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Consequences of a future climatic scenario for the anchovy fishery in the Alboran Sea (SW Mediterranean): A modeling study

D. Macías [a,*], D. Castilla-Espino [b], J.J. García-del-Hoyo [b], G. Navarro [c], I.A. Catalán [d], L. Renault [e], J. Ruiz [c]

[a] European Commission, Joint Research Centre (JRC), Institute for Environment and Sustainability, Water Research Unit, Via E. Fermi, 2749, 21027 Ispra, VA, Italy
[b] Universidad de Huelva, Métodos Cuantitativos para la Economía y la Empresa, Plaza La Merced, 11, 21071 Huelva, Spain
[c] Departament of Ecology and Coastal Management, Instituto de Ciencias Marinas de Andalucía (CSIC), Avd. Republica Saharaui s/n, CP 11510 Puerto Real, Spain
[d] Department of Ecology and Marine Resources, Institut Mediterrani d'Estudis Avancats (IMEDEA,CSIC-UIB), 21 Miquel Marques, CP 07190 Esporles, Illes Balears, Spain
[e] SOCIB, Sistema d'observació i predicció costaner de les Illes Balears, Parc Bit, Naorte, Bloc A 2ºp. pta. 3, Palma de Mallorca, Spain

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ABSTRACT

The Alboran basin is one of the most productive areas of the Mediterranean Sea and supports an anchovy fishery with a history of remarkably variable landings. Past and present anchovy recruitment levels are highly sensitive to changes in the strength and direction of the incoming jet of Atlantic waters, which modulate the hydrographic features of the basin. Here, we analyze plausible consequences for the anchovy fisheries in the region based on a projected physical scenario for the end of the century obtained using a coupled hydrological–biogeochemical model. Our model predicts a substantial increase in horizontal water velocity and a negligible change in the associated biological production, which likely indicates reductions in anchovy stock, catches and revenues. Alternative policies are analyzed here for the economic scenario that is expected to emerge under future conditions of oceanographic features, pelagic ecosystem dynamics and anchovy landings in the Alboran Sea.

1. Introduction

Climate change is expected to affect oceanic conditions worldwide, with increases in sea surface temperature (SST) and vertical stratification (Boop et al., 2001; Sarmiento et al., 1998) as well as changes in water-mass properties and associated circulation patterns (IPCC, 2007). This scenario will likely alter marine biological production (e.g., Sarmiento et al., 2004) and fishery yields.

The Mediterranean Sea is thought to be sensitive to global climate change due to its particular characteristics; it is a semi-enclosed basin with a very restricted connection with the open ocean, and it is located at semi-tropical latitudes and surrounded by heavily populated countries. Expected future changes in the Mediterranean include (i) an increase in the seawater temperature, (ii) reductions in freshwater inputs (precipitation and river inflow), (iii) an increase in the ocean–atmosphere heat flux (i.e., an increase in evaporation) and (iv) an increase in human pressure (Vargas-Yáñez et al., 2008). The latter includes urbanization, industrialization and touristic exploitation (with associated impacts on land use, food demand, water disposal and coastal erosion), intensive agriculture and aquaculture as well as over-fishing (DeMadron et al., 2011).

One of the hot spots for observing climate change in the Mediterranean is the Alboran Sea (Fig. 1), located at the southwestern entrance to the basin and constituting the basin's unique connection with the open Atlantic Ocean. This connection is made through the water interchange at the Strait of Gibraltar, which forms an anti-estuarine circulation pattern with a surface inflow of fresh and warm Atlantic waters and a deep outflow of salty and cold Mediterranean waters (Armi and Farmer, 1988; Lacombe and Richez, 1982). This double circulation is maintained by the negative hydrological budget of the Mediterranean basin, in which evaporation exceeds inputs via precipitation and river discharges (Béthoux, 1979), as well as by the thermohaline circulation forced by winter deep-water formation within the Mediterranean (DeMadron et al., 2011).

