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A review of biological patterns of the blue-red shrimp *Aristeus antennatus* in the Mediterranean Sea: a case study of the population of Antalya Bay, eastern Mediterranean Sea

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Summary: During three surveys between September 2009 and June 2011, a total of 20867 specimens of *A. antennatus* were caught from the 127 successful hauls with a total towing time of 219.5 h. Carapace length ranged between 12-61 mm for females (mean length, 35.8±8.2 mm) and 14-35 mm for males (24.8±3.4 mm). The two-way MANOVA shoved that depth had a significant effect on the abundance ($p<0.05$) and biomass ($p<0.01$) indices. However, season showed an insignificantly effect on both indices. The highest values of abundance and biomass were obtained in the depth stratum of 500 m. There was a statistically significant difference in the overall sex ratio from the expected 1:1 ($p<0.05$). The highest percentages of mature adult females (carapace length >27 mm) were recorded in June, July and August. The monthly gonadosomatic index of *A. antennatus* females changed seasonally, reaching a maximum value between July and August. The length-weight relationships in female and male specimens exhibited a strong negative allometry. The monthly length-frequency distributions showed that females of *A. antennatus* exhibited a maximum of six modal size groups per year. The recruitment of young-of-the-year took place mainly between January-April. The fishing mortality, reference point ($F_{0.1}$) of fisheries mortality and exploitation rate were 0.498 year^{-1}, 0.444 year^{-1} and 0.524 year^{-1}, respectively. The fishery activity and the biological aspects of *A. antennatus* in the Antalya Bay have a lot of common and non-common points with other areas of the Mediterranean Sea. The above-mentioned differences could be attributed to the different oceanographic and environmental parameters in the present study area.

Keywords: blue-red shrimp; *Aristeus antennatus*; Antalya Bay; Mediterranean; growth; mortality.

Revisión de las pautas biológicas de la gamba roja *Aristeus antennatus* a lo largo del Mediterráneo: comparación con un caso de estudio de la población de gamba de la bahía de Antalya en el Mediterráneo Oriental

Resumen: Se realizaron tres campañas de muestreo entre septiembre de 2009 y Junio de 2011 en el golfo de Antalya. En ellas se capturaron un total de 20867 ejemplares de *A. antennatus* a partir de 127 lances efectivos realizados en un total de 219.5 h. La longitud del caparazón de las hembras se mantuvo en un rango de 12-61 mm (media 35.8±8.2 mm), mientras que en los machos fue de 14-35 mm (media, 24.8±3.4 mm). La significación estadística entre la profundidad y los índices de abundancia y biomasa se testaron mediante una ANOVA de doble vía ($p<0.05$ y $p<0.01$, respectivamente); sin embargo, la estacionalidad no fue significativa para los mismos índices ($p<0.05$). Los mayores porcentajes de hembras maduras (CL>27 mm) se registraron entre junio y agosto; meses en los cuales también se observaron los máximos índices gonadosomáticos de estas hembras. En ambos sexos la relación talla-peso presentó una fuerte alometría negativa. La distribución de frecuencias de tallas mensuales señaló para las hembras seis modas por año. El reclutamiento anual se detectó entre enero y abril. La mortalidad por pesca y la tasa de explotación fueron de 0.498 año^{-1}, 0.444 año^{-1} y 0.524 año^{-1}, respectivamente para los tres períodos de muestreo. En el bahía de Antalya la actividad pesquera y los aspectos fundamentales de la biología de *A. antennatus* presentan una alta similitud con resultados obtenidos de otras poblaciones del Mediterráneo Central y Occidental. Las pocas diferencias que se destacan se atribuyen a las particulares condiciones oceanográficas y ambientales del área de estudio.

Palabras clave: gamba roja; *Aristeus antennatus*; bahía de Antalya; Mediterráneo; crecimiento; mortalidad.

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INTRODUCTION

The blue-red deep-water shrimp *Aristeus antennatus* Risso, 1816 (Penaeoidea: Aristeidae) is one of the most important species of the deep-water ecosystems in the Mediterranean Sea. It has been collected on the slope bottoms (40 m; Olguner and Deval 2013), extending down to a depth of least 3300 m (Sardà et al. 2004).

During the last 30 years a variety of aspects of the blue-red shrimp have been studied in detail mainly in the northwestern and central Mediterranean. These aspects include fishery (Demestre and Lleonart 1993, Cartes and Demestre 2003, Gorelli et al. 2016), biology (Orsi Relini and Relini 1998, García-Rodríguez 2003, Cartes et al. 2008), ecology (D'Onghia et al. 1997, Relini et al. 2000, D'Onghia et al. 2009), physiology (Puig et al. 2001) and genetics (Sardà et al. 2010, Roldán et al. 2009). In the eastern Mediterranean (eastern Ionian Sea), some studies have also been carried out in the ecology (Papaconstantinou and Kapiris 2001, Guillen et al. 2012), biology (Kapiris 2004, Kapiris and Thessalou-Legaki 2009) and fishery (Deval et al. 2009).

In the last 20 years, deep-water trawl fishery has been carried out off the Mediterranean coasts of Turkey to exploit both red shrimps (the giant red shrimp *Aristaemorpha foliacea* Risso, 1827 and *A. antennatus*) as target fishery species. Antalya Bay (NE Mediterranean) is one of the two major fishing areas in the region. In 2013, annual landings of red shrimps in Turkish seas were 1364 t (Anonymous 2013), but to our knowledge hitherto only one study (Deval et al. 2009) has been carried out. Therefore, the present work aims to contribute to the knowledge of the blue-red shrimp's distribution, abundance and biology using data obtained in the framework of the various projects which have been carried out in deep waters in Antalya Bay. More specifically, the purpose of the present work is to provide the first systematic scientific data regarding the size composition, depth distribution, growth, sex ratio and mortality rates of the blue-red=shrimp population in its most eastern part and to compare its biology with findings on other blue-red shrimp populations in exploited areas of the Mediterranean Sea. This information will be a useful tool for managing this valuable resource locally for its sustainable fishery and management.

