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Oceanography of the Gulf of Artabro (northwestern Iberian Peninsula) in early spring: General patterns

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ABSTRACT

The COPLA 393 cruise was carried out from 22-29 March 1993 on the continental shelf located between the Sisargas Islands and Cape Prior (northwest Spain). Forty-one stations distributed into five sections perpendicular to the coast were sampled, with the aim of investigating spring conditions in the Gulf of Artabro. Salinity and temperature profiles were obtained, and nutrients, chlorophyll, primary production, light, specific composition and abundance of plankton (including bacteria and phytoflagellates) were determined. The present study provides the first survey of conditions prevailing at the beginning of the spring in the entire Gulf of Artabro.

The hydrographic situation is relatively complex, with a quite well defined thermic-saline front perpendicular to the coastline in the central part of the Gulf of Artabro. The water west of the frontal area was more saline (13.2 °C; 35.85 psu), whereas east of the front colder and less saline waters prevailed (12.8 °C; 35.75 psu). When the cruise was carried out, the primary production (35-155 mg C m^{-2} h^{-1}) and chlorophyll *a* concentration (< 2 mg m^{-3}) were relatively low and a dispersion of the phytoplankton communities was observed. Mean biomass of the microzooplankton and the mesozooplankton were typical of winter (8.8 and 23 mg dw, respectively). Bacteria (1.5×10^5 cel ml^{-1}) and microflagellates (phytoflagellate autotrophs: 790 cel ml^{-1} and heterotrophs: 960 ml^{-1}) also had low abundances. The atmospheric conditions, which favoured an early spring bloom in February, had changed. There were areas with phytoplankton typical of winter, with predominance of microflagellates, cryptophyceae and small dinoflagellates, and other areas with low abundance of phytoplankton but with a high specific diversity. The latter were the remains of the spring bloom, which had occurred some days before the beginning of the cruise. Therefore, we suggest that the bloom-dispersion regime may be a common feature, existing normally in this gulf, as a consequence of the occurrence of early blooms in winter and the varying environmental conditions in the February-March period.

Key words: Hydrography, front, spring bloom, chlorophyll, plankton, Gulf of Artabro, Galicia.

RESUMEN

Oceanografía del golfo de Artabro (noroeste de la península Ibérica) a principios de la primavera: modelo general

La campaña COPLA 393 se llevó a cabo entre el 22 y el 29 de marzo de 1993 en la plataforma continental comprendida entre las islas Sisargas y el cabo Prior. Se muestrearon 41 estaciones distribuidas en cinco secciones perpendiculares a la costa. Su objetivo fue investigar las condiciones hidrográficas y la floración de primavera en el golfo de Artabro. Se obtuvieron perfiles de salinidad y temperatura, datos de nutrientes, clorofila, producción primaria, luz incidente, composición específica y cuantificación del plancton (in-

cluyendo bacterias y fitoflagelados). Su estudio ha proporcionado, por primera vez en la totalidad del golfo de Artabro, información acerca de las condiciones reinantes al comienzo de la primavera.

La situación hidrográfica es relativamente compleja, con un frente térmico y salino bastante bien definido perpendicular a la línea de costa en la parte central del golfo de Artabro. Hay agua más salina al oeste (13,2 °C; 35,85 ups) de la zona frontal y al este un cuerpo de agua más fría y de menor salinidad (12,8 °C y 35,75 ups). Cuando se llevó a cabo la campaña, la producción primaria (35-155 mg C m^{-2} h^{-1}) y la concentración de clorofila a *(< 2 mg m^{-3}) eran bajas y se observa una dispersión de las comunidades de fitoplancton. Tanto el microzooplancton como el mesozooplancton presentan biomasas medias típicas de invierno (8,8 y 23 mg de peso seco, respectivamente). También bacterias (1,5 × 10^5 células ml^{-1}) y microflagelados (fitoflagelados autótrofos: 790 células ml^{-1} y heterótrofos: 960 células ml^{-1}) mostraron bajas abundancias. Las condiciones atmosféricas que favorecieron una temprana proliferación primaveral de fitoplancton en febrero habían cambiado. Hay zonas con fitoplancton propio del invierno, con predominio de microflagelados, criptofíceas y pequeños dinoflagelados junto con otras de baja abundancia de fitoplancton, pero una alta diversidad específica. Son los restos de la floración primaveral que tuvo lugar días antes del comienzo de la campaña. Por ello, el régimen proliferación-dispersión debe darse corrientemente en este golfo como consecuencia de la proliferación temprana y de las cambiantes condiciones ambientales en febrero-marzo.*

