MSFD.

Several years later, similar initiatives mainly through EU projects have addressed such topics. A current example is the ongoing DOORS project which aims to establish innovative/smart observations in the Black Sea for sustained biogeochemical monitoring (novel sensor technologies and multi-sensor platforms) that will address MSFD requirements. It also aims to increase the observing capability of existing offshore stations operated by DOORS partners (e.g. EUXINUS and MONOS platforms, Euro-Argo floats, gliders), and to produce high-quality observations of climate-sensitive trace gases, seawater acidification, and nutrient availability. This will be achieved by integrating off-the-shelf and novel autonomous sensors, addressing essential ocean variables (EOVs) as defined by the Global Ocean Observing System (GOOS). Offshore-coastal-shelf areas with monitoring buoys will serve as real-environment test platforms for novel sensors, whilst two Argo floats equipped with biogeochemical sensors and one glider will be deployed for sustained biogeochemical monitoring.

Data availability in SES per descriptor				
		Initial Assessments	Scientific Evaluation	
	Descriptor (2008/56/EC)	Data availability	Data availability Coastal systems	Data availability Open sea
1	Biological diversity	medium	medium	low
2	Non-indigenous species	low	low	low
3	Commercially exploited fish and shellfish	medium	medium	low
4	Marine foodwebs	low	low	low
5	Eutrophication	high	high	medium
6	Sea-floor integrity	medium	medium	low
7	Hydrographical conditions	low	medium	high
8	Contaminants	medium	medium	low
9	Contaminants in fish and other seafood	medium	medium	low
10	Marine litter	low	low	low
11	Underwater noise and other forms of energy	low	low	low

Figure 11. Assessment of data availability per MSFD descriptor during the PERSEUS FP7 project (Crise et al., 2015)

4.1.3 The current contribution

Currently, Argo data contribute to the national MSFDs in a rather indirect way and for specific Descriptors. These are mainly: D5 "Eutrophication" which is described as: "*Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters*", D7 "Hydrographical Conditions" which is described as: "*Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems*", and in a less extend, D11 "Energy Inc. Underwater Noise" which is described as: "*Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment*". For these 3 Descriptors, and for some of their Criteria, integrated Argo data have been sparsely used in an inhomogeneous way within several previous GES monitoring and assessment reports (Figs. 12, 13).

Descriptor 5, has had a relatively small contribution from the BGC-Argo datasets that are mostly related to the following parameters: a) Nitrates, b) Chlorophyll a, c) Dissolved Oxygen, and d) Irradiance, which are associated with the Criteria: D5C1, D5C2, D5C4, and D5C5 accordingly (Figs. 13, 14).

For the Descriptor 7 assessment, Argo data are more widely used and the physical parameters (temperature and salinity profiles) are mainly included in the different national GES reports. For both Criteria of D7 (D7C1: Permanent alternation of hydrological conditions; D7C2: Adverse effects from permanent alternations of hydrological conditions) Argo data are used but in most cases not explicitly referenced. However, Argo contribution is currently "hidden" in the 3-D models of "operational oceanography" programmes although, as highlighted in the MSFD related to D7 documents, there is a need for 3-D in-situ measurements to complement satellite observations (which yields only surface information).

For Descriptor 11, Argo contribution is restricted in test cases which, however, are of increased value since underwater sound data are particularly sparse. Although the concept of attaching hydrophones to water profiling floats is not a new concept this has not been evolved into an operational network yet. In 2004, Guymer *et al*. claimed that the high level of international commitment to Argo and its global coverage are stimulating thoughts about which other sensors could usefully be added to the basic float platform: acoustic measurements are one such candidate, as well as exploring the feasibility of using hydrophones as acoustic rain gauges within the Argo float programme for calibrating satellite-derived estimates of underwater sound. Four years later, Riser et al. (2008) examined observations of rainfall and wind speed from a specially-modified Argo profiling float, which carried a passive acoustic listener (PAL) sensor package that monitored the spectrum of acoustic noise along the float trajectory at intervals of a few minutes and used a set of existing algorithms to estimate the wind speed and rainfall rate from these noise spectra. Currently, very limited sound data from free-drifting profilers have contributed to D11.

As previously mentioned, a survey was performed within the Euro-Argo community regarding the current status of MSFD implementation in the different countries in relation to national Argo programmes. The results showed that the links of Argo and MSFD are still far from a mature stage. In many cases, it was reported that no direct link is set, whilst for some countries, there was no information available. For some other cases there is an existing Argo contribution to MSFD but in an indirect way. The outcomes of the survey are summarized in Table 2 and reveal that currently, Argo data are either utilized by MSFD in integrated products (ex. CMEMS products), or not used at all.

