Condition and recruitment of *Aristeus antennatus* beyond fishing ground (to depths of 2200 m) in the Mediterranean: relationship with environmental factors

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The red shrimp ***Aristeus antennatus*** is likely the most important target species in deep sea fisheries in the Mediterranean. Most of the large amount of biological information available for *A. antennatus* come from commercially exploited depths (e.g. Relini-Orsi and Pestarino 1981, Demestre and Fortuño 1992, Carbonell *et al.* 2006), whilst beyond commercial depths, where we find an important part of the population, e.g. > 1000 m in the deep Mediterranean, studies are still largely incomplete, with a practically unexistent seasonal sampling.

The aim of this study was to analyze the spatial and temporal variability of *A. antennatus* along its entire depth distribution in the Balearic Basin (to 2200 m depth), identifying variables that control its biological cycle. For this, we analyzed:

1) Seasonal and spatial changes of hepato-somatic, gonado-somatic indices and of the density of smallest juveniles (*ca.* 1 yr age, Cartes and Demestre 2003);
2) The environmental variables (temperature, salinity, particulate organic matter, POM, dissolved oxygen) that control *A. antennatus* habitat.

Such approach has hardly attempted in deep-sea biology and results obtained can therefore be applicable to the study and management of *A. antennatus* and other deep sea species.

The study area comprised the Balearic Basin (between Catalonia coasts and the Balearic Islands, Figure 1), in the NW Mediterranean: sampling was performed on muddy bottoms on mainland and insular slope areas.

Nine surveys were performed between 2007 and 2012, from 427 to 2233 m. An OSTB-14 bottom trawl, standard gear for study of deep-sea megafauna (Cartes *et al.*, 2008) was used in the majority of hauls performed (71 of a total of 80 hauls), with some additional commercial hauls. Densities are calculated on the former, so they are comparable, e.g. among depths/seasons. Hauls were performed over the entire Balearic Basin covering fishing grounds (to *ca.* 900 m depth) and deeper depths free of trawling activity.

Sampling is unique in the deep Mediterranean, covering seasonality to depths of 2200 m. However, we presented results after we built a virtual year, due to logistic constraints. This composite year (2007 to 2012) is reasonable to analyse shrimp's biology, because reproduction of *A. antennatus* in a same area is known to occur in the same season year after year (Carbonell *et al.* 2006, Figure 2).

