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'Ecomálaga': an ecosystem analysis of the Mediterranean coast around Málaga, Spain

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Abstract. In October 1992, the Oceanographic Centre of Málaga of the Spanish Oceanographical Institute (IEO) started a monitoring project, *Ecomálaga*, which collects physical, chemical, biological and sedimentological data from the Alborán Sea shelf. The project is coordinated with similar projects in the Atlantic and Mediterranean Centres of IEO. The ultimate objective is to understand the long-term changes of the essential marine-environmental parameters.

So far, nine quarterly surveys have been carried out – from October 1992 to December 1994. The following variables were registered: *abiotic*: location, weather, water temperature, salinity, pH, dissolved oxygen, chlorophyll a, nitrate, nitrite, phosphate, silicate; *biotic*: zooplankton biomass and species composition, and ichthyoplankton. The granulometric composition and organic matter content of sediments are also included.

Data are stored in a computerized data base named Ecomálaga Data Base, with contributions from geology, physics, plankton biology and marine chemistry. The data base not only contains separate files for each research topic, but also allows for interchange between these files, resulting in a synoptic data output. It offers the users an output in the form of synthetic records of each station sampled.

The analysis of the data indicates seasonal influences and a inshore-offshore gradient, as well as an Atlantic influence on the stations located in the transect closest to the Strait of Gibraltar.

Keywords: Alborán Sea; Aquatic ecosystem; Atlantic influence; Data base; Environmental parameter; Long-term change; Mediterranean Sea; Monitoring.

Introduction

The Centro Oceanográfico de Málaga (Oceanographic Centre of Málaga) of the Instituto Español de Oceanografía, IEO (Spanish Institute of Oceanography) started with the acquisition of oceanographical data in 1914, aboard the Navy gunboat Vasco Núñez de Balboa. The first operation, which was carried out on the Málaga coast, is number 116 of the 1914 survey. It took place on October 27 between 9.05 and 11.30 a.m. and it used a trawl with a Richard plankton net (de Buen 1916). This net served for the collection of superficial plankton, an idea proposed by Révena of the Museum of Monaco. Later, in 1927, a working plan for the coastal laboratories of IEO was initiated through a Ministerial Order. The routine work anticipated consisted of weekly registrations and monthly samplings at fixed stations, including measurements of temperature, salinity, water transparency, analysis of plankton groups and plankton volume (de Buen 1932).

In March 1955, the chemical determinations of salinity, oxygen and nutritive salts were repeated (Fernández & Val 1963). Subsequently, in 1977, a new phase of monthly sampling in the Bay of Málaga was started, which included temperature, salinity, plankton biomass and ichthyoplankton identification (Rodríguez 1983; Rodríguez & Rubín 1986a,b).

In 1978, within the framework of the Action Plan for the Mediterranean – UNEP/MAP – IEO created the Observation Network for the Marine Environment (ROMM), in which the Oceanographic Centre of Málaga carries out the collection of monthly multidisciplinary data in the sector between the Strait of Gibraltar and Motril (Granada). This project has led to scientific publications (Camiñas 1983, 1986; Camiñas & Cortés 1986; Cortés 1985; Gil 1988). Once this UNEP/MAP program was finalized, the program MEDPOL-II was initiated in 1981. Within this new framework, a series of multidisciplinary surveys in the region of Málaga were carried out (García & Camiñas 1985; Gil 1985).

In 1992, the Oceanographic Centre of Málaga started an interdisciplinary monitoring system, which by 1993 had developed into a research project called *Ecomálaga* (Camiñas 1993). This project followed from the necessity of having available a historical series of oceanographic data in all Spanish territorial, littoral, peninsular and insular areas, which were needed for the monitoring of effects of climatic change in the marine environment and for the development of forecast systems in the coastal seas (Anon. 1993).

Objectives of Ecomálaga

The research project Ecomálaga forms part of the '*Radiales*' project aiming at an interdisciplinary investigation of the aquatic environment. The main objective of Radiales is to carry out regular and continuous sampling of the physical and chemical parameters and of the plankton communities along the Spanish marine territory; with the ultimate aim of obtaining a historical series of oceanographic data. This main objective includes the following particular scientific objectives (Valdés 1993):

- Seasonal and interannual variability of oceanographic processes which characterize the shelf and slope regions of the Iberian peninsula and the Balearic islands.

- Interannual variability of abundance and structure of the plankton communities.

- The effect of physical processes on the dynamics of the plankton populations.

