

1 The role of EMODnet Chemistry in the European challenge for 2 Good Environmental Status

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9 **Abstract:** the European Union set the ambitious objective to reach within 2020 the goal of Good Environmental Status.
10 The Marine Strategy Framework Directive (2008) represents the legislative framework that drives Member States
11 efforts to reach it. The Integrated Maritime Policy supported the need to provide a European knowledge base able to
12 drive sustainable development by launching in 2009 a new European Marine Observation and Data Network
13 (EMODnet). Through a stepwise approach, EMODnet Chemistry aims to provide high quality marine environmental
14 data and related products at the scale of regions and sub-regions defined by the Marine Strategy Framework Directive.
15 The Chemistry Lot takes advantage and further develops the SeaDataNet pan-European infrastructure and the
16 distributed approach, linking together a network of more than 100 National Oceanographic Data Centres providing data
17 from more than 500 data originators. The close interaction with EEA, RSCs, ICES and EMODnet-MSFD coordination
18 group allows to assess the most proper set of information necessary for the MSFD process. EMODnet Chemistry
19 provides aggregated and validated regional data collections for nutrients, dissolved gasses, chlorophyll and
20 contaminants, properly visualised with OGC WMS and WPS viewing services. Concentration maps with 10-year
21 moving window from 1960 to 2014, by season and for selected vertical layers are computed and made available.
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23
24 **Keywords.** Marine chemistry; Europe; Marine Strategy Framework Directive; Good Environmental Status;
25 Eutrophication; Contaminants;

26 1. Introduction

27
28 The European Union has set the ambitious objective to reach within 2020 the goal of Good Environmental Status (GES)
29 for our oceans and seas. The challenge consists in facing the environmental degradation caused by years of
30 unsustainable and inefficient growth model. The Marine Strategy Framework Directive (MSFD, European Commission
31 2008) adopted in 2008, with its eleven descriptors and related indicators, represents the legislative framework and the
32 backbone of this work. **MSFD defines the GES in Article 3 as: “The environmental status of marine waters where these
33 provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive”. GES means that
34 the different uses made of the marine resources are conducted at a sustainable level, ensuring their continuity for future
35 generations. Going more in detail for the restoration and the safeguard of this status, the ecosystems (including their
36 hydro-morphological, physical and chemical conditions) should be fully functioning and resilient to human-induced
37 environmental change, the decline of biodiversity caused by human activities should be prevented and biodiversity is
38 protected. The human activities (introducing substances and energy) shouldn’t cause pollution effects and noise from
39 human activities should be compatible with the marine environment and its ecosystems.**
40

41 This process is at the moment in the half way between the adoption (2008) and its deadline (2020). The main features of
42 this strategy are: the ecosystem approach (to provide an integrated evaluation of the activities affecting our seas) and the
43 common efforts required by the Member States for the cooperation between neighbouring countries.

44 Some efforts have already been undertaken by European Member States which provided in 2012 the initial assessment
45 on the state of the environment of the national marine waters. This assessment reported on environmental status
46 determined in a holistic way, according the 11 descriptors, and on the objectives and targets to reach GES following the
47 articles 8, 9 and 10 of the MSFD.

48 The results of the first phase allowed to recognize gaps and needs in data availability, large heterogeneity of
49 methodological approaches to report information and spatial inconsistency within Member States regarding coastal –
50 offshore data. These outcomes clearly indicated that more efforts are urgently needed if the EU is to reach its goal.
51 More has to be done on the cooperation side and especially on the integration between Member States and Regional Sea
52 Conventions (RSC). The report from the Commission on the first phase of implementation of MSFD indicates a high
53 level of heterogeneity among Member States reports and in several cases poor data availability and accessibility
54 (Dupont et al., 2014; Palialexis et al., 2014)

55 As a consequence, evaluation at higher level (Regional and EU) is difficult to perform. This first phase of MSFD
56 implementation has somehow brought Europe one step closer to the ecosystem approach. However, the recognized gaps
57 in data and information, the high heterogeneity in assessment approaches should guide the stakeholders involved in
58 MSFD implementation to develop a more homogeneous approach. In view of the revision of the assessment in 2018,
59 several efforts are required to overcome the shortcomings identified in the first reporting phase. Going more in detail,
60 the actions should be focused on different aspects like: revised criteria for GES, methodological standards and
61 standardised methods for monitoring, assessment and data availability, implementation of integrated information
62 systems at regional and EU level.

63 In the field of marine research, during the last decades several oceanographic data management initiatives faced the
64 challenge of data availability, interoperability and resilience at Pan-European level (EU MAST MTP II MATER 1996-
65 1999, EU MAST-INCO MEDAR 1999-2001, FP6 SeaDataNet 2006-2011, FP7 SeaDataNet2 2011-2015).

