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The RADMED monitoring program: towards an ecosystem approach

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Abstract

In the Western Mediterranean, the IEO-RADMED monitoring program is already conducting many of the evaluations required under the Marine Strategy Framework Directive (MFSD) along the Spanish Mediterranean coast. The different aspects of the ecosystem that are regularly sampled under this monitoring program are the physical environment and the chemical and biological variables of the water column, together with the planktonic communities, biomass and structure. Moreover, determinations of some anthropogenic stressors on the marine environment, as contaminants and microplastics, are under develop.

Data are managed and stored at the IEO Data Center that works under the SeaDataNet infrastructure and are also stored under the IBAMar database. In combination with remote sensing data they are used to address open questions on the ecosystem in the Western Mediterranean sea.

1 Introduction

The term "fixed oceanographic stations" was defined as "oceanographic stations at which observations are taken continuously and periodically for periods of one year or more" (Landis, 2004). Operational Oceanography (OO) can be defined as "the activity of systematic and long-term routine measurements of the seas and oceans and atmosphere, and their rapid interpretation and dissemination" (EuroGOOS, 2014). OO includes "a routinely collection, interpretation and presentation of data from the ocean and atmosphere with the purpose of giving a reliable description of the actual conditions of the ocean including its living resources, establishing a marine database from which time series and statistical analysis can be obtained for descriptions of trends and changes in the marine environment including consequences for the living conditions in, on and around the sea and providing prognoses for the future developments of the conditions in the sea" (Buch and Dahlin, 2000). Systematic observation includes

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remote sensing facilities (satellite, radar, etc.) and local and in-situ attended systems (moorings, ships of opportunity, regular research vessel cruises, etc.), together with autonomous or semiautonomous devices (sea level, buoys, drifters, gliders, profilers).

One example of "fixed oceanographic stations" OO program is the California Cooperative Oceanic Fisheries Investigations (CalCOFI), a unique partnership of the California Department of Fish and Wildlife, NOAA Fisheries Service and Scripps Institution of Oceanography. This organization was formed in 1949 to study the ecological aspects of the sardine population collapse off California. Today their focus has shifted to the study of the marine environment off the coast of California, the management of its living resources, and monitoring the indicators of El Niño and climate change. CalCOFI conducts quarterly cruises off southern and central California, collecting a suite of hydrographic and biological data on station and underway (Bograd et al., 2003; McClatchie, 2013). Examples in the Mediterranean sea are the DYFAMED time-series site (Marty, 2002) that, even though it is a single station, forms part of the recently implemented Mediterranean Ocean Observing System on Environment (MOOSE, http://www.moose-network.fr/) and the HYDROCHANGES program (Schroeder et al., 2013).

The Marine Strategy Framework Directive (MSFD) adopted in July 2008 (DIRECTIVE 2008/56/EC) aims at achieving or maintaining a Good Environmental Status (GES) by 2020 at the latest. It is the first legislative instrument in relation to the marine biodiversity policy in the European Union (EU), as it contains the explicit regulatory objective that "biodiversity is maintained by 2020", as the cornerstone for achieving good environmental status. The decisions adopted by the EU authorities for the achievement of GES in the Mediterranean have to be based on appropriate scientific information resulting from the analysis of comparable data sets provided by sea-region scale monitoring programs. According to Article 11 of the MSFD, monitoring programs shall be compatible within marine regions or sub regions and shall integrate and complement the monitoring requirements imposed by other EU legislation.

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A field in which coordination among countries and large scale monitoring is essential is the physical oceanography developed on regular research vessel cruises. As regards to MSFD, Descriptor 7 is specially focused on the changes induced by human activities in ocean circulation, but the understanding of ocean dynamics is crucial also for interpreting the data obtained from almost any monitoring program carried out at sea. This particular aspect is, unfortunately, not yet included in any descriptor. Proposals for developing coordinated monitoring programs related to physical oceanography in the Mediterranean and Black sea have been recently presented by CIESM, such as "Designing MED-SHIP, a program for repeated oceanographic surveys" (CIESM, 2012), or the "Continuous, long-term measurements of temperature and salinity of Mediterranean deep waters in key areas – a priority in the current context of global warming" HYDROCHANGES program (Schroeder et al., 2013). They respond to an urgent necessity of coordinating efforts and take advantage of synergies because, despite hydrographic monitoring have been carried out in the Mediterranean region by means of regular research vessel cruises in several areas, even following similar sampling protocols, there is still an important lack of coordination.