- Linking the physical, chemical and biological phenomena and their variability.

The Ecomálaga project developed as a scientific support for oceanographic and fishery investigations taking place in the Alborán Sea within the framework of national and international programs. (García & Palomera 1995; García et al. 1995).

The basic scientific objectives of the Ecomálaga project coincide with those described for Radiales. Furthermore, the following specific objectives have to be added:

- To compare the environmental and biological variables in the four survey areas – which are geographically separated and oceanographically differentiated– with the objective of interpreting and quantifying the variability of the processes and testing the validity of littoral circulation models.

- To obtain information on the zooplankton abundance and variability, and particularly on the species of commercial interest in that zone, such as the sardine (*Sardina pilchardus*) and the anchovy (*Engraulis encrasicholus*), as well as the opportunist species that affect the abundance and structure of the exploited species, such as the boarfish (*Capros aper*).

- To record the basic data which permit the interpretation of environmental changes at a local level and the influence of these variables on the microstructure of otoliths and the larval condition of small pelagic organisms.

- To study the interannual and seasonal variability of the oceanographic processes in the northern region of the Alborán Sea.

- To analyse the changes, once a year or less frequently, in the composition and structure of the superficial sediments and their displacement.

- To analyse, at a subregional geographical scale, the effects of climatic change.

- To register the necessary basic data for the evaluation of the impact of the changes resulting from catastrophic changes of the littoral on the marine environment in the foreseeable future.

- To create, maintain and upgrade the Ecomálaga data base.

The Ecomálaga data base

The Ecomálaga data base is a multidisciplinary data base which channels diverse sources of information, allowing a synthetic vision on an annual basis as well as results regarding individual surveys and interactions occurring in the marine environment. The data included in the data base may be used for the analysis of marine environmental conditions of the Spanish peninsular and insular shelf, enabling a detailed understanding of effects of global changes in the marine ecosystems. Finally, the Ecomálaga data base offers scientific support to marine research projects carried out in the Alborán Sea by different national and foreign teams.

General framework

The oceanographic framework of the project is the northern region of the Alborán Sea, in the extreme west of the Mediterranean (Fig. 1). The Alborán Sea has been the subject of many scientific investigations. However, a complete picture of the long-term variations concerning different aspects of the ecosystem is not yet available. It is important to pay attention to oceanographical processes occurring at the continental margins, linking different research areas and, in this way, understanding the existing relationships between the physical, chemical, biological and geological processes involved in the ecosystem balance. Thus, an integral view on the Alborán marine ecosystem is obtained and its behaviour and dynamics under natural conditions understood.

The Alborán Sea forms a transition zone between the Atlantic and Mediterranean domains. Hydrographically, it is characterized by the Atlantic jet current which penetrates the Strait of Gibraltar in ENE direction, whereafter it is led towards the Moroccan coast by the Coriolis effect –producing a great anticyclonic gyre in the western sector. The variability of this anti-cyclonic gyre and the inflowing Atlantic jet has been investigated by field studies (Cano & Castillejo 1972; Cano 1977, 1978), satellite imagery analysis (Heburn & La Violette 1990) and numerical modeling (Preller 1986).

In the northwestern sector of the Alborán Sea, near Gibraltar, divergence areas exist between the Atlantic water inflow and the northern littoral provoking the

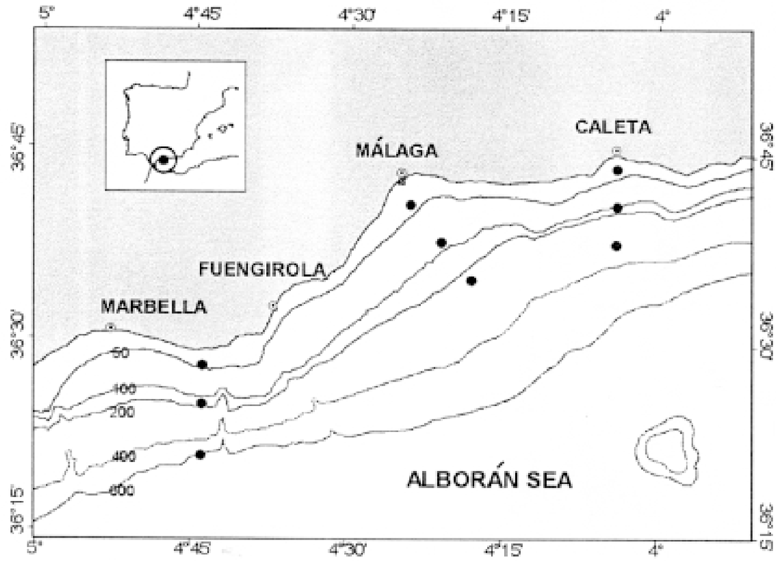

Fig. 1. The oceanographic framework of the Ecomálaga project: the northern region of the Alborán Sea in the extreme west of the Mediterranean.