66 Interoperability is defined as “the ability of a system to work with or use the parts of another system”, while resilience
67 is defined as "the ability of a system to cope with change". The translation of these principles in the oceanographic data
68 management consists in the development of a long life system able to easily interact with other systems. As example the
69 adoption of common formats for data and metadata and a system of common vocabularies ensure that the network of
70 involved persons is working in a homogeneous environment from the syntactic and semantic point of view (speaking a
71 common language). The resilience is safeguarded by metadata and quality flags that provide clear knowledge of which
72 kind of information the users are handling even long time after the data measurement (e.g. use of historical data for time
73 series studies).

74 Since 2007, the Directive establishing an Infrastructure for Spatial Information in the European Community (INSPIRE,
75 2007/2/EC) has been the driving principle to ensure that the European spatial data infrastructures are compatible and
76 usable in a transnational context. The Directive requires that common implementing rules are adopted for the
77 organisation, accessibility and sharing of spatial information with a focus to the implementation of interoperability of
78 spatial data sets and services. Marine data management communities, developed in the framework of European
79 initiatives such as the above mentioned MATER (1996-1999) and MEDAR (1999-2001) that converged later in the
80 SeaDataNet (2006-2015) experience, faced the challenge to provide access to the huge amount of already existing but

81 fragmented and inaccessible data collected by EU oceanographic institutes. This was done developing a system able to
82 collect, standardise, quality control and share the information, taking into proper account the data policies.

83 **The simple but efficient idea was the active collection of the EU oceanographic data at national level carried out by a**
84 **network of National Oceanographic Data Centres (NODCs). The collection of those data was done in direct**
85 **communication with the data originators to ensure the best set of measured data and related metadata. Metadata, that are**
86 **all the information needed to describe exhaustively the data, reply to a set of basic but fundamental questions like: who,**
87 **where, when, what and how about the collected information. For this reason they are key elements to enable efficient**
88 **browsing and discovering.**

89 Between the data collection and sharing, the crucial steps to ensure interoperability and reliability consist in
90 standardization and quality control.

91 **The standardization is done at two main levels by following the interoperability principles provided by INSPIRE:**
92 syntactic and semantic. The first is done providing common formats for the files providing metadata and data (XML
93 ISO, ascii). The second is done **by means of** a set of common vocabularies that let to “use the same language” to
94 describe data and metadata over time, different projects and nationality.

95 The quality control procedures provide the necessary labelling to complete the harvested information with the
96 evaluation of their reliability.

97 Finally the registered users can access the needed information according to data access and usage policies defined in
98 agreement with the originators.

99 In order to extend this approach to different disciplines of the marine environment, at EU level, the Directorate-General
100 for Maritime Affairs and Fisheries (DG-MARE) launched since 2009 a set of thematic contracts to establish a European
101 Marine Observation and Data Network (EMODnet).The aim of the initiative was to improve the availability of high
102 quality marine environmental data at the scale of regions and sub-regions of the Marine Strategy Framework Directive,
103 to build a knowledge base that can assist in the implementation of marine policies and drive sustainable development.
104 The EMODnet Lots with their infrastructure could play a central role specifically for countries where the Regional Sea
105 Conventions are less mature to support the need of qualified and standard information at national, regional and bigger
106 scale.

107 **2. Background**

108 A pilot project was launched by DG-MARE in 2009 to create the components of the European Marine Observation and
109 Data Network (so called ur-EMODnet), as proposed in the EU Green Paper on Future Maritime Policy (European
110 Commission 2006), consisting in six thematic data portals managing data on bathymetry, marine geology, chemistry,
111 biology, seabed habitats, and physical oceanography. Based on the successful experience of the SeaDataNet (SDN)
112 project (7th Framework Program), EMODnet Chemistry adopted its approach (Vinci et al., 2013). The principle was to
113 take advantage of its efficient and distributed infrastructure for the management of data deriving from in situ and remote
114 observation of seas and oceans. This infrastructure can be considered a European de-facto standard, as it already
115 involves around 100 institutes (nodes) from 35 countries and is adopted and continuously adapted according to specific
116 requirements for chemical data management.

117 SeaDataNet is actively involved in the development of standards that follow the INSPIRE implementing rules to ensure
118 interoperability such as:

- 119 • Common metadata standards based on the Extensible Mark-up Language (XML), based on ISO 19115/19139
120 schema;
- 121 • Standard data transport formats **Ocean Data View** (ODV) ASCII, MEDATLAS and NetCDF (CF);
- 122 • Common quality control methods and quality flag scale;
- 123 • Common Vocabulary Web services, used to mark-up metadata and data, covering a broad spectrum of
124 disciplines and governed by an international board (SeaVox);
- 125 • SOAP Web services for various communication tasks;
- 126 • Open Geospatial Consortium (OGC) compliant services (Web Map Service, Web Feature Service, Web
127 Processing Services) for viewing services of data products.