The Atlantic inflow (AI, Fig. 1) feeds and controls the main hydrographic features of the Alboran Sea (Bormans and Garret, 1989; García-Lafuente et al., 1998), including the presence of one or two oligotrophic gyres in the central basin (WAG and EAG in Fig. 1) and a rich upwelling region along the northwestern coast (Gleizon et al., 1996; Minas et al., 1987) (black zone in Fig. 1). These circulation features (and associated biological niches) exhibit strong variability (Gomis et al., 1997; Tintoré et al., 1991; Viúdez et al., 1998) that is mainly related to fluctuations in the energy of the AI (e.g., Flexas et al., 2006; Sarhan et al., 2000), which is largely controlled by remote (Crepon, 1965; Macías et al., 2008) and local (Candela et al., 1989) meteorological conditions.

* Corresponding author. Tel.: +39 0332 78 9636.
E-mail address: diego.macias-moy@jrc.ec.europa.eu (D. Macías).

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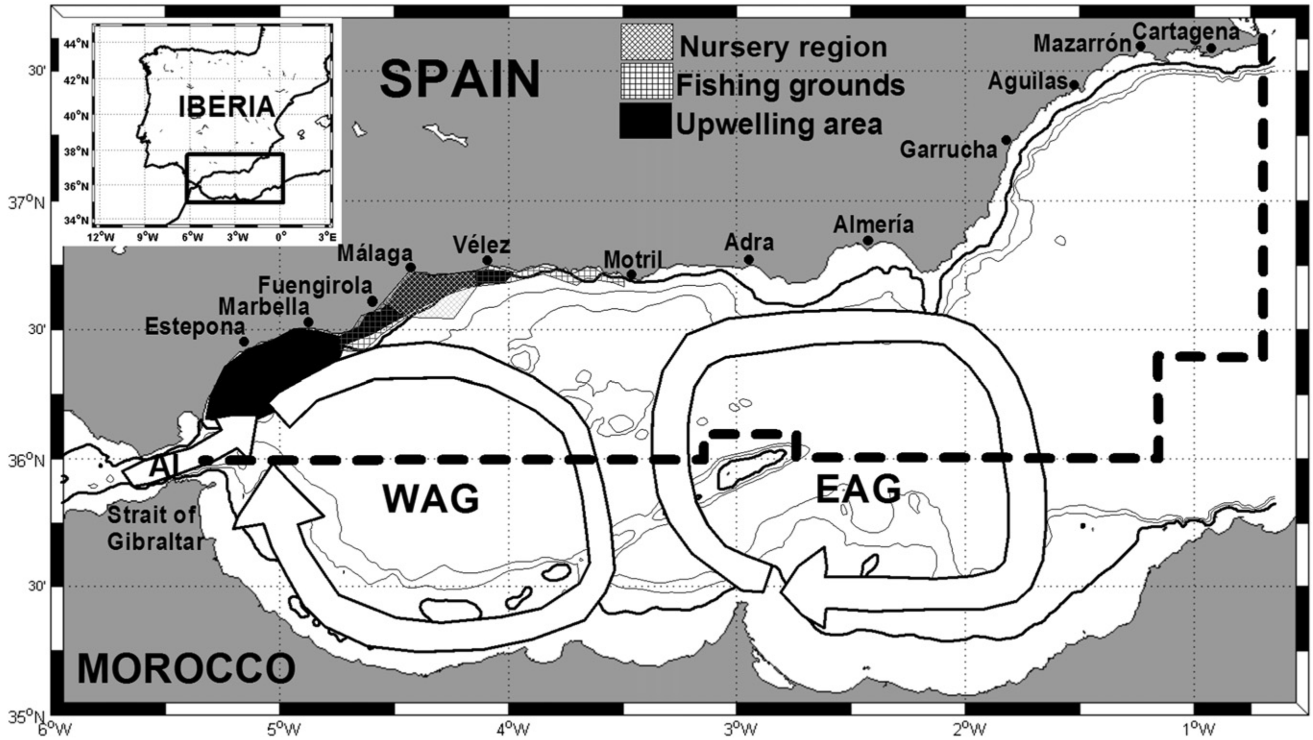

Fig. 1. The Alboran Sea with its main hydrographic and biogeographic signatures. Bathymetric lines (bold line = 200 m depth) and the main port names are included. Bold dashed line: zone GSA01 of the General Fisheries Commission of the Mediterranean (GFCM). AI: Atlantic inflow; WAG: Western Alboran Gyre; EAG: Eastern Alboran Gyre.