enrichment of the surface layers, upwelling deep waters in the proximity of Gibraltar. A high phytoplankton productivity is associated with this region (Cortés et al. 1985), and, at its western border, with high zooplankton biomass (Camiñas 1983; García & Camiñas 1985). The littoral currents over the shelf are mainly dependant on the wind (Arévalo & García 1983), while there is a clear influence of the general current situated outside the shelf (Cano & García 1991). The effects of this current on the zooplankton community and the environmental parameters determine an annual cycle of zooplankton which is quite different from nearby areas (Rodríguez 1983). On the whole, the coastal area is under the direct influence of the Atlantic jet current, which, *i.a.* displaces eggs and larvae in a seaward direction. Information from annual surveys from 1991-1993 shows that larvae are abundant in the open sea; the Atlantic flow acts here as a carrier of eggs and larvae (Rubín et al. 1992; García Lafuente et al. 1995).

The general distribution scheme for nitrates is modified in the Alborán Sea with high values for nutrients found at superficial levels due to the processes of divergence which cause the upwelling of rich sub-surface waters (Rubín et al. 1992). This upwelling on the Málaga coast and its relationship to the divergence effects, causing the cyclonic gyres in this zone, has been studied using chlorophyll, temperature and salinity data (Cortés et al. 1985). The other fertilization process of the Alborán Sea is produced by the Atlantic stream, although this effect is only apparent in the summer in the proximity of the Strait of Gibraltar. Here a diminution of nutrients from west to east occurs, leading to an oligotrophic character in the superficial waters in the east (Rubín et al. 1994).

The present superficial sediment distribution on the Iberian continental shelf of the Alborán Sea shows a strong influence of the water exchange in the Strait of Gibraltar. The sediments show a great textural variety with gravel, sand and mud, both calcareous and non-calcareous; there are also zones of non-deposition. There is an important silicyclastic sedimentation in the mouth of the main rivers. These deposits are composed of mud and sand and decrease in thickness in a seaward direction. The inner shelf is dominated by sand bodies and rocky substrate, while the outer shelf and slope consist mainly of muddy sediments. Some channel systems are recognized in the shelf-break; they transport suspended and frictional surface matter to the deep basin.

Material and Methods

Ecomálaga depends on a network of 13 stations situated in four distinct oceanographic areas. Nine stations are spread over the continental shelf of the Alborán Sea and constitute the transects of Cabo Pino, Málaga and Caleta de Vélez. The other four stations are situated in the area surrounding Alborán Island. The coordinates of the fixed sampling stations are given in Table 1.

At each station, the following operations are carried out: CTD probe; Niskin bottles supplied with inversion thermometers; a Bongo-40 plankton trawl with nets of 250 and 235µm; superficial sediments are collected with a Shipek grab. The Niskin bottles are located at standard depths of 1 (surface), 10, 20, 50 m and at bottom level.

Table 1. Location of the fixed sampling stations.

Station	Latitude (N)	Longitude (W)
1	36° 28' 20"	04° 44' 36"
2	36° 25' 43"	04° 44' 50"
3	36° 21' 10"	04° 44' 53"
4	36° 41' 76"	04° 24' 35"
5	36° 38' 32"	04° 21' 22"
6	36° 35' 60"	04° 18' 62"
7	36° 44' 12"	04° 03' 99"
8	36° 41' 25"	04° 03' 85"
9	36° 38' 28"	04° 03' 90"
10	35° 59' 08"	03° 02' 00"
11	35° 57' 18"	03° 02' 00"
12	35° 55' 17"	03° 02' 00"
13	35° 54' 15"	03° 02' 00"

All operations carried out at sea, the order of sampling, sampling time, the exact location from the start to finish of the operation and possible incidents, are recorded in the Navigation Diary by the captain of the vessel. For each of the sampling stations different standard forms are prepared: station control, which includes basic data about the campaign, location, vessel and climatology; sample sheet for the physical-chemical parameters; sample sheet for zooplankton and biomass.