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130 The partnership involved a subgroup of the SeaDataNet network of National Oceanographic Data Centres (NODCs)
131 with specific experience in data collection, in data analyses, validation, and creation of products and in the technical
132 partners who further developed SDN infrastructure. The Chemistry Pilot project was focused on the collection and
133 management of data on some chemical parameters relevant for the MSDF (contaminants and fertilisers), in three
134 matrices (sediment, seawater and biota) and in three areas of interest: the North Sea, the Black Sea and some spots in
135 the Mediterranean Sea.

136 The comparison of the harvested data between sea basins highlighted a highly heterogeneous situation according to the
137 different parameters. Data distribution consisted, on one hand, in coastal time series stations monitored at regular
138 temporal scale, on the other, in data homogeneously distributed at basins level, but discontinuously in time. Furthermore,
139 high heterogeneity in data managed resulted in the different sampling and analytical protocols adopted, as well as in the
140 different target species. As a last step of the pilot project data visualizations were provided as interpolated maps when
141 data were homogeneously distributed in time and space and as time series plots to allow visualization of data with
142 fragmented spatial coverage. The viewing products were made available on the dedicated web portal in OGC compliant
143 format (WMS layers).

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145 **3. EMODnet**

146 The positive outcomes from the pilot project confirmed the interest in the further development of a marine observation
147 infrastructure able to provide data and knowledge required to support the development of marine economy whilst
148 supporting environmental protection needs, as underlined in the Green Paper Marine Knowledge 2020 (European
149 Commission 2012). The new phase includes data collection for all European sea-basins: the Baltic Sea, the North-East
150 Atlantic Ocean, the Mediterranean Sea and the Black Sea and involves 46 partners (**Fig.1**), both from research institutes
151 and national monitoring agencies.

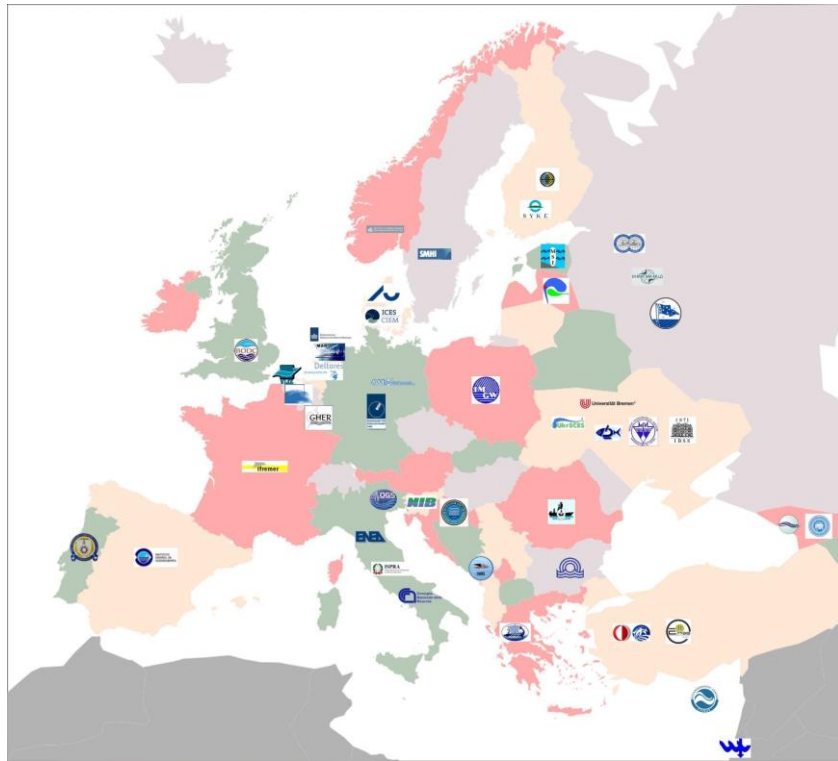


Fig. 1: Geographic coverage of EMODnet Chemistry partnership. Logos indicate the nationality of the partner institutes.

