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Estimating Secondary Production in the Deep-water Shrimp, *Aristeus antennatus* (Risso, 1816) in the Catalano-Balearic Basin (Western Mediterranean)

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Abstract

The red shrimp *Aristeus antennatus* (Decapoda: Aristeidae) is a dominant deep-water species in the mid-bathyal depths of the Catalano-Balearic Basin (western Mediterranean), where its bathymetric distribution extends to 2261 m. It is the main target species in deep-sea fisheries and it is captured by trawlers at depths between 400 and 800 m. In the northwestern Mediterranean annual catches of *A. antennatus* have risen to 200–300 tons and it is a species of a high commercial value. This study used a dataset of *A. antennatus* size-frequencies based on samplings performed in 1988 at two bathymetric zones from the Catalano-Balearic Basin: 1) a monthly sampling performed at mid-slope depths (450–800 m) and 2) a sampling performed at the lower slope (between 862–2 261 m) in 3 successive surveys from end of June, July and October. Two methods were used to estimate production and production/biomass of *A. antennatus*: 1) the weight-specific growth rate model based on growth parameters K and L_∞ deduced from the Von Bertalanffy model and, 2) the cohort-based (increment summation) method. The results obtained at different periods and depth ranges were compared between them and discussed in the context of the biological cycle of this species.

Key words: *Aristeus*, depth, deep-water, growth, length, Mediterranean, shrimp

Introduction

The red shrimp, *Aristeus antennatus* (Risso, 1816) (Decapoda: Aristeidae) is widely distributed at bathyal depths (200–1440 m) throughout the Mediterranean Sea and in the Atlantic Ocean from Cape Verde Islands to Portugal coasts (Zariquiey-Alvarez, 1968). The species has also been collected farther north in the Cantabrian Sea–Bay of Biscay (J. Cartes, personal observation: *Prestige-Plataforma 0403* cruise: 25 April 2003 off Santander). In the Catalano-Balearic Basin (western Mediterranean), *A. antennatus* is distributed on the slope between 450 m (Abelló *et al*., 1988) and 2 261 m depth (Cartes, 1993). This species also attains great depths in the Algerian basin (to 1714 m in the SW of the Balearic Islands: Maynou and Cartes, 2000).

Aristeus antennatus is a dominant species in the mid-bathyal depths of the Catalan Sea (western Mediterranean) where it is captured by bottom trawling at depths between 400 and 800 m. In the northwestern Mediterranean, *A. antennatus* is the main target species of the deep-sea fishery and it has a high commercial value. It has been exploited since the 1960s off the Iberian coast (Bas, 2002) with annual catches that rose to a maximum of 900 tons in 1974–75. Over a six year period (1984–89), results of length cohort (LCA) and virtual population analysis (VPA) suggested levels of exploitation for this species were close to the optimum (Demestre and Lleonart, 1993). Apart from its interest as fishery resource, *A. antennatus* is of considerable ecological interest with some apparently contradictory features in its biology such as: 1) the possession of planktotrophic larvae (being the first instar of the *nauplius* stage), and 2) a recruitment of early juveniles restricted, on the basis of the available data, to depths below 1000 m in the Catalan Sea area. This shrimp has a different size structure in the upper part of its distribution (to *ca.* 1000 m depth), where adult specimens, mainly females, dominate and below 1000 m where populations are mainly composed by juveniles and by males (Sardà and Cartes, 1993). Recruits are progressively more important at greater depths. A widely diversified diet mainly based on infaunal organisms (Cartes, 1994) and a high food consumption (Maynou and Cartes, 1997) are important features of the trophic ecology of *A. antennatus*.

Production (P) and production (P)/biomass (B) P/B ratios are important parameters in ecological studies related to the flux of energy through ecosystems. Also, estimates of *P* and *P/B* are especially important in species subjected to fishery exploitation, particularly in deep-sea ecosystems where food is considered to be the main limited factor. No previous attempts to calculate *P* and *P/B* have been made for this species, although growth parameters have been estimated (e.g. Demestre and Lleonart, 1993). Therefore, the objective of this study is to give first results on the production and *P/B* ratios at this deep-sea red shrimp.

Material and Methods

We used a dataset of *A. antennatus* size-frequencies based on sampling carried out in 1988 at two bathymetric zones in the Catalano-Balearic Basin (western Mediterranean) (Fig.1) for *P* and *P/B* calculations:

1) Middle slope (depth range: 450–800 m): monthly samplings performed off Blanes, a fishing ground situated around a submarine canyon, using commercial trawlers. A total of 17 740 individuals were measured (see details in Demestre and Lleonart, 1993). Populations were mainly composed of adult females at this depth level.