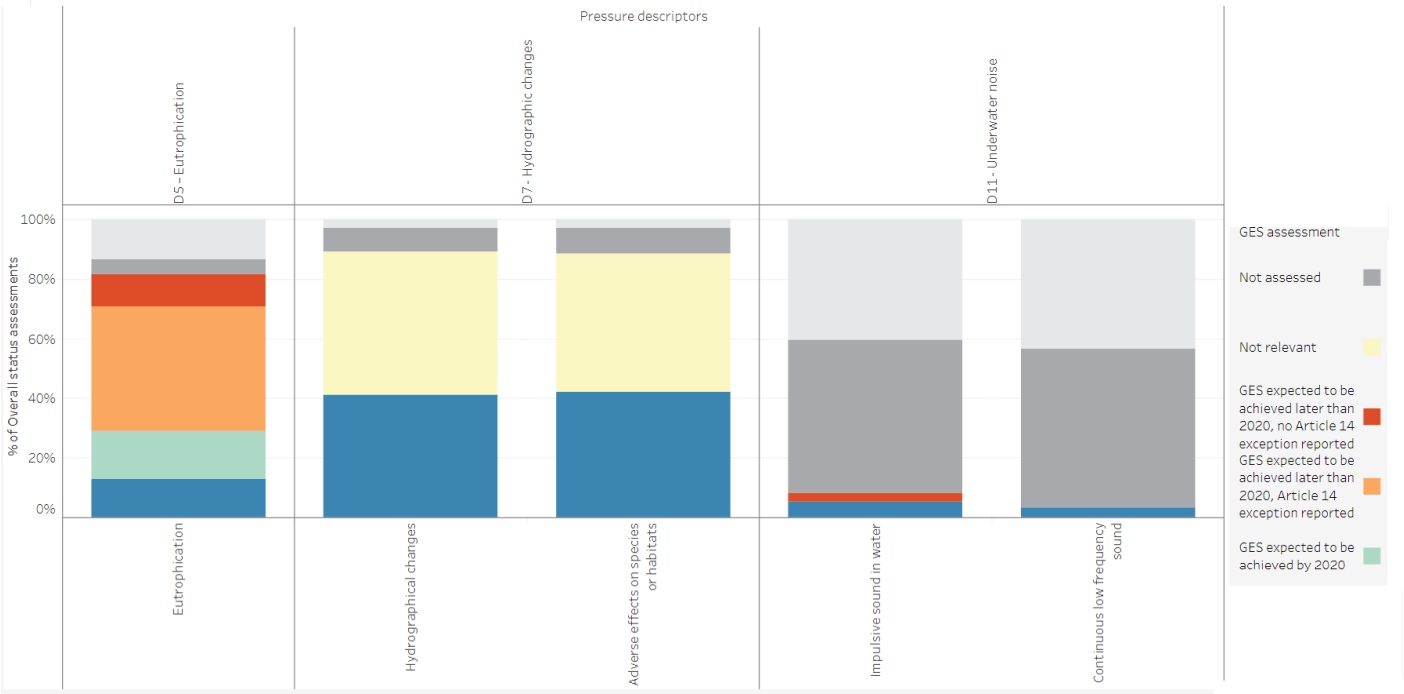

Figure 12. Overall status of features reported for descriptors 5, 7, and 11 as the percentage of reports in each of the "GES achieved" categories (Last update September 2020 https://water.europa.eu/marine/data-maps-and-tools/msfd-reporting-information-products/ges-assessment-dashboards)

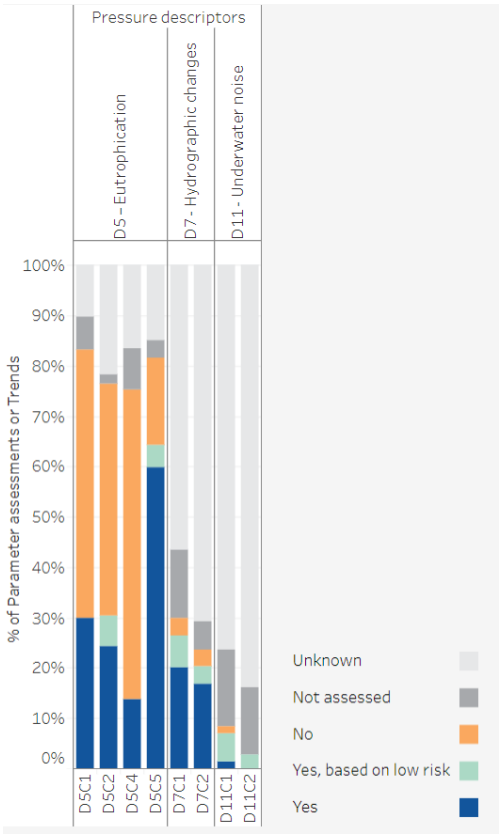

Figure 13. Integrated parameter-level results from the reporting of Finland, France, Germany, Ireland, Italy, Netherlands, Poland, Portugal, Spain expressed as the percentage of parameter reports in several criteria of descriptors 5, 7, and 11 (D5C1: Nutrient concentration; D5C2: Chlorophyll a concentration; D5C4: Photic limit; D5C5: Dissolved Oxygen concentration; D7C1: Permanent alternation of hydrological conditions; D7C2: Adverse effects from permanent alternations of hydrological conditions; D11C1: Anthropogenic impulsive sound; D11C2: Anthropogenic continuous low-frequency sound), (Last updated September 2020 https://4ater.europa.eu/marine/data-maps-and-tools/msfd-reporting-information-products)

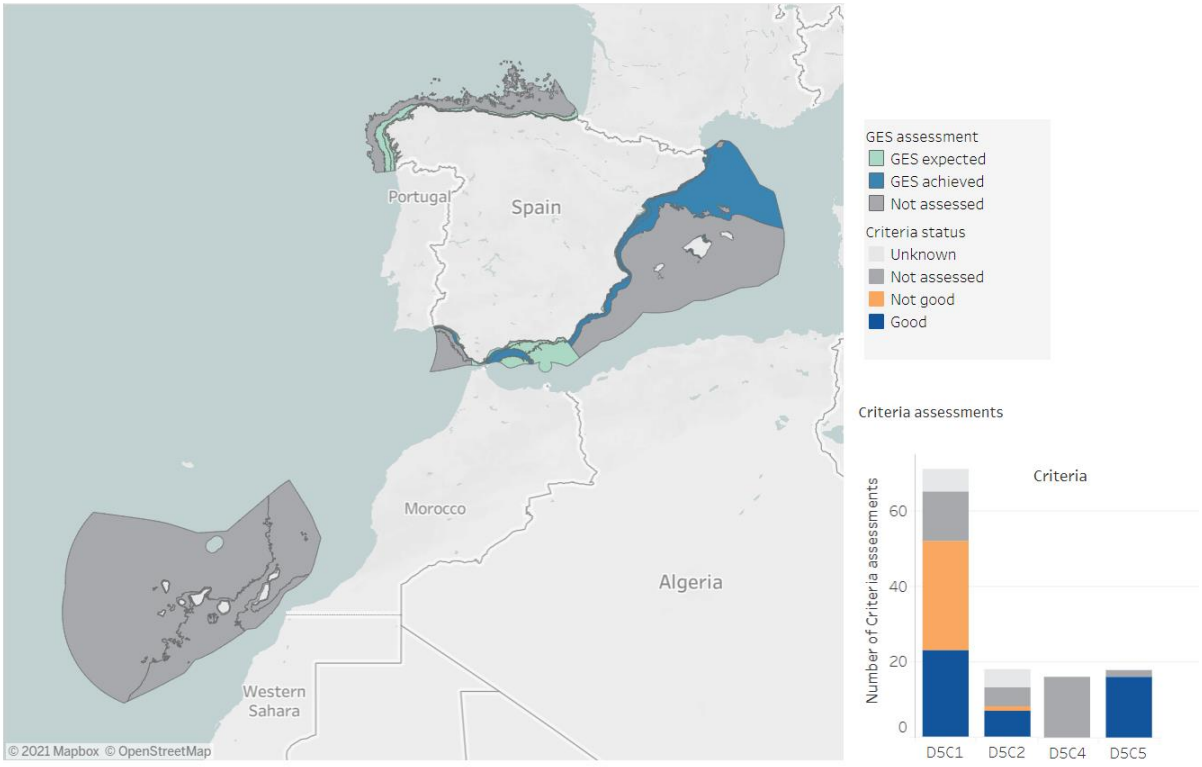

Figure 14. Environmental status assessment reported by Spain on several criteria of D5-Eutrophication ((D5C1: Nutrient concentration; D5C2: Chlorophyll a concentration; D5C4: Photic limit; D5C5: Dissolved Oxygen concentration) (Last update October 2020 https://water.europa.eu/marine/data-maps-and-tools/msfd-reporting-information-products/ges-assessment-dashboards).