The RADMED project "series tempoRAles de Datos oceanográficos del MEDiterráneo" (time series of Mediterranean oceanographic data) was stablished in 2007, founded by the Instituto Español de Oceanografía, IEO. It was designed to integrate previous monitoring programs developed by different IEO Centers along the Spanish Mediterranean coast (former ECOMALAGA, ECOMURCIA, ECOBALEARES, ECOCIRBAL), some of them running since the 90's. The RADMED project has unified techniques, sampling strategies and analysis to optimize them and to provide a modern and efficient operational oceanography system that produces the data demanded by the current oceanographic research as well as policy makers, and other social demands. The main objective of this project focuses on the determination of a "reference environmental status of the sea" that will help to study the variability of physical, chemical and biological parameters, their oscillations and long term trends. One of the last goals of the RADMED program is to provide reliable information on the marine environment to managers and politicians, as a tool to contribute to the marine system planning.

Actually there are other programs trying to establish the environmental status of the western Mediterranean sea with an ecosystem perspective, like (e.g. but not only) the MERMEX program (de Madron et al., 2011) or the LIONEX and ALBOREX experiments proposed under the PERSEUS project (www.perseus-net.eu), but running under a biannual perspective, and proposals like the CIESM MED-SHIP already cited, not yet implemented. The aim of this work is to present the RADMED monitoring program to the Mediterranean scientific community to help and promote future collaboration on the development of the coordinated sea-region scale monitoring programs as required by the MSFD.

2 RADMED scientific motivations

The general circulation in the Mediterranean sea is cyclonic along the continental slope (e.g. Millot, 1985). Through the Strait of Gibraltar there is an inflow of surface Atlantic Water (AW) that spreads across the Alboran Sea and configures the Algerian Current. In the northwestern Mediterranean the AW from the Algerian sub-basin joins to that coming from the Tyrrhenian sea, configuring the Northern Current (NC), which flows along the continental slope. When it arrives to the Balearic sub-basin it crosses the Balearic channels, while a branch of this current flows northeastward along the northern slope of the Balearic Islands, giving rise to the Balearic Current (BC). See Fig. 1 for a graphical description of the main hydrographic and geographic features of the western Mediterranean sub-basin.

Two water masses are found at intermediate depths, the Levantine Intermediate Water (LIW), formed in the eastern Mediterranean Sea, and the Western Intermediate Water (WIW) formed seasonally during winter convection processes in the Gulf of Lion over the continental shelf and the slope (e.g. Vargas-Yáñez et al., 2012). Western Mediterranean Deep Water (WMDW) if formed during deep winter convection events in the Gulf of Lion and the Ligurian Sea (MEDOC-Group, 1970). Intermediate and deep water masses reach the Balearic channels after circulating along the continental slope of the northwestern Mediterranean. WIW is transported by the Northern Current (NC) into the Gulf of Valencia and the Ibiza channel between the end of the winter and beginning of the spring; however, it is not found at the Balearic channels every year (López-Jurado et al., 2008). Its presence in the Balearic channels at the beginning of the summer determines the regional circulation and the meridional position of the density front originated by the confluence of new AW (fresher and hotter), just arrived through the Strait of Gibraltar, and resident AW (saltier and colder), at the northern part of the western Mediterranean, with important implications on the ecosystem (Balbín et al., 2014b, and references therein).

After the winter 2005 an abrupt change in the Western Mediterranean deep water was observed, with the appearance of a complex termohaline structure that implied the contribution of different water masses (López-Jurado et al., 2005). This structure, denoted as the "Western Mediterranean Transition" (WMT) (CIESM, 2009), affected to the whole Western Mediterranean Sea. There is no agreement on the relative importance of the different deep water formation mechanisms that have originated this phenomena. Nevertheless, it seems evident that the anomalies observed in the Eastern basin, the "Eastern Mediterranean Transient" (EMT) (CIESM, 2009), as in the Western one, the WMT, are the result of factors, as the increase of the salinity in the Mediterranean Sea or the extreme winter forcing, very probably induced by climatic oscillations and indirectly by the climatic change.

It has been shown that not only the anthropogenic pressures but also the environment variability and the hydrographic phenomena that generate deep water, as the cascading or deep convection events that occur in the Mediterranean, affect to biological processes that happen in the whole water column and over the sea floor (p.e. Company et al., 2008; Guijarro, 2012; Rodríguez et al., 2013; Carbonell et al., 2014; Hidalgo et al., 2014) and therefore to the marine resources and their exploitation.

The basic strategy of the RADMED monitoring program is to sample seasonally areas where differences in the large scale oceanographic conditions could be expected. This monitoring comprises productive areas such as the Alboran Sea, oligotrophic waters as those to the north of Cape Palos and around the Balearic Islands, or areas of special biological interest as those surrounding the delta of the river Ebro. Coastal, shelf and deep stations are sampled to get information on the shelf-slope gradient. Deep stations provide a description of the water column, including intermediate and deep water masses and their anomalies along the time. Sampling quarterly along the year allows to filter out the seasonal cycle for the long term climatic studies. It also allows the study of some seasonal phenomena such as the intermediate and deep water formation and transport, or the biological processes. It also enables the description of shelf-slope and latitudinal gradients in the biochemical distributions of the waters surrounding the Spanish coast.