Palabras clave: *Hidrografía, frente, proliferación primaveral, clorofila, golfo de Artabro, Galicia.*

INTRODUCTION

The hydrography of marine waters off the northwest Iberian Peninsula has been studied generally in connection with the upwelling that usually occurs during summer (e.g. Fraga, 1981). These periodic events have been surveyed on a macro-scale (Ríos, Pérez and Fraga, 1992) and recently, on a meso-scale in the Galician coastal area (Prego and Bao, 1997), and on a local scale (Prego and Varela, 1998) in the Gulf of Artabro. However, the general oceanographic characteristics of this gulf in winter-spring have not been described previously.

The Gulf of Artabro occupies an area of 1 500 km^2, with a shelf from the coastline to the 200-m isobath. It is formed by a long arc which goes from the Sisargas Islands to Cape Prior, and which includes the three major Galician Rias Altas (Ferrol, Betanzos-Ares and A Coruña). The COPLA cruises conducted the first a local-scale sampling of this area, and this article presents the results for early spring.

At the time we began our study, the only information available about this gulf was from a transect in front of A Coruña, with stations to a depth of 80 m. This transect has been sampled monthly since 1988. The data obtained led to the description of two annual oceanographic cycles, corresponding to the years 1988-1989 (Valdés *et al.*, 1991) and 1991-1992 (Casas *et al.*, 1997). These cycles represent an equalisation of the water column from November to March-April. They also indicate the presence of warm and saline water in autumn, and a maximum of plankton biomass in spring. Afterwards, during 1993, pollution caused by the sinking of an oil tanker off A Coruña was monitored, using data from the COPLA cruises and the aforesaid transect. Although this research included the Gulf of Artabro, it considered specifically the impact of pollution, and found that there were no significant differences in the composition, abundance, biomass and production of plankton when the results from the COPLA cruises were compared with those obtained over the preceding years (Varela *et al.,* 1996).

MATERIALS AND METHODS

The present study of springtime oceanographic conditions in the Gulf of Artabro is based on data obtained during the research cruise COPLA 393 (COruña PLAtform, March 1993). This cruise was made from 22-29 March 1993 on the continental shelf located between the Sisargas Islands and Cape Prior (figure 1).

The sampling was carried out at 41 stations distributed into five sections perpendicular to the coast, at the depths of 0, 5, 10, 20, 30, 40 50, 60, 75, 100, 125, 150, 175 and 200 m from the surface to the bottom, using 5-l Niskin bottles.

Salinity and temperature profiles were taken at all the stations with a CTD Seabird 25 (squares in figure 1).

In six stations of each section (empty and crossed squares in figure 1), nitrate was deter-

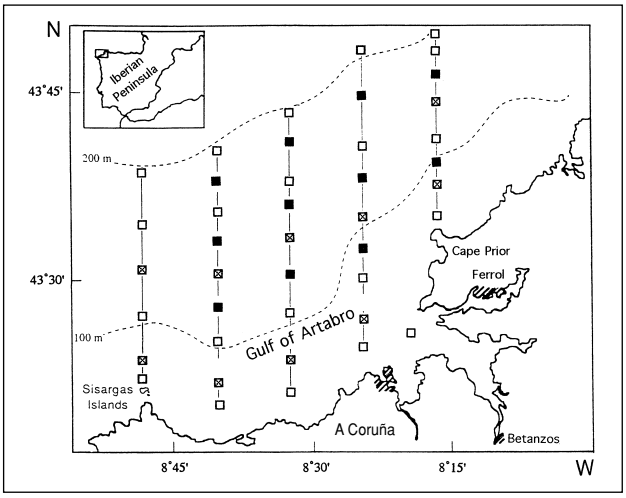

Figure 1. Map of the Gulf of Artabro area studied, with sampled stations' positions shown as squares. Dark squares are only CTD stations; crossed squares are CTD, chemical and biological stations; and empty squares are CTD and chemical stations

mined with an autoanalytser Technicon AAII following the Hansen and Grasshoff (1983) method. Chlorophyll *a* was determined by fluorimetry, following the Yentzsch and Menzel method (1963), using a Turner Design fluorometer.