Table 2. Level of Argo contribution to national MSFDs as reported by the members of Euro-Argo ERIC

Country	Current level of Argo contribution to the MSFD	Comments
Germany	No direct link of Argo	MSFD officers recognize the importance of Argo physical parameters data of the water column
France	No direct link of Argo	Argo data are indirectly used through CMEMS in the global ocean indicators products.
Italy	Argo data are currently indirectly used by ISPRA through CMEMS products.	ARPA, ISPRA, and other national institutes are involved in data collection for MSFD. Further in-situ data are collected through CMEMS and EMODNet Chemistry

Spain	No direct use of Argo data to the MSFD. Argo data are incorporated in ocean products that are used for D7	The monitoring of the Environmental status of the Sea for the MSFD is mainly carried out by the IEO. More biochemical observations are required. Argo data are essential to monitor the long-term changes in the surface waters and for the assessment of the upper ocean response to climate change. Nationally, data Argo profilers from SOCIB and IEO are a key component.
UK	No information available	
Finland	Argo programme is not contributing directly to the Finnish Baltic Sea monitoring programme.	The Baltic Sea monitoring programme is a part of the implementation of the MSFD in Finland. The need of Argo data is recognized in the sub-programme "Monitoring the physical parameters of the water column", where temperature, salinity and visibility are the parameters in focus
Bulgaria	The BulArgo programme is contributing directly to the MSFD in Bulgaria.	The Argo temperature and salinity profiles were used for assessment of the physical parameters of the water column in the Marine reporting unit - Open sea for the period 2012-2017 (2nd cycle of MSFD Article 8 GES reporting)
Ireland	No direct link of Argo	The Dept. of Health, Planning & Local Government is the competent authority to implement MSP and MSFD in Ireland with technical support from the Marine Institute. A new MSP/MSFD collaboration team was set up in the Marine Institute last year and at present, they are not using Argo data
Portugal	No direct use of Argo. The Portuguese IOC Interministerial Committee gave its assent to the use of Argo floats in Portuguese waters.	Portugal intends to use Argo to help monitor environmental conditions. Argo floats equipped with biogeochemical sensors will allow for the observation of marine biogeochemical processes and ecosystem dynamics, covering a wide range of spatial and temporal scales.
Poland	No information available	
Norway	Not included in the MSFD	No information available regarding Argo use for relevant to MSFD environmental policies implementation
Greece	Argo data contribute to MSFD under the monitoring and assessment of D7	An amendment on the Greek MSFD legislation has been asked by HCMR for the official reference of Argo as the main contributor to the MSFD monitoring programme

4.2 The potential contribution of Argo to the MSFD

The MSFD emerged several years after the Water Framework Directive (WFD), which has a similar approach, however, it explicitly deals with national coastal waters, whilst MSFD deals with the open sea environment. Still referring to national territorial waters though, it is restricted within the coastal self–open sea zones. Under this aspect, the expansion of Argo in these zones is closely related to the contribution of Argo to the MSFD. Through the provision of newly introduced datasets in these regions, parameters for several indicators for the description of GES will require a significant contribution from the in-situ observing components in order to be addressed. The estimation of qualitative descriptors

such as eutrophication, alternations of hydrography and noise, are some examples of how in-situ observations and particularly Argo data can contribute to MSFD. However, a closer examination of the Directive's requirements shows that Argo data on both physical and biogeochemical parameters are valuable for the assessment of several other Descriptors. In fact, Argo data are extremely useful for the description and construction of the overall hydrographic picture, a process important for the evaluation of long-term changes in ecosystems, in order to properly interpret many Indicators' results.

4.2.1 Argo and MSFD Descriptors 5, 7, 11

The most obvious links of Argo data with MSFD descriptors are on Descriptors 5, 7, and potentially 11, in the context of the provision of data that are directly associated with the relevant Descriptor. More specifically, with regards to D.5 "Eutrophication (Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters)", BGC-Argo can play a crucial role as a potential systematic provider of Nitrates and phosphate, dissolved oxygen, Chlorophyll-a, and bio-optics datasets. Such evolution will be particularly important for MSFD since such kinds of parameters are difficult to be recorded. Until now, main efforts are undertaken with R/V expeditions in order to acquire such data from the water column of offshore areas.

Regarding D7 "Hydrographical Conditions (Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems)" is focused on the hydrography which is characterized by the physical parameters of seawater: temperature, salinity, depth, currents, waves, turbulence, turbidity (related to the load of suspended particulate matter). These parameters play a crucial role in the dynamics of marine ecosystems and can be altered by human activities, especially in coastal areas. Physical oceanography is the field in which new technologies, such as remote sensing, autonomous devices and models, are already routinely applied for marine environment monitoring, but there is still a considerable potential for using them to address MSFD needs. The potential Argo contribution to D7 is strong especially taking into account the expansion of the Argo array in the EMS. Presently, the added value of Argo physical parameters data is mainly capitalized in the quality of CMEMS models and products (Le Traon et al., 2019). Furthermore, regarding these parameters, Argo can act in synergies and complementary with other observing platforms. MSFD D7 focuses explicitly on permanent alterations and it is understood that it concerns mainly future activities with potential hydrological impact at a larger scale than the scale of impacts addressed in the WFD. The MSFD hydrographical data requirements include the WFD requirements and some additional ones (in relation also to D6) such as, topography and bathymetry of the seabed, habitat types, ice cover, upwelling, pH and pCO2.

