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Oceanographic and meteorological forcing of the pelagic ecosystem on the Gulf of Cadiz shelf (SW Iberian Peninsula)

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ABSTRACT

The spatial and temporal distribution of physical, chemical and biological variables of the NE continental shelf of the Gulf of Cadiz were analyzed monthly during almost three annual cycles. This analysis was performed with the aim of deriving the main forcing factors controlling variability at inter-annual, seasonal and short-time scales. Meteorological forcing related to heavy episodes of rainfall that affected river discharges and the wind regime, controlled both the currents along the shelf together and the nutrient concentrations of the surface waters. Meteorological forcing in turn determined the subsequent development and maintenance of phytoplankton blooms. Superimposed on the seasonal cycle typical of temperate latitudes, the inputs of continental nutrients mainly from the Guadalquivir River, along with episodes of upwelling favored by the predominance of westerly winds triggered phytoplankton growth on the shelf, highlighting the markedly relevant role of this large estuary in the control of the biological activity on the shelf.

1. Introduction

The productivity of marine ecosystems is controlled by environmental physico-chemical conditions. In particular, the biological productivity of continental shelf seas in mid latitudes is a complex reflection of the seasonal cycle plus a wide variety of processes at different scales; including upwelling, shelf-break fronts, tides and river discharges (Mann and Lazier, 1996). Consequently, the pelagic ecosystem of a continental shelf sea must be analyzed considering these different scales of variability.

The continental shelf of the Gulf of Cadiz from the east of Cape Santa Maria to the west of the Bay of Cadiz has a wide width (around 50 km) and receives important fluvial inputs associated with the discharge of large rivers such as the Guadiana, the Guadalquivir, and the Tinto–Odiel (Fig. 1). The strong influence of large rivers on the productivity of continental shelves, particularly after high discharge events, is a well known feature worldwide (Lohrenz et al., 1997; Dagg et al., 2004; Mckee et al., 2004). The wide shelf of the Gulf of Cadiz and the peculiarities of its geographical location probably contribute to the high phytoplankton pigment concentrations within the area, as observed in the Benguela upwelling system (Patti et al., 2008). The coastal fringe of the Gulf of Cadiz is also characterized by the presence of waters warmer and colder than those detected in the rest of the basin during summer and winter, respectively (Vargas et al., 2003), and by considerable meteorological forcing caused by quasi-permanent episodes of winds. Thus, zonal winds and the associated Ekman pumping generates upwelling when blowing from the west whereas downwelling occurs during easterlies (García Lafuente and Ruiz, 2007). The combination of warm, nutrient-rich waters (due to the influence of the Guadalquivir River and the predominance of westerlies) create a suitable environment for spawning and the subsequent development of early life stages of commercial fish species like anchovy (García et al., 2002; Catalán et al., 2006a; Ruiz et al., 2006), sardine (Baldó et al., 2006) and several demersal fish species (Catalán et al., 2006b).

In order to study the mechanisms responsible for the temporal variability in productivity of this continental margin, monthly cruises were carried out during almost three annual cycles along the northeastern shelf between the mouth of the Guadiana River and the Bay of Cadiz. Based on a total of 31 oceanographic cruises performed between March 2002 and September 2004, temporal and spatial patterns of a range of biogeochemical variables in surface seawaters were examined, with the aim of studying their short-time scale, seasonal and inter-annual variability. By short-time scale we consider the meteorological events with a frequency of variability between days to weeks (also known as synoptic weather scale of variation). This data set represents the most complete oceanographic investigation available for the whole south Atlantic Iberian coast and

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one of the largest in the temperate Atlantic in terms of both spatial coverage and sampling frequency.

2. Materials and method

2.1. Study area

The continental shelf studied was located between the mouth of the Guadiana River and the Bay of Cadiz (Fig. 1). Thirty-one monthly cruises were conducted between March 2002 and September 2004 on board the RV *Regina Maris*. The exact dates, acronyms and details of each cruise are summarized in Table 1. For each cruise, a grid composed of at least 30 stations was completed (Fig. 1), with CTD profiles being obtained at each station from the surface to the bottom of the water column (maximum depth is 100 m). In summer months the number of stations sampled was increased to 40.