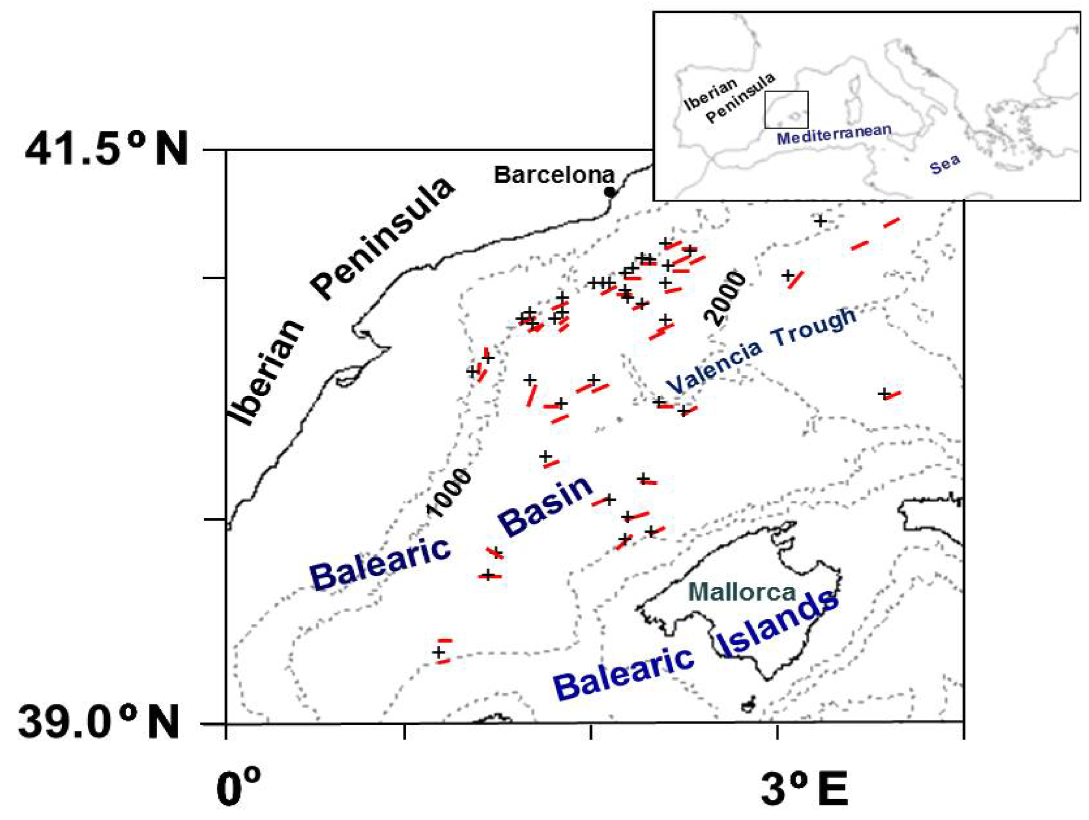

Figure 1. Location of hauls in the Balearic Basin, indicating bottom trawls (---) and CTD profiles and Multicorer samples (+) performed to collect environmental data in the near-bottom water column.

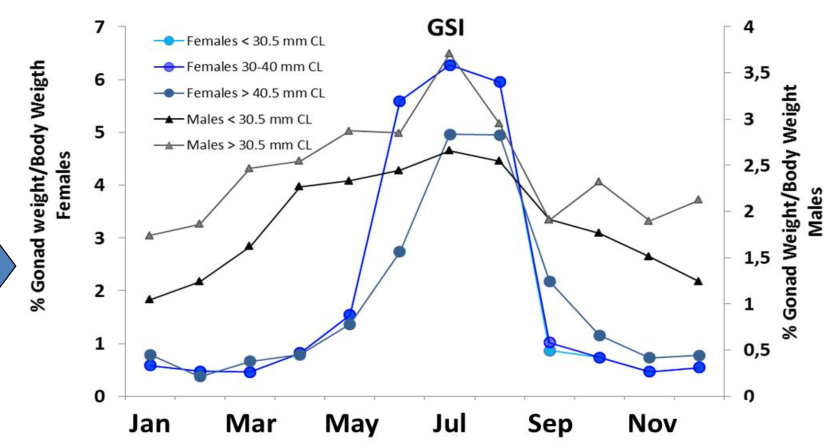

Figure 2. *A. antennatus*: Mean monthly GSI of males and females of different stages of maturity collected throughout an annual cycle off Mallorca Island over depths of 600-800 m, integrating the period 1991-2010.