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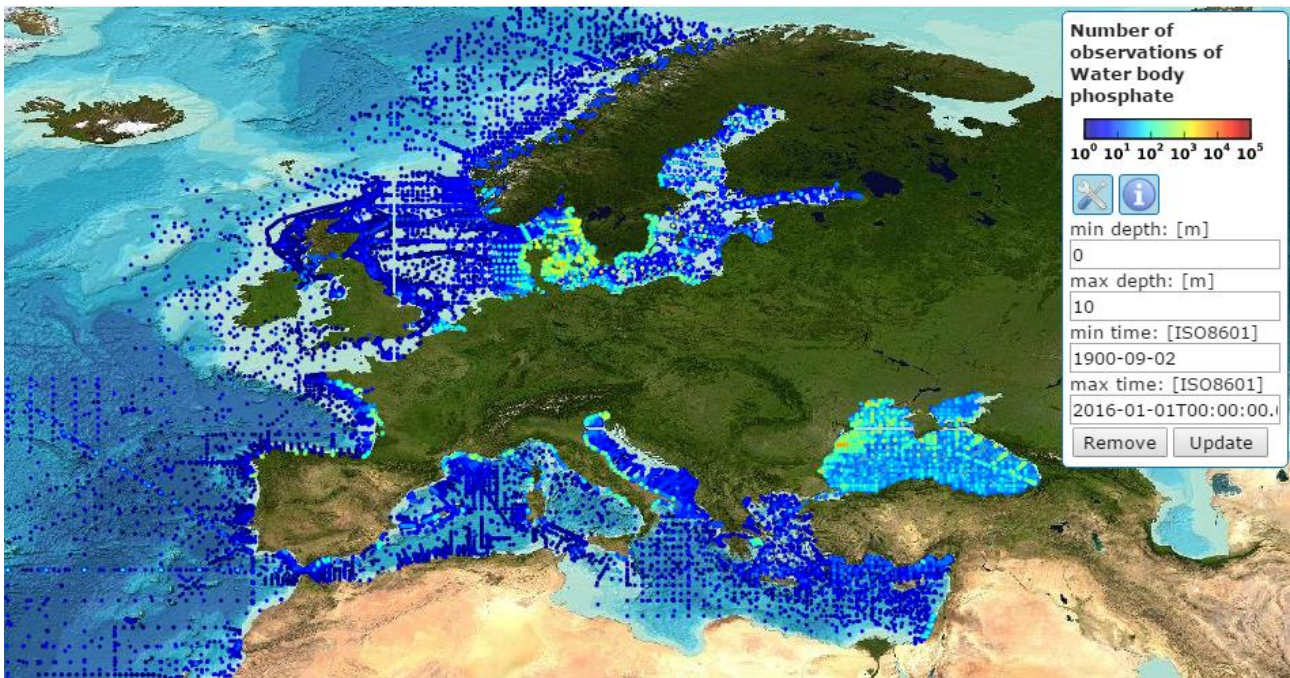
155 Data managed by EMODnet now include also silicates, chlorophyll, partial pressures of dissolved gases (oxygen and
156 carbon dioxide), plastics (polyethylene, polypropylene) and acidity (pH, pCO₂, Total Inorganic Carbon, alkalinity).

157 Data collection and product generation for all European basins is carried out by 5 Regional leaders, responsible for the
158 North Sea, the Baltic Sea, the Atlantic, the Mediterranean, and the Black Sea.

159 In order to better tune EMODnet efforts for the requirements of the MSFD, several initiatives have been carried out to
160 strengthen the dialogue with the Regional Sea Conventions and the Marine Observation and Data Expert Group
161 (MODEG) and a MSFD – EMODnet coordination group involving Regional Sea conventions, Member States and
162 relevant stakeholders has been established jointly by DG Mare and DG Environment. Besides, regular meetings with
163 INSPIRE implementing groups are organized to discuss on the most feasible and useful products and services to
164 provide.

165 4. Data collection and Access

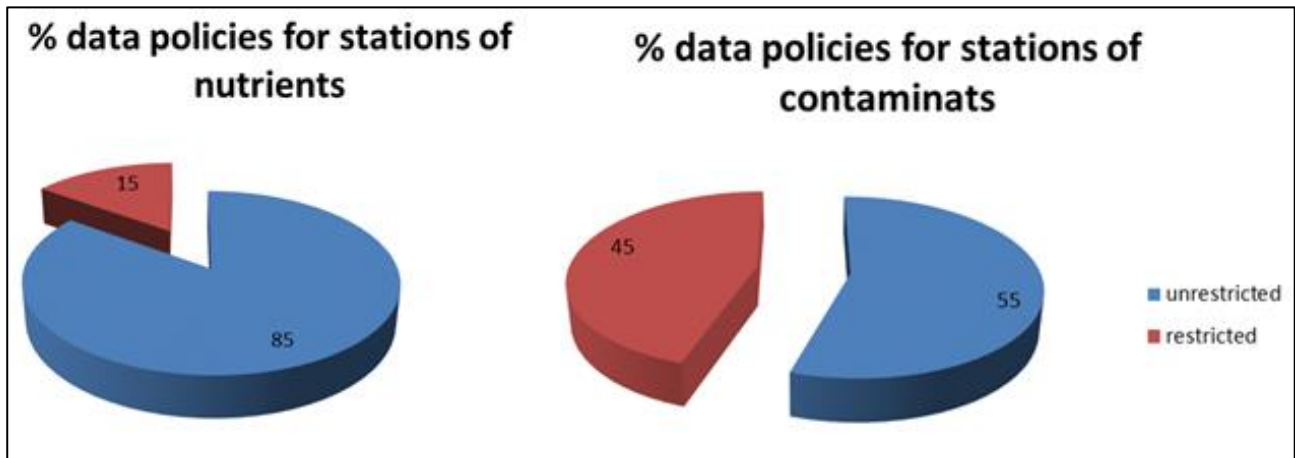
166 Data harvesting is a fundamental activity of EMODnet and it is carried out by the network of NODCs that supervise the
167 national availability of research and environmental monitoring data, provided respectively by research institutes and
168 environmental agencies (Fig.2). NODCs maintain regular contact with data originators collecting and enriching data
169 with the best set of relevant metadata to ensure the reliability of the information. NODCs are also responsible for the
170 first quality control of data, flagged with quality information.