2) Lower slope (depth range: 862–2 261 m): three successive surveys performed at the end of June, mid-July and end of October, with a standardized deep-sea trawl OTSB-14 (Merrett and Marshall, 1981). A total of 1 901 specimens were measured (Sardà and Cartes, 1993). Populations were mainly composed of juveniles and adult males.

Two methods have been applied for production and *P/B* calculations:

1) the cohort-based (increment summation) method (Crisp, 1984) was applied to a fraction of the lower slope (between 1 500 and 2 200 m) population sampled between end of June and end of July. Natural mortality values were also calculated for the cohorts (subcohorts) deduced.

Limits between the three cohorts (1, 2 and 3) distinguished (see Figs. 2 and 3) were established with the help of the Battacharya method and also arbitrarily. In general, similar cohorts were distinguished by both procedures. The Battacharya method distinguished between the cohorts 1 and 2, whereas the cohort 3 were separated arbitrarily. Growth, production and mortalities were calculated for these 3 established cohorts.

2) the Crisp 3A model (1984) was applied to the middle slope and lower slope populations. According to this method, production (*P*) is

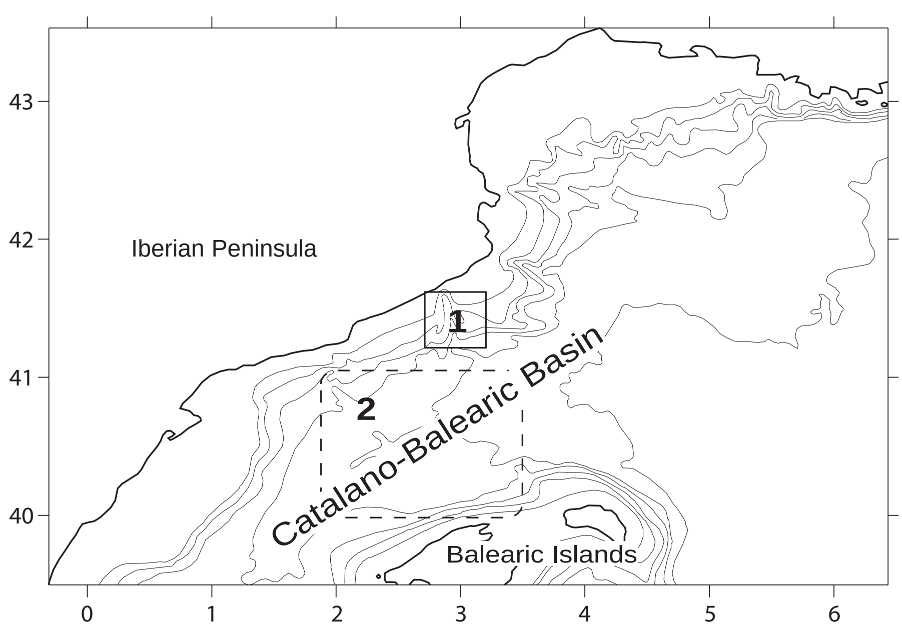

Fig. 1. Map of the study area indicating the two sampling areas (1) around the Blanes canyon and (2) at lower slope depths in the Catalano-Balearic Basin.

calculated using weight-specific growth rate (see also Brey *et al*., 1990):

$$P = \Sigma\, N_i \cdot w_i \cdot G_i \cdot \Delta t,$$

where N_i is the number of specimens in the i-th size-class, w_i is the mean individual weight, G_i the weight-specific growth in length of size-class i and Δt is the sampling period. This model requires a knowledge of the growth population parameters deduced from Von Bertalanffy model (Von Bertalanffy, 1934). For the population dwelling on the middle slope (males and females separately), these parameters were already available (Demestre and Lleonart, 1993). In addition, we calculated the growth parameters of the lower slope populations (without separating sexes) between June