MATERIALS AND METHODS

The present study was carried out in Antalya Bay, eastern Mediterranean (Fig. 1), within the framework of multidisciplinary projects. All samples were collected by the research vessel R/V *A kdeniz Su* (26 m length, 800 HP) at an average speed of 2.5 knot with a conventional commercial otter-trawl. Towing duration was between 1 and 5 hours according to the aim of the survey and to the ground-structure. The otter-trawl used, with a 600-meshes mouth opening, made of polyethylene, had a head-rope of 35 m and a cod-end made of a 44-mm diamond stretch mesh equipped with a polyamide cod-end cover with a 24-mm stretch mesh. The specimens of *A. antennatus* were collected during three surveys: (i) DEEP, in which monthly samples were caught between September 2009 and June 2010 at

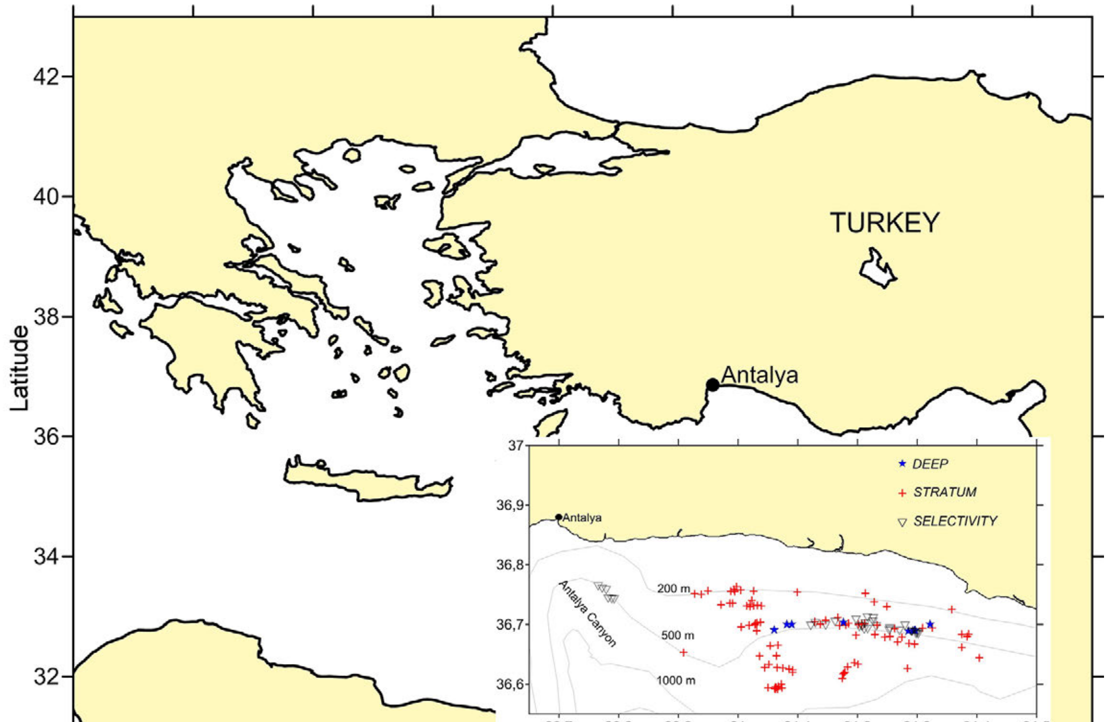

Fig. 1. – Bathymetry map of the study area in Antalya Bay. The positions of the hauls realized from 200 to 990 depth for three surveys.

depths of 400-560 m; (ii) STRATUM, in which hauls were carried out in eight bathymetric strata (100 m interval) at depths of 200-900 m on a monthly basis from July 2010 to June 2011; and (iii) SELECTIVITY, in which additional experimental fishing trials were carried out from 4 to 18 June 2011 at a depth of between 340 and 670 m. Only the data of the STRATUM survey were used for the spatial and temporal distribution of the species, because the other two surveys were carried out only in the commercial blue-red shrimp area and in their preferable depth range, according the bibliographical resources.

From the number (n) and weight (kg) of the individuals for the swept area, the abundance (n km^{-2}), biomass (kg km^{-2}) and CPUE (n h^{-1}) indices were estimated using the software AdriaMed Trawl Information System (ATrIS; Gramolini et al. 2005) per haul and stratum. The swept area was calculated according to the wing spread of the net (17.5 m) and the start-end points algorithm in ATrIS.

The sex of 4650 specimens from the DEEP survey and 2180 specimens from STRATUM survey was determined from the secondary sexual characteristics by macroscopic observations. Carapace length (CL) was measured to the nearest mm and the length-frequency standardized distributions (number of specimens standardized to a unit swept area, km^{-2}) were represented by sex, month and season. The similarity in the length-frequency between sexes was tested by Kolmogorov-Smirnov (K-S) test at p=0.05. Individuals smaller than 20 mm CL for both sexes and females bigger than 27 mm were considered as young-of-the-year and mature adults, respectively (Sardà et al. 2004). The abundance and proportion (%) indices were also estimated for each haul in which they were caught. Significant tendencies in abundance, biomass, proportion of mature adults and juveniles with depth were tested by a non-parametric correlation (Spearman) analysis. In order to evaluate the recruitment of *A. antennatus*, the percentage (%) of young-of-the-year in the total number of caught individuals was calculated for both the DEEP and STRATUM surveys._

One-Way ANOVA was used to test for preference differences of mean CL by sex between depth strata. Additionally, statistical differences were tested by non-parametric χ^2 and Kruskal-Wallis (K-W) tests. The sex ratio [F/(F+M)] was calculated for the whole population ant the χ^2 test was used to assess the predominance of the females.

