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Life history of the bathyal octopus *Pteroctopus tetracirrhus* (Mollusca, Cephalopoda) in the Mediterranean Sea

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ABSTRACT

The life cycle of the deep-sea octopus *Pteroctopus tetracirrhus* was studied from monthly samples obtained throughout the year in different areas of the western Mediterranean (mainly around the Balearic Islands and along the coast of the Iberian Peninsula). A total of 373 individuals (205 females, 168 males) were analyzed; females ranged from 4.5 to 14.0 cm mantle length (ML) and males from 4.5 to 11.5 cm ML. There were few small-sized octopuses (<7 cm ML) in the samples, which might indicate that these individuals inhabit rocky grounds that are not accessible to trawlers or waters deeper than the maximum depth sampled (800 m). The species occurred more frequently around the Balearic Islands than along the Iberian Peninsula as they appeared in 20% and 7%, respectively, of the hauls in these areas. The octopus inhabits the lower continental shelf and upper slope in both areas, primarily between 200 and 500 m depth. Modal lengths were followed from autumn, when recruits were caught by trawlers, to summer, when reproduction took place. Females grew from 8 to 10 cm ML from winter to spring, but this modal size did not increase further in summer; males grew from 7 to 9 cm ML from winter to spring. The total disappearance of large individuals after summer suggests a life cycle lasting a single year. The evolution of the monthly mean sizes showed that the growth was best described by log-linear functions in both sexes. The length at first maturity was clearly higher in females (12 cm ML) than in males (8 cm ML). A total of 30 different prey items, belonging to four major taxonomic groups (crustaceans, osteichthyes, cephalopods and gastropods), were identified in the stomach contents. The diet of the octopus was based on crustaceans and teleosts, which accounted for 75% and 23% of the prey items, respectively. Cephalopods and gastropods were accessory prey as they only represented 1.6% and 0.7%, respectively, of the total. The octopus showed a marked preference for the benthic fish *Symphurus nigrescens* and the endobenthic crustacean *Alpheus glaber*. The bathymetric distribution of *P. tetracirrhus* coincides with those of these two main prey, which suggests that the distribution of the octopus might be strongly linked to its trophic resources.

1. Introduction

Cephalopods belonging to the Order Octopoda, which include the Cirrata and Incirrata forms, are abundant in demersal deep-sea communities, where the incirrates (Collins and Villanueva, 2006) prevail on the upper slope and cirrates on the lower slope and abyssal plains (Allcock et al., 2003). In contrast with their shallow-water relatives, little is known about the life histories of the deep-sea incirrate octopuses (Barratt et al., 2007). Deep-sea octopods, that is, those octopus species that inhabit the region below the edge of the continental shelf or

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deeper than approximately 200 m depth, have a series of morphological and histological adaptations for living in such deep, cold, twilight waters. Morphological characteristics were reviewed by Voss (1988), who considered the following main adaptations: (1) loss of the ink sac: in contrast with shallow-water octopuses, this organ is small, degenerate, or absent in deep-sea species because in the absence of light an ink jet does not work as a defence mechanism; (2) reduction of the crop, radula and posterior salivary glands, which is probably related to the change to small, soft-bodied prey; (3) reduction of the gills, in response to decreased metabolic activity in the cold deep-sea waters; (4) large eggs, which are presumably associated with crawl-away young with no, or a very short, planktonic stage, a factor that limits their geographical distribution; (5) subgelatinous tissues: with increasing depth, the mantles are increasingly modified because of the decrease in musculature and the appearance of a gelatinous material that is probably a means of reducing metabolic requirements. All these morphological changes, among others such as the presence of few but large spermatophores, the enlarged ligula from the hectocotylus arm or the reduction of the sucker rows or sucker sizes, are evolutionary adaptations to living in deep-water habitats, since it is thought that deep-sea octopuses are derived from their shallow-water relatives (Voss, 1967). Although very little is known about the physiological adaptations of cephalopods to the deep sea (Seibel et al., 1997), there is a clear trend of decreasing metabolic rates with increasing depth in oceanic species, which is believed to result from decreased locomotory capacity for visually cued predator/prey interactions in the low ambient light levels of the deep sea (Seibel et al., 1997; Seibel and Childress, 2000). However, this does not apply to benthic octopods that have greater opportunities for crypsis and refuge, and consequently have similar metabolic rates regardless of habitat depth (Seibel and Childress, 2000).