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173 **Fig. 2: Density and distribution of water body phosphate harvested stations**

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Data access is regulated by a data policy (defined in agreement with data originators) which aims to establish a balance between the right of the originator to get proper acknowledgment for data acquisition, and the need for open access through free and unrestricted exchange of data, meta-data and data products. The analysis of data policies for EMODnet Chemistry data shows differences between data access restrictions for nutrients and contaminants (Fig. 3).



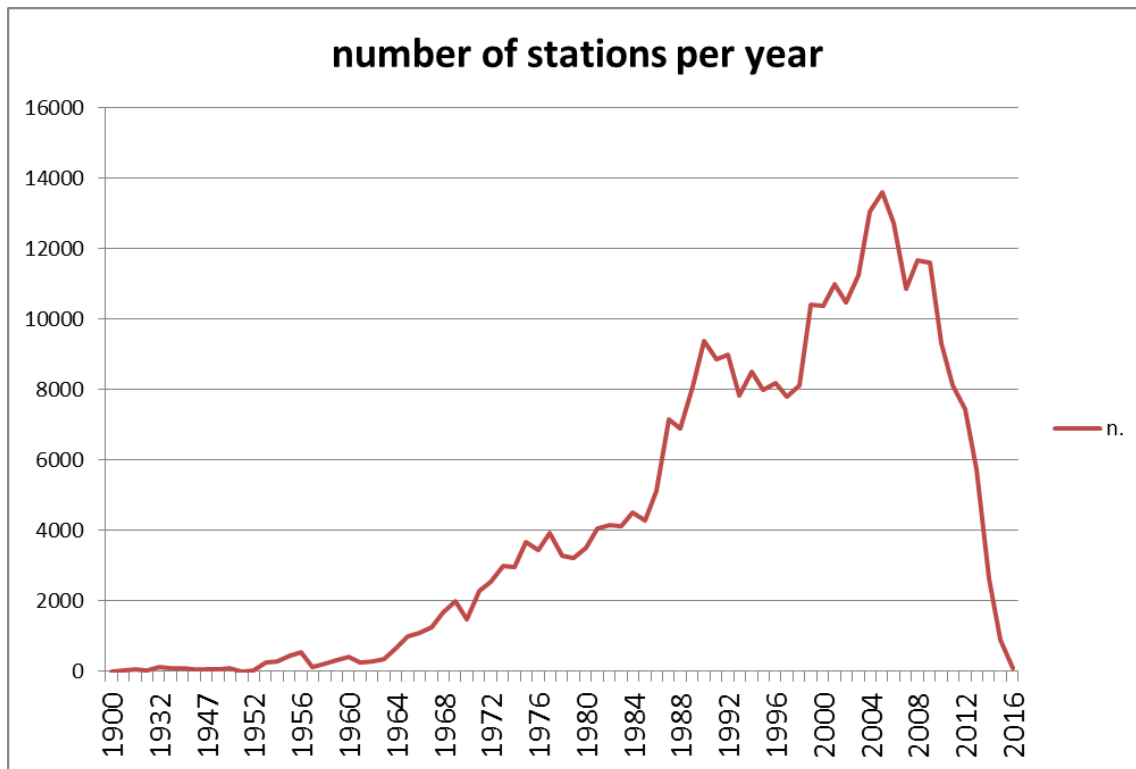
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181 **Fig. 3: Data policy for nutrients and contaminant data**

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Data requests from registered users are handled by NODCs through a data policy management system. Unrestricted data are freely available while restricted ones need negotiation with data originators. This kind of filter on data access is an effective way to establish contacts and trust between data originators and data management centres, ensuring correct acknowledgement, which ultimately encourages data sharing.

