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Atmospheric-induced variability of hydrological and biogeochemical signatures in the NW Alboran Sea. Consequences for the spawning and nursery habitats of European anchovy

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ABSTRACT

The north-western Alboran Sea is a highly dynamic region in which the hydrological processes are mainly controlled by the entrance of the Atlantic Jet (AJ) through the Strait of Gibraltar. The biological patterns of the area are also related to this variability in which atmospheric pressure distributions and wind intensity and direction play major roles. In this work, we studied how changes in atmospheric forcing (from high atmospheric pressure over the Mediterranean to low atmospheric pressure) induced alterations in the physical and biogeochemical environment by re-activating coastal upwelling on the Spanish shore. The nursery area of European anchovy (*Engraulis encrasicolus*) in the NW Alboran Sea, confirmed to be the very coastal band around Malaga Bay, did not show any drastic change in its biogeochemical characteristics, indicating that this coastal region is somewhat isolated from the rest of the basin. Our data also suggests that anchovy distribution is tightly coupled to the presence of microzooplankton rather than mesozooplankton. Finally, we use detailed physical and biological information to evaluate a hydrological–biogeochemical coupled model with a specific hydrological configuration to represent the Alboran basin. This model is able to reproduce the general circulation patterns in the region forced by the AJ movements only including two variable external forcings; atmospheric pressure over the western Mediterranean and realistic wind fields.

1. Introduction

The North-western (NW) sector of the Alboran Sea is highly dynamic with strong mesoscale activity (Tintoré et al., 1991; Viúdez et al., 1998; Gomis et al., 1997) such as fronts, cyclonic and anticyclonic gyres and upwellings (Minas et al., 1987; Gleizon et al., 1996) involving water masses of diverse composition and origin (Gascard and Richez, 1985), including Surface Atlantic Water (SAW), North Atlantic Central Water (NACW) and a mixture of different Mediterranean Waters (MWs).

The main forcing agent modulating the hydrological processes in this zone and in the entire Alboran Sea basin is the Atlantic Jet (AJ), which enters through the Strait of Gibraltar (Bormans and Garret, 1989; García-Lafuente et al., 1998). This flowing jet contributes to the maintenance of the two main anticyclonic gyres that characterize the circulation within the Alboran Sea, the Western Alboran Gyre (WAG) and the more elusive Eastern Alboran Gyre (EAG) (e.g., Lacombe, 1971; Arnone et al., 1990).

Atmospheric pressure forcing has been found to greatly affect the interchange of water masses through the Strait of Gibraltar (e.g. Candela et al., 1989; García-Lafuente et al., 2002) and, thereby, the velocity of the incoming AJ (García-Lafuente et al., 1998). This modulation in the AJ velocity forces a change in its incoming direction (Sarhan et al., 2000, Vargas-Yáñez et al., 2002), which, in turn, alters the upwelling mechanisms in the northern coast of the NW Alboran basin (Sarhan et al., 2000; Macías et al., 2007). Also, wind forcing (another direct consequence of atmospheric pressure distribution) can influence the position and intensity of the AJ, modulating the distribution of the water masses within the NW Alboran Sea (e.g., Sarhan et al., 2000; Vargas-Yáñez et al., 2002; Macías et al., 2008).

Biogeochemical signatures in this area are tightly coupled with physical forcing. Typically, high concentrations of both nutrients and phytoplankton are found in the north, close to the Spanish shore, in a zone known as the Estepona upwelling (García-Lafuente and Cano, 1994) and further east in Malaga Bay (Fig. 1). An oligotrophic region associated with the WAG is observed in the south (Minas et al., 1987; Packard et al., 1988). However, the variability of the hydrodynamic conditions has a strong influence on these biogeochemical patterns

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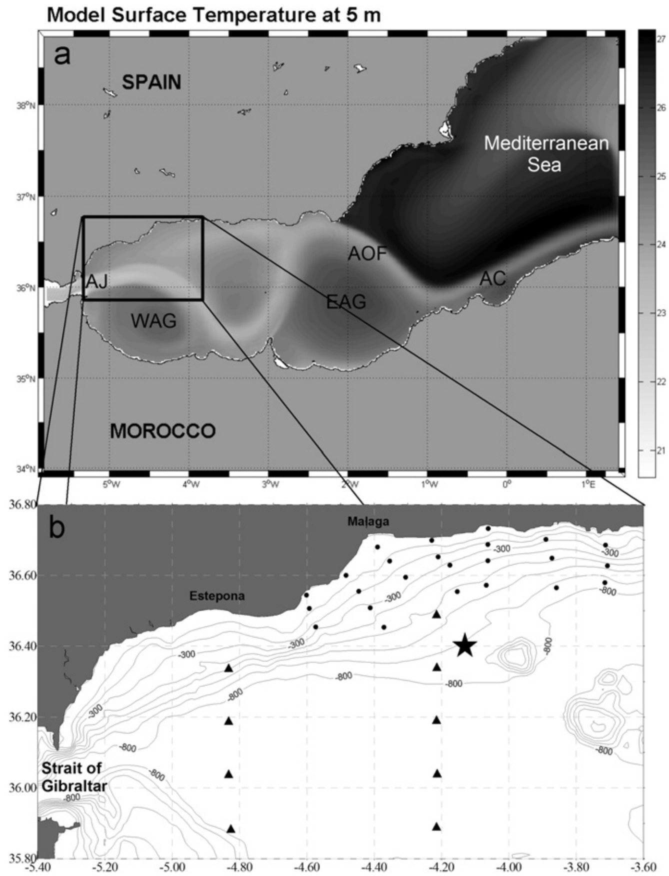

Fig. 1. (a) Model domain showing the surface temperature for the climatologic July. AJ: Atlantic Jet, WAG: Western Alboran Gyre, EAG: Eastern Alboran Gyre, AOF: Almería–Orán Front, AC: Algerian Current. (b) Sampling site. Star marks the position at which wind data where extracted from the climatological model. Triangles show the stations of the two north–south transects. Black dots represent the positions of the sampling grid in the coastal region. Contour is bathymetry each 100 m.

(e.g. Macías et al., 2008) and on the size structure of the pelagic community in the area (Rodríguez et al., 1998; Prieto et al., 1999).

The two coastal settings with high biological productivity in the NW Alboran Sea (the Estepona upwelling and Malaga Bay) may constitute an ideal habitat for hatching and to act as a nursery for small pelagic fishes (SPFs) like the European anchovy (*Engraulis encrasicolus*) (henceforth called anchovy) and sardines (*Sardina pilchardus*). However, Malaga Bay is a much more suitable region than the Estepona upwelling because, along with its high primary productivity, its hydrography favors the creation of retention structures (Agostini and Bakun, 2002).

Therefore, many authors have indicated that the Malaga Bay region is the key zone for post-larvae accumulation and even for the spawning of SPF, which agrees well with the historical data on the "*chanquete*" (SPF larvae) fisheries in the region (García et al., 1981). NW Alboran Sea anchovy landings have suffered drastic oscillation and a strong reduction in the last few decades (Giráldez et al., 2009). Most of the anchovy standing stock biomass is composed by zero-age class (Giráldez and Abad, 1995) so population oscillations and decline could be related with early-life stages survivorship controlled by environmental conditions (e.g., Ruiz et al., 2006).

However, very little is known about the processes involved in the spawning-recruitment sequence that creates the high inter-annual changes in stock abundance. For this purpose, the use of spatially explicit physical–biological models (i.e., with embedded individual-based models) may be crucial (e.g., Allain et al., 2007; Parada et al., 2008).

The objective of the present work is to present the main characteristics of the NW Alboran Sea and of the Malaga Bay during the anchovy spawning season, which peaks in July–August (Giráldez and Abad, 1995; Rubín, 1996). We aim to evaluate the effects of the change in atmospheric conditions in the whole basin and in the inner shelf area in order to determine how well isolated is this region from the general circulation patterns in the open sea. The field and satellite data obtained will also be used to assess the output of a hydrological–biological coupled model (ROMS-bio) specifically designed to represent the hydrodynamics of the region of interest. We then evaluate the usefulness of this coupled model to be used as an input for an individual-based model (IBM) of anchovy in the region (in a forthcoming paper), which should be able to increase the understanding of the recruitment and fishery variability of SPF in the Alboran region.

2. Methods

2.1. Field data sampling

A research cruise was conducted during the period 21–26 July 2008 on board the RV *Regina Maris* in the NW Alboran Sea (Fig. 1b) to characterize the summer physical and biogeochemical properties of the region. Two different sampling strategies were adopted: (i) two north–south transects in the eastern and western sides of the NW Alboran to characterize the general circulation patterns in the region (Fig. 1b, black triangles) the western one performed during the 25th of July (WT in Fig. 2) and the eastern one during the 26th of July (ET in Fig. 2) and (ii) a sampling grid (Fig. 1b, black points) in the northern portion of the basin (from 21st to 24th, Fig. 2) to characterize potential spawning and nursery areas for the European anchovy according to the published literature (e.g., García et al., 2003).

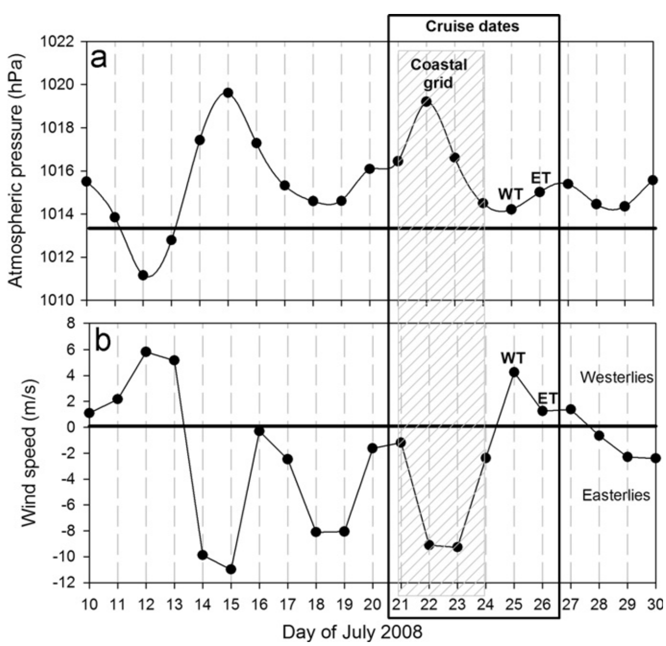

Fig. 2. Meteorological conditions of the basin from 10th to 30th of July 2008. Upper panel, atmospheric pressure over the Western Mediterranean calculated according to the text. Lower panel, wind intensity and direction (positive westerlies, negative easterlies) calculated by the atmospheric model for the sampling site (star in Fig. 1). Each sampling phase is marked in the figure, the coastal grid, the western transect (WT) and the eastern transect (ET).