The northern shelf region of the Alboran Sea (NALS) has been described as a suitable area for the spawning of anchovy and other small pelagic fish (SPF) (e.g., Agostini and Bakun, 2002; Catalán et al., 2013; García et al., 2003; Macías et al., 2011) because this region constitutes a sheltered yet productive area (fueled by recirculation from the nearby upwelling) fulfilling the requirements of the ocean triad hypothesis (Bakun, 1998).

The NALS is included in the Alboran Sea fisheries management unit GS01 defined by the General Fisheries Commission for the Mediterranean (GFCM, FAO). The vast majority of landings of SPF in the GS01 are, at present, captured in the NALS. The area includes the Spanish fishing ports located in the South Mediterranean Maritime Region of Spain (excluding Ceuta and Melilla) and the Garrucha fishing port area of the Eastern Maritime Region of Spain (thick broken line in Fig. 1). The pelagic fishery has been exploited since the first decade of the 20th century, and the fishing mainly targets anchovies and, to a lesser extent, sardines. A historical profile of anchovy landings (data not shown) displays increasing landings from 1939 to 1982, with two peaks in 1952 and 1982. Subsequently, landings decrease sharply until 2010, with a remarkable peak in the year 2001 (Ruiz et al., 2013). The period of high landings during the late 1970s was partially contaminated with catches from the African coast, where some of the largest vessels based in ports in GS01 occasionally fished, and the data for these landings cannot be disaggregated (Abad and Giraldez, 1990). Therefore, the whole dataset cannot be interpreted as an abundance index. However, for the last two decades, the policy-makers have limited the fishing zones of the fleet to the GS01 area (Fig. 1); hence, only this final part of the catch data series could be considered as indicative of anchovy abundance (after appropriate analysis) in the NALS.

Most of the anchovy standing stock biomass in the NALS is composed of the zero-age class (Giráldez and Abad, 1995), and therefore the population oscillations and decline during the last two decades could be related to early-life-stage survivorship, which is controlled by environmental conditions (e.g., Ruiz et al., 2007). This anchovy population is mainly targeted by a fleet of small-sized (6–12 m) purse-seine vessels that primary operates in the Malaga Bay area (dashed region in Fig. 1). This fleet currently registers landings of 13,700 tons of a variety of pelagic fish species that represent more than 11.3 million euros annually. The anchovy is the most valuable pelagic fish species in the NALS area. The mean anchovy price is twice the price of sardine and five times the price of mackerel. Anchovy captures represented 42% of the total fish catch in the NALS region in 2002 and progressively decreased after this period as anchovy became scarce. This fleet directly employs 662 people whose wages are affected by the variability of the anchovy fish stock; each wage is a share of the revenue attained per fishing trip. Therefore, oscillations and decline of the anchovy population have put at considerable risk not only the economic sustainability of the whole fleet but also the economic conditions of the employees of this fishery.

Climate change is expected to alter the hydrodynamic and biological conditions of the Mediterranean Sea and, hence, of the Alboran Sea. The consequences of such changes are still uncertain, but we used a coupled hydrodynamic–biogeochemical model forced by future atmospheric conditions (obtained from Gualdi et al., 2008) to explore how currents and primary production in this basin will likely change under the expected climatic scenario A1B from the IPCC, which assumes a rapid economic growth, a global population reaching 9 billion in 2050, the quick spread of new and efficient technologies and a balanced emphasis on all energy sources. Those changes in the environmental conditions of the basin were projected into expected anchovy landings using a recently published conceptual model of anchovy population control by hydrodynamic conditions in the NALS (Ruiz et al., 2013). Using the Ruiz et al. (2013) model, future environmental changes were transformed into fishery scenarios, and the economic consequences of such fisheries scenarios were evaluated by an autoregressive capital-revenue model. Finally, the socioeconomic consequences of the projected economic scenario were explored using a conceptual framework.

This paper is structured as follows: in the Methods section, we describe a) a coupled hydrodynamic–biogeochemical model used to simulate present conditions and predict a future environmental state