By maximizing the availability of data to a larger community, SeaDataNet promotes the use of these data, thereby ensuring that their maximum value can be realized and thus contribute to increase knowledge of the marine

189 environment. Fig. 4 shows temporal distribution of nutrient data, spanning from 1900 to 2016; table 1 shows the
 190 number of stations for parameters with more data available.
 191



192
 193 **Fig. 4: Temporal distribution of nutrient data, spanning from 1900 to 2016 (counting 90 profiles in the current year; updates**
 194 **May 2016).**

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Parameter	n.
Phosphate concentration parameters in the water column	305896
Nitrate concentration parameters in the water column	262378
Silicate concentration parameters in the water column	245755
Dissolved oxygen parameters in the water column	198357
Ammonium and ammonia concentration parameters in water bodies	188666
Nitrite concentration parameters in the water column	181642
Salinity of the water column	151969
Chlorophyll pigment concentrations in water bodies	145374

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 199 **Table 1 number of stations for the parameters with more data available**

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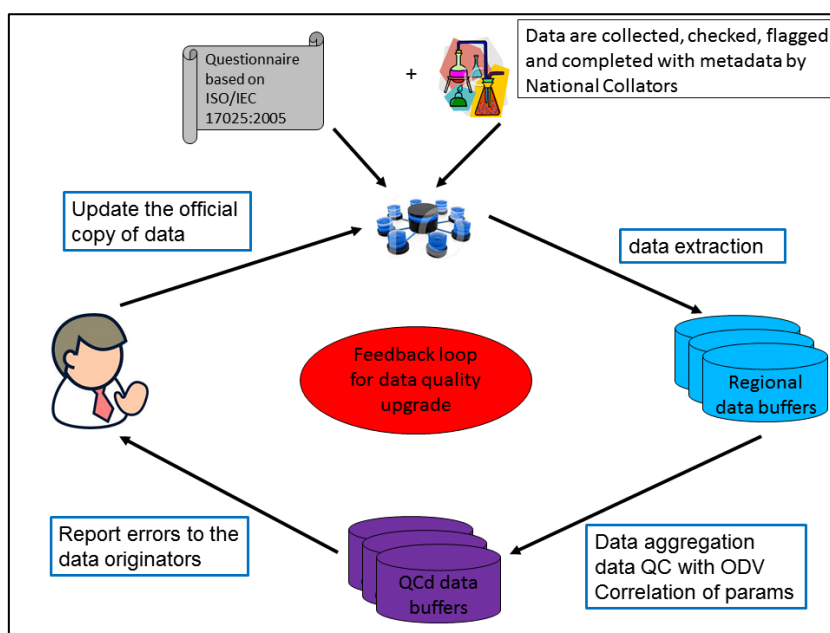
201 **5. Data Quality**

202 The quality of the data is a key issue when merging heterogeneous data coming from different sources, periods and
 203 geographic areas. Within EMODnet chemistry community, commonly agreed and standardized data quality control
 204 (QC) protocols have been defined (Holdsworth, 2010) to guarantee consistency among comprehensive databases which

205 include data from different and/or unknown origin and covering long time periods. As a first step, the data are checked
 206 and completed by collators with a standard set of metadata that provide the basic information necessary for their long
 207 term use. Afterwards, data undergo a validation loop which consists in several validation steps. The first is done by data
 208 collators, prior to the inclusion in the decentralized infrastructure and the second step, which consists in regional quality
 209 control, is performed at regional scale on aggregated datasets. The first quality controls (QC) ensure that position and
 210 time of data are realistic and compare measurements with broad ranges and specific regional ranges. Whenever
 211 available, data are also compared with climatology. As a result of the first QC step, all data are archived with a quality
 212 flag value that provides information about their reliability.

213 At this point, data aggregation and regional quality control are performed at regional scale, following a common
 214 protocol. **Data aggregation is done with the objective to unify the various analytic terms into a unique aggregated term
 215 with conversion to a unique measurement unit. The ODV software has a built-in aggregation procedure applying a
 216 number of business rules like possible units conversions. (Lowry R. et al., 2013)**

217 **The main goal of this activity is to obtain a harmonized dataset (e.g. a unique dataset of phosphate concentration in the
 218 water column starting from different datasets of phosphate concentration expressed with different units) that could be
 219 used to generate homogeneous data products. The results of the regional quality control are sent to the data collators
 220 (NODCs) to correct errors or anomalies in the original copy of the data available in the EMODnet infrastructure. This
 221 feedback loop guarantees data quality upgrade (Fig.5).**



222
 223 **Fig. 5: Data validation loop**
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225 To improve and homogenize the quality control procedures and standards adopted (at least at regional level), a quality
 226 control survey has been carried out within EMODnet Chemistry community, in order to collect the best practices in data
 227 validation and highlight gaps of the different institutes involved (Vinci et al., 2015).