Niskin bottle data. Water samples are taken with PVC Niskin bottles, supplied with inversion thermometers. The parameters studied include: temperature, salinity, dissolved oxygen, pH, chlorophyll a, phosphate, nitrate, nitrite and silicate; for the standard analysis methods see Cortés & Varela (1992).

Secchi disc. Water transparency is measured with the Secchi disc.

CTD data. A 'SBE-25' CTD probe was used for the measurement of conductivity, temperature and depth; in addition fluorescence and pH were measured. The probe was lowered to a maximum depth of 200 m. The data were filtered to obtain 1-m interval samples. Salinity was expressed in p.s.u. (Practice Salinity Units) (Lewis & Perkins 1981) and density was calculated from the revised state equation by Millero & Poisson (1981).

Plankton sampling. A 'Bongo-40' net, equipped with two independent flow meters 'General Oceanics 2030' and one depth-meter gauge, was employed to carry out 'double-oblique' trawl from the surface to 100 m depth. Two different mesh sizes were used, a 250 µm for determining the zooplankton biomass and a 350 µm for taxonomic identification of the ichthyoplankton.

Sediment sampling. Surface sediment sampling was carried out by a grab (Shipek), taking a subsample for organic matter analysis (chemical method, using dichromate). Granulometric analysis was carried out by sieving: a first separation by wet sieving in order to separate the very fine fraction (mud and silt) and a second dry sieving to differentiate sand and fine gravel categories. Carbonate measurements are based on the Bernard method.

Data base application. The Ecomálaga data base is based on the DBFast Windows 2.0 application; system requirements are minimally:
- PC 80386r;
- Windows 2.0;
- 4 Mb RAM;
- VGA Screen display.

All data collected during the nine surveys from October 1992 to December 1994, as well as the cruise report and separate scientific data, have been stored in a standardized way. Four functional parts are involved:

1. Data base maintenance. All files are continuously updated. Within each file, registers can be added, eliminated or modified; data can be located from a data code; register groups can be listed and files can be saved and re-indexed.

2. Data base maintenance. This includes six files corresponding to surveys, stations, sedimentology, physics, chemistry and plankton. Each of these files has a name, a keyword including either the code of the survey, or that of the station, the depth, or the three combined, and a series of fields defining the specific content of that file (sedimentology, chemistry, plankton, or physics, in addition to the campaign and station data).

3. Data base results. Lists can be obtained for all files through the report designer or a list of selected data from the group selection. Synoptic results can be obtained per station.

4. Data base manager. Files can be formatted into tables with standard rows and columns. Operations of on- and off-records and modifications thereof can also be performed, but with an overall view with regard to the number of registers.

Results

Physical data

Winter 1993

An Atlantic influence was noticed in the entire area studied, with uniform superficial salinity values (36.8 - 36.9 p.s.u.). The temperatures were normal for this season, between 14.5 and 15°C. The interface was quite deep, about 85 or 90 m, except at station 5 where it was at 50 m.

Winter 1994

The Atlantic influence was similar to that of the previous year, but only for stations 1, 2 and 3; for the rest of the stations, the salinity oscillated between 37.1 and 37.4 p.s.u. Temperatures were generally lower, 0.8°C lower than in 1994. The inter-face was less deep – situated between 60 and 80 m.

Spring 1993

Outstanding characteristic were:
- Salinities were generally very high – even higher further east and further in-shore; they varied between 36.8 p.s.u. at station 3 and 38.1 p.s.u. at station 7. Surface salinities of more than 38 p.s.u. are exceptional.
- Temperatures of the surface layer were low for the time of the year –between 13.8 and 15°C– as could be expected: as the salinity values indicated, deeper water had reached the surface. The deepest interface was found at stations 6, 2 and 3, at 20, 30 and 50 m respectively. Elsewhere, the interface was very close to the surface. For this year and season, there was a strong haline front in the Málaga Bay in a NW-SE direction.

Spring 1994

The salinity values were not as high as in the previous year; they also flushed from W to E and from S to N. This is logical given that the Atlantic current enters the bay in the southwest part. The (surface) temperatures, milder than those of the previous year oscillated between 14.2 and 15°C. The interface was deeper, even more so in the SW (towards the east of Gibraltar). It varied between 60 m at station 3 and at the surface at station 7. A haline gradient at the surface was also found, albeit weaker than the year before.