3 Material and methods

Water column temperature, salinity, dissolved oxygen, fluorescence and turbidity are sampled with CTDs (conductivity, temperature, and depth) equipped with additional sensors in every oceanographic station. Chlorophyll *a* and inorganic nutrients along the water column are sampled using a carousel water sampler at standard depths. Carbon dioxide (CO_2) is the most important green house gas and the carbonate system in seawater plays an important role in the biogeochemical cycles and is intimately linked to the processes of photosynthesis and respiration. Therefore, pH, total Alkalinity and partial pressure of CO_2 in air and surface water have been included in the RADMED sampling strategy since 2010. Phytoplankton and zooplankton are sampled by bongo nets to determine their biomass and taxonomic composition.

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3.1 Geographical extension and temporal resolution

The RADMED monitoring program samples regularly every season a fixed distribution of stations, arranged on transects normal to the coast, alongside the Spanish Mediterranean coast, from Barcelona to the Alboran Sea and around the Balearic Islands. The stations distribution is shown in Fig. 2.

3.2 Hydrographic sampling

Every station is hydrographically sampled down to the bottom. The hydrographic sampling is done using CTDs, mainly model SBE 911 and as spare instruments the models SBE 25 or SBE 19+, installed in a carousel water sampler SBE 32. Additional sensors are connected to the CTDs. A SBE 43 sensor, a redesign of a Clark electrode sensor, is used to record the dissolved oxygen (DO). Fluorescence data, obtained with a WET Labs ECO fluorometer, measures the chlorophyll *a* concentration that provides an indication of phytoplankton biomass (Cullen, 1982). The turbidity sensors used in these cruises are either transmissometer (Sea Tech Inc. and WET Labs C-Star) or optical back-scatter sensors (Seapoint).

The CTDs are descended at an average speed of less than $1\,\mathrm{m\,s^{-1}}$. The salinity (S), temperature (T) and the DO are derived using the Sea-Bird Electronics Data Processing routines. The conductivity and DO sensors are calibrated using the carousel water samples. Calibrations are performed for selected depths of the water column at least once by campaign, when it lasts less than a week, and are done at least at the beginning and at the end of the campaign, when it is longer. The spare CTD is cross-calibrated with the SBE911 using the carousel at least once every campaign. The DO determinations to calibrate the SBE 43 sensor are performed by the Winkler titration method (Strickland and Parsons, 1972) and by direct spectrophotometric of total iodine at 456 nm (Pai et al., 1993; Labasque et al., 2004). The DO uncertainty is estimated to be $\pm 0.1\,\mathrm{mL\,L^{-1}}$. The salinity calibrations are done using a Gildline 8400 Autosal and uncertainty is estimated to be ±0.002.

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Additionally to the water column sampling, since 2013, continuous surface sampling is done with a SBE 21 SeaCAT thermosalinograph that determines sea sub-surface (pumped-water) salinity and temperature.

An Airmar PB-200 weather station provides wind speed and direction, atmospheric pressure, temperature and humidity.

3.2.1 Biochemical sampling

Biochemical sampling is done using the carousel water sampler at standard depths that are "surface", 10, 20, 50, "Deep Chlorophyll Maximum" (DCM), 75, 100, 200, 300, 500, 700, 1000 m and "bottom". These standard levels may be modified below 100 m to sample the core of intermediate water masses, the Western Mediterranean Intermediate Water (WIW), at around 100 to 200 m, and the Levantine Intermediate Water (LIW), between 300 and 500 m. Occasionally, up to three levels are sampled at the bottom if the WMT, is detected, to characterize the "old", the "new" and the "cascading" WMDW (CIESM, 2009).

The samples obtained with the carousel are analyzed for chlorophyll *a*, nutrients, pH, alkalinity and phytoplankton abundance. The pH and alkalinity samples are collected from the carousel of Niskin bottles at standard depths after sampling for DO calibrations.

After that, the nutrients samples are collected using 12 mL vials that are kept frozen at −20 °C until they are analyzed on the laboratory. Nitrate, nitrite and silicate concentrations are determined according to the method of Armstrong et al. (1967), modified by Grasshof (1969). Phosphate concentrations are determined by the method of Treguer and Le Corre (1975). All these methods are adapted to oligotrophic waters and analyses are performed with a Technicon Autoanalyzer AAII and QuAAtro Marine of SEAL Analytical.

The pH samples of sea water are collected in a clean borosilicate glass container and immediately measured using a glass/reference electrode cell (Dickson and Goyet, 1994). Alkalinity samples are also collected in a clean borosilicate glass container.