228 **6. Data products**

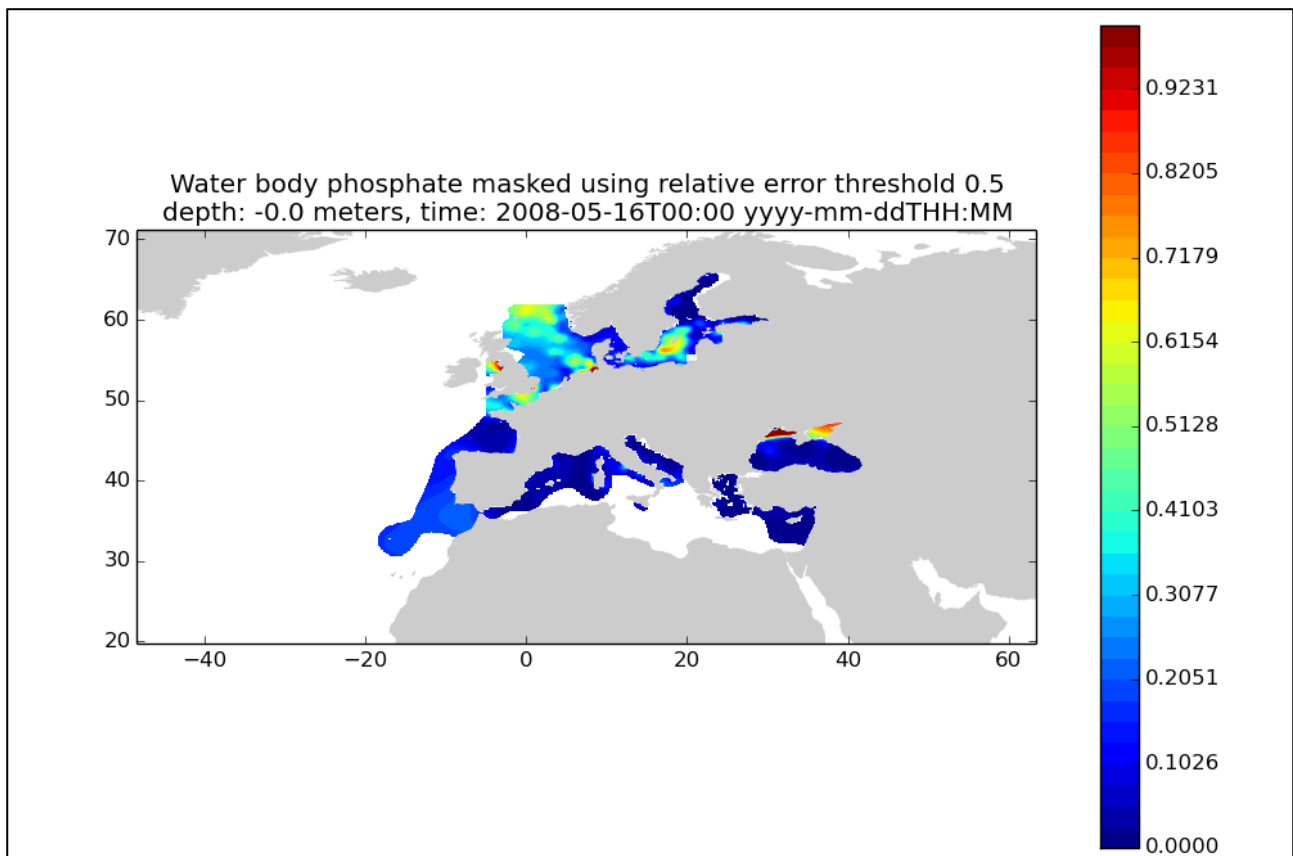
229 In order to accomplish the Marine Strategy Framework Directive requirements, EMODnet Chemistry developed
 230 products suitable to visualise the time evolution of a selected group of measurements and to calculate spatially

231 distributed data products specifically relevant for MSFD descriptor 5 (eutrophication), 8 (chemical pollution), and 9
232 (contaminants in seafood) as typically done with satellite data (Colella et al., 2016; Gohin et al., 2008)

233 The interpolated maps have been produced with the Variational Inverse Method (VIM; Brasseur et al., 1996), using the
234 software DIVA (Data-Interpolating Variational Analysis; Troupin et al., 2010). DIVA is an appropriate numerical
235 implementation of VIM suitable for oceanographic data spatial analysis as it is designed to obtain a gridded field from
236 the availability of non-uniformly distributed observations (Barth et al., 2010; Troupin et al., 2012).