With regards to the D11 "Energy incl. Underwater Noise (introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment)" things are more complicated since technological upgrades will be required in the future. However, the continuous technological upgrade of the Argo floats seems to promise that reliable monitoring of underwater ambient sound is a matter of time by adapting appropriate acoustic sensors (hydrophones) with associated hardware and software. Based on the above sections, specific issues related to the MSFD Descriptor 11 could be identified which Euro-Argo network could significantly contribute to. Roemmich et al. (2019) mention that possible new extensions are being tested on Argo floats, including PALs not only for wind and rain, but also for anthropogenic noise and mammals, while André et al. (2020) mention that future challenges for Argo technological developments in France include developing and/or testing acoustic sensors. So, it is foreseen that technological advancements towards reliable acoustic Argo floats, as

presented in section D below, are just around the corner. Last but not least, Tyack et al. (2021) suggest that among the actions required to be taken by stakeholders (including hydrophone operators, ocean acoustics and bioacoustics scientists, national funding agencies, and others) is the creation of a sustainable data repository. A repository to which hydrophone operators will be encouraged to submit processed data, perhaps along the lines of the network of Argo floats, which are continually recruited and whose metadata are constantly curated. More specifically, the Argo platforms contribution can be divided into two categories for D11:

a. Standard CTD-equipped Euro-Argo floats

CTD data from the standard Argo floats can easily provide time series of Sound Speed Profiles (SSPs) for many marine areas and up to considerably deep waters, such as those prevailing in the Mediterranean Sea, and SSPs are a critical environmental input data for all types of underwater acoustic numerical propagation models in order to efficiently calculate the sound pressure field in ocean waveguides. These models are the core of algorithms for estimating shipping noise footprint, taking into account AIS (Automatic Identification System) data, ship's source data and other environmental parameters except SSPs (bathymetry, seabed properties). Shipping noise modelling is a highly recommended solution for estimating levels of shipping noise in large areas where measurements alone cannot provide a representative picture. Last, shipping noise is the dominant type of continuous anthropogenic sound in the marine environment which should be addressed by the MSFD criterion D11C2. So, the Euro-Argo network of standard CTD-equipped floats could be considered as an alternative source of important information towards the assessment of continuous anthropogenic sound.

b. Acoustic Euro-Argo floats

Euro-Argo floats equipped with acoustic measuring sensors (hydrophones) could contribute to the effort of ambient sound monitoring in the oceans by complementing measurements from existing fixed stations, enabling dense spatial and temporal recordings of the ocean sound spectra in selected areas of deployment. Assessment of continuous anthropogenic underwater noise (MSFD D11C2) would benefit from acquiring sound pressure levels measured in "quiet" marine areas, served as reference conditions for continuous sound (marine sound levels corresponding to all ambient sound except anthropogenic), as well as in heavy noise-polluted areas, at appropriate time periods and frequency bands of interest. These measurements at various marine areas and depths could also be a means to evaluate the combined results of numerical models predicting the noise levels from shipping and wind.

The ongoing technological advancements are expected to allow for assessing sound levels at the MSFD-indicated frequency bands (and optionally additional ones) with recommended metrics (SPL, SEL) and exploit instrumentation aligned to TG Noise recommendations. Last but not least, deployment of acoustic Argo floats at selected depths, areas and periods could provide more detailed information (distribution and abundance) about key/representative species, which is highly desirable not only for the biodiversity Descriptor 1 but also for the assessment of D11. However, we should keep in mind that the integration of hydrophones into free-drifting profilers will be a challenging and difficult procedure mainly because of the countries' reluctance to provide sound data from their EEZ for both economic and military reasons.

4.2.2 Argo and other MSFD Descriptors

The potential contribution of Argo data to MSFD is multi-dimensional and exceeds the input for eutrophication and hydrography solely. From several discussions with MSFD officers, it is agreed that hydrographic monitoring should cover not only the data to assess D5 and D7 related indicators but also to gather data for describing an overall hydrographic scenario and reflect long-term changes in ecosystems, in order to properly interpret other indicators' results. This becomes obvious from the investigation of the 11 GES descriptors. Many Criteria expressed in some of them will depend greatly on the information on the hydrographic and hydrodynamic conditions of the sampled area. Such examples are D1 "Biodiversity", D2 "Non-indigenous Species", and D3 "Commercial Fish and shellfish" for which, the background hydrography and a variety of biochemical parameters are crucial for their assessment (Fig. 15). Similarly, in relation also to D6 "Sea-floor Integrity", parameters such as ice cover, upwelling, pH and pCO2 can be valuable. Especially for the marine organisms that are subject to anthropogenic pressures the ocean physical state plays a crucial role in their survival and subsequent reproduction. Another case example that Argo can address is the monitoring of temperature changes that may occur in deeper or stratified areas, impacting benthic communities (EEA, 2020). Therefore, both the hydrographic and biogeochemical data registered within the framework of MSFD monitoring programs, designed for addressing descriptors other than D7 and the information generated by the various existing more global and permanent platforms for hydrographic monitoring, should be taken into account within the framework of the future MSFD monitoring system in a given region.

