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Population Dynamics and Biological Patterns of Commercial Crustacean Species in the Antalya Bay, Eastern Mediterranean Sea: III. The Giant Red Shrimp *Aristaeomorpha foliacea* Risso, 1827

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Abstract

Current study focuses on the population dynamic and pattern of the giant red shrimp *A. foliacea* as the third part of series