The carapace length-weight relationships was estimated by the adjustment of an exponential curve ($W=aCL^b$) converted into its logarithmic expression ($\log W= \log a+b \log CL$), where W is wet weight, *a* is the intercept and *b* the slope. A Student t-test was applied to determine the significance of differences between the isometric growth (b=3) and estimated *b* value of the equation.

The maturity stages of the gonads from 425 female specimens were estimated between December 2009 and November 2010, according to the macroscopic colorimetric scale given by Levi and Vacchi (1988) and Kapiris and Thessalau-Legaki (2009). According to the above-mentioned methods, four stages of development were established on the basis of ovarian colour and size: flesh-coloured, immature, Stage I; light grey, maturing, Stage II; dark grey, early mature, Stage III; pale black, ripe, Stage IV. Recently spent individuals were separated from those belonging to Stage I (Stage V). For this purpose 40 female individuals (CL≥35 mm) from each month (if possible) were examined. Female specimens at Stage III and Stage IV were considered mature. The total weight (TW, g) and the gonad weight (GW, g) were measured to the nearest 0.0001 g. Seasonal variation in reproductive activity was assessed by inspecting the monthly variation in gonadosomatic index (GSI), which was estimated from 396 females of *A. antennatus* as [(GW/TW)×100].

Modal components in the female standardized length-frequency date were analysed with Bhattacharya's method by means of the FiSAT II software (Gayalino et al. 2002). Growth rate (Von Bertalanffy equation) was estimated by adjusting the growth curves to the age-size values obtained from the modal progression analysis of the frequency distribution of sizes of captured individuals. Bhattacharya's method, implemented in the FiSAT package, was used to identify and isolate the different normally distributed size groups in the polymodal length-frequency distribution of the females blue-red shrimp separately. The growth performance index φ′ (Pauly and Munro 1984) of the blue-red shrimp in the study area was estimated using the equation $\varphi'=\log_{10}K+2\log_{10}L_\infty$. Using the FiSAT II software, the instantaneous total mortality coefficient (Z) was estimated through the linearized length-converted catch curve method (Pauly 1990), while the instantaneous natural mortality coefficient (M) was estimated using the multiple regression model of Pauly (1980) (mean annual sea water temperature, 14°C). Additionally, using the Yield software (Branch et al. 2000) the coefficient of reference point of the fishing mortality ($F_{0.1}$) was also estimated. The exploitation ratio (E) was estimated as E=F/Z, where F is the fishing mortality (F=Z-M). Since the few males collected monthly did not allow us to identify cohorts through modal progression analysis, mortality rates and exploitation condition were only studied for females.

RESULTS

During the surveys, a total of 20867 specimens of *A. antennatus* were caught from the 127 successful hauls with a total trawling time of 219.5 h. The fishery data and other haul characteristics are given in Table 1.

Length structure and length-depth correlation

Temporal and spatial standardized length-frequency distributions of blue-red shrimp during the STRATUM surveys, by sex, are shown in Figures 2 and 3. The K-S test revealed the existence of a significant difference between standardized length-frequency distributions of the sex as a whole ($D_{obs.}$=0.673, $D_{crt.}$=0.019; p<0.05). The CL ranged between 12-61 mm for females

Table 1. – Abundance, biomass, catch per unit effort and haul characteristics of the three trawl surveys in Antalya Bay. Dr, depth range; Hn, number of hauls; TT, trawling time; LR, min-max length range of carapace; n, number of specimens caught; S_R, sex ratio; *, surveys carried out only in the commercial fishing area.

Survey	Date	Dr (m)	Hn	TT (h)	n	LR	S_R%	n km^{-2}±sd	kg km^{-2}±sd	n h^{-1}±sd
DEEP*	Sep 09-Jun 10	400-560	10	45.5	5319	12-60	76	1546±1591	21.9±19.8	118±112
STRATUM	July 10-Jun 11	200-990	87	121.0	2697	12-61	81	451±917	7.35±16.2	34±73
SELECTIVITY*	June 11	340-670	30	98.0	12851	14-60	-	2233±1955	35.0±31.0	151±134

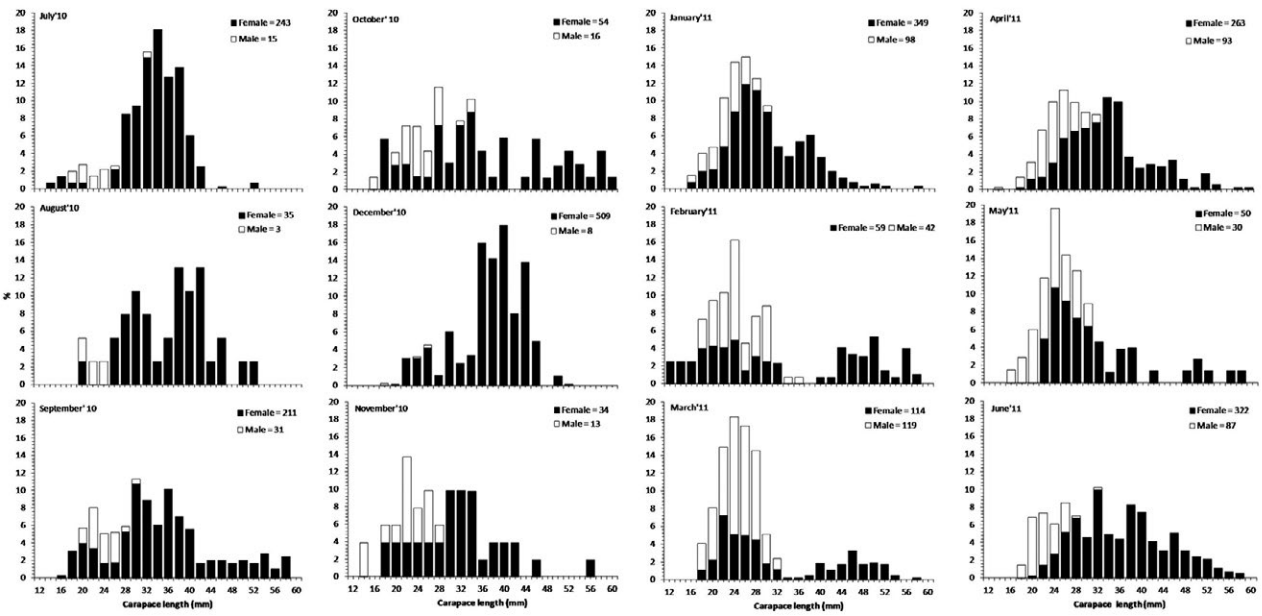

Fig. 2. – Monthly length-frequency standardized distributions by sex of *A. antennatus* caught during the STRATUM survey. Closed squares, females; open squares, males.