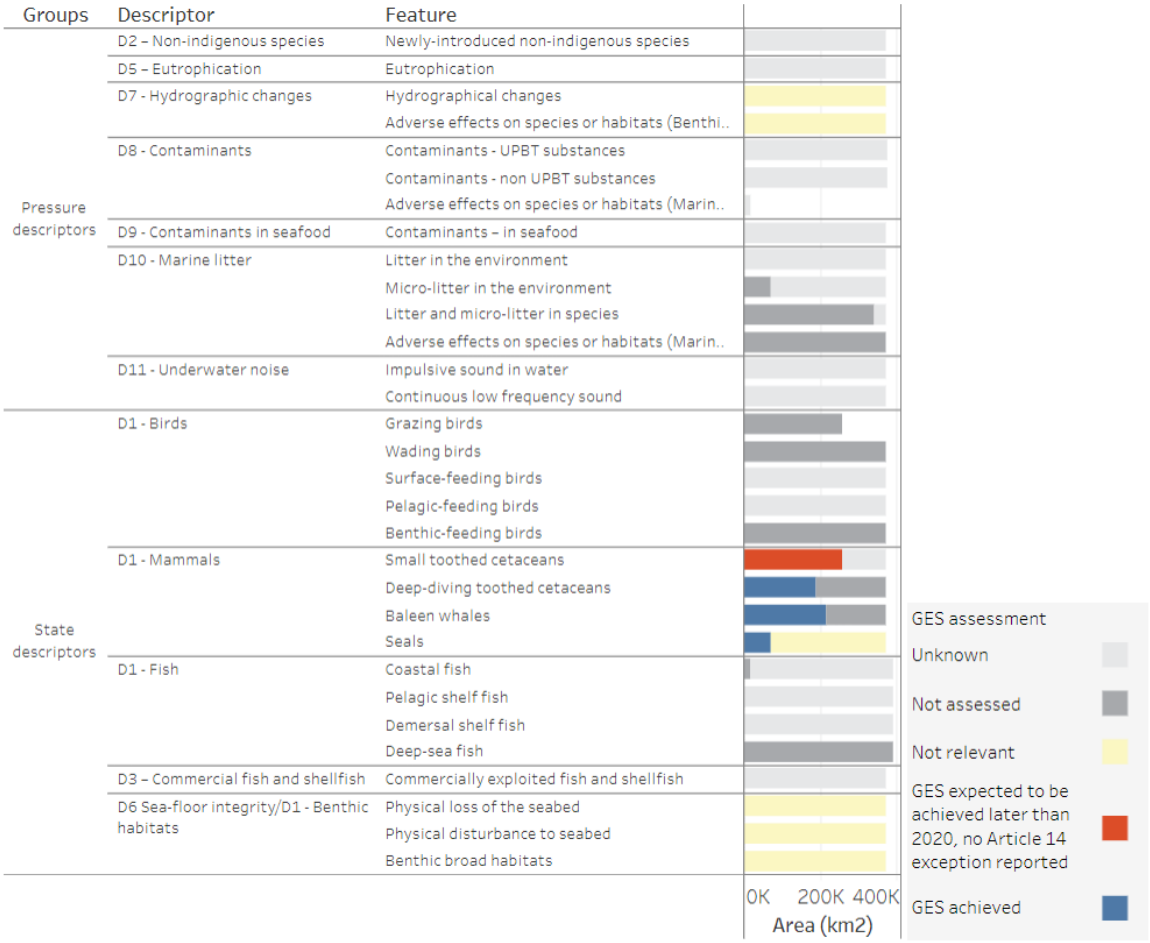

Figure 15. France assessment of the environmental status of a number of features per descriptor under the 2018 update of MSFD Article 8, which were reported electronically to the European Commission. The following dashboard shows the marine waters' area where, for those features, the Good Environmental Status has been achieved, not yet achieved or is unknown or not assessed. This overview of the French 2018 scientific assessment displays many features as unknown or not assessed, which does not account for the extensive assessment work done by scientists.

4.2.3 Argo Data for MSFD

According to the previous, it seems that an exact identification of the important parameters acquired by the Argo programme for the description of GES is not an easy process. It will still require more input and feedback from the scientific teams that are undertaking monitoring and assessment activities for the MSFD. Furthermore, each national MSFD implementation has different needs and possibly adopts different Criteria and measures to address according to the MSFD updated policy. An attempt however to summarize the MSFD important parameters and the level of Argo's potential contribution in relation to the water column and the geographical area is presented in Table 3.

Table 3. The potential level of Argo contribution to basic parameters required by MSFD

MSFD important parameters	MSFD important Geographical areas and other aspects	Potential Argo contribution
Temperature, Salinity	Coastal shelf	High
	Open sea	High
Currents	Coastal shelf	Medium
	Open sea	low
Dissolved Oxygen	Coastal shelf	Medium
	Open sea	High
pCO2, pH	Coastal shelf	Low
	Open sea	Medium
Light, Noise	Coastal shelf	Medium
	Open sea	Medium
chl-a, other pigments	Coastal shelf	Medium
	Open sea	Medium
Nutrients	Coastal shelf	Low
	Open sea	Medium
Pollutants, Litter	Coastal shelf	Low
	Open sea	Low
Physical Parameters	Coastal shelf/Data from several layers of the water-column	High
	Open Sea/Data from several layers of the water-column	High
	Coastal shelf /Cost-effectiveness	Medium
	Open Sea/Cost-effectiveness	High
Biogeochemical parameters	Coastal shelf/Data from several layers of the water-column	High
	Open Sea/Data from several layers of the water-column	High
	Coastal shelf/Cost-effectiveness	Low
	Open Sea/Cost-effectiveness	Medium

4.3 Intergovernmental recommendations

A consistent policy for the European seas is a long-term objective of the EU's legislation, i.e. the EU's Marine Policy. Jointly with the EU Marine Policy, its environmental pillars, the WFD and the MFSD, along with several regional conventions, demand a good state of the ecosystem. In addition, the Copernicus Marine Environment Monitoring Service (CMEMS) relies on quality-controlled observations to provide regular and systematic reference information on the physical state, variability and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas. Argo is the single most important in-situ observing system required for the Copernicus Marine Environment Monitoring Service (CMEMS). Argo and satellite data are assimilated into CMEMS models used to deliver regular and systematic reference information on the state of the ocean for the global ocean and the main European Seas. The discussion on the links of CMEMS and MSFD started some years ago. A central event dedicated to the links between CMEMS and MSFD was organized by Copernicus in October 2019 in Brussels (Fig.16). In the event, HCMR participated representing both Greek Argo and MSFD. The discussion outcomes can be summarized in the need of MSFD for more "specific" to GES in-situ datasets along with downscaled sub-regional model outputs. Both these recommendations affect Argo strategy for deployments in the EMS. With regards to regional conventions, currently only UNEP-MAP has been approached and discussions have started focusing on the Mediterranean area. From the UNEP-MAP's point of view the potential of Argo is big, however, its contribution should be specifically described after discussions with the relevant thematic and regional activity centres.