Depth trends relationships of GSI and HSI

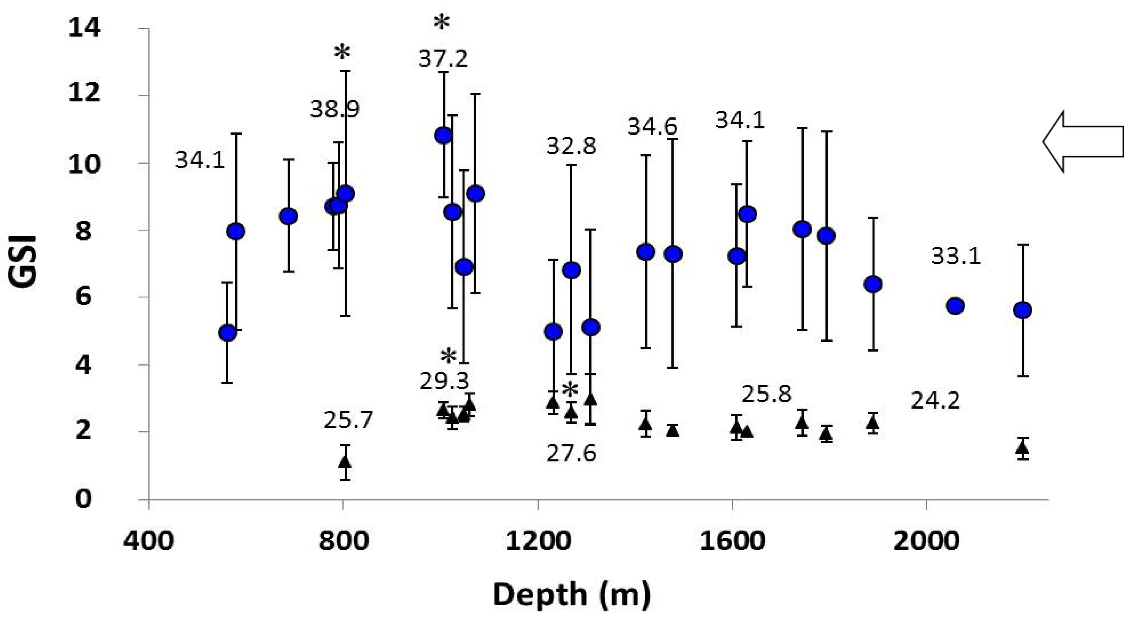

Figure 3. Average GSI for females (●) and males (▲) of *A. antennatus* (with SD) vs depth along the Balearic Basin. Numbers represent mean sizes of specimens; asterisks (*) are significant differences in mean sizes between contiguos groups.

- The highest mean GSI (8.4-10.8) of females (●) in stages 5-6 were found (in July) at 792-1071 m. GSI significantly increased until *ca.* 1100 m, decreasing deeper (Figure 3).
- Mature males (▲) followed a similar depth related trend.
- Highest densities of both males and females in April-May, the pre-reproductive period of females, occurred at depths between 797 and 1096 m. Mating seems to take place at such depths.