At the second and fourth stations of each section (crossed squares in figure 1), starting from the coast, more detailed measurements were made. Primary production was measured by incubation on board at the depth of 100, 50, 25, 10 and 1 % of the surface irradiance (PAR). Irradiance was measured with a LI-COR sensor connected to the CTD. Specific composition and abundance of phytoplankton were analysed from samples fixed with Lugol's solution in a Nikon Diaphot inverted microscope. Biomass of microzooplankton was measured from samples obtained with 40-µm WP2-type nets, 20 cm in diameter, during vertical hauls, from 40 m and 20 m to the surface. Samples of mesozooplankton (> 250 µm) were obtained by double-oblique hauls with a Judey-Bogorov 250-µm net, from the bottom to the surface. Biomass of mesozooplankton was measured following the Lovegrove method (1966). Total abundance of bacteria was determined from samples fixed with glutaraldehyde (10 % final concentration), following the Hobbie, Daley and Jasper (1977) method. Abundances of autotrophic flagellates (> 5 µm) at the depths corresponding to 100, 10 and 1 % of the PAR radiation were determined using an epifluorescent microscope. The total number of flagellates was determined from samples fixed with Lugol's solution by observation under an inverted microscope with phase contrast.

RESULTS AND DISCUSSION

The study area comprised water with a higher salinity than the Eastern North Atlantic Central Water (ENACW) (Fiuza, 1984) mass, which can typically be found at depths of 70-500 m off the Galician coast, and which upwells during summer (Fraga, 1981). The T-S diagram (figure 2) shows that between the

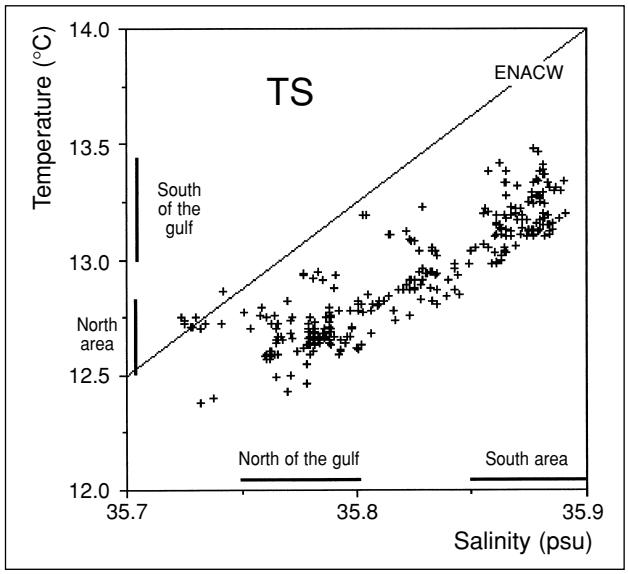

Figure 2. Salinity-temperature diagram of all Gulf of Artabro stations. Only data from depths of 0, 5, 10, 20, 30, 40, 50, 60, 75, 100, 125, 150, 175 and 200 m were plotted

Sisargas Islands and Cape Prior, salinity varied from 35.72-35.89 psu and the temperature from 12.4-13.5 °C. This corresponds to a temperature typical of winter in the Gulf of Artabro (approximately 12 °C; Valdés *et al.,* 1991) while the salinity near the coast was similar to that of the water transported by the poleward current (35.8-36.0 psu; Frouin *et al.,* 1990). The latter is a surface current, which moves northward all along the Iberian Atlantic Coast, mainly during autumn and winter (Haynes and Barton, 1990). The presence of this poleward seawater was due to dominant winds that, in days previous to the cruise, were favourable to upwelling (figure 3).

The surface map of isotherms and isohalins (figure 4) shows the dispersion of points in the T-S di-