Samples are then treated with mercuric chloride to poison them preventing further biological activity and the container is closed to prevent any further exchange of CO_2 or water vapor with the atmosphere. Samples are analyzed by the potentiometric seawater alkalinity determination with two final end points (Perez and Fraga, 1987; Dickson and Goyet, 1994; Pérez and Fraga, 2000; Dickson et al., 2007) with an automatic potentiometric titrant (Titrando model 808 Metrohm).

The 1 L samples of chlorophyll *a* from the carousel water sampler at standard depths down to the 100 m are filtered and kept frozen at −20 °C until they are analyzed by fluorometry (Holm-Hansen et al., 1965) using a Turner 10AU spectro-fluorometer previously calibrated with pure chlorophyll *a*.

The phyto and bacterioplankton abundance samples are collected from the carousel water sampler using standard bottles (125 mL) for microphytoplankton and using cryovials (5 mL) for nano and picophytoplankton and for bacterioplankton, at standard depths down to 100 m. Micro-phytoplankton samples are treated with an acidified Lugol's iodine solution and nano-, pico-, and bacterioplankton samples are treated with glutaraldehyde solution and immediately frozen at in a liquid nitrogen container. Microphytoplankton samples are examined and analyzed by inverted microscopy (LDMIL Leica) previous a sedimentation procedure (Uttermöhl, 1958). Nano-, pico-, and bacterioplankton abundances are performed (Shapiro, 1995) with a flow cytometer (FACScalibur Becton and Dickinson). For bacterioplankton analysis a subsample was stained with Syto-13 stain solution (Gasol et al., 1999).

Sea surface CO_2 partial pressure is measured in a flowing stream of sea water that is obtained by pumping surface sea water from the bow of the ship for underway analysis (Dickson et al., 2007). This underway measurement is made by a SUNDANS (Surface UNderway carbon Dioxid partial pressure ANalySer) system.

3.2.2 Biological sampling

Zooplankton samples are taken at across-shelf and slope to complete the characterization of the planktonic system, considering its biomass and taxonomic composition.

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Samples are collected by a 20 cm mouth diameter bongo net fitted with 250 and 100 µm mesh bongo net, performing oblique hauls from 100 m to the surface or from 5 m above the bottom to the surface if the station is shallower. The net is fitted with a flowmeter (General Oceanic model 2030) in order to measure the volume of filtered water. The 250 µm sample is divided in two subsamples using a Folsom Plankton splitter. One of the subsamples is preserved in 4 % neutralized formaldehyde buffered with borax and used for taxonomic analysis. The other subsample is frozen at −20 °C and the zooplankton biomass determined following Lovegrove (1966). The same procedure is followed with the 100 µm sample after filtering it onboard through a 250 µm mesh to extract the larger mesozooplankton fraction, separating it from the smaller one.

3.2.3 Data management

All RADMED CTD and biogeochemical data are integrated into the IEO Data Centre (CEDO, Centro Español de Datos Oceanográficos) following standard procedures and after that are incorporated into the SeaDataNet infrastructure (http://www.seadatanet.org/). At the same time all these data are included into the IBAMar database. IBAMar is a regional database (Lopez-Jurado et al., 2014; Aparicio-González et al., 2015) that brings together all the physical and biochemical data provided by multi-parametric probes and water samples taken during the cruises managed by the Balearic Oceanographic Centre of the Instituto Español de Oceanografía, (COB-IEO) during the last four decades. Initially it compiled data from hydrographic profiles obtained from CTDs equipped with several sensors, but it has been recently extended to incorporate data obtained with hydro casts using oceanographic Niskin bottles. The result is an extensive regional database that includes physical hydrographic data as temperature, salinity, DO, fluorescence and turbidity, as well biochemical data, specifically, dissolved inorganic nutrients (phosphate, nitrate, nitrite and silicate) and chlorophyll *a*. Independent teams had used different technologies and methodologies during the four decades of data sampling, however, for the IBAMar database data have been reprocessed using the same protocols, and a standard quality control methodology has been applied

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to each variable. The result is a homogeneous and quality controlled data regional database. IBAMar database at standard levels is freely available for exploration and download from http://www.ba.ieo.es/ibamar/ (Aparicio-González et al., 2015).

Biological data (biovolume, zooplankton biomass, phytoplankton abundance and composition, nutrients, chlorophyl) and some meteorological parameters are included in the IEO SIRENO ("Seguimiento Integrado de los REcursos Naturales Oceánicos") database. The cruises metadata, also known as Cruise Summary Reports (CSR), are systematically sent to the IEO-Data Center and included in the global CSR database, currently linked to the European Infrastructure SeaDataNet and also the POGO initiative (http://www.ocean-partners.org/). It gives visibility to the RADMED activity and also allows the IEO accomplish its international liabilities.