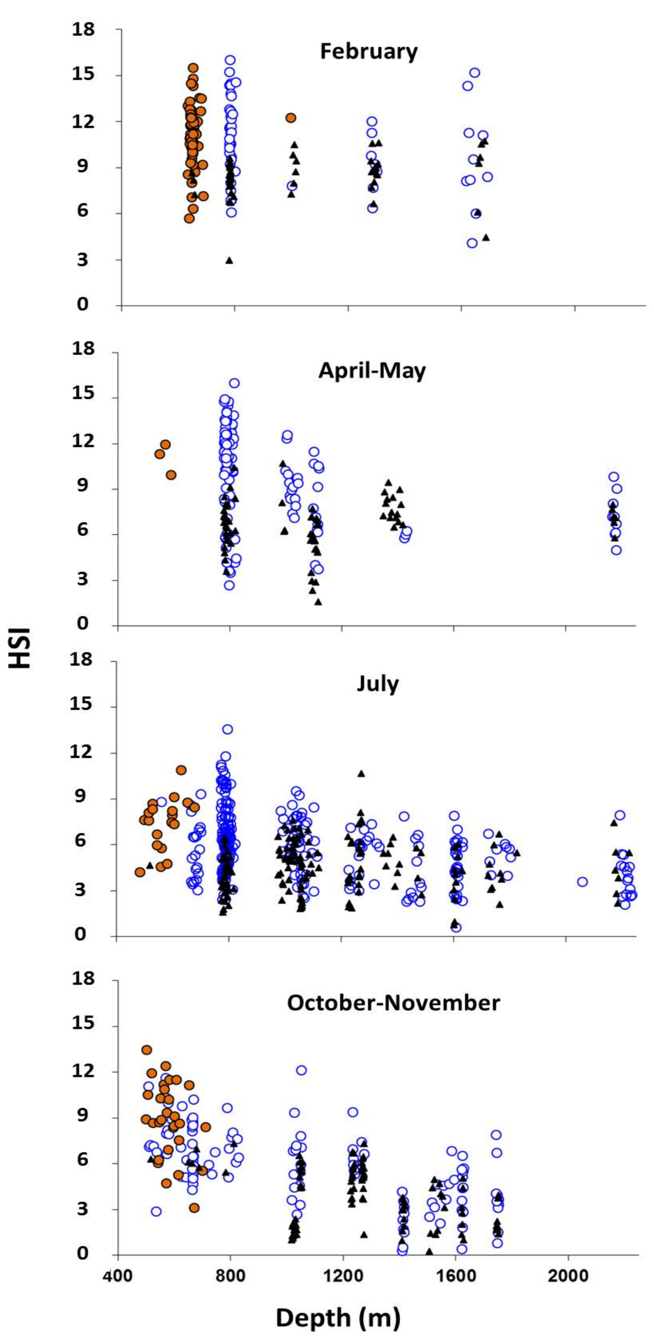

Figure 4. HIS for females (●, ○) and males (▲) in the Balearic Basin. Full circles are adult females collected into submarine canyons.

- The HSI of *A. antennatus* females (●, ○; Figure 4), decreased with depth, down the entire slope out of the reproductive period, especially in October-November, after spawning.
- The nutritional condition of females in these periods is consistent with higher food consumption on benthic prey (ophiuroids, polychates) at canyon heads (Cartes 1994; ●) in autumn and winter. Both HSI and female density increased in canyons during those periods (in our case in Besòs Canyon).
- This suggests a regular seasonal migratory pattern by females: i) to the upper slope in periods of water mass homogeneity (autumn-winter) to feed, a fattening period in where females increase their energy reserves (HSI), and; ii) downslope (800-1100 m) for mating and to spawn in periods of water mass stratification (spring-summer).
- The highest GSI, mating and spawning areas are found at depths considerably deeper than the fishing grounds historically exploited, which limit in the Balearic Basin is at *ca.* 800-900 m.

