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Satellite-derived conditions and advection patterns off Iberia and NW Africa: Potential implications to sardine recruitment dynamics and population structuring

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ABSTRACT

Surface velocity estimates from wind and altimeter data, together with satellite-derived sea surface temperature and chlorophyll, were used to explore the advection patterns and environmental conditions using a simple Lagrangian model. Although the model is generic (only considering the physical transport), the results are of particular interest for sardine (*Sardina pilchardus*) early life stages, due to the spawning dynamics of the species off Iberia and NW Africa. Particles were released on the shelf of the Iberian and northern African Atlantic coasts every five days from 1998 to 2004 and advected for 27-days. Trajectories were computed using combinations of three surface velocity constituents: Ekman velocity, geostrophic velocity derived from sea level anomaly maps and mean geostrophic velocity derived from two mean dynamic topographies. Daily time series of sea surface temperature, chlorophyll-a concentration and water depth where constructed for each particle trajectory. The results showed strong regional and seasonal dependence of the transport due to wind, with average seasonal cycles of the percentage of particles found in the shelf reflecting the anticipated effect of the seasonal north–south migration of the trade wind belt. The addition of the geostrophic transport led to the attenuation of seasonal cycles and higher mean/maximum values in the probability of retention within the shelf. This increased capacity for retention even during strong upwelling conditions seems to have been overlooked by theories aiming to describe the reproductive strategies of pelagic fish and understand recruitment dynamics based primarily on wind variability. On the other hand, the average surface chlorophyll values indicated a distribution area with higher primary production for particles that never leave the shelf, in comparison to those that return to it or are found in the open sea a month after release, which is in agreement with existing hypotheses that offshore advection is detrimental to larval survival mainly due to the higher risk of starvation. Finally, the exchange between adjacent shelf areas was generally small (less than 5%) within the study period, with the exception of the Gulf of Cadiz. In the latter area, up to 50% of particles released in the southern Iberian shelf reached the Moroccan shelf in several events, contradicting previous suggestions that the Strait of Gibraltar acts as a physical barrier that promotes genetic differentiation among neighbouring sardine populations in the Atlantic. Overall, these results provide useful insights for the study of sardine dynamics in the northeast Atlantic but the unexpectedly high sensitivity of summary metrics (namely retention probability) to the choice of surface velocity field preclude firm conclusions and indicate alternative routes for future studies.

1. Introduction

Small pelagic fish (SPF) dynamics are largely driven by inter-annual variation in recruitment, with abrupt changes in abundance, demography and fishery landings often resulting from the entry of a single strong year-class (or several weak) into the population (e.g. Blaxter and Hunter, 1982). Although it is generally acknowledged that year class strength of SPF will depend on processes occurring both at the planktonic (i.e. egg and larval stage) and at the juvenile (i.e. when young fish have developed all meristic properties of adults but are still sexually immature) phase (e.g. Watanabe et al., 1995), the most common framework to assess the role of environmental conditions on SPF recruitment is to study the impact of the environment on fish survival during early life stages (Heath, 1992). Early life stages typically include the egg (from fertilization to hatching) and yolk–sac larval stage (up to the onset of exogenous feeding) and the stage of feeding larvae (up to the metamorphosis into juveniles). Prior to the onset of exogenous feeding (typically 1–2 weeks for SPF) survival is mainly conditioned by predation, whereas in the feeding larval stage (typically 2–4 months for SPF) starvation also becomes an important factor (Blaxter and Hunter, 1982; Heath, 1992).

Among the environmental conditions with a potential impact on planktonic early life stages of SPF, the study of cross-shelf transport has attracted a lot of attention (Parrish et al., 1981; Bakun and Parrish, 1982; Bakun, 1996; Logerwell et al., 2001; Stenevik et al., 2003; Santos

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et al., 2004, 2005; Miller et al., 2006). Earlier studies were based on the assumption that transport into the typically oligotrophic off-shelf regions should lead to starvation and thus be detrimental to larval survival and ensuing recruitment, especially at eastern boundary current systems under the influence of seasonal or permanent upwelling where sardines and anchovies (SPF with important fisheries worldwide) are particularly abundant (wasp–waist systems, where SPF dynamics can shape the entire pelagic ecosystem). More recently, cross-shelf transport and advective losses were incorporated into a more complex hypothesis (the Ocean Triad), which considers that recruitment success of SPF will depend on the interplay of processes that control enrichment, concentration and retention during planktonic life stages (Bakun, 1996; Stenevik et al., 2003; Miller et al., 2006).