The website of the IEO Mediterranean Group on Climate Change (MGCC, http://www.ma.ieo.es/gcc/) offers information about the IEO monitoring systems as well as useful products as statistics of temporal series and mean values of data that are also accessible. The information presented in this web is mainly addressed to the scientific community. Nevertheless, the MGCC also considers of great importance the scientific spreading to the general public, specially to students. For this reason some activities and wide public information is also included in the website.

3.2.4 Collaboration with other programs

The RADMED team has collaborated traditionally with different research national and international programs, not only using its facilities and protocols but also optimizing sailing time to develop opportunity measurements during the campaigns. The routine sampling and the ship availability within the RADMED monitoring program allow us to carry out more detailed studies within some areas with a special interest from a physical or ecological point of view. These studies are focused on processes occurring on smaller spatial scales than those monitored in the RADMED monitoring program. Nevertheless, the RADMED monitoring program provides an oceanographic framework for the correct interpretation of data collected within such projects. On the other hand, these specific projects provide additional information that can be incorporated to the RADMED data bases establishing reciprocal benefits for both RADMED and these smaller scale projects. Examples of this collaboration are the DESMMON project ("Desarrollo y Estudio de un Sistema de Monitorización multidisciplinar en el Mediterráneo Occidental") funded by the Spanish Ministry I + D + i Plan, or the PERSEUS (Policy-oriented marine Environmental Research for the Southern European Seas) and IRIS-SES (Integrated Regional monitoring Implementation Strategy in the South European Seas) projects, funded by the EU 7th FP.

The RADMED team also collaborates with other monitoring strategies as the TUNIBAL program, focused on ichthyoplankton ecology around the Balearic Islands (Alemany et al., 2010) or the HYDROCHANGES program, that comprise an international set of deep moorings for the long-term monitoring of the hydrological variability in the Mediterranean Sea (Schroeder et al., 2013). The RADMED team has installed a new mooring within this program, whose purpose is to restore the Ibiza channel Hydrochanges mooring that was "temporarily interrupted" between March 2005 and June 2014. The mooring is placed in the continental slope at the north of the Ibiza channel, close to station 25 on the map of Fig. 2. It consists of an Aquadopp currentmeter and a SBE37 CTD at 18–20 m above the bottom. The mooring maintenance is planned to be every 6 months within the RADMED monitoring program. Additionally, a second mooring will be installed in the next months at the NE of Menorca, close to station 88 on the map of Fig. 2.

4 Main RADMED scientific results

One of the main advantages of RADMED is that the sampling is always done over a regular grid. This fact helps the development of studies related to the annual cycles of different variables, their seasonal and interannual variability, the effects of winter convective processes, the presence of water masses, mesoscale structures, transport

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and exchange between basins, cycles, trends and possible climate changes, as well as environmental and ecological studies of species.

In this context, and among other studies, RADMED has allowed to monitor the evolution of the deep waters thermohaline anomaly in the West Mediterranean (WMED), first observed in 2005 (López-Jurado et al., 2005) and that now affects the whole Western Mediterranean Basin. Figure 3 shows the temporal evolution of the potential temperature, θ, vs. salinity, S, at a deep station NE of Menorca (number 88 in the map of Fig. 2) from 2004 (before the thermohaline anomaly) until nowadays. It is possible to observe the contribution of three water masses, the old WMDW, "O" point, that has being shifted upwards hundreds to thousands of meters by the new WMDW, "N" point, and the waters originated by cascading, "C" point, that occupy the bottom of the water column (CIESM, 2009). This structure is slowly dissipating thought the potential density anomaly of the deep waters has increased from 29.11 $kg\,m^{-3}$ to 29.12 $kg\,m^{-3}$ since 2004.

RADMED data have also been used to characterize the spatial distribution and the temporal variability of the different oceanographic variables along the Spanish Mediterranean Sea and around the Balearic Islands. As an example, Fig. 4 shows the T, S, DO, and fluorescence, from the Alboran Sea to Barcelona, along the Spanish Mediterranean coast during the RADMED-0309 campaign that was conducted during March of 2009. Temperatures below 13 °C together with DO content above 5 $mL\,L^{-1}$ at the Balearic Sea, indicate the presence of WIW. There is a clear north-south gradient in surface salinity with the higher values at the north, corresponding to resident AW, and the lower values at the Alboran Sea, corresponding to the recent AW coming from the Strait of Gibraltar. The Alboran Oxygen Minimum Zone (Packard et al., 1988) is clearly observed at the Alboran Sea stations at around 300 m. Fluorescence at this time of the year is quite low everywhere except for the stations at the Alboran Sea where an upwelling episode is observed.