(mean= 35.8±8.2 mm) and 14-35 mm for males (mean =24.8±3.4 mm). There was a significant difference (t=2.18, p<0.05) in the CL between sexes.

No statistically significant relationship between mean CL and depth was detected in females. In contrast, a statistically significant decreasing trend with depth was detected in males (p<0.01)

Abundance-depth and biomass-depth indices

The D (n km^{-2}), BI (kg km^{-2}) and CPUE (n h^{-1}) indices calculated by single and pooled strata and by season obtained for *A. antennatus* caught during the STRATUM survey are reported in Table 2. The bathymetrical distribution of *A. antennatus* was limited and was present in 40 hauls of the total of 63 hauls carried out in strata deeper than 400 m (Fig. 4). The highest BI (15.2 kg km^{-2}) and D (993 n km^{-2}) were recorded at the 500 m stratum. The D value fluctuated between 4 and ~5122 n km^{-2} (mean=451±697), with most samples (89%) ranging less than 1000 n km^{-2} (Fig. 5A). BI values showed a similar pattern, varying between 0.01 and 101.1 kg km^{-2} (mean=7.3±16.2). The percentage of BI values less than 10 kg km^{-2} in hauls was 78%, and only in six hauls were the values higher than 20 kg km^{-2} (Fig. 5B). All the above indices showed the maximum values in winter.

The two-way MANOVA showed that depth had a significant effect on the D (p<0.05) and BI (p<0.01) indices. However, the season and interaction of season × depth showed an insignificant effect on both

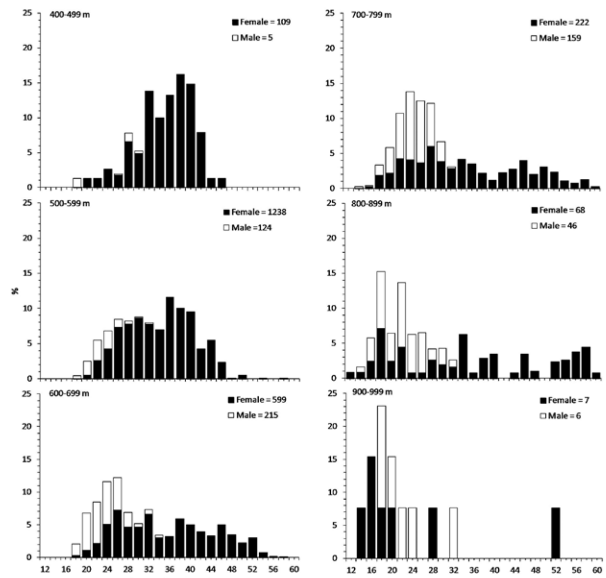

Fig. 3. – Length-frequency standardized distributions of *A. antennatus* caught during the STRATUM survey by depth strata. Closed squares, females; open squares, males.

indices (Table 3). Only a poorly positive significant trend (r=0.489) between strata and the D of the young females was detected (p<0.01). No statistically significant correlation between strata was observed for any of the other indices analysed (p>0.05) (Table 3).

The highest values of red shrimps catches were found in the red shrimp fishing grounds in the DEEP

Table 2. – Mean abundance (n km^{-2}), biomass (kg km^{-2}) and catch per unit effort (n h^{-1}) indices with standard deviation (sd) computed by strata and seasons for *A. antennatus* from the STRATUM survey. OH, occurrence in hauls.

	Hauls	OH (%)	n km^{-2}±sd	kg km^{-2}±sd	n h^{-1}±sd
Stratum (m)					
200	12	0	-	-	-
300	12	0	-	-	-
400	15	20	68±228	1.16±4.1	5±17
500	14	57	993±1678	15.20±29.6	77±137
600	14	93	484±583	8.92±12.7	34±40
700	12	75	417±549	6.59±8.7	30±39
800	7	87	228±81	4.01±5.3	15±15
900	1	100	152	0.82	11
400-900	63	63.5	451±917	7.35±16.2	34±73
Season					
Summer	16	56	467±844	8.80±15.8	32±56
Autumn	19	58	112±191	1.97±3.7	7±14
Winter	15	67	743±1471	11.7±26.8	59±124
Spring	13	75	594±751	8.3±10.6	43±56
	63	63.5	451±917	7.35±16.2	34±73

and SELECTIVITY surveys (p<0.01). (Table 1). The overall mean biomass (BI) and abundance (D) values were 21.9 kg km^{-2} and 1546 n km^{-2} for DEEP, and 35.0 kg km^{-2} and 2233 n km^{-2} for SELECTIVITY.

Sex ratio

There was a statistically significant difference in the overall sex ratio (0.81) from the expected 1:1 (χ^2=38.44. p<0.05). The monthly sex ratio showed a predominance of females during the year, ranging between 0.49 (March) and 0.98 (December). The sex ratio did not differ significantly from 1:1 in February and March (p>0.05). The proportion of females in the total catch by length classes showed a predominance of females for individuals ≥26 mm CL. Generally speaking, this ratio did not differ significantly from 1:1 in length classes between 14 and 25 mm CL (p>0.05).