Summer 1993

Surface salinity values surpassed 37 p.s.u. at most stations, but 36.5 p.s.u. at station 3, the only station in direct contact with the entering Atlantic water. In the TS (temperature versus salinity) curve referring to water masses an intrusion of Atlantic water at ca. 60 m of depth was observed. This situation is typical of frontal stations. For the other stations, the surface salinity was very uniform, oscillating around 37.1 p.s.u. The temperatures of the superficial layer were also quite uniform at all stations (oscillating around 21°C), except for station 3, where the temperature was only 18°C, due to the upwelling Atlantic water from the west. The interface was situated at a depth of 50 to 30 m.

Summer 1994

The hydrological situation was similar to that of the previous year, but the surface salinity values were lower.

Autumn 1993

The Atlantic influence was small; the surface water had salinity values of 37.0 to 37.7 p.s.u. The water was cold for the season (September), with values around 16°C. The interface was situated between the surface and 30 m deep. As can be expected, surface salinities and the temperatures were higher toward the east.

Autumn 1994

The Atlantic influence was notable. Except for the coastal stations, the salinity did not exceed 36.5 p.s.u. in the surface layers. The surface temperatures (19 °C) were much higher, even in October. The interface was found much deeper, at 70 to 80 m. On the whole, values were uniform at all stations.

Chemical data

Winter 1993/1994

Dissolved oxygen. A maximum at the surface of 6.06 ml/l (St. 6/1994) and a minimum of 4.61 ml/l (St. 7/1993). No marked differences between the years.

Chlorophyll a. Values are characteristic of the time of the year, with a surface maximum of 1.97 mg/m^3 (St. 2/1993) and a minimum of 0.26 mg/m^3 (St. 7/1994).

Nutrients. Values at the surface were higher in 1994 than in 1993. Maximum and minimum values at the surface for both years were:

NO_3^-	2.84 mmol/l (St. 1/1994);	0.04 mmol/l (St. 6/1993)
NO_2^-	0.36 mmol/l (St. 7/1994);	0.02 mmol/l (St. 6/1993)
PO_4^{3-}	0.27 mmol/l (St. 7/1994);	0.07 mmol/l (St. 2/1993)
SiO_4^{3-}	2.29 mmol/l (St. 1/1994);	0.67 mmol/l (St. 3/1993)

Spring 1993/1994

Dissolved oxygen. The surface values oscillated between 6.03 ml/l (St. 9/1994) and 4.76 ml/l (St. 4/1994). No big differences were observed between the years.

Chlorophyll a. At the surface, the extreme values were 4.89 mg/m^3 (St. 8/1993) and 0.45 mg/m^3 (St. 3/1994). The values found were concordant with the spring peak which the phytoplankton presented. The highest values of chlorophyll corresponded to those in 1993.

Nutrients. In general, the nutrient values at the surface were higher in 1993 than in 1994. This situation is the opposite of that observed in January. The differences are more notable in the transects of Caleta de Vélez and Málaga, which confirms the existence of local upwelling mentioned in the salinity section. At the surface, maximum and minimum values were:

NO_3^-	6.15 mmol/l (St. 7/1993);	0.03 mmol/l (St. 9/1994)
NO_2^-	0.29 mmol/l (St. 4/1994);	0.01 mmol/l (St. 9/1994)
PO_4^{3-}	0.29 mmol/l (St. 4/1993);	0.04 mmol/l (St. 8/1994)
SiO_4^{3-}	5.35 mmol/l (St. 5/1993);	0.17 mmol/l (St. 9/1994)

Summer 1993/1994

Dissolved oxygen. The extreme values at the surface were 6.30ml/l (St. 1/1994) and 5.55 (St. 5/1994) ml/l.

Chlorophyll a. The maximum and minimum values found were 1.07 mg/m^3 (St. 3/1994) and 0.04 mg/m^3 (St. 6/1993). The values are lower than in other seasons.

Nutrients. Generally the nutrient values are low along the three transects, with the exception of a high phosphate value (0.52 m mol/l) at the coastal station 4 in the Málaga transect.

Autumn 1992/1993/1994

Dissolved oxygen. The oxygen values were somewhat lower in 1992 but they were similar in 1993 and 1994.

Chlorophyll a. Extreme values at the surface were maximally 4.24 mg/m^3 (St. 1/1992) and minimally 0.23 mg/m^3 (St. 3/1994).