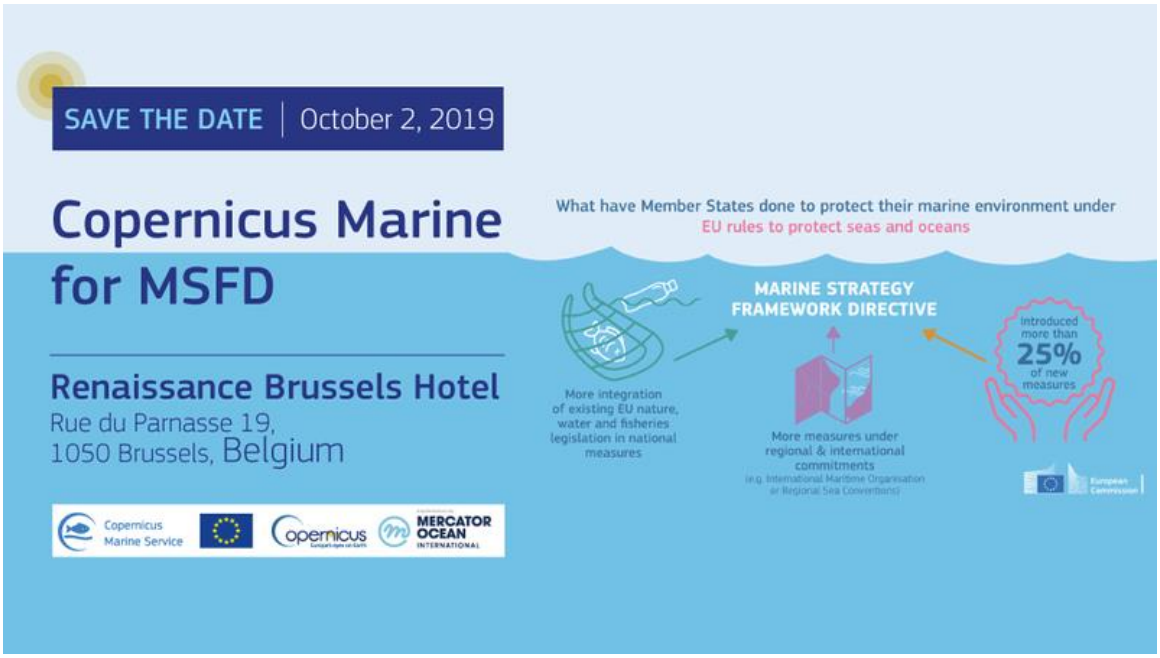

Figure 16. The event organized by Copernicus related to the contribution to the MSFD in October 2019 in Brussels

5 Ongoing activities and future planning

5.1 Ongoing activities

From the side of the European Argo community, the main ongoing activities towards the establishment of links with MSFD are undertaken by the Euro-Argo RISE partners and the Euro-Argo ERIC's efforts. As mentioned previously, HCMR has included Argo monitoring in the Greek MSFD reports (Fig. 17). It has also asked for an official amendment of the Greek MSFD legislation that will include the Argo monitoring infrastructure amongst the contributors for the description of the GES in the updated Greek MSFD plan. An unofficial translation of the proposed parts is the following: "…*In addition, the vertical measurements (profiles) in the water column provided by the Argo type floats of the National Research Infrastructure "Greek Argo" and the European Research Infrastructure "Euro-Argo ERIC" will be utilized. The positions of all the monitoring points mentioned above, except for the profiles from the Argo floats which are not mentioned in fixed points, are recorded on maps and are presented in Annex I of this Technical Bulletin*." Regarding this request there is no update yet (as of December 2021), however, it is expected that the Greek case will be the first that will mention Argo contribution officially.

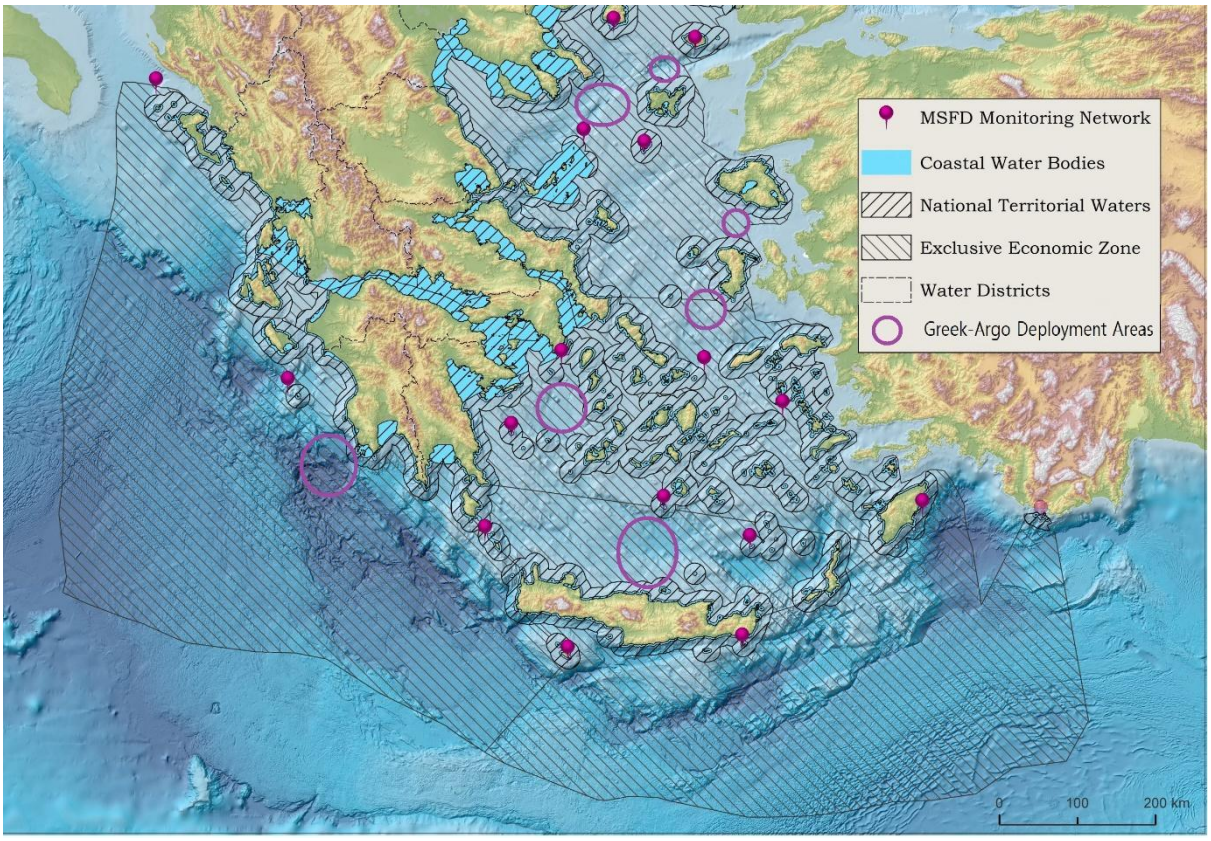

Figure 17. Map of the geographical extent of the Greek MSFD programme including the Greek Argo floats deployment areas (Modified from https://io.hcmr.gr/science-for-society/support-to-policies/msfd)