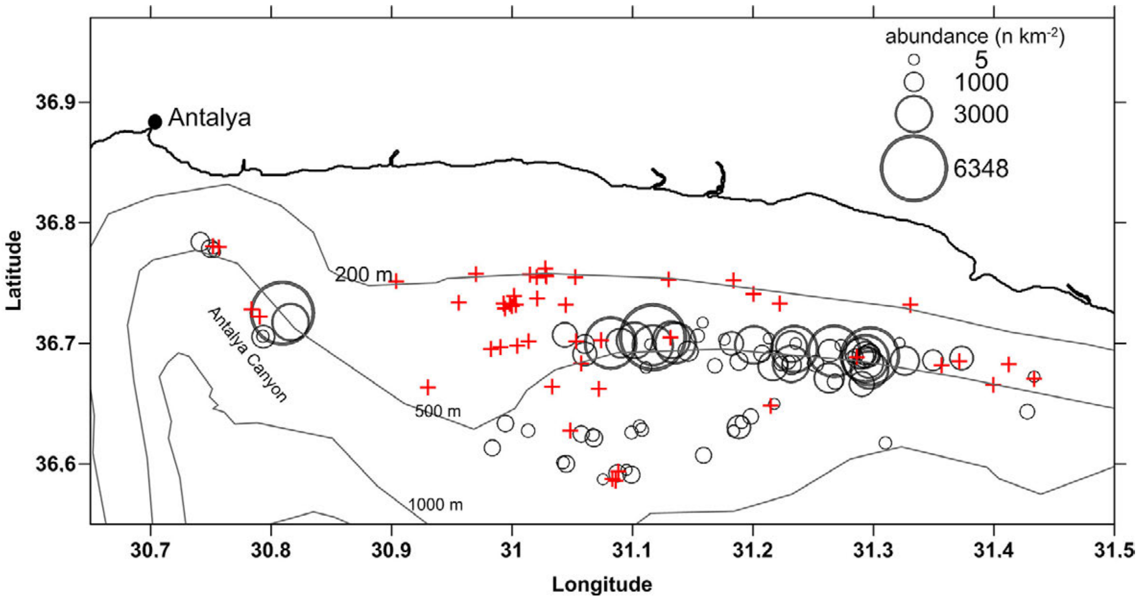

Fig. 4. – Overall abundance index of *A. antennatus* from all three surveys in Antalya Bay, (+, specimens were not sampled).

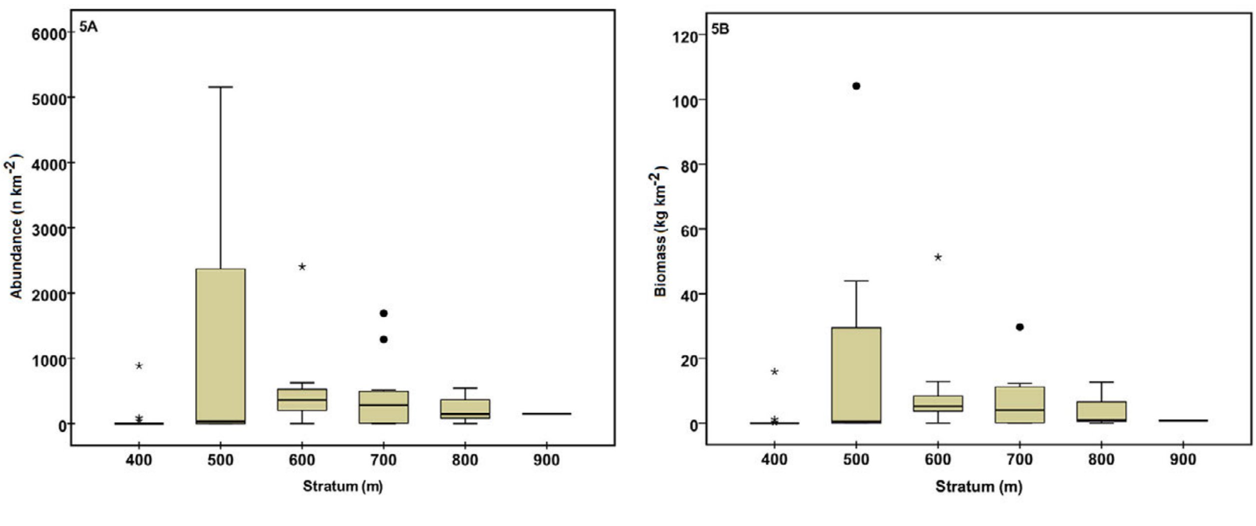

Fig. 5. – Box and whisker plot representations of the spatial variation of the abundance and biomass indices of *A. antennatus* from STRATUM surveys.

Table 3. – Results of the two-way MANOVA for significant testing in log-transformed abundance (n km^{-2}) and biomass (kg km^{-2}) of *A. antennatus* between strata and seasons; * p<0.05; ** p<0.01.

Source	Dependent variable	df	MS	F	Sig.	Tukey HSD
Stratum	log-abundance	5	6.374	5.396	**0.001****	400 *vs* 500;600;700
	log-biomass	5	0.844	3.209	**0.012***	and 800
Season	log-abundance	3	0.789	0.668	0.577	
	log-biomass	3	0.349	1.308	0.285	
Stratrum×Season	log-abundance	12	1.976	1.673	0.109	
	log-biomass	12	0.315	1.197	0.318	