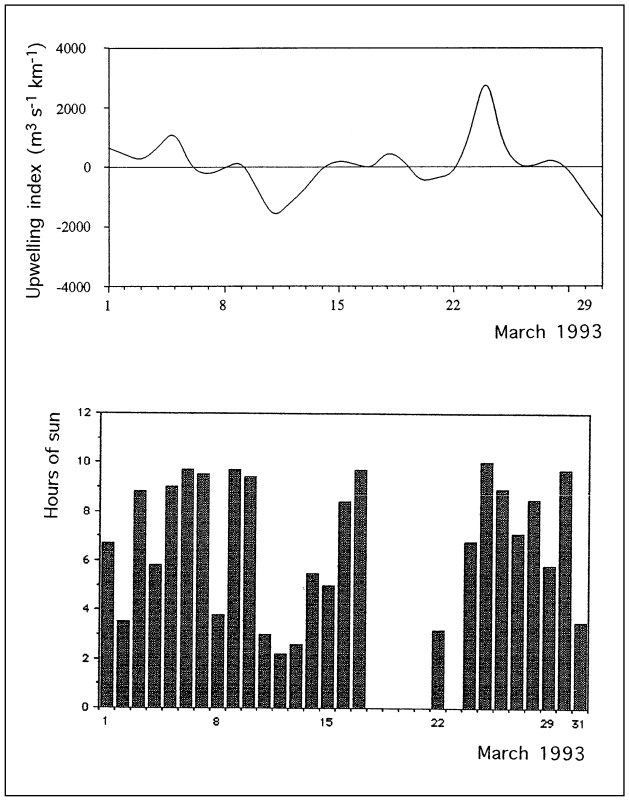

Figure 3. Daily values of the upwelling index and of sun hours for March 1993 in the Gulf of Artabro area (from data recordered at Centro Meteorológico de A Coruña

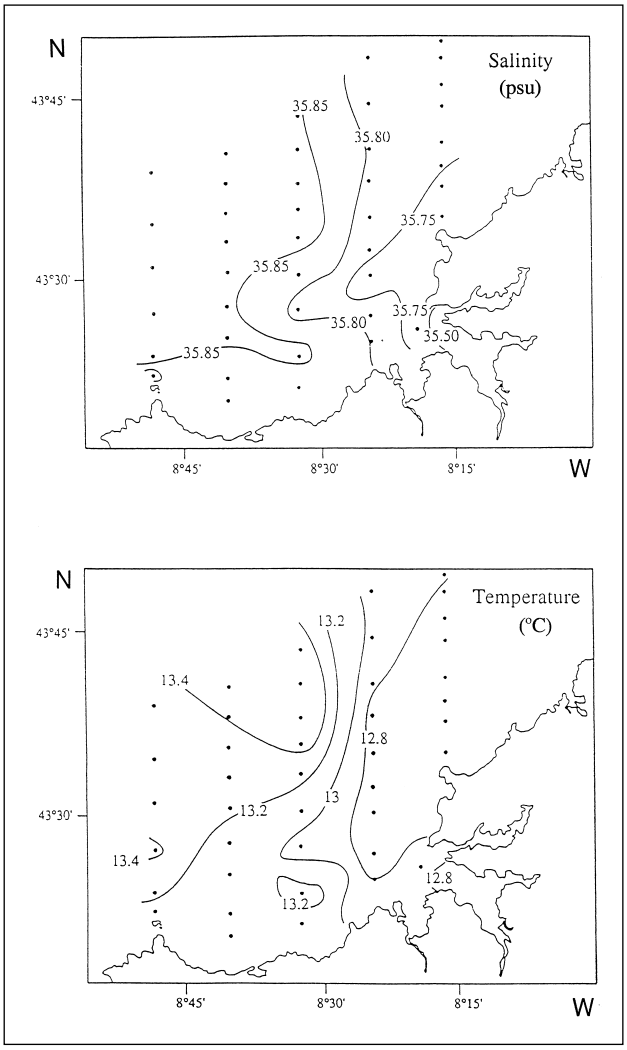

Figure 4. Surface salinity and temperature contours in the Gulf of Artabro during the study

agram (figure 2). In the southern area of the gulf, there is warmer (13.0-13.4 °C) and saltier (35.85-35.90 psu) water, compared with the seawater in the northern area (12.5-12.8 °C and 37.75-35.80 psu). Both water masses and their slight mixing in the frontal zone are shown in the T-S diagram of figure 2. The thermic-saline front is marked by the isoline of 13.0 °C or the 35.80 psu in figure 4. We also noted a limited influence of the water of the Betanzos-Ares, A Coruña and Ferrol Rias on the gulf area, due to the slight drop in surface salinity at the mouths of these rias.

Chlorophyll concentrations and primary production rates were relatively low at all stations, never exceeding 2 mg m^{-3} of chlorophyll *a* and 155 mg C m^{-2} h^{-1} of production. The most productive areas were the stations near the coast (110-155 mg C m^{-2} h^{-1}), and the poorest were next to the mouths of the rias, where the measured production rates did not surpass 40 mg C m^{-2} h^{-1}. High chlorophyll concentrations occurred either near the coast or next to the continental margin, with an area of minimum concentration (lower than 0.5 mg m^{-1}) located approximately between the isobaths at depths of 100 and 150 m. This distribution does not seem to be associated with nutrient limitations, except for the central part of the gulf, where nitrate concentration is lower than 1 µmol (figure 5). This nutrient salt showed an irregular surface distribution, probably due to the local phytoplankton uptake. The exception appeared in the minimum nitrate band (lower than 2 µmol; figure 5) which coincided with the thermic-saline front.