Seasonal climatologies of temperature, salinity and DO were computed at selected stations of the RADMED monitoring program (Balbín et al., 2014a). Those climatologies reflect the appearance of WIW around the Balearic Islands in winter, spring and summer that the MEDAR-MEDATLAS climatologies (MEDAR-Group, 2002) do not show, due to the better spatial (regional) resolution.

MEDATLAS and RADMED data have been used to construct the longest temperature and salinity time series ever analyzed in the Western Mediterranean (1900 to 2008) (Vargas-Yáñez et al., 2010). These time series show that both the upper and intermediate layers have warmed throughout the 20th century. Long term and decadal variability in the upper layer correlate with surface air temperature in the Northern Hemisphere and heat absorbed by the upper North Atlantic Ocean, suggesting that the time series analyzed in this work reflect the present heat absorption of the oceans in the context of global warming.

RADMED dataset has help also the historical analysis of phenomena like the water masses transport through the Balearic channels (Heslop et al., 2012), the cascading processes in the Western Mediterranean (Puig et al., 2013) or the WIW formation processes (Vargas-Yáñez et al., 2012).

5 Discussion

The IEO-RADMED monitoring program is already conducting many of the evaluations required under the MSFD Descriptors 5 (eutrophication) and 7 (hydrographical conditions) along the Spanish Mediterranean coast. The physical environment and the chemical composition of the water column that condition the primary production are regularly sampled. Primary producers are studied by microscopy, flow cytometry and total chlorophyll *a* analysis. The photosynthetic activity and the respiration of organic matter together with the gas interchanges with the atmosphere determine the carbon cycle. The CO_2 atmosphere–ocean interchange is one of the most important in the actual context of climate change and is being sampled continuously using a SUNDANS system. The relations with the next trophic level can be estimated from the zooplankton studies. The higher trophic relations with zooplanktivourous and tertiary consumers are actually not being considered. The heterotrophic bacteria are essential for the decay of the organic matter to close the cycle. The study of bacteria is conducted by flow cytometry, as previously cited, distinguishing the type of bacteria depending on the amount of DNA. Finally, it would be very interesting to study the transference of organic matter to the benthos and also the CO_2 content of the sediment. The future implementation of this aspect by sediment traps installed in the HYDROCHANGES moorings or by dredges is under study.

There are other descriptors required by the MSFD that could be easily implemented within the RADMED campaigns like the study of microplastics in the open sea by Neuston nets or performing dredges at critical points to characterize also the sediment contaminants.

There are many programs trying to determine the correct sampling period and spatial distribution of the stations of the monitoring programs that have to fulfill the MSFD requirements. This is the objective of the IRIS-SES (Integrated Regional monitoring Implementation Strategy in the South European Seas) project where RADMED appears as a pilot action to implement CO_2 and pH routine measurements and the HYDROCHANGES mooring line. The scientific results provided by the RADMED monitoring program together with the actual knowledge of the system and the preliminary conclusions of the IRIS-SES project suggest that the temporal resolution of the program is enough for most of the data requirements but it would be necessary to improve the spatial distribution of stations to describe the main hydrographical features of water masses along the Spanish coast (Gulf of Valencia) and at the Alboran Sea (extending some of the actual transects to the Alboran gyres and the Almería-Oran Front). The Gulf of Valencia has been eventually sampled under the PERSEUS project with the aim of "detect and compliment the data gaps".

The new monitoring technologies, which permit to get synoptic information from large areas, as satellite images, or continuous recording of oceanographic parameters as buoys or moorings that allow to deal with the short scale environmental variability, or automatic systems like the gliders, thought cannot sample all the environmental

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parameters over the whole water column, are also of outmost importance and should be considered as a very useful tool to compliment the information provided by the RADMED monitoring program.

As indicated by Saraiva Nogueira and Armando Valladares (2012), "…our knowledge about the seas and oceans is rather limited. Future challenges, like climate change, cannot be assessed, nor can reasonable mitigation measures be taken without oceanographic data. Ocean services are expected to deliver on the promise of continuous forecasts of the state of the ocean environment. The knowledge needed for such forecasting capability cannot be obtained from research activities which are restricted in duration and project oriented. Scientific research has to be based on, and supplemented by, operational long-term ocean observations to provide analyses, predictions and other information products". From this perspective the IEO-RADMED monitoring program is being a key tool to confront these challenges. Right now, it is a program not so exhaustive as the CalCOFI program but it provides more regular and structured information than the few programs running in the Mediterranean Sea. The purpose of the RADMED team is to coordinate with those programs and make use of the new monitoring technologies to implement a monitoring service that is able to answer the MSFD requirements.

6 Conclusions

All the information obtained along the RADMED monitoring program is being used to study the biological resources and their dependence on the physic-chemical variables, the CO_2 atmosphere–sea interchange and also physical effects like deep and intermediate water masses formation, modification and transport, and oscillations and trends in environmental variables.

