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Role of mesoscale eddies in shaping the spatial distribution of the coexisting *Engraulis encrasicolus* and *Sardinella aurita* larvae in the northwestern Mediterranean

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ABSTRACT

In recent years a northward expansion of *Sardinella aurita* has been reported in the Western Mediterranean. Spawning of this species takes place in summer coinciding with *Engraulis encrasicolus*, the dominant species in the region. Since both species inhabit the continental shelf, their larvae coexist during this period of the year. The circulation in the region is characterized by the Northern current, flowing along the continental slope. This current displays strong mesoscale activity presenting a meandering path and series of anticyclonic eddies over the shelf. These eddies are fed from offshore by the Northern current and by coastal waters from inshore thus merging and concentrating water from their both sides. The study analyses the role of mesoscale eddies shaping the distribution of *S. aurita* and *E. encrasicolus* larvae along the Catalan coast. Data covering the whole shelf and slope were obtained in 3 oceanographic cruises conducted in the summers of 2003 and 2004. *E. encrasicolus* larvae were found scattered on the whole continental shelf being particularly abundant over the shelf break and in the northern third of the region, associated with the intrusion of the Northern current. *S. aurita* larvae showed a more coastal distribution, being almost absent at the shelf break and under the influence of the Northern current. The observed spatial distribution of larval sizes evidenced the spawning preferences of each species and the transport and concentration of larvae of both species inside the eddies, as they entrain water from its two sides. This behaviour helps to ensure better survival conditions due to higher food availability brought from the offshore side but in an environment without dispersion.

1. Introduction

Small pelagic fish show large natural fluctuations in population size that vary on interannual and long-term time scale (Chavez et al., 2003; Lluch-Belda et al., 1989; Martín et al., 2012). These species have a short life span, feed on a short plankton-based food chain and their wide fluctuations in population size are the result of highly variable, environmentally-driven, and annual recruitment pulses (Alheit and Hagen, 1997; Cury and Roy, 1989). Recruitment success is controlled to a large extent by egg and larval survival, which in turn is dependent on suitable oceanographic conditions influencing the larval distribution, retention and transport (Bakun, 1996; Govoni, 2005; Hare et al., 2002). In particular, fronts and eddies that have been reported to support high levels of biological activity are widely hypothesized to be essential spawning habitats for pelagic species (Bakun, 2006) and important nursery habitats for fish larvae (Bécognée et al., 2009; Govoni et al., 2010).

The dynamics of the northwestern Mediterranean basin is characterized by a general cyclonic circulation contouring the entire northern continental slope of the basin, from the Corsica Channel to the Gulf of Valencia. This current, called the Northern Current, is in geostrophic equilibrium with a shelf-slope density front that runs along its path, and leaves fresher and cooler waters on its coastal side (Font et al., 1988; Millot, 1987). The current, that extends down to a depth of 300–400 m, is characterized by surface velocities up to 30–50 cm s^{-1}, decreasing with depth (Castellón et al., 1990; Salat, 1995). The Northern Current displays significant mesoscale activity, such as meanders, filaments and eddies that develop and propagate along its path (Albérola et al., 1995; Flexas et al., 2002; Millot, 1991; Rojas et al., 1995; Sammari et al., 1995). The generation of eddies in this area has been associated with the direct effect of wind curl, either locally or advected by the current from the Gulf of Lions, where winds are stronger and more frequent (Flexas et al., 2005; Rubio et al., 2005).

The Catalan Sea, located in the northwestern Mediterranean Sea, is characterized by a continental shelf that is generally quite narrow. It clearly widens in the southernmost part in the vicinity of the Ebro River Delta, and in the north between two major submarine canyons south of the Gulf of Lions. Different studies in this area have analysed the role played by the Northern Current and its associated front on primary production (Estrada and Margalef, 1988; Estrada et al., 1999) and zooplankton distribution and metabolism (e.g. Alcaraz et al., 2007; Masó et al., 1998). High zooplankton biomass and fish larvae concentrations have regularly been observed along the shelf break in relation to the frontal convergence (Sabatés et al., 1989). The front may act also as a barrier preventing the dispersal of fish larvae towards the open

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sea (Sabatés et al., 2007a). However, the patterns observed are subject to considerable spatiotemporal variability due to the mesoscale activity of the front, which can show seasonal variations in its location, strength and narrowness (Sabatés et al., 2004).

The most abundant small pelagic fish in the northwestern Mediterranean are the European sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*). Round sardinella (*Sardinella aurita*) is a thermophilic species particularly frequent in the warmer waters of the eastern and southwestern basins. Nevertheless, in recent years an increasing abundance and gradual expansion northward of *S. aurita* has been documented along the western Mediterranean coasts in relation to a progressive sea water warming (Sabatés et al., 2006; Tsikliras, 2008). In the northwestern Mediterranean, the reproductive periods of the two dominant species, sardine and anchovy, take place in completely opposite periods of the year: autumn-winter and spring-summer respectively (Palomera et al., 2007). Their eggs and larvae dominate the ichthyoplanktonic fraction in neritic areas of the northwestern Mediterranean coasts during these periods (Sabatés et al., 2007a). Round sardinella reproduces in the summer, from the end of June to September when the surface waters reach the highest temperature of the year (Palomera and Sabatés, 1990; Somarakis et al., 2002). Therefore, the spawning periods of the anchovy and round sardinella coincide during the summer. Since both species inhabit the continental shelf, their larvae coexist in the plankton during this period of the year. The spawning of both species has been reported to be associated with river plumes in coastal waters, although spawning of anchovy also occurs more offshore (Palomera et al., 2007). Maximum densities of anchovy larvae occur at the shelf break, while round sardinella larvae have a more coastal distribution (Palomera and Sabatés, 1990; Palomera, et al., 2007; Sabatés et al., 2009).

In general, pelagic fish spawn at locations that provide favourable habitat conditions for their larvae, but when different fish species spawn at the same time and place, their respective offspring may interact in some way. Such a situation can be found in the Catalan Sea caused by the northward expansion of *S. aurita* in the western Mediterranean, which has led to the coexistence of its larvae with those of the dominant species, *E. encrasicolus*. The objective of the present study was to analyze how the mesoscale water dynamics shape the spatial structures of *S. aurita* and *E. encrasicolus* larvae in the Catalan Sea. In particular the role of mesoscale eddies on larval concentration, retention and survival is discussed.

2. Material and methods

The study area was located in the Catalan Sea, NW Mediterranean (Fig. 1). Three oceanographic surveys were performed in summer, during two consecutive years, coinciding with the spawning period of *S. aurita* and *E. encrasicolus* in the western Mediterranean (Palomera and Sabatés, 1990): 18–25 July, 2003; 23 June–1 July and 21–29 July, 2004. In each survey, 66 sampling stations were located on transects perpendicular to the shoreline, from near the coast to the slope.

Stations were located 7.5 nautical miles apart and the distance between transects was 10 nautical miles (Fig. 1). Vertical profiles of the basic hydrographic variables (temperature, salinity and fluorescence) were obtained with a Neil Brown Mark III-CTD (WOCE standard)

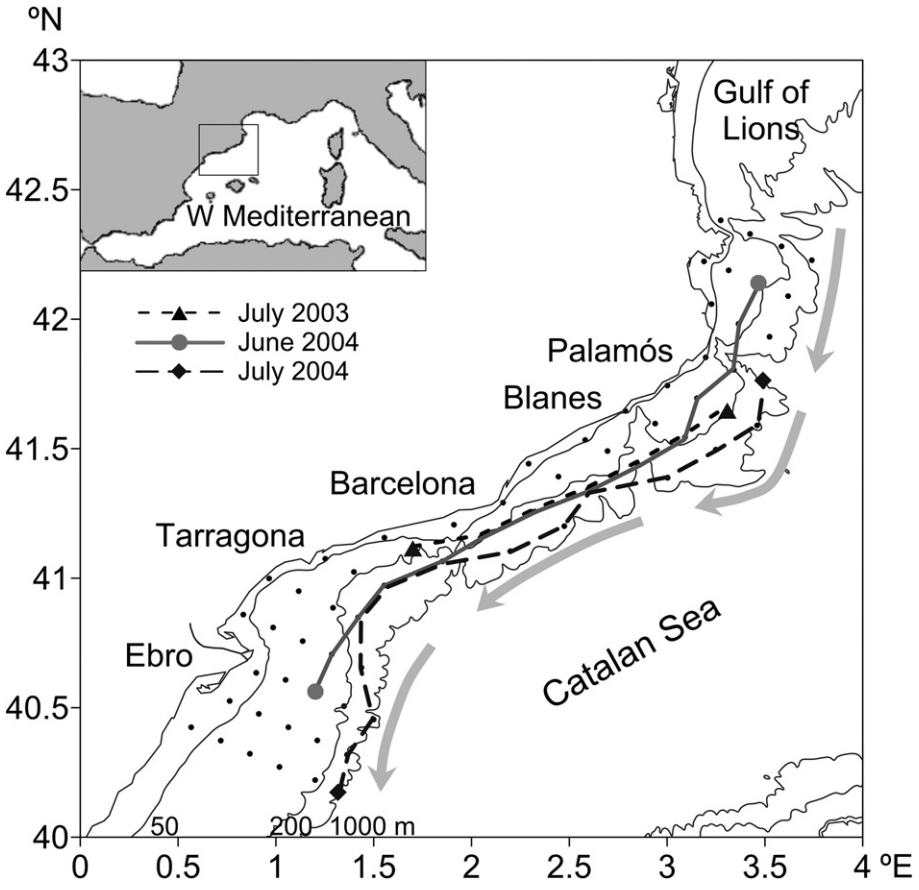

Fig. 1. Map of the study area showing the sampling stations. The isobaths shown are 50, 200 and 1000 m. Arrows indicate the typical path of the Northern current. Lines indicate the vertical sections sowed in Fig. 4 for each cruise.