The historic data obtained at the aforesaid transect defined the typical annual planktonic cycle (Casas *et al.*, 1997), in which the spring bloom occurs generally in March, with high values of chlorophyll and primary production. The low values of chlorophyll and production at the end of March registered

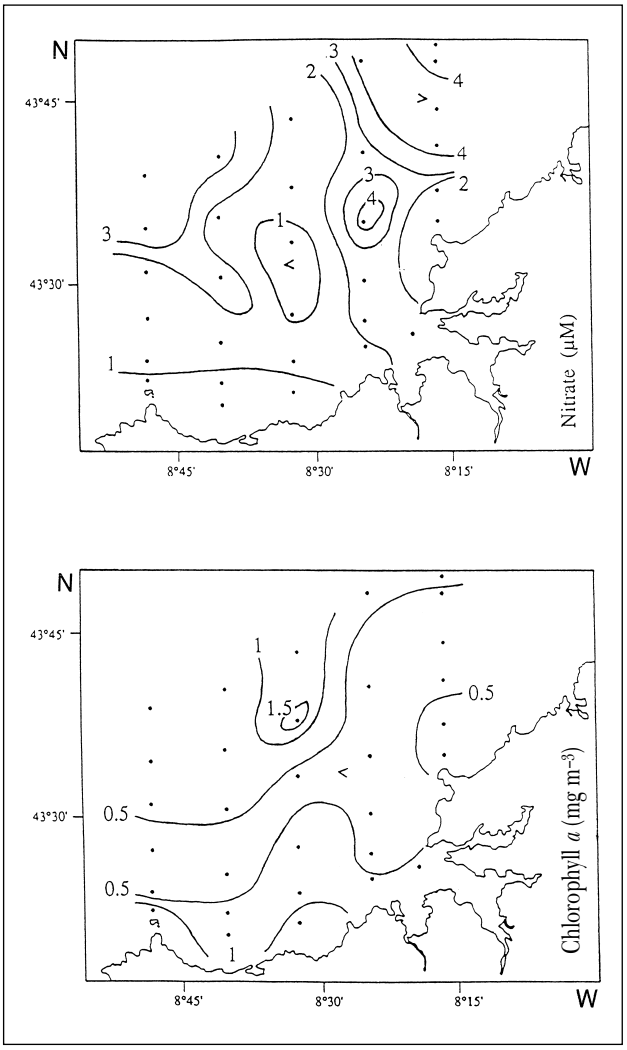

Figure 5. Contours of nitrate at the surface and averaged chloropyll *a* concentartions from 0-50 m in the Gulf of Artabro during the study

during the COPLA 393 cruise are the result of the early spring bloom in 1993 (Varela *et al.,* 1996). Favourable meteorological conditions for plankton development, which had been stable since February, changed some days before the cruise, to a wintry scenario. Therefore, winter phytoplankton, with predominance of microflagellates, cryptophyceae and small dinoflagellates, prevailed (table I), alternating with low abundances of phytoplankton. However, specific diversity was high, and some species were similar to those described as typical of the spring bloom at A Coruña transect (Casas *et al.,* 1997). These are the remains of the spring bloom that occurred a few days before the beginning of the cruise.

Table II shows average values of chlorophyll *a* (0.62 mg Chl m^{-3}) and of primary production

Table I. List of the most abundant Protozoa and phytoplankton taxons in early spring during the COPLA 393 cruise