Recruitment of small juveniles

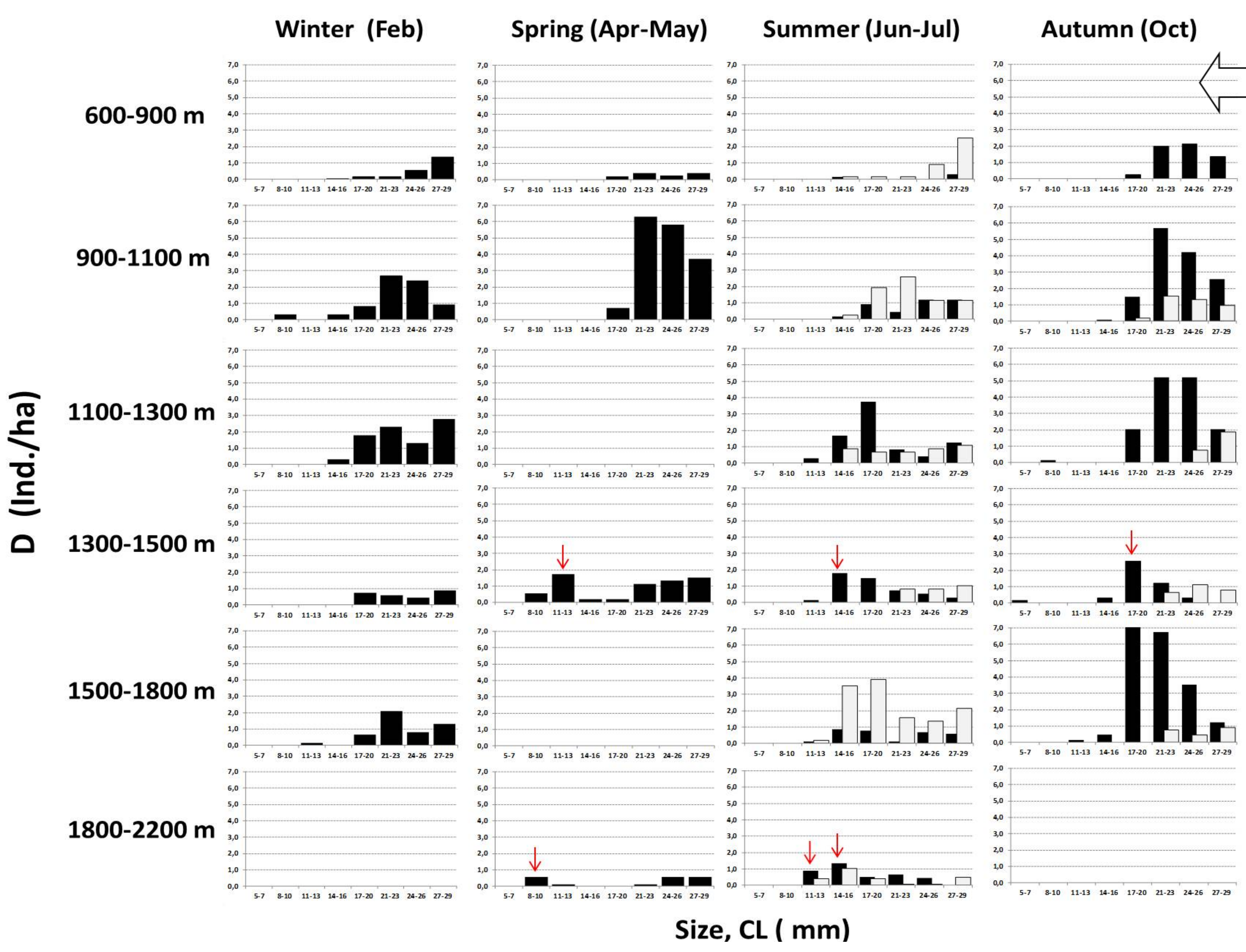

Figure 7. Size-distribution (CL mm) of *A. antennatus* recruits by depth interval in the Balearic Basin.

- The smallest juveniles of *A. antennatus* (6 mm CL) were collected at 1300-1500 m in October (only few specimens).
- Peaks of small juveniles (red arrows in Figure) appeared in spring (April-May) at 1300-1500 m and 1800-2200 m.
- These April-May recruits developed from the previous year (June to September), so they were *ca.* 1 yr aged.
- Recruit peaks persisted in summer (July), growing at 1300-1500 m from 11-13 mm CL (May) to 14-16 mm CL in July.
- Similar size increments occurred at 1800-2200 m.

