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Influence of the hydrodynamic conditions on the accessibility of *Aristeus antennatus* and other demersal species to the deep water trawl fishery off the Balearic Islands (western Mediterranean)

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ABSTRACT

Monthly catches per unit of effort (CPUE) of adult red shrimp (*Aristeus antennatus*), reported in the deep water bottom trawl fishery developed on the Sóller fishing ground off northern Mallorca (Western Mediterranean), and the mean ocean surface vorticity in the surrounding areas are compared between 2000 and 2010. A good correlation is found between the rises in the surrounding surface vorticity and the drops in the CPUE of the adult red shrimp. This correlation could be explained by assuming that most of the surface vorticity episodes could reach the bottom, increasing the seabed velocities and producing sediment resuspension, which could affect the near bottom water turbidity. *A. antennatus* would respond to this increased turbidity disappearing from the fishing grounds, probably moving downwards to the deeper waters. This massive displacement of red shrimp specimens away from the fishing grounds would consequently decrease their accessibility to fishing exploitation. Similar although more intense responses have been observed during the downslope shelf dense water current episodes that occurred in a submarine canyon, northeast of the Iberian peninsula. The proposed mechanism suggesting how the surface vorticity observed can affect the bottom sediments is investigated using a year-long moored near-bottom current meter and a sediment trap moored near the fishing grounds.
The relationship between vorticity and catches is also explored for fish species (*Galeus melastomus*, *Micromesistius poutassou*, *Phycis blennoides*) and other crustacean (*Geryon longipes* and *Nephrops norvegicus*), considered as by-catch of the deep water fishery in the area. Results appear to support the suggestion that the water turbidity generated by the vorticity episodes is significant enough to affect the dynamics of the demersal species.

1. Introduction

The decapod crustacean red shrimp, *Aristeus antennatus* (Risso, 1816), a demersal species distributed throughout the Mediterranean and the north-eastern Atlantic, from Portugal to the Cabo Verde Islands (Arrobas and Ribeiro-Cascalho, 1987), mainly occurs in the muddy bottoms of the slope, between 400 and at least 3300 m (Sardà et al., 2004). This species is one of the most valuable deep-water fishing resources in the western and central basins of the Mediterranean, remaining at a low level of exploitation in the eastern basin (Papaconstantinou and Kapiris, 2001) and revealing important bathymetric migrations (Relini et al., 2000). However, despite its wide bathymetric distribution, it is mainly exploited between 400 and 800 m depth, and is the target species of the well-developed deep water bottom trawl fishery on the western basin slope (Sardà et al., 2003).

The trawl fleet operating off the Balearic Islands (western Mediterranean) is characterized by its versatility, which is determined by the specific dynamics of the resources, among other factors (e.g. sea conditions and fish market). Bottom trawlers not only target different species, but they also change the fishing location at a given time of the year, as well as the fishing tactics during the same fishing trip. Palmer et al. (2009) defined four fishing tactics in this fishery, related to the exploitation of different bathymetric strata and target species.

The annual catches of the red shrimp in the Balearic Islands are estimated to be around 100–200 t, which represents 10% of the landings and 40% of the earnings in the trawl fishery (Guijarro et al., 2012). Sóller, one of the most important fishing grounds for red shrimp around the Balearic Islands, is situated North of Mallorca (solid black line area in Fig. 1), where an important part of the island fleet is concentrated during the summer months (Moranta et al., 2008), when catches of large specimens occur. The red shrimp population in this fishing ground shows important seasonal variations throughout the year (such as the high abundance of juveniles recruiting to the fishing grounds in autumn–winter and the high abundance of large spawning females

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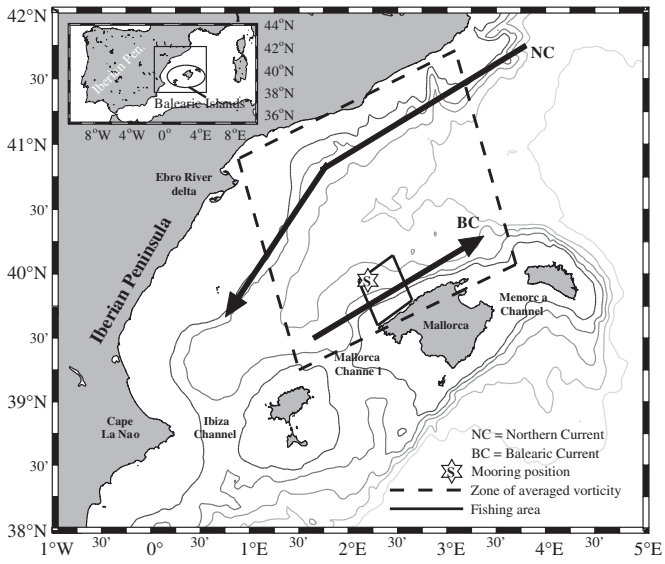

Fig. 1. Map of the studied area in the western Mediterranean. The unbroken line encloses Sóller fishing grounds where *Aristeus antennatus* is exploited and the broken line corresponds to the zone where the time series of vorticity has been calculated. Mooring location is indicated by a star.

during the summer), compared with the other nearby fishing grounds, south of Mallorca (Guijarro et al., 2008).

