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The deep-sea recruitment of *Aristeus antennatus* (Risso, 1816) (Crustacea: Decapoda) in the Mediterranean Sea

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ABSTRACT

Recruitment of *Aristeus antennatus* over the species' entire depth range and distribution area in the Mediterranean Sea is described. Because of the dearth of information on the recruitment of deep-sea species in the literature, the findings reported here take on special significance. Samples were collected at depths between 900 and 2800 m on seven trawl surveys using three samplers: an OTMS trawl, an Agassiz bottom frame trawl, and a Macer-Giroq suprabenthic sledge, computing a total of 80, 26 and 14 trawls, respectively. Early juveniles (≤15 mm CL) were observed to be present down to a depth of 2800 m and to attain maximum percentage abundance between 1350 and 2000 m. Spring was the season of peak abundance for juveniles. Several hypotheses explaining this deep-sea recruitment are discussed, including oceanographic events coupled with enrichment of the bathyal bottoms and competitive exclusion in deep-sea species. Studying the deep-sea recruitment of *A. antennatus* contributes to our understanding of the species' life history and supplies knowledge essential to proper management and sustainable exploitation of the species.

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1. Introduction

A thorough knowledge of the recruitment of marine species is essential to an understanding of both the biological and ecological underpinnings of their life histories and population dynamics as well as of the effect of fishing in the case of exploitable species. Studies on recruitment, defined as the spatio-temporal presence of juveniles on the fishing grounds, in nursery areas, or in areas where they settle to the bottom are scarce, and the recruitment processes of many species are still largely unknown. Recruitment may be well known and may even have been quantified in the case of certain commercial species and is a component of studies into the population dynamics of exploited stocks with a view to ascertaining the stock-recruitment relationship (Beverton and Holt, 1957; Chambers and Triple, 1997; Cushing, 1988; Haddon, 2001). To a large extent, fisheries management looks to recruitment as a basis for the sustainability of the resource. Recruitment studies are commonly performed for such commercial species as cod and small pelagics (Agostini and Oliver, 2001; Guisande et al., 2001; Palomera et al., 2007; Stein and Borovkov, 2004), focusing mainly on coupling between larval survival, primary production, and oceanographic conditions in the species' habitats. However, up to date the studies on deep-sea species recruitment are very scarce, with a lack of knowledge on juveniles distribution and on the process that allow this recruitment in areas far from the main energy source (continental and surface primary production).

Following the discovery of communities associated with the mid-oceanic ridges, recruitment processes for deep-dwelling species have gained special interest. Young and Eckelbarger (1994) reviewed different evidence of deep-sea recruitment of invertebrates, in the main associated with deep hydrothermal vents along the mid-Atlantic ridge (Gustafson and Lutz, 1994). The larvae of most of these species are planktotrophic, spending their early stages in the euphotic zone (Carbonell et al., 2010; dos Santos, 1998, 2008; Heldt, 1954, 1955) and then descending to the bottom, following an ontogenetic migration, where they settle and grow to adulthood (Bouchet and Waren, 1994). However, recruitment continues to represent a bottleneck in studies of the life history of deep-dwelling species because of the scant literature presently available and the difficulties in interpreting relationships between environmental conditions and recruitment success. What is more, commercially exploited deep-water species tend to be especially vulnerable, making recruitment particularly important (Duun et al., 2009).

Recruits and juveniles cannot be sampled by conventional fishing methods where recruitment areas do not coincide with normal fishing grounds. This is the case of migratory species and species with distribution ranges extending to great depths beyond the fishing areas. Quantitative data are unavailable in most such cases, because much research on deep-dwelling marine organisms is primarily exploratory (Gage and Tyler, 1991; Merrett and Haedrich, 1997; Sardà et al., 2003).

Some studies on crustaceans point to an association between deep-water crustaceans and energy sources, defined as food supply

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directly or indirectly available to the earliest juvenile stages. In the case of the genus *Plesionika* in the Mediterranean Sea (Puig et al., 2001), ovigerous females and juveniles of four species are associated with the nepheloid layers at depths between 400 and 800 m. *Plesionika acanthonotus*, the *Plesionika* species with the deepest distribution, down to 1000 m, is the sole exception. Nepheloid layers have not been detected at such depths. The life cycle of this latter species does not match any nepheloid layers, and hence juveniles of this species are distributed uniformly over the same depth distribution range as adults. Puig et al. (2001) postulated that because nepheloid layers are common along the continental margins, the life histories of deep-water species are probably adapted to the existence of these structures, which are an available source of energy for juveniles. Following this pattern put forward by Puig et al. (2001), in habitats where there is no nepheloid layer, recruitment of species takes place over the entire distribution range where ovigerous females occur. The absence of energy-supply structures and lower predation levels in the deepest zones probably results in extensive recruitment rather than the concentrated recruitment common to more inshore-dwelling species, hence recruitment at great depth can be assumed to be a broad phenomenon occurring widely in the species rather than a discrete occurrence. Furthermore, the presence of nepheloid layers is related to other oceanic structures like fronts between oceanic water masses (Font et al., 1988), which appear to influence larval distribution and subsequent settlement of juveniles on the bottom (Company and Sardà, 1997; Gustafson and Lutz, 1994; Scheltema, 1994).