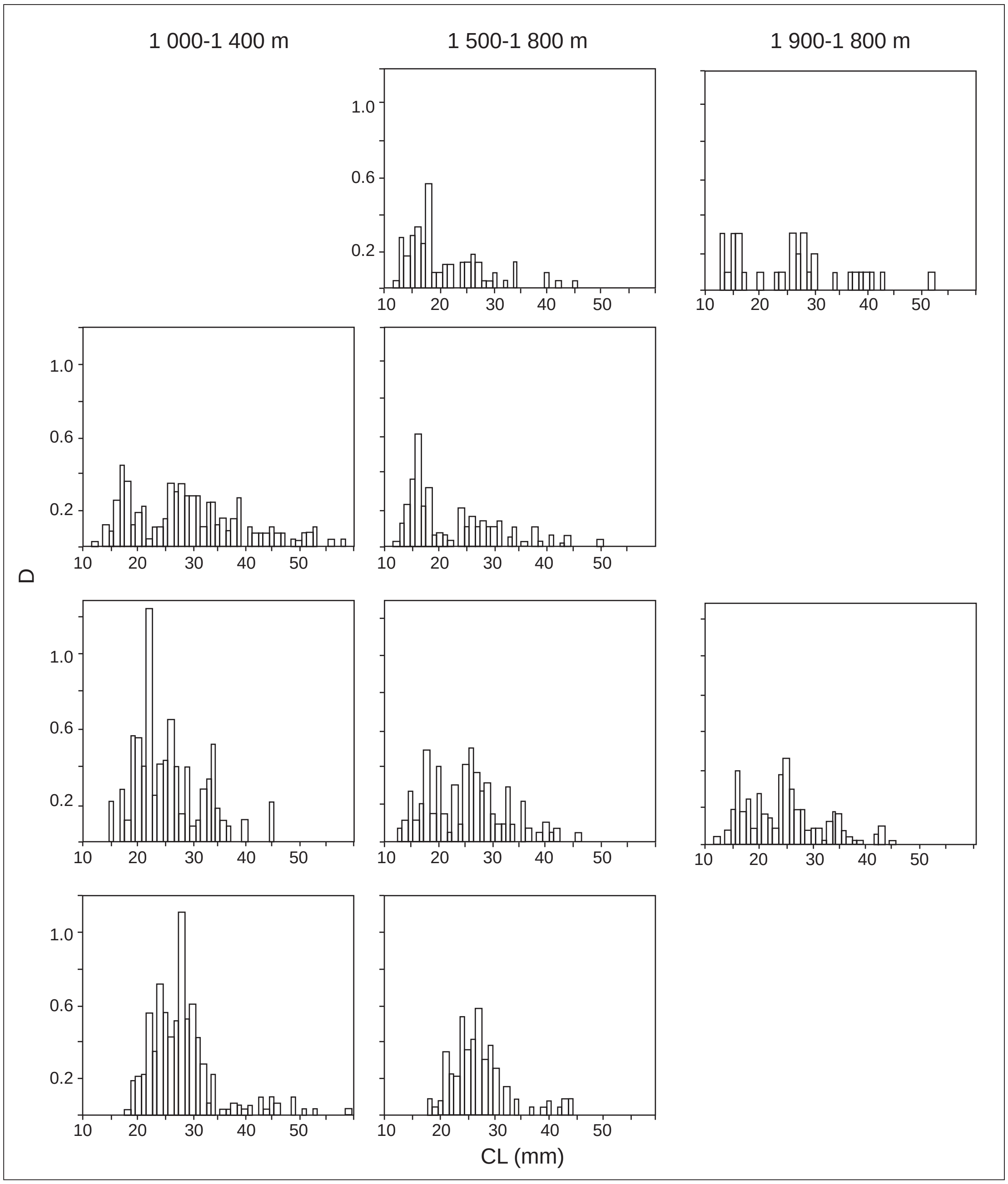

Fig. 2. Size structure of *Aristeus antennatus* on the lower part of its distribution. D: density (individuals/ha); CL: cephalotorax length.