	No. of samples	Average	S.D.
Dinophyceae			
Amphidinium sphenoides	10	0.09	0.22
Cachonina (niei) hallii	39	3.03	4.82
Ceratium furca	9	0.15	0.46
Dinoflagellates > 30 μm	41	1.04	2.22
Dinoflagellates < 30 μm	65	15.8	13.9
Gyrodinium glaucum	20	0.26	0.71
Gyrodinium spirale	24	0.22	0.37
Prorocentrum balticum	19	0.32	0.62
Prorocentrum micans	14	0.82	2.85
Protoperidiniumum bipes	13	0.27	0.70
Scrippsiella irochoidea	24	2.89	12.52
Torodinium sp.	18	0.21	0.42
Diatomophiceae			
Asterionella japonica	21	0.39	0.95
Chaetoceros affinis	9	0.33	1.88
C. didymus	22	1.17	3.46
C. gracilis	50	27.1	46.7
C. socialis	26	363	1 360
Chaetoceros spp.	12	0.25	0.87
Cerataulina pelagica	17	0.41	1.21
Leptocylindrus danicus	34	1.49	2.81
Navicula cf. salinarum	17	0.13	0.26
Nitzschia longissima	52	2.37	3.57
N. longissima var	38	2.20	5.46
Pseudonitzschia pungens	59	4.42	7.32
Pseudonitzschia pungens var	14	0.10	0.22
Pseudonitzschia delicatissima	35	0.55	0.82
Schroederella delicatula	28	4.31	13.41
Thalassionema nitzschioides	32	0.40	0.60
Euglenophyceae			
Eutreptia spp.	12	0.48	1.74
Flagellates			
8-10 μm	65	56.3	86.3
5- 8 μm	65	110.5	132
3- 5 μm	65	624	646
< 3 μm	65	505	632
Chrysophyceae			
Solenicola setigera	19	3.28	8.31
Distephanus speculum	16	0.45	1.02
Cryptophyceae			
Cryptomonas spp.	62	42.6	69.5
Protozoa			
Ciliata > 30 μm	62	3.32	3.31
Ciliata < 30 μm	49	2.66	2.41

(2.1 mg C h^{-1}) which are very low and typical of wintry conditions or stages after the spring bloom in the area (Casas, 1995; Bode and Varela, in press). Likewise, the microzooplankton and meso-

Table II. Average values of biological data obtained in Gulf of Artabro during this study. (*): dry weight

	Unit	No. of samples	Average	S.D.
Chlorophyll *a*	mg m^{-3}	253	0.62	0.38
Primary production	mg C m^{-2} h^{-1}	11	85.4	36.7
Mesozooplankton*	mg m^{-3}	17	23.1	11.6
Microzooplankton*	mg m^{-3}	17	8.85	6.88
Bacteria	$\times 10^5$ cel ml^{-1}	39	1.54	1.18
Autotrophic phytoflagellates	cel ml^{-1}	38	793	1 144
Hetertrophic phytoflagellates	cel ml^{-1}	38	957	1 329

zooplankton had relatively low average values (8.8 and 23 mg dw, respectively), compared with those found in the same study area during more productive periods (Valdés, Álvarez-Osorio and Miranda, 1992). Bacteria and microflagellates had similar average abundances to those obtained in winter, but generally lower to those reported for other seasons (Varela *et al.,* 1996). However, a wide variability in biological parameters was observed (table II). Varela *et al.* (1996) and Bode and Varela (in press) reported the existence of different microplankton populations in some parts of the study area during the COPLA 393 cruise. The greatest differences were in the populations found in the Ferrol Ria (with abundant blooming diatoms) and in the Betanzos Ria (with a predominance of heterotrophic flagellates).

All of the biological data suggest a stage of low production, after the spring bloom that had occurred several days before. This can be explained by a change in the meteorological conditions. During the entire month of February, and at least until 11 March 1993 (10 days before the beginning of the COPLA 393 cruise), the area of the shelf off A Coruña presented spring bloom conditions: average chlorophyll *a* values of 5.6 mg m^{-3} in February and 3.5 mg m^{-3} in March, and 5.3 mg C m^{-3} h^{-1} of primary production in February and 5.4 mg C m^{-3} h^{-1} in March. When the weather changed, light radiation was very low (figure 3). This low solar irradiance could explain the post-bloom scenario's low plankton production.

CONCLUSIONS

1. The hydrographic situation in the Gulf of Artabro during this early spring cruise was relatively complex. There was warm and saline water, probably of southern origin, and a thermo-haline front perpendicular to the coastline in the central part of the gulf.

2. The primary production and chlorophyll concentrations were low during the research cruise in the Gulf of Artabro due to the disappearance of the meteorological conditions that had favoured an early spring bloom. The change to a quasi-wintry situation also caused the dispersion of the phytoplankton communities and a low planktonic biomass. The bloom-dispersion regime could have occurred in this gulf as a consequence of the early bloom, and the changeable environmental conditions in February-March.

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