Environmental analysis

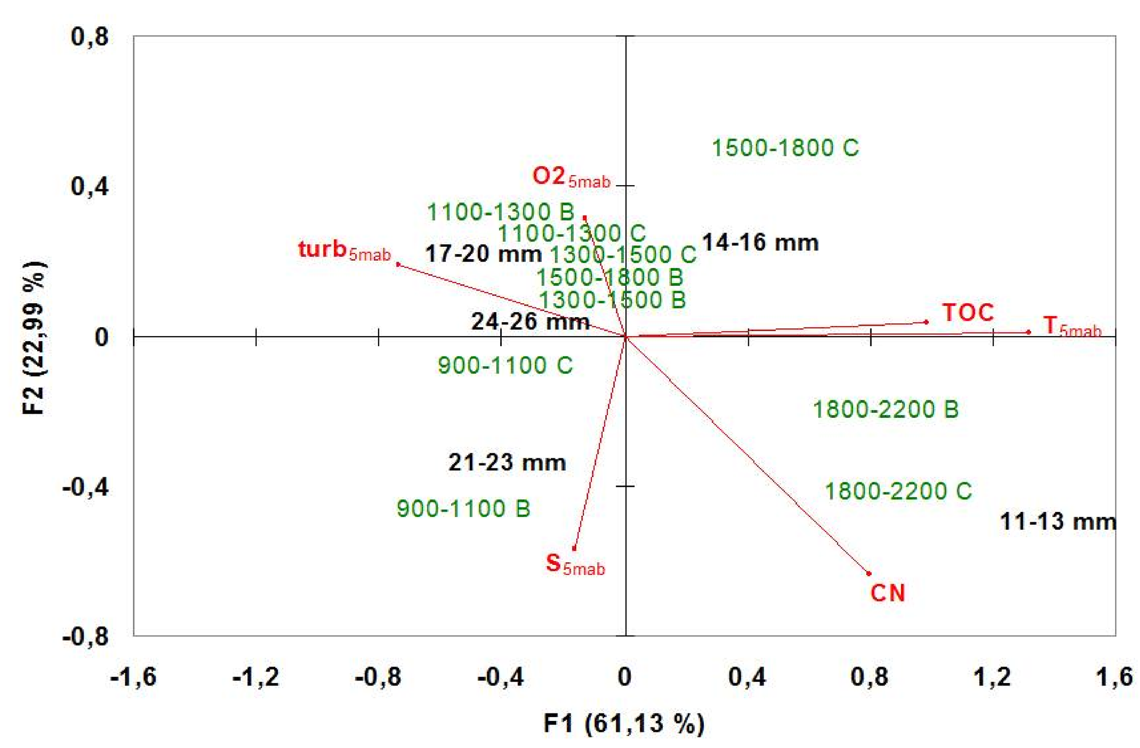

Figure 8. CCA for size classes of small *A. antennatus* by depth interval in the Balearic Basin and relationship with environmental near-bottom and sediment variables. T: temperature; S: salinity; turb: turbidity; TOC: Organic Carbon; CN. C vs N ratio.

CCA relationships between small juveniles of *A. antennatus* (CL < 26 mm) and the environmental variables in each depth-stratum (off Catalonia, C, and insular slope off Balearic Islands, B) were:

- Juveniles of 11-13 mm CL were mainly linked to higher C:N and TOC in sediments, at 1800-2200 m, both at C and B.

- At 1100-1500 m, and deeper to 1800 m in the insular part, juveniles of 14-19 mm CL occupied depth strata with higher near-bottom turbidity and greater O_2 concentration.