There are up to nine incirrate benthic octopods in the Mediterranean Sea, of which only three, *Octopus salutii* (Verany, 1836), *Pteroctopus tetracirrhus* (Delle Chiaje, 1830) and *Bathypolypus sponsalis* (Fischer and Fischer, 1892), can be considered deep-sea forms based on their bathymetric distribution and their mean depth of occurrence, which falls well below the 200 m depth (González and Sánchez, 2002). Of the three deep-sea forms, *B. sponsalis* and *P. tetracirrhus* are two small-sized species that are externally very similar and that share many of the traits typical of the deep-water inhabitants cited above. Both species have flaccid, gelatinous bodies, relatively large eyes, relatively small suckers, a reduced ink sac (*P. tetracirrhus*) or no ink sac (*B. sponsalis*), a moderately (*P. tetracirrhus*) or highly (*B. sponsalis*) enlarged ligula, and females that lay a small number of eggs that are of medium (*P. tetracirrhus*) or large (*B. sponsalis*) size in comparison with coastal octopuses (Mangold-Wirz, 1973a). From the differences between these two species, it is clear that *B. sponsalis* has characteristics that are more adapted to life in the deep sea. This can be explained by the fact that although *B. sponsalis* has been caught at depths as deep as 1835 m (Villanueva, 1992b), the deepest limit of *P. terracirrhus* seems to be at approximately 750 m depth (González and Sánchez, 2002). In fact, *B. sponsalis* was the only incirrate octopod captured in samples taken between 1000 and 2000 m depth in the western Mediterranean basin (Villanueva, 1992b). However, *O. salutii* has morphological characteristics of both the deep-sea and coastal forms, since it has a muscular but more flaccid mantle than its shallow-water relatives, well-developed suckers but a very large ligula, and the females lay a moderate number (2000–4000 according to Mangold-Wirz et al., 1976) of medium-sized eggs (e.g. larger than *Octopus vulgaris* but smaller than *P. tetracirrhus* (Mangold-Wirz, 1973a)).

Biological aspects, including diet, of *B. sponsalis* and *O. salutii* have been analyzed in recent years (Quetglas et al., 2001, 2005), but the studies dealing with *P. tetracirrhus* date back decades (Mangold-Wirz, 1963, 1973a; Mangold, 1965; Boletzky, 1976). After such a long time it is necessary to update the knowledge of this last species and shed light on issues not previously studied. Consequently, in the present paper we analyze the life cycle of the fourhorn octopus *P. tetracirrhus* from monthly samples caught throughout the year in the western Mediterranean. We report aspects such as the spatial and bathymetric distribution, population structure, reproduction and growth. For the first time in the literature, the diet is assessed from stomach content analyses of wild-caught individuals. Finally, we review the presently scant knowledge of the biology and global distribution of this deep-sea octopus.

2. Material and methods

The octopuses used for biological sampling were caught by commercial bottom trawlers (mesh size: 40 mm) off the island of Mallorca (Balearic Sea) and also by scientific surveys (mesh size: 20 mm) made around the Balearic Islands, along the entire Mediterranean coast of the Iberian Peninsula and in some areas of the Algerian coast (western Mediterranean, Fig. 1). These octopuses were obtained between the years 1995 and 2005 and, although rather unbalanced, the samples covered the whole year from January to December.

Once captured, the individuals were kept frozen and analyzed subsequently in the laboratory where the following measurements were taken: mantle length (ML, to the nearest 0.5 cm), total weight (TW, to the nearest 0.1 g), gonad weight (GW), digestive gland weight (DGW) and stomach weight (all to the nearest 0.01 g), sex and maturity stage. The following three-stage maturity scale adapted from Sánchez and Obarti (1993) was used: (I) immature (ovary whitish, very small and with no signs of granulation; spermatophoric organ transparent or whitish); (II) maturing (ovary yellowish with a granular structure; spermatophoric organ with white streaks of sperm); and (III) mature (ovary very large with plenty of eggs; spermatophoric sac with spermatophores).

To determine the relationship between mantle length and total weight, the parameters of the power formula $TW = aML^b$ were calculated for females, males and for the