The IEO-RADMED monitoring program is already conducting many of the evaluations required under the MSFD Descriptors 5 (eutrophication) and 7 (hydrographical conditions) in the Western Mediterranean. Due to the sampling time pattern and the extensive spatial coverage, these surveys are suitable to gather relevant information for other Descriptors of the Environmental State whose scale of time and spatial-variability are similar. In particular samplings are useful for the description of the plankton biodiversity (Descriptor 1, biological diversity) and might be also combined with the samplings necessary to the assessment of contaminants (Descriptor 8) and of marine litter (Descriptor 10).

It is necessary to remark the usefulness of the new monitoring technologies, and the monitoring facilities already existing in the Mediterranean Sea, that not replace but complement traditional sampling surveys.

Finally, IEO-RADMED and equivalent programs in the Mediterranean Sea could and should be coordinated and standardized to get a global view at basin scale.

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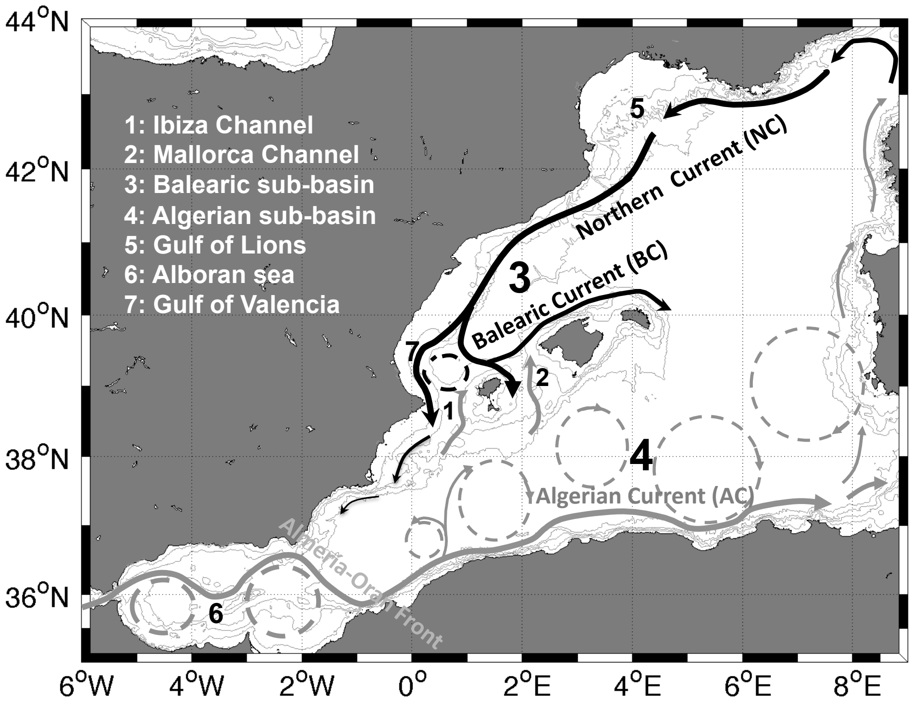

Figure 1. Western Mediterranean Sea and main currents characterizing the regional circulation. The Algerian, Northern and Balearic currents are shown as thick arrows and the Algerian gyres are indicated as light dotted arrows. Light gray lines denote isobath (100, 500, 1000, and 2000 m).

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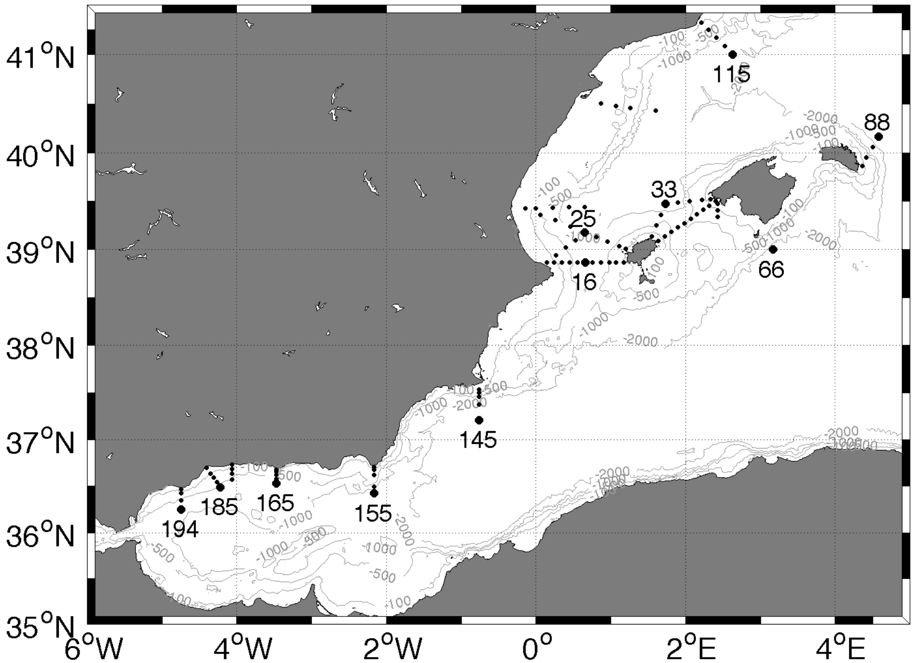