Environmental gradients and trophic relationships

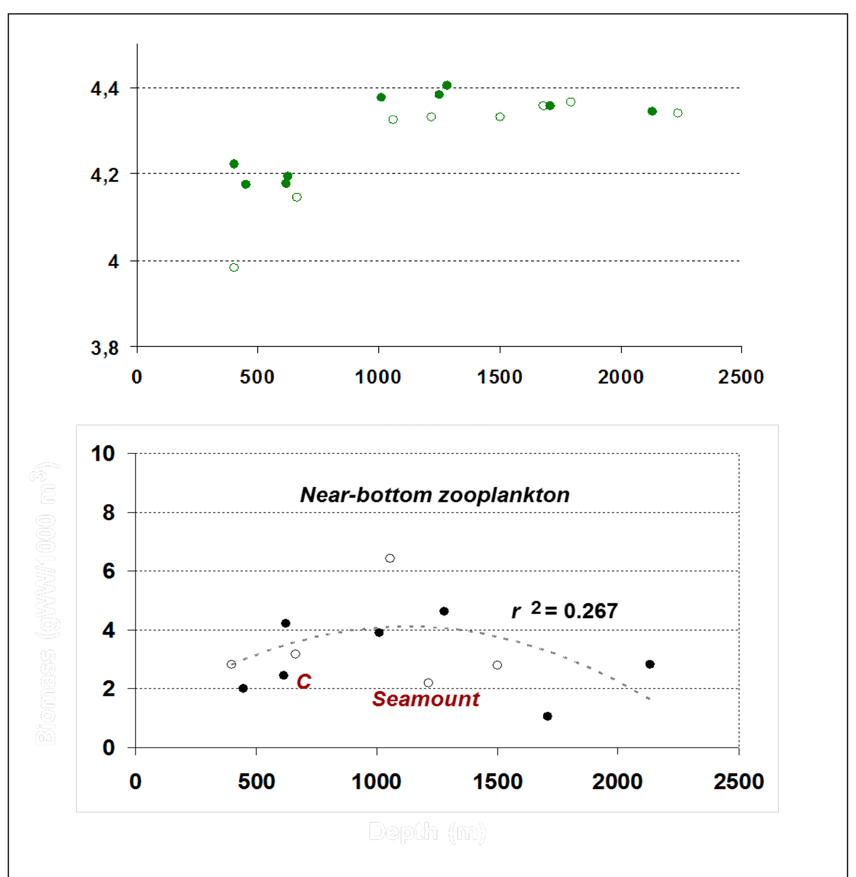

Figure 5. Concentration of dissolved oxygen near the bottom (at 5 m above) increase at > 1000 m in the Balearic Basin (upper), below Levantine Waters (LIW) influence. At 1000-1300 m, where O_2 peaks, it has also been recorded highest biomass of near-bottom zooplankton (Cartes et al. 2013). Such conditions may enhance A. antennatus recruitment.

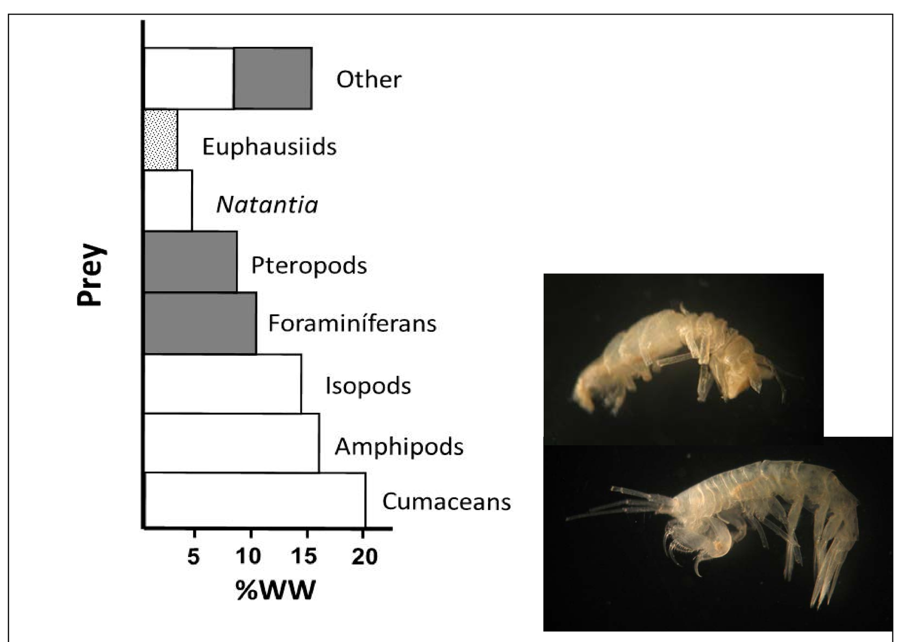

Figure 6. Suprabenthos (especially peracarids as ilustrated) and foraminiferans are main prey exploited by A. antennatus during its 1st age of live at extreme depths (1000-2200 m) of its distribution (Cartes, unpublished). WW= wet weight.

- The finding of high reproductive condition of *A. antennatus* at depths of 800-1300 m in the Balearic Basin, below fishing grounds, indicates what important is to study the biology of deep-sea species, especially those submitted to fishery pressure, over their whole depth range and not only on the fishing grounds.
- The simultaneous study of shrimps, of habitat variability and prey availability over the full life-cycle depth range allows explanation of reproductive, growth and recruitment patterns. For example, the exclusive distribution of recruits (age *ca.* 1 yr) at > 1000 m were linked to best food availability in sediments and higher near-bottom turbidity and O_2 concentration.
- Aggregation of small juveniles occurred both over the Catalan (mainland) and Balearic (insular) slopes (see Figure 7). So, near-bottom recruitment in the 1st year of live follows basically the same pattern all around the Balearic Basin. Also, reproductive animals migrate seasonally from upper part of canyons (500-600 m) to depths > 1000 m. All this movements indicates high short-term dynamims within the population, suggesting that we do not have distinct meta-populations of *A. antennatus* in the Balearic Basin.
- All these findings may contribute to the optimal management of *A. antennatus* fisheries, especially given an increasing tendency by the fleets to fish deeper, moving to depths where the species preferently are mating and spawning, over the lower slope.

References

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