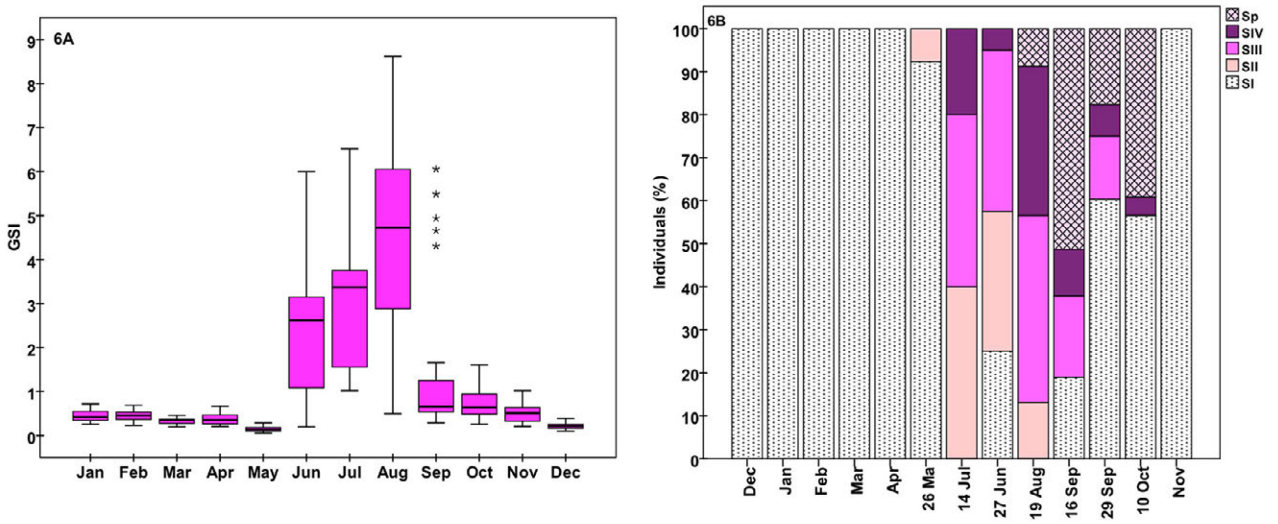

Fig. 6. – A, changes in gonadosomatic index (GSI) of standard size classes (CL≥35 mm). B, stages of gonad maturity per month of *A. antennatus* females caught during surveys in Antalya Bay.

The Kruskal-Wallis test showed statistically significant differences of percentage of females between seasons (χ^2=9.617; p<0.05) and strata (K-W test; χ^2=15.573; p<0.05). The proportion of the females ranged from 0.58 (spring) to 0.83 (autumn) and a significantly negative trend was observed (r=–0.553, n=38; p=0.000). The percentage of females was 93.5% at the highest stratum (400 m) and showed a decreasing trend to 53.8% at the deepest stratum (900 m).

Reproduction pattern

The stage of gonad maturity per month of *A. antennatus* females is presented in Figure 6. The monthly GSI changed seasonally and the maximum value was shown in August. From November to May, when the immature females predominated (St. I), the GSI remained stable (Fig. 6A). Ovarian maturation started at the end of May (St. II = 8%) and the first mature females (Sts. III and IV) were found in June (43%). Maximum presence of mature gonads showed a peak in August (60%) and decreased sharply during September (16 September, 30%; 29 September, 22%). The spawning occurred with a peak between August and September (Fig. 6B). The smallest female with mature gonads (in Stage III) measured 24 mm CL.

Length-weight relationship

Using the pooled data sets of 1240 specimens between 19 and 58 mm, a single regression equation covering the whole sampling period was produced for each sex separately. Females (t=47.869) and males (t=14.91) exhibited a similar performance, with a strong negative allometric growth:

$$\text{Females: } TW = 0.0035\times CL^{2.375} \quad r^2=0.987$$
$$\text{Males: } TW= 0.0026\times CL^{2.460} \quad r^2=0.894$$

Age and growth parameters

The monthly length-frequency distributions in combination with the results of the Bhattacharya method showed that females of *A. antennatus* exhibited a maximum of six modal size groups per year. The estimated growth parameters (CL_∞=64.7 mm, K=0.278 $year^{-1}$, t_0=–0.541 $year^{-1}$) were derived from the mean length-at-age estimation under a non-seasonal growth assumption. The mean CL per year in *A. antennatus* (females), using the parameters of the Von-Bertalanffy growth factor, was 21, 32, 40, 46, 50 and 54, respectively. The growth performance index of the female blue-red shrimp in the study area was calculated as φ′=3.073.

Recruitments

The maximum percentage of young-of-the-year (CL<20 mm) appeared mainly between January (4%) and April (2.5%). The percentage of recruits of the studied species was very low and this fact could be attributed to its wide depth range.

Mortality and status of exploitation

The natural (M) and total mortality (Z) values were estimated as 0.452 year^{-1} and 0.950 year^{-1}, respectively. The fishing mortality (F_{curr}), the reference point ($F_{0.1}$) of fishery mortality and the exploitation rate (E) were 0.498 year^{-1}, 0.444 year^{-1} and 0.524 year^{-1}, respectively. Since F_{cur} is slightly higher than 0.444, the stock of *A. antennatus* females in the Antalya Bay was considered in fully exploited status.

DISCUSSION

The results of the present study really improved the knowledge and the literature concerning the fishery and the biology of this ecologically and commercially important decapod, offering the latest data regarding its population in the Antalya Bay, eastern Mediterranean. Females showed a greater mean CL than males, indicating a size dimorphism. The measured CLs of both sexes in this study were similar to those of other surveys conducted in the Mediterranean Sea (Table 4).

It is worth noting that after an analytical research, Sardà (1989) reported that *A. antennatus* shows the highest CL values in the Ligurian Sea, medium values in the regions of Sicily, Sardinia and Catalonia and the smallest values along the coasts of Murcia and Algarve (Spain). According to this verification, the specimens caught in Antalya Bay are included in the medium category. These differences could be attributed to differences in the oceanographic and environmental conditions or to the genetic differences of populations, but neither of these hypotheses has yet been proven.

The population structure of this aristeid shrimp in the study area showed an increasing proportion of males and juveniles with depth, as has also been recorded in other deep-sea regions of the Mediterranean. In the Catalan Sea males predominated over females in depth zones below 1000 m and, accordingly, the younger individuals play a progressively more important role in the population with increasing depth in several Mediterranean areas (Sardà and Cartes 1993, D'Onghia et al. 1997).