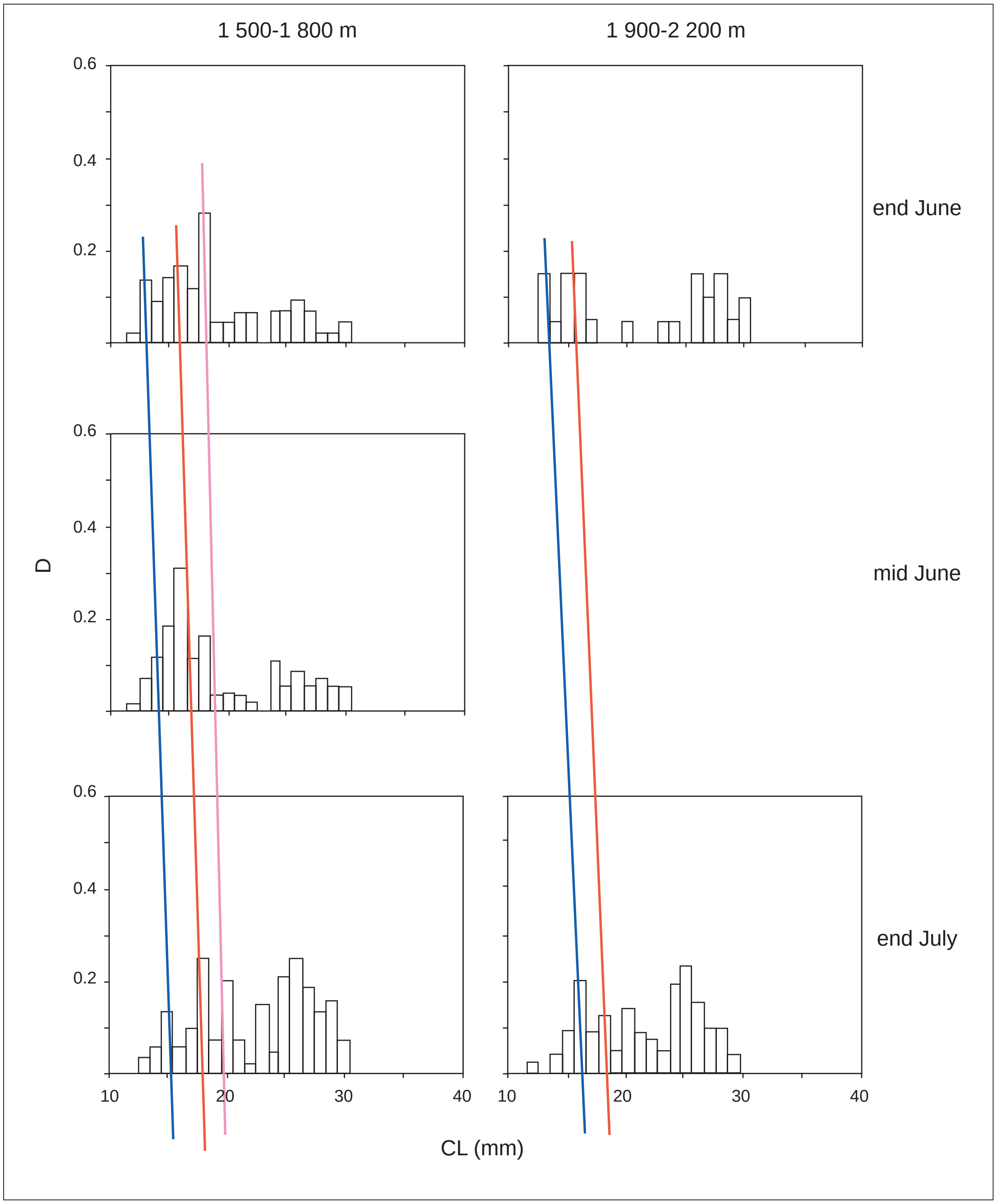

Fig. 3. Growth of cohorts between end of June and end of July in *Aristeus antennatus* collected below 1 500 m depth. D: density (individuals/ha); CL: cephalotorax length.

and July/October 1988 for 3 depth ranges 1 000–1 400 m, 1 500–1 800 m and 1 900–2 200 m.

Results and Discussion

Juveniles were progressively more abundant in the population with increasing depth (Fig. 2). Recruitment basically occurred at depths greater than 1400 m and no cohorts of small juveniles (cephalothorax length CL, <20 mm) were distinguished between 1 000 and 1 400 m. Above 20 mm CL, modal classes overlapped and it was not possible to identify new cohorts.

Growth of cohorts (Fig. 3). On the lower slope, between 1 500 and 1 800 m, the modal size of the smallest cohort (cohort 1) increased from CL 13 mm (end of June) to CL 15 mm (end of July). Cohort 2 increased from CL 16 1mm (end of June) to CL 18 mm (end of July) with density of size-class 16 increasing from end of June to mid-July. Finally, cohort 3 grew from CL 18 mm (end June) to CL 20 mm (end of July).

Between 1 900 and 2 200 m, where no mid July samples were available, cohort 1 modal size increased from CL 13 mm (end of June) to CL 16 mm (end of July), and cohort 2 grew from 15–16 mm (end of June) to 18 mm CL (end of July). Cohort 3 was missing from this level maybe due to migratory movements up the slope with increasing size.

Assuming this interpretation is correct, the growth of *A. antennatus* was found to be linear in June–July, with a cohort modal size increasing by *ca* 2 mm a month. Juveniles smaller than 17 mm CL were rarely captured on the upper-middle slope (to 1 000 m) in a previous seasonal study performed in the same area (codends used of *ca* 6 mm)(see Sardà and Cartes, 1997).