The Sóller fishing ground is located on the island slope.(Massutí et al., 2014–in this issue), in a well known very active area, with numerous eddies normally generated by some instabilities of the Northern current or the Balearic current (Fig. 1), particularly more intense during winter (October–March; Amores et al. (2013)). These eddies, clearly visible on satellite images, have been known to reach the deeper waters, and their effects are usually felt down to the seabed, where their velocities may increase to several times those of the mean currents measured in the zone (Amores et al., 2013). These strong bottom currents of the order of 25 cm/s are known to produce sediment resuspension which, in turn, may generate additional cross slope turbidity currents (Thomson et al., 2010).

In the western Mediterranean, the red shrimp distribution, and its accessibility to fishing exploitation, has been shown to be mainly influenced by geomorphology (Sardà et al., 1994, 1997) and hydrodynamics (Bombace, 1975; Demestre and Martín, 1993; Ghidalia and Bourgois, 1961; Guijarro et al., 2008; Relini and Relini, 1987; Sardà et al., 2009). These last factors are probably linked to regional and large-scale climatic patterns (Carbonell et al., 1999; Massutí et al., 2008; Maynou, 2008). In a recent study, Company et al. (2008) revealed that the downslope shelf dense water current events into submarine canyons, along the whole northern Catalan margin, strongly affected the red shrimp landings. These downslope shelf dense water current events are one of the main processes contributing to the shelf-deep ocean exchange (Ivanov et al., 2004), enhancing organic-matter flux and deposition, increasing suspended particulate matter concentrations and transport of organic matter from coastal zones to the deep ocean (Bosley et al., 2004; Canals et al., 2006; Company et al., 2008). In the northern Catalan margin, it exerts a negative effect on the catches of red shrimp and a positive effect for recruitment, due to the transportation of the particulate organic matter. The increase of suspended particulate matter also appears to be related to the abundance of other crustacean species such as pandalids and penaeid (Lin et al., 1992; Puig et al., 2001) and to the enhancement of benthic productivity and biodiversity inside canyon habitats (Rowe et al., 1982; Schlacher et al., 2007; Vetter et al., 2010). In addition to downslope shelf dense water current, mesoscale eddies have also been reported to be responsible of transport of shelf sediments to the deep ocean, resuspension of bottom sediments creating turbidity layers and formation of sediment plumes around their periphery (Washburn et al., 1993). The influence of vorticity (as indicator of eddy development) on catchability of marine species has been mostly addressed for pelagic organisms such as tuna fisheries (Hyder et al., 2009; Kai and Marsac, 2010; Ramos et al., 1996; Zainuddin et al., 2006). However, the effect of such physical processes has also been explored for benthic species, which are also linked to variables that describe water column properties and structures (Beentjesa and Renwick, 2001; Palamara et al., 2012).

The objective of this work is to analyze the possible links between the presence of eddies (which will be quantified by their associated surface vorticity) affecting the Sóller fishing ground and the red shrimp yields of the deep water trawl fishery developed in the area. This relationship is also explored for other demersal species frequently caught by the deep water bottom trawl fishery developed in the area (Guijarro and Massutí, 2006), which consist of three fishes (*Galeus melastomus*, *Micromesistius poutassou* and *Phycis blennoides*) and two decapod crustaceans (*Geryon longipes* and *Nephrops norvegicus*), with the objective of discussing their different responses in relation to their living habits.

A year-long near-bottom current meter and a sediment trap moored near the fishing grounds are used to infer the mechanism to explain how the surface vorticity observed can affect the bottom sediments and, in turn, the red shrimp yields.

2. Data and methods

2.1. Catches

Daily time series of the landings from the bottom trawl fleet have been obtained from the official sale bills of OP Mallorca Mar, the fishery producer organization of Mallorca, between 2000 and 2010 (both years included). Each daily sale bill was assigned to one fishing tactic (FT) or a combination of them following the methodology described by Palmer et al. (2009). Landings were standardized to CPUEs (catches per unit of effort), referred to as kilograms caught per day and boat. For *A. antennatus*, only catches obtained from the middle slope fishing tactic, developed between 600 and 800 m depth, have been considered, because this is the target species for this FT. Moreover, the daily sale bills distinguished red shrimp catches into two size categories (small and large) up to year 2004, and three categories (small, medium and large) from 2004 to the present day. According to Guijarro et al. (2008), two different categories were defined in order to homogenize the available data, small (including individuals with a carapace length <32 mm) and medium-large (adults, with a carapace length ≥ 32 mm). For this analysis, only those of the medium-large sized category, mainly adult females, were considered. Juveniles are not taken into account for two reasons:

1. The fishing fleet mainly targets large individuals (adults) due to their higher commercial value. This fact would surely provoke a bias when trying to relate juvenile catches with abundances
2. Adult and juvenile red shrimps present a clear different bathymetric distribution. Adult individuals are mainly located at the 500–800 m range, where the fishing fleet is developed. But the highest concentrations of juveniles are situated deeper than 1000 m (Sardà et al., 2003), where the bottom trawl fishery is forbidden. So juvenile catches do not properly reflect the juvenile population abundances.

From the entire fleet that currently operates in Mallorca, only five boats regularly fish in the zone of interest (Sóller) throughout the year (other boats fishing in this area only in summer are not considered). Among these five boats, exclusively two devote most of their efforts to red shrimp fishery along the middle slope and they were the only ones finally considered for the analysis.

Finally, as a direct response to hydrodynamics changes in a daily basis is not expected, a monthly average was calculated according to