Nutrients. The range of values at the surface was similar in the three transects and in the three sampled years, with the exception of station 9 at Caleta de Vélez (1992) which had high surface values for nitrates, phosphates and silicates. The values oscillated between:

NO_3^-	5.55 mmol/l (St. 9/1992);	0.04 mmol/l (St. 6/1992)
NO_2^-	0.16 mmol/l (St. 4/1993);	0.01 mmol/l (St. 6/1992)
PO_4^{3-}	0.45 mmol/l (St. 9/1992);	0.06 mmol/l (St. 3/1992)
SiO_4^{3-}	3.48 mmol/l (St. 9/1992);	0.48 mmol/l (St. 8/1992)

Plankton data

Two types of data were analyzed: firstly, egg and larvae abundance and distribution of the sardine (*Sardina pilchardus*) and anchovy (*E??* *encrasicholus*); secondly, zooplanktonic biomass (Table 2). A zooplankton community description is in progress.

Maximum fish egg and larval abundances were found during the winter surveys; this is mainly influenced by the spawning of sardines at their seasonal peak. Maximum fish egg density was found at station 8 in January 1993 (535 eggs/m^2), of which 503/m^2 were sardines. In 1994, maximum egg density was only 27 eggs/m^{2,}

During the survey period, anchovy spawning has been extremely low. The only noteworthy value occurred at Caleta de Vélez in the summer of 1994, with 21eggs/m^2, together with low anchovy larval densities (maximum of 6 larvae/m^2). These observations are in agreement with a historical drop of adult anchovy density from the Alborán Sea coasts (Giráldez & Abad 1995).

With respect to larval densities, the maximum value observed was 432 larvae/m^2 at station 9 of Caleta de Vélez during the summer period of 1993. Such a high value is due to the occurrence of larvae of mesopelagic species, mainly myctophids and gonostomatids.

The transects of Málaga and Cabo Pino show distinct spring spawning peaks during the analyzed period due to the influence of a variety of fish species that spawn during this period of the year, such as certain species of the *Sparidae* family.

Zooplankton biomass was sampled in 1994. The maximum value expressed in dry weight was observed at station 5 (38.74 mg/m^2) off the transect of Málaga in January, whereas the minimum was found in station 3 (3 mg/m^2) off Cabo Pino in July (Table 2). Maximum zooplankton biomass values were observed in summer at some stations, and in winter at others. Two maximum mean values were found, one in winter and the other in summer (Table 2).

Table 2. Zooplankton biomass data (mg/m^3) for three transects with two stations each and mean values at four sampling times.

Transect	Cabo Pino		Málaga		Caleta de Vélez		
Station / Sampling	2	3	5	6	8	9	Mean
9401	9.52	16.98	38.74	12.83	6.74	7.53	15.39
9404	7.37	-	9.56	3.78	13.44	6.08	8.05
9407	10.95	3.0	16.04	17.51	32.43	30.08	18.34
9410	9.53	6.15	11.72	11.51	12.66	4.90	9.41
Mean	9.34	8.71	19.02	11.41	16.32	12.15	

Sediments

Variations in sedimentation data were greater than expected. This may be due to ship drift during the operations, or to real changes of the depositional unit.

Conclusions

- In the winter of 1993, the depth of the interface in the transect of Málaga was notably less than in the other transects. This suggests a cyclonic circulation in this bay.

- The drop in surface temperature in 1994 was accompanied by an increase of the nutrient concentration at the surface. The highest ichthyoplankton biomass values appeared to be related to sardine spawning in this season.

- In the spring of 1993 very high salinity values appeared in conjunction with very low temperatures, indicating up-welling processes of deep Mediterranean waters.

- The maximum values of dissolved oxygen and chlorophyll a were found in the layer under the surface, which is due to the effect of high temperatures at the surface and the excess of incidental light for the phytoplankton.

- Concentrations of nutrients were generally low. The increase of other nutrients seems to indicate a contamination effect by the sewage of residual waters.

- Anchovy spawning peaks in summer and shows a clear seasonality.

- Autumn oceanographic conditions vary over the years with, for instance, a marked Atlantic character of the surface waters in 1994 and a Mediterranean character in the same zone in 1993. The decrease of chlorophyll a in 1994 could be associated with the occurrence of a superficial warm layer and a greater thickness of the (less saline) Atlantic layer.

- Seasonal variations in sedimentation in the upper units were expected, but not found – maybe due to the inaccuracy of the data.

- The biological, physical and chemical data acquired and analysed in the Ecomálaga project present a great heterogeneity and variability, which is basically due to the variability of the inflowing Atlantic current at the Strait of Gibraltar.

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