No recruitment of small juveniles (CL <18 mm) occurred in October. Demestre (1990) reported mature (mating) females between May and October in the present study area, with peaks of abundance of reproducing individuals in July–September. In view to the planktotrophic behaviour of the *A. antennatus* nauplius, it seems unlikely that the recruitment of early juveniles here reported at 1 400–2 200 m is a consequence of eggs released and larvae hatched in the same year (1988), but more likely about one year earlier. This period may also comprise embryonic development in the eggs because *A. antennatus* females do not retain eggs on their pleopods. The smallest individual of *A. antennatus* had a CL of 7 mm and it was captured in December (Sardà and Cartes, 1997) with a suprabenthic sledge, a sampling gear designed to catch the motile fauna living near the bottom (Cartes *et al*., 1994).

The growth parameters of *A. antennatus* living below 1 000 m depth are presented in Table 1. In general, the growth coefficient *K* was higher (between 0.32–0.38) than values obtained on the middle slope where the smallest size-classes were absent (see Demestre and Lleonart, 1993).

P and *P/B* ratios

On the upper-middle slope, the (annual) *P/B* ratios calculated for these populations were 0.38 for females and 0.58 for males. On the lower slope *P/B* (Crisp model 3A) ranged between 0.13 and 0.72 (Table 2), depending of depth range and the period of the *P/B* calculations. Both sexes were combined because of the rather low number of individuals collected.

The production (wet weight) of cohorts 1, 2 and 3 (Table 3) at 1 500–1 800 m oscillated between 0.104 g/ha (cohort 1) and 0.289 g/ha (cohort 3). At 1900–2200 m, *P* oscillated between 0.215 g/ha (cohort 1) and 0.384 g/ha (cohort 2). Comparing these results to those deduced on the basis of the Crisp 3A model (see Table 2), the cumulative production for cohorts 1–3 (0.672 g/ha at 1 500–1 800 m and 0.599 g/ha at 1 900–2 200 m) was below the production value calculated for the whole population using the growth instantaneous model, representing 30.1% and 41.4% of the whole production, respectively.

TABLE 1. Growth parameters for *Aristeus antennatus* deduced from the Von Bertalanffy model.

	K	L_∞ (mm)
500–800 m[1]		
females		
males	0.300.25	7654
1 000–1 400 m	0.35	71
1 500–1 800 m	0.32	70
1 900–2 200 m	0.38	73

[1] taken from Demestre and Lleonart (1993).

TABLE 2. Production (*P* in g/ha, wet weight) and production/biomass (*P/B*) ratios for *Aristeus antennatus* at the lower slope of the Catalano-Balearic Basin.

	P	*P/B*	*P*	*P/B*
	27 June–28 July		27 June–28 October	
1 000–1 400 m			15.768	0.45
1 500–1 800 m	2.228	0.16	10.544	0.72
1 900–2 200 m	1.447	0.13		

TABLE 3. Production (*P* in g/ha, wet weight) and production/biomass (*P/B*) ratios of the 3 cohorts of *Aristeus antennatus* identified on the lower slope of the Catalano-Balearic Basin (monthly values).

27June–28 July	*P*	*P/B*	*P*	*P/B*	*P*	*P/B*
	Cohort 1		Cohort 2		Cohort 3	
1 500–1 800 m	0.104	0.29	0.279	0.27	0.289	0.26
1 900–2 200 m	0.215	0.46	0.384	0.42		

The (monthly) *P/B* of cohorts 1–3 ranged between 0.26 and 0.29 at 1 500–1 800 m, and between 0.42 and 0.46 at 1 900–2 000 m (Table 2). These ratios were higher than values calculated for the whole population at the same bathymetric range: 0.16 and 0.13, respectively (Table 2). The (annual) *P/B* ratios calculated for the the upper-middle slope population (females: 0.38; males: 0.58) were, on average higher than those obtained for deeper populations, smaller in size.

***Mortality* (*M*)**. The mortality values were 0.016 (cohort 1), 0.019 (cohort 2), 0.106 (cohort 3) at 1 500–1 800 m, 0.127 (cohort 2) at 1 900–2 200 m (calculated for a 1 month period). However, these results must be treated with caution due to the apparent migration up the slope of small individuals as they grow. Also they are not annual, but monthly, mortality values. Annual *M* values presented by Demestre and Lleonart (1993) were 0.5–0.8 for the whole mid-slope population. However, the mortality values obtained here seem to be consistent with simultaneous observations on the feeding behaviour of potential predators of *A. antennatus* in the same area. *Aristeus antennatus* is an uncommon prey in stomach contents of deep fishes and large invertebrates (e.g. other decapods). The most important trophic contribution was found for the bony fish *Alepocephalus rostratus,* only accumulating a low 0.06 % IRI, the dietary index of relative importance (Carrasson, 1994).

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