Figure 2. RADMED monitoring program sampling stations. Thicker and numbered dots refer to deep stations used for water masses climatological studies. Light gray lines denote isobath (100, 500, 1000, and 2000 m).

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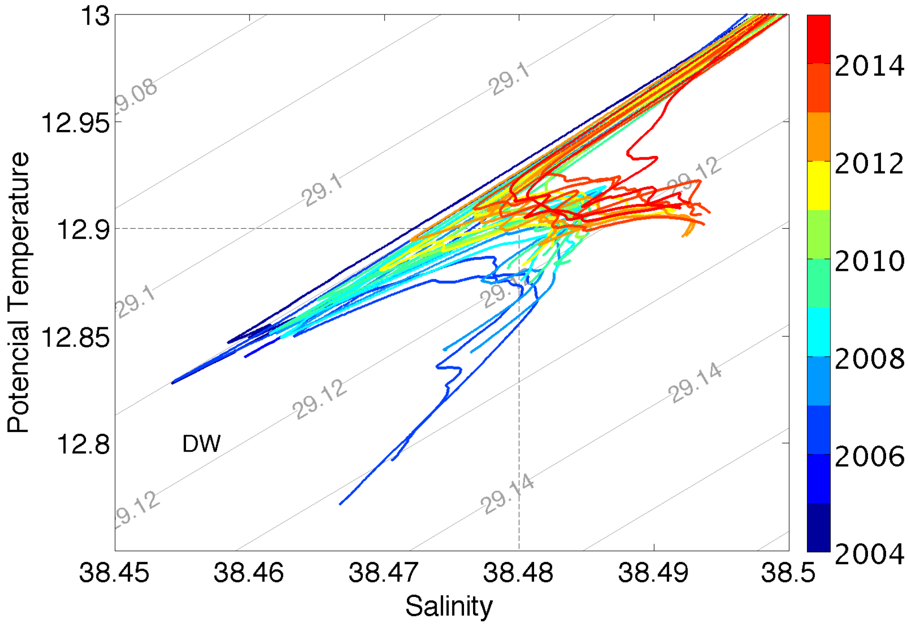

Figure 3. θ–S diagram at RADMED station 88, NE of Menorca Island from 2004 to 2014. Grey lines represent isopycnals. Colorbar indicates the date when the station was visited.

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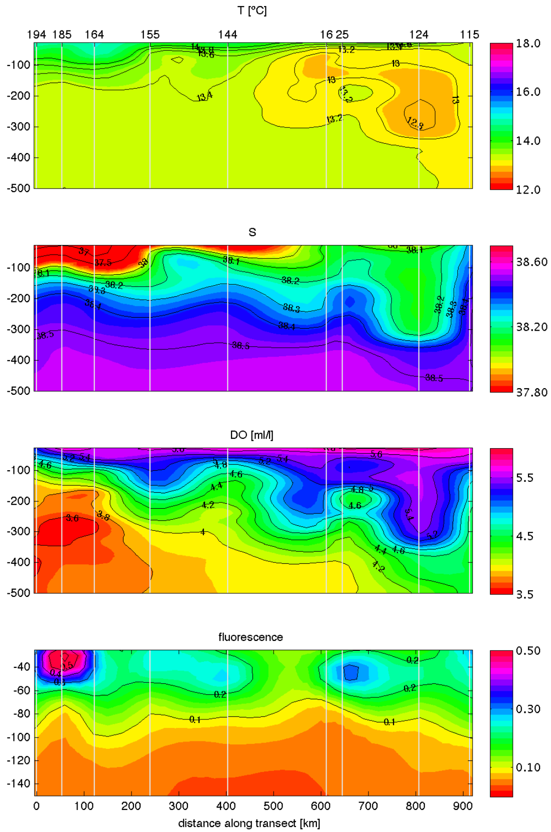

Figure 4. Temperature, T, salinity, S, dissolved oxygen, DO, and fluorescence along the Spanish Mediterranean coast during the RADMED-0309 campaign. Fluorescence data are shown only down to 150 dbar for clarity. Grey lines indicate station position and station numbers are shown on the top of the figure.

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