There is a strong relationship between CL and the depth. An increase in the mean CL with depth has been observed in both sexes on the Spanish Mediterranean coast (Carbonell et al. 1999), in the Ligurian Sea (Orsi Relini and Relini 1998), and only for females on the continental shelf off Portugal (Figueiredo et al. 2001). On the other hand, Sardà and Cartes (1993) reported that the CL of this species showed a tendency to decrease rapidly with depth in the Catalan Sea, and the same pattern was also observed in the Greek Ionian Sea (Kapiris 2004).

The positive correlation between depth and the abundance of younger female individuals and their presence mainly in the deeper layers (500-900 m in the Antalya Bay) in the trawler fishing phase from winter (January) until early summer (April) reinforce our suggestion that there is a vertical distribution of the young-

Table 4. – Summary of biological parameters (L_∞, K and t_0), identified age groups by sex, mortality and length-weight relationships (*a* and *b*) of *A. antennatus* in various Mediterranean areas. M, natural mortality; Z, total mortality; NLS, Northern Ligurian Sea; TS, Tyrrhenian Sea; SS, Sardinian Sea; SSMI, South Sicily and Maltese Island; WI, Western Ionian; EI, Eastern Ionian; CM, Central Mediterranean; WM, western Mediterranean); *from Papaconstantinou and Kapiris (2001).

Area	References	Sex	CL (mm)	CL_∞ (mm)	K(year)	φ′	Age groups	M	Z	E	*a*	*b*
WM	Demestre and Lleonart 1993	F	15-63	76	0.30	3.23	5	0.50	-	-	0.004	2.32
		M	17-42	54	0.25	2.86	4	0.80	-	-	0.003	2.47
WM	Sardà and Demestre 1987	F	-	76	0.30	3.24	6	-	1.33	-	0.005	2.47
		M	-	54	0.29	2.93		0.41	1.46	-	0.004	2.32
WM	Carbonell et al. 1999*	F	-	73	0.36	3.32	-	0.54	-	-	-	-
		M	-	55	0.38	3.06	-	0.56	-	-	-	-
WM	García-Rodríguez and Esteban 1999	F	15-39	73	0.36	3.28	4	-	-	-	0.003	2.48
		M	15-37	55	0.38	3.06	-	-	-	-	0.002	2.42
WM	Gorelli et al. 2016	F	-	76	0.30	-	-	0.5	-	-	0.003	2.47
		M	-	54	0.25	-	-	0.8	-	-	0.004	2.31
NLS		F	13-67	68	0.23	3.04			0.50-1.49	0.31-0.72	-	-
		M	11-43	-	-	-			-	-	-	-
TS		F	15-65	66	0.24	3.02			0.60-1.10	0.42-0.58	0.005	2.28
		M	17-37	-	-	-			-	-	0.003	2.46
TS		F	19-70	67	0.24	3.03			0.35-1.94	0.66-0.79	0.003	2.39
		M	18-40	–	–	–			-	-	-	-
SS	Anonymous 2008	F	11-64	65	0.25	3.01	6	0.4	0.52-1.13	0.44-0.62	0.003	2.44
		M	13-39	–	–	–			-	-	0.002	2.45
SSMI		F	19-60	69	0.53	3.40			-	-	0.008	2.17
		M	18-40	–	–	–			-	-	0.013	2.01
WI		F	15-68	67	0.24	3.03			0.55-1.30	0.33-57	0.002	2.49
		M	15-42	-	-	-			-	-	0.003	2.46
EI		F	23-53	58	0.29	2.99			0.31-0.55	0.27	-	-
		M	25-32	-	-	-			-	-	-	-
Sicilia	Arculeo et al. 2011	F	15-59	69	0.65	-	4	-	-	-	-	-
		M	17-34	37	0.80	3.04	3	-	-	-	-	-
CM	Spedicato et al. 1995	F	-	67	0.60	3.43	5	-	-	-	0.002	2.48
Algeria	Mouffok et al. 2008	F	18-65	71	0.50	3.40	-	-	-	-	0.002	2.45
		M	16-41	43	0.30	2.70	-	-	-	-	0.002	2.46
EI	Papaconstantinou and Kapiris 2001	F	12-62	65	0.39	3.23	5	0.55-0.70	0.70	-	0.011	2.05
		M	9-45	58	0.43	3.16	4	0.62-0.79	0.79	-	0.010	2.05
Antalya	Present study	F	12-61	65	0.28	3.07	6	0.45	0.95	0.53	0.003	2.37
		M	14-35	-	-	-	-	-	-	-	0.003	2.46

Table 5. – Reproductive pattern of *A. antennatus* in various Mediterranean areas.

Area	References	Gonad maturation	Maximum presence
Murcia, Catalonian Sea	Martínez-Baños et al. 1990, Sardà and Demestre 1987	May-October	July
Ibiza Chanal	García-Rodríguez and Esteban 1999	May-September	June-September
Sardinia	Mura et al. 1992	June-October	July
Ligurian Sea	Orsi Relini and Relini 1979	July-December	July-September
Algeria	Mouffok et al. 2008	May-September	June- August
E. Ionian Sea	Papaconstantinou and Kapiris 2001	May-August	July-August
Antalya	Present study	June-September	August-September

er fraction of the population at depths inaccessible to commercial trawling, indicating that there is not a high exploitation for young blue-red shrimps. The presence of this part of the population in deeper layers allows us to suggest that a part of the spawning stock remains at the lower depths for several months. The same result has been also ascertained in the Catalan Sea (Demestre and Fortuño 1992). This presence will be very effective for the survival of the species in the study area, as in many other Mediterranean areas.

Aristeus antennatus is a eurybathic species with a known depth range of between 40 and 3300 m and high abundances around 700 m. The present study confirms the positive correlation between abundance, biomass values and depth strata of both sexes, as has been previously reported in other Mediterranean areas. Its distribution ranges from 100 to 1000 m in the Italian Ionian Sea (Relini et al. 2000), down to 800 in the eastern Ionian (Papaconstantinou and Kapiris 2001) and between 900 and 1000 m off Catalonia (Demestre and Martín 1993, Sardà et al. 1998, Tudela et al. 2003).

Depth affects the sex ratio of *A. antennatus*. At depths of 400-700 m females predominate over males (Martínez-Baños 1997, Tursi et al. 1996, Kapiris 2004), while at depths of 1000-3300 m the population is composed virtually exclusively of males in the Mediterranean Sea (Sardà et al. 2004). The known population structure of this shrimp species, with increasing proportions of males and juveniles with depth, has also been recorded in deep-sea regions of other areas of the Mediterranean. The fact that the sex ratio in the present study did not differ from 1:1 in February and March could be attributed to the increased mating period of this species in the eastern (Kapiris and Thessalou-Legaki 2009) and western part of the Mediterranean Sea (Carbonell et al. 2008).

The breading season was extended from late spring to early autumn in Antalya Bay, with a peak in August and September. The period of maximum presence of mature gonads for *A. antennatus* in Turkish waters (July-September) was prolonged in comparison with other studies of the central and western Mediterranean (June-August) (Mura et al. 1992, Sardà and Cartes 1993, Mouffok et al. 2008), but the present result coincides with the study of Orsi Relini and Relini (1979) in the Ligurian Sea (Table 5). The smallest mature female of *A. antennatus* (24 mm CL) in this study is between the range of the values obtained in the Catalan Sea (15.9-26 mm CL) (Demestre 1995), in the C. Tyrrhenian Sea (Papaconstantinou and Kapiris 2001) and in the N. Tyrrhenian Sea (Righini and Abella 1994), and lower than the smallest mature female found in the Greek Ionian Sea (Kapiris and Thessalou-Legaki 2009).

These are the first data on the length-weight relationship of the species in Antalya Bay and show a negative allometry ($b<3$) in both sexes of *A. antennatus*, particularly in females. This negative allometry has been previously reported in the western and central Mediterranean (Table 4). The b values of both sexes of *A. antennatus* obtained in the present study assume a similar robustness of the individuals caught between the study area and other Mediterranean areas.

The values of the Von Bertalanffy equation of the females in the Antalya Bay are very close to the values calculated for the central Mediterranean (from the northern Ligurian to Ionian Seas), suggesting that they show a high increase in growth in the study area (Table 4). The highest CL_∞ value for same species was estimated from the western Mediterranean studies (Martínez-Baños 1997, García-Rodríguez and Estebean 1999). Generally speaking, the values of the parameters of the Von-Bertalanffy growth factor equation support the view that growth is faster in females than in males (the higher the CL_∞, value, the lower the coefficient K, the greater the maximum life and the coefficient of performance of growth). Six age groups were determined for females of this species in the study area, taking account of the seasonal distributions of the CL. The majority of the age determined groups in the Mediterranean for females is between 4-6, although some studies (Orsi Relini and Relini 1998, Cau et al. 2002) appear to agree in attributing to the females of *A. antennatus* a slow growth and a long life span (6-10 years). The lack of a sufficient number of males from the samplings and, therefore, the difficulty of following age groups because of their slow growth lead us to be cautious about drawing conclusions about their age. According to data from the literature, the number of age groups of females obtained in this study is among the highest values estimated in the Mediterranean. This could be attributed to the range of CL of the specimens caught and the fishing effort carried out by the local fleet in the areas. The φ' estimated values for females ranged from 3.02 to 3.43 in the whole Mediterranean basin, highlighting a similarity of the growth of females among different areas (Table 4).

The estimated values of *A. antennatus* mortalities in the study area do not differ from other estimations obtained in other Mediterranean areas, despite the different level of fishery pressure exerted in these areas by the local populations (e.g. the Italian Ionian Sea and the NW Mediterranean) (Table 4). It is worth noting that the estimated values of M in the present study are lower than those estimated in the eastern Ionian Sea (Papaconstantinou and Kapiris 2001), where the stock is unexplored, although the total mortality in the eastern Ionian is significantly lower than in our area. The total mortality for both the MEDITS and the GRUND surveys fluctuated for all geographical sampling areas between 0.350 year^{-1} (southern Tyrrhenian Sea) and 1.490 year^{-1} (northern Ligurian Sea) for all years from 1994 to 2004 (Anonymous 2008). In the same surveys, high variation was observed in all the study areas, with the highest exploitation rates in the northern Ligurian Sea (0.39-0.72 year^{-1}), the Sardinian Sea (0.43-0.60 year^{-1}) and the central Tyrrhenian Sea (0.42-0.58 year^{-1}). Anonymous (2008) pointed out that exploitation rates higher than 0.3 to 0.4 represent an unsustainable exploitation condition. Fishery and biological data, such as growth, reproduction and mortality of *A. antennatus* in the Antalya Bay show many similarities, but also some dissimilarities, to those found in other areas of the Mediterranean Sea.

In conclusion, the admittedly small differences between the present and the previous studies could be attributed to the different hydrological conditions and environmental parameters in the various areas of the Mediterranean basin, as Sardà et al. (2004) also pointed out. This study could be considered as a scientifically valuable tool because it improves the scant knowledge and management of this recourse in the eastern Mediterranean and is the first attempt to cover the gaps in important scientific data in the whole Mediterranean basin. This economically and ecologically important species in the SE Mediterranean could become a target species with new potential for the local fisheries sector. For this reason, it is also recommended to improve the monitoring of landing and fishing effort and to increase knowledge on some poorly known aspects of the biology and population dynamics of this species, such as recruitment and seasonal movement. Many aspects need to be clarified through detailed studies in the future but the present data offer valuable information for fishery management aimed at achieving a sustainable exploitation of the blue-red shrimp.

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