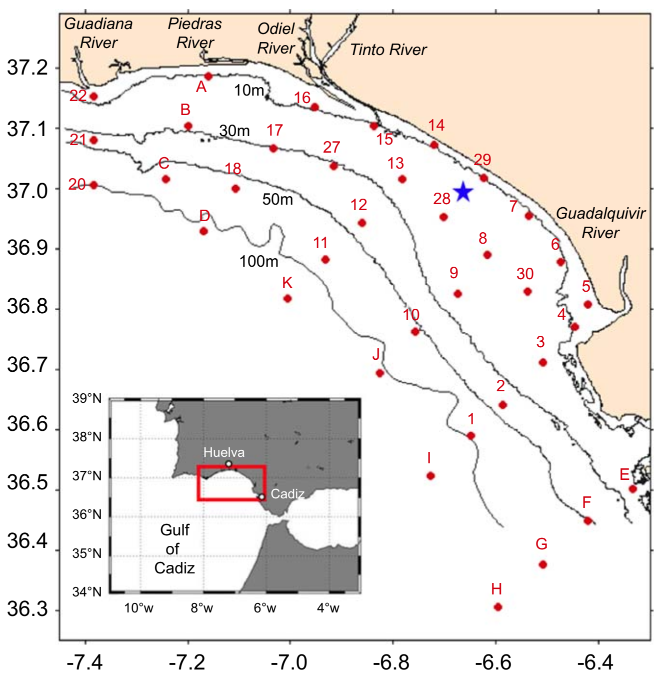

Fig. 1. Map showing location of stations sampled. Stations 1–30 were sampled in all the cruises, while Stations A–K were sampled in specific cruises during spring and summer seasons (more details in Table 1). The location of the current meter RCM-9 is also shown (*). A general location map with the situation of meteorological stations (Huelva and Cadiz) is plotted in the inset.

2.2. Measurements

2.2.1. Nutrients, phytoplankton biomass and suspended matter

Samples for inorganic nutrient analysis (30 ml), total chlorophyll (500 ml), chlorophyll in the size fraction above 20 μm (3 l), and suspended matter (1 l) were collected at each sampling site in surface waters. Nutrients (nitrate, nitrite, ammonium, phosphate and silicate) were analyzed with a TRAAC 800 autoanalyser, although in the present study only nitrate, phosphate and silicate are considered and discussed. Three litres of seawater were filtered through a 20 μm mesh, and the material retained was washed with filtered sea water. Chlorophyll analysis (both total and fractioned) was conducted by filtering samples through Whatman GF/F glass fiber filters (0.7 μm pore size), extracting in 90% acetone, and measuring [Chla] by standard fluorometric methods (Parsons et al., 1984) using a Turner Designs Model 10. The fluorometer was calibrated using pure chlorophyll *a* from the cyanobacterium *Anacystis nidulans* (Sigma chemical Co.) with the concentration determined spectrophotometrically.

Total concentrations of suspended particulate matter were measured gravimetrically on preweighted Whatman GF/F filters after rinsing with distilled water. Organic matter lost on ignition was determined after baking the filters for 3 h at 500 °C, giving the concentration of mineral and, by subtraction, organic suspended matter.

2.2.2. Meteorology and currents

The North Atlantic oscillation (NAO) is a climatic phenomenon that greatly contributes to variability in the weather system over the North Atlantic and Europe. The winter (December through March) index of the NAO is based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland since 1864. NAO index data was provided by the Climate Analysis Section (NCAR) [Boulder, USA], (http://www.cgd.ucar.edu/cas/jhurrell/indices.html) (Hurrell, 1995).

Hourly values for the wind vector and daily records of precipitation were obtained from two meteorological stations of the Agencia Estatal de Meteorología (AEMET) located at Huelva and Cadiz. Historical data (from 1870 to 2007) of precipitation was

Table 1
Chronology of cruises, 2002–2004.

Year Cruise	2002 Date [*n*]	Year Cruise	2003 Date	Year Cruise	2004 Date
–	–	M15	15–18 January [30]	M27	12–14 January [33]
–	–	M16	17–20 February [30]	M28	12–14 February [33]
M5	22–24 March [30]	M17	09–13 March [30]	M29	17–19 March [33]
M6	02–05 April [30]	M18	23–26 April [33]	M30	14–16 April [31]
M7	07–10 May [30]	M19	20–22 May [33]	M31	12–14 May [33]
M8	11–14 June [30]	M20	09–13 June [40]	M32	14–18 June [40]
M9	02–05 July [30]	M21	30 June–4 July [40]	M33	12–16 July [40][a]
M10	07–10 August [30][b]	M22	06–09 August [33]	M34	11–13 August [33][a]
M11	11–14 September [30][c]	M23	10–13 September [33]	M35	22–24 September [33][a]
M12	09–12 October [30][c]	M24	01–05 October [33]	–	–
M13	06–09 November [30]	M25	05–07 November [33]	–	–
M14	03–05 December [30]	M26	02–04 December [33]	–	–

n: total number of stations sampled.

[a] No phosphate data.
[b] CTD malfunction.
[c] No nutrient data.