Aristeus antennatus represents a special case of a eurybathic species with a depth distribution ranging between 100 and 2800 m in the Mediterranean. Besides being the most economically important crustacean species, it also has the broadest depth distribution (Sardà et al., 2004a). To date, evidence of deep-water recruitment by this species down to a depth of 1200 m has been published (D'Onghia et al., 2009; Sardà et al., 2004b). Recruiting by pre-adult juveniles takes place on fishing grounds on the middle slope (400–900 m) from a mean carapace length (CL) of 24 mm, primarily in winter and spring. Using a Macer-Giroq suprabenthic sledge with a mesh size of 500 μ, Sardà and Cartes (1997) collected (127) small individuals (<16 mm CL) down to a depth of 1200 m. Sardà et al. (2004a, 2004b) found a single pre-adult individual at 2800 m, taken by trawl gear (OTMS, Sardà et al., 1998) with a 12-mm stretched mesh lifter. Mura et al. (1997) and D'Onghia et al. (1997, 2005) also reported *A. antennatus* juveniles ranging over depths between 500 and 1200 m. D'Onghia et al. (2009) concluded that recruitment at depth occurs as a discrete phenomenon.

Nevertheless, because of the difficulties intrinsic to deep-sea sampling of live organisms using trawl gears extant to date, the data available are insufficient to be able to define a comprehensive model of recruitment for *A. antennatus*. Recently, two complementary exploratory fishing surveys were carried out, a seasonal study under the PROMETEO programme and a spatial study under the BIOFUN programme, down to a depth of 2800 m These studies have yielded more precise information on the presence of juveniles by depth and season, that is, on the deep-sea recruitment pattern for this species. Sampling over the entire distribution range of a eurybathic, bottom-dwelling species commercially exploited on the middle slope depths has, for the first time, provided evidence of deep-sea recruitment over a wide bathymetric range. This paper discusses these new patterns and the causes contributing to the deep-sea distribution of juveniles of *A. antennatus* as an example of adaptation of a deep-dwelling population to its habitat.

2. Material and methods

2.1. Sampling

Samples were collected on oceanographic-fishery surveys carried out in the framework of the PROMETEO and BIOFUN programmes. The PROMETEO survey comprised cruises in the western Mediterranean off Catalonian coast (Fig. 1) by the oceanographic research vessel García del Cid (length: 38 m) between October 2008 and November 2009. The programme consisted of five seasonal surveys carried out at depths between 900 and 1500 m in the southern part of the Blanes submarine canyon in the western Mediterranean, taking samples at depth intervals of 150 m (Annex). A second oceanographic survey with the oceanographic vessel Sarmiento de Gamboa was carried out in June 2009 as part of the BIOFUN programme, sampling bottoms in the western Mediterranean (Balearic Sea southwest of Eivissa). The depths sampled were 1200, 2000, and 2800 m.

In all of 88 bottom otter trawls, using the OTMS trawl (Sardà et al., 1998), 80 hauls caught individuals of the deep-sea red shrimp *A. antennatus* (see Annex in Supplementary Information). The gear opening during the haul was measured by remote Scanmar sensors as 12 m for the horizontal opening and 1.3 m for the vertical opening. Towing speed was around 2.5 knots and cod end was covered with a lifter of 12-mm stretched mesh.

A further 36 trawls carried out using the Agassiz frame trawl were performed. Gear size was 2.5 m in width and 1.2 m in height. This trawl also used a 12-mm stretched, but towing speed was slower, 2.0 knots. All samples were collected at 900, 1050, 1200, 1350, 1500, 2000, and 2800 m over the course of the two programmes.

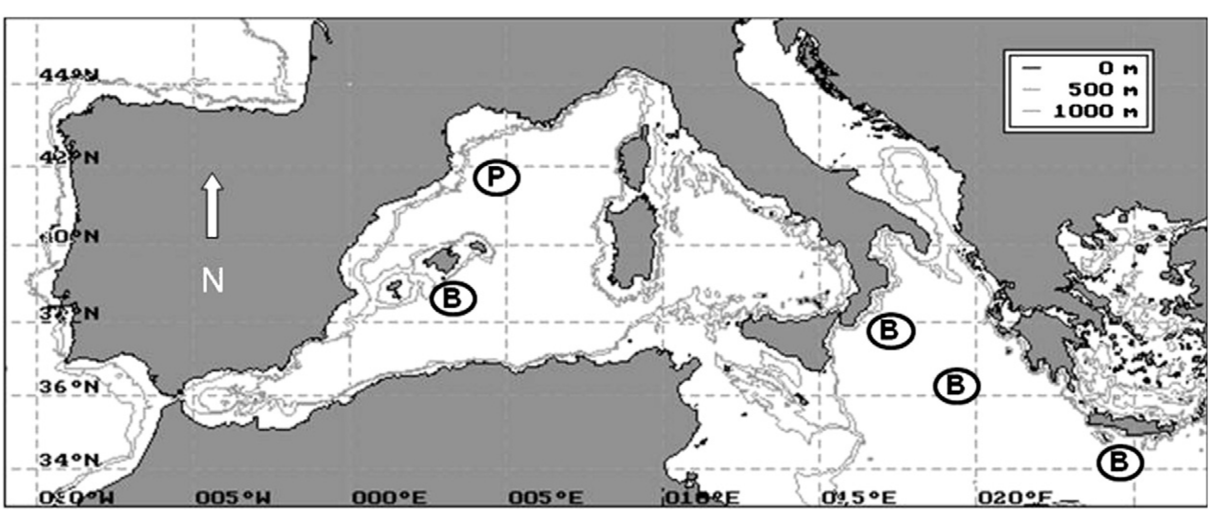

Fig. 1. Mediterranean map showing the sampling zones during Prometeo cruise (P) and Biofun cruise (B).