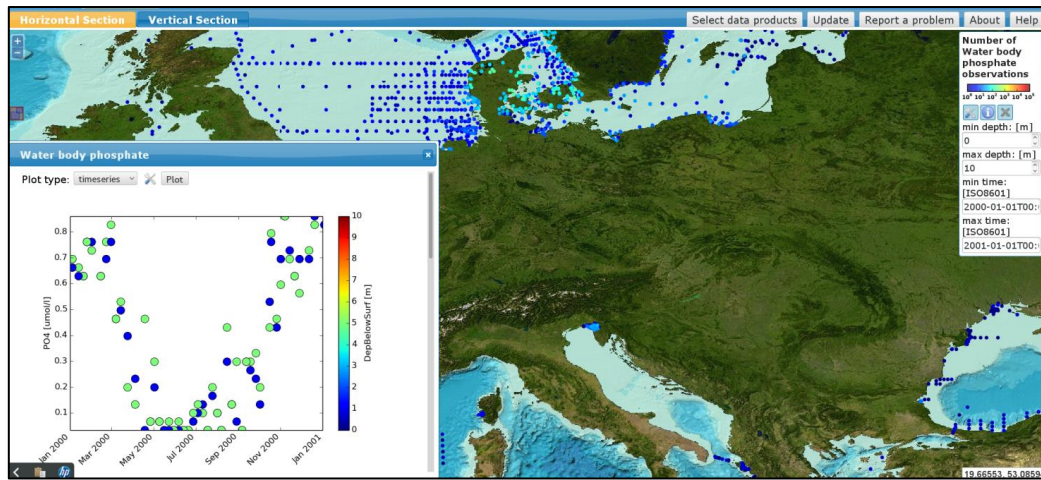
237 Interpolated maps are now generated, mainly for nutrients, with 10 years moving window in order to find a balance
238 between the duration of the environmental evaluation cycle for Member States (to provide maps with a time frame near
239 to the 6 years process of the Member States evaluation) and the number of years that guarantee a sufficient data
240 coverage.

241 An example of a visualization useful for the assessment of eutrophication and in particular of nutrient concentration in
242 the water column is presented in Fig. 6, which displays surface distribution of phosphate concentration in spring for the
243 decade 2003-2013 (centered in 2008).



244
245 **Fig. 6: 10 years average of water body phosphate concentration ($\mu\text{mol-P l}^{-1}$) in the surface layer for all EU sea basins (years**
246 **2003-2013). Interpolated Maps can be selected from the Ocean Browser viewing service interface with the following steps:**
247 **choose “Select data products” button, scroll and choose in the pop-up window from the list of available products and then**
248 **select “Add layer” in the lower left corner of the pop-up window. Maps can also be downloaded in different formats**
249 **obtaining results as in this example (PNG file).**

250
251 Profiles and time series plots are automatically generated from the Regional aggregated and validated datasets (called
252 Regional buffers), thanks to a service bases on WPS OGC standard, and can be dynamically customized. (Fig.7)



253 **Fig. 7: Screenshot from the web portal showing the Time Series dynamically plotted and visualized thanks to the OGC WPS**
 254 **services**
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256 There are ongoing efforts to develop a more efficient information management thanks to a system of data buffers hosted
 257 in a cloud system. Data are harvested and validated in buffers and are then used for product generation.
 258

259 **7. Conclusions and perspectives**

260 EMODnet is a long term marine data initiative developed through a stepwise approach aiming to ensure that European
 261 marine data will become easily accessible, interoperable and free of restrictions on use. EMODnet Chemistry started in
 262 2009 to fulfil EU Marine Strategy Framework Directive requirements for the assessment of eutrophication and
 263 contaminants, following EU INSPIRE Directive rules.

264 With the start of EMODnet phase II, DG MARE and DG ENV started a coordination table to agree on a joint process
 265 and to identify how EMODnet can best contribute in practical terms to the MSFD. EMODnet Chemistry implemented a
 266 set of recommendations, in communication with regional sea conventions (RSC) contracting parties. The situation is not
 267 homogeneous in EU sea basins. While much of the chemistry and contaminant data are well organized within OSPAR
 268 Commission and Helsinki Convention (HELCOM), namely in the North and Baltic sea respectively, EMODnet
 269 Chemistry has a more useful role in the Mediterranean where these outputs are less well organized. A Memorandum of
 270 Understanding with the Commission on the Protection of the Black Sea against Pollution (Bucarest Convention) to
 271 formalize the cooperation in terms of providing dedicated access to EMODnet Chemistry regional products for
 272 supporting management of MSFD indicators as well as increasing participation in the Advisory Groups meetings is
 273 under preparation. A similar step is under discussion with the Information and Communication Regional Activity
 274 Center (INFO-RAC) through the United Nations Environmental Programme, Coordinating Unit for the Mediterranean
 275 Action Plan for the Barcelona Convention (UNEP/MAP).

276 These on-going efforts show the importance of EMODnet Chemistry results and the extensions that might be planned in
 277 view of the last EMODnet implementation phase aiming at a full resolution.

278 In the next years, EMODnet Chemistry could play an important role in the European environmental reporting landscape
 279 with two main tasks. The first task consists in providing standardized and quality checked buffers of data for specific
 280 Regions. The second task is to act as an umbrella providing standards, best practices and infrastructure to aggregate at
 281 Regional level the single member states.
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