Additionally, regarding the efforts to bring UNEP-MAP on-board there is also an official letter of intent pending after the discussion made and the invitation send by HCMR on behalf of both Euro-Argo, Greek-Argo, and MSFD Greece, stating:

"Dear Sir/Madam,

This is a joint request on behalf of the Euro-Argo ERIC, the Greek Argo Infrastructure, and the Greek MSFD implementation team. As you are probably aware, the Argo oceanographic platform array in Europe is continuously expanding under the efforts of the Euro-Argo ERIC community https://www.euro-argo.eu/. This expansion is based on technological advancements, especially in Biogeochemical monitoring (BGC-Argo extension https://biogeochemical-argo.org), and geographical extensions, especially into European Marginal Seas (Argo strategy available here: https://archimer.ifremer.fr/doc/00374/48526).

Regarding the Mediterranean Sea, there has been an unprecedented rise of float coverage during the last decade. These technological and geographical advancements have created the ideal conditions for a substantial contribution of Argo in the Mediterranean to the description of GES and to the strong contribution to national MSFD implementation. However, although such contribution currently exists informally, the Argo infrastructure is not currently described in the national MSFD plans, and its current contribution is significantly weaker than its full capabilities.

Greece has been leading an effort to include Argo monitoring in the updated Greek MSFD legislation by referring to Argo for the monitoring and assessment of many descriptors. Other Mediterranean countries that are part of the Euro-Argo community have also expressed this will. With regards to this, we think UNEP-MAP could play a catalytic role in boosting this effort by providing us with your views and recommendations on how to proceed with a more adequate, efficient, and official contribution to MSFD in the Med.

What we kindly ask from your side at this first stage is a brief letter of support on this effort, and a short paragraph expressing your views and recommendations on what the contribution of the Argo infrastructure should mainly focus on.

If you could please, share this request with your colleagues that are experts in the different fields related to MSFD implementation.

It would be highly appreciated if you could send us your feedback by the end of this year.

Thank you in advance,"

Judging from the positive feedback received during conversations with UNEP-MAP, it is expected that an official response will allow the further advancement of the Euro-Argo RISE efforts.

Additional ongoing activities related to the contribution of Argo to MSFD are the technological advancements regarding floats and sensors. Amongst these, the ability of floats to sample in shallow coastal areas should be mentioned as shown in several test cases of Euro-Argo RISE in the Mediterranean (Euro-Argo RISE D6.2), in the Black Sea (Euro-Argo RISE D6.3), and in the Baltic Sea (Euro-Argo RISE D6.4). Such evolution implies both changes in float technical abilities and new tools for monitoring and controlling their missions (see for example Euro-Argo RISE D6.1).

Furthermore, the new state-of-the-art sensors and the capability of their integration onto floats is an ongoing process that will largely affect the evolution of the BGC-Argo component and thus, a large part of Argo contribution to the European Environmental Policies. An indicative example of fast progressing sensor technology for Argo floats is the aforementioned hydrophones integration process. Efforts to develop and test floating profilers with acoustic capability for both military and civilian/scientific purposes have already been made, such as the previous devices of the French company NKE Instruments, PAOLA (military), PROVOR AC and PROVOR AC2. Based on these efforts, the expected

technological specifications of Argo floats equipped with PAM sensors are: self-ballasted floats to be deployed anywhere in the global ocean; equipped with high performances acoustic components; allow for selectable frequencies band and acquisition depths and programmable surfacing time; operate at a wide range of operating temperatures and depths down to several hundred meters (up to several hundreds of dBar due to hydrophone limitation); allow remote control and transmission of profiles according to profiling depth and acoustic points through iridium telemetry, as well as a considerable number of acquired profiles depending on water depth and the number of acquired spectra; provide data logger capability and GPS positioning. More specifically, the acoustic board of the expected technology for acoustic Argo floats should allow for multichannel recording, broadband acquisition, 24 bits digitization, wide dynamic range, fully calibration, embedded acoustic signal processing and low power consumption, while the hydrophones adapted to the Argo floats should meet the specifications suggested in TG Noise guidelines (Dekeling et al., 2014). Moreover, as regards the sound levels at different measuring frequency bands, the third-octave bands with centred frequencies 63 Hz and 125 Hz, as well as all third-octave bands with centred frequencies in the broadband hydrophone range could be selected and values for Sound Pressure Level (SPL) and Sound Exposure Level (SEL) could be provided to address D11 C11.2 of MSFD.

Another important ongoing progress that should be taken into account is the review process of the Directive itself. Article 23 of the MSFD sets an obligation to review the Directive by 2023 and, where appropriate, propose any necessary amendments. The review of the MSFD will follow both the evaluation and impact assessment processes. The European Commission has published a combined roadmap/inception impact assessment for this review in April 2021 whilst, it launched the public consultation on 22 July 2021. The evaluation of the Directive will thoroughly investigate the performance of the MSFD and will assess the relevance of this instrument in the context of the European Green Deal. Several criteria will be used for the evaluation such as the Directive's effectiveness, efficiency, coherence with other policies, relevance and EU added value. Building on the evaluation, the Commission will prepare an impact assessment to explore different policy or legislative options and their potential impacts. For the Euro-Argo community, this is important since the Commission will engage with all those interested in its consultation strategy through a number of outreach activities. The consultation activities will be a key component to gather information and capture the experience, views and ideas of stakeholders involved in and impacted by the MSFD.

5.2 Next steps and recommendations on future activities

Within this report it is shown that the potential contribution of Argo to MSFD is dependent on several factors. These are either related to the strengthening of the links between the Argo community and the national MSFD teams, or to other external factors such as the technological advancements on sensors and observing platforms, and changes in the future European Environmental policies. With regards to the latter, the previously mentioned MSFD update procedure is ongoing and, between spring 2021 and autumn 2022, several targeted consultation activities will gather inputs from selected experts and stakeholders around key identified issues. These activities that will include workshops, and surveys, should be closely followed by the Euro-Argo Infrastructure and its members, in order to give feedback and prepare for tomorrow's Argo contribution. The outcomes and analysis of all the consultation activities will be published by the Commission in a synoptic report at the end of the entire consultation process.

From the Euro-Argo point of view, the Argo future contribution to the MSFD has been discussed between the members and some preliminary expectations and suggestions are summarized in Table

4. In the upcoming period the wide range of Argos' capacities for environmental monitoring should be further promoted. These can be focused on the climate, where the Deep Argo expansion provides enhanced climatic information and estimation of the climate effect into the oceans, and the capability of BGC-Argo to record CO2, and pH levels. Such expansions can boost climate studies, improve climatic models and thus update our estimations and action plan for the achievement of the 2030 Climate Target Plan. Another point that Argo should focus on is the contribution of Argo on ecosystem monitoring (D'Ortenzio et al., 2021). This is more directly related to the MSFD needs and to the efforts of Euro-Argo to develop, with the help of the European Commission, a long term European contribution to the Argo biogeochemical component. This will also strengthen the existing and future valuable contribution of BGC-Argo on the validation of Copernicus Satellite data and Ecosystem models related to the contribution to the assessment of the GES.

Table 4. MSFD future needs and associated Argo potential contribution per country-member of the Euro-Argo ERIC

Country	MSFD monitoring future needs	Argo potential contribution
Germany	Monitoring needs in the Baltic	Interaction with HELCOM
France	No direct link of Argo	Discussion plan to start with the MSFD committee in 2022
Italy	The BGC float data are of great interest for the assessment of human-induced eutrophication (MSFD D5) and will be taken into account for the MSFD implementation	Targeted deployments of Argo BGC floats in the areas surrounding the Italian coasts (Ligurian,Tyrrheniann, Ionian, Adriatic)
Spain	The major needs in response to the MSFD are the enhancement of the Argo profiler coverage in the coastal ocean	Argo data to be used complementary as comparison. As soon as more biochemical data are available, they will be used to fill in gaps. Strengthen the integration of Argo data with data from coastal and open ocean multidisciplinary ocean observing platforms
UK	No information available	No information available
Finland	Indicators defined in the first part of the Finnish Baltic Sea monitoring programme could benefit from Argo monitoring in the open seas. The Argo programme should provide high-quality data from multiple cores and BGC parameters for the Baltic Sea monitoring	The core Argo measurements are taken continuously on average once a week, in the Baltic Sea basins. Many of the floats have also BGC-sensors providing e.g., oxygen, fluorescence, and turbidity and therefore they could contribute to the Finnish Baltic Sea monitoring sub-programmes, e.g., "Eutrophication"(BALFI-d05): "Monitoring of the chemical parameters of the water column" (BALFI-d05-1) and "Phytoplankton pigments" (BALFI-d05-3) more widely
Bulgaria	The BGC float data could be a unique source of information for the assessment of Human-induced eutrophication (MSFD D5) – indicators: Transparency, Chlorophyll a, Nutrients and HAB and biodiversity (MSFD D1.4- pelagic habitat).	The use of BGC-Argo floats will provide core variables such as oxygen, nitrate, and chlorophyll for the implementation of MSFD in Bulgaria especially for the Open Sea MRU where the in situ data is irregular and with limited special coverage
Ireland	No information available	No information available
Portugal	Important for the MSFD monitoring activities to acquire more coastal data. DO is an MSFD mandatory parameter for D5 and indirectly we can also evoke an indicator of the quality of the background for benthic life and its diversity, (D6).	Develop coastal Argo. Complementing coastal monitoring stations with information from Argo buoys to analyse/calibrate the drawbacks of the latter in coastal/shallow waters. The well-established methods used by Argo in the large oceans can falsely flag coastal changes in gradients as measurement errors, like large differences in salinities caused by drifting of relatively

		small distances or strong salinity gradients due to rivers runoff. Other added-values of the use of Argos in shallow waters would be the calibration of its Oxygen and CTD sensors for the top surface layer.
Poland	No information available	No information available
Norway	Not included in the MSFD	No information available regarding Argo use for relevant to MSFD environmental policies implementation
Greece	Need for physical and biogeochemical parameters in the Aegean, Ionian, and Levantine Seas	Sustain and expand Greek Argo deployments (including BGC floats in the sub-regions of Greek MSFD interest under synergies with other platforms (Glider, buoys, etc.)

Some additional strong points raised from the MSFD agencies and regional conventions is that the Argo array can be used as an indirect way of extending monitoring for GES in offshore areas beyond the restriction of national waters jurisdictions. However, the most important is the advantageous role of Argo platform due to its cost effectiveness and coverage capacity. MSFD implementation will require large scale, continuous and intensive sampling programs, able to account for the high spatial and temporal variability characterizing marine ecosystems. Undoubtedly, such programs will be costly, both in terms of human and economic resources, and because of that it is imperative to look for the most cost-effective sampling strategies and methodologies, to minimize such costs. Each monitoring or samples analysis system has been firstly described, and then its adequacy for providing data required by the selected indicators for evaluating MSFD descriptors discussed. Whenever relevant, such new systems have been compared with the currently used systems, always taking into account the cost- effectiveness point of view. Argo array is capable of providing data in a continuous way from the temporal point of view, or covering synoptically large areas, as well as those analytical techniques providing more precise data at lower cost, should be taken into account when developing the MSFD monitoring programs.

Finally, the future technological evolution of floats is another strong point towards the potential contribution of Argo to the MSFD. This can be investigated both under the aspect of new sensors to monitor additional environmental parameters, and the capability of floats to sample between the coastal-self and the deep offshore areas. Under Euro-Argo RISE project, an important step regarding the Argo expansion into the coastal areas of the EMS was attempted with preliminary successful outcomes (Euro-Argo RISE D6.1; Euro-Argo RISE D6.2; Euro-Argo RISE D6.3; Euro-Argo RISE D6.4). As presented in these reports, the increased float coverage in specific sub-basins can lead to enhanced monitoring and investigation of variable and transitional areas and will be a valuable source of information regarding the hydrography and ecosystem functioning. Such evolution will also strengthen the contribution of Argo to the description of the GES. Furthermore, with regards to climatic variability studies, enhanced Argo coverage into sub-basins of marginal seas will help the investigation of extreme events over the coastal zone and the description of their possible impacts on the marine system (Kassis and Varlas, 2020). Such information can be used for the description of short scale events and the enhancement of coupled met-ocean forecasting. It can also be potentially important for aquaculture and fisheries along with environmental agencies related to ecosystem preservation.

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