The approaches that have been used to study the relation between cross-shelf transport and SPF recruitment indices can be roughly divided into two groups: first, a statistical approach that either explores the empirical correlation between recruitment and environmental indices based on the assumption that cross-shelf transport is primarily wind driven (e.g. Santos et al., 2001; Guisande et al., 2001; Borges et al., 2003), or uses pattern recognition techniques to identify favourable environmental periods and compare them with the birth-date distribution of recruits (Hardman-Mountford et al., 2003); second, a Lagrangian approach where particle-tracking models are used to estimate interannual variation in cross-shelf transport and environmental conditions and associate them with corresponding variation in recruitment strength (e.g. Bernsten et al., 1994; Polovina et al., 1999; Griffin et al.,

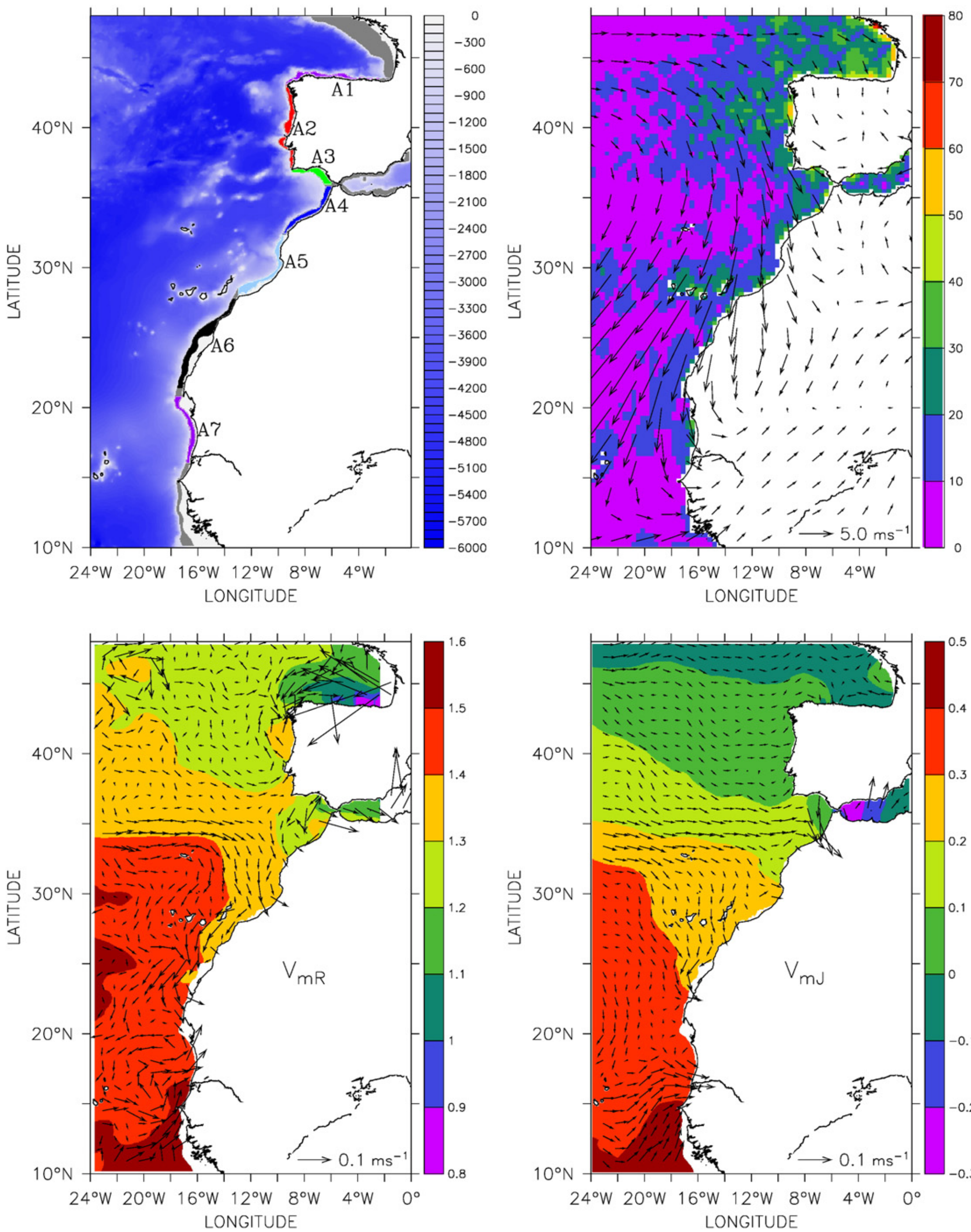

Fig. 1. Bathymetry of the study area (upper left). Coloured/gray shades/patterns in the shelf region represent the seven areas selected for particle release. Mean formal mapping error for all sea level anomaly maps from Jan-1998 to Jan-2006, with superimposed summer season (Jul–Aug–Sep) seven year (1998–2004) average wind velocity (ms^{-1}) (upper right). Mean dynamic topographies (m) and mean geostrophic velocities (ms^{-1}, bottom), derived from Rio and Hernandez (2004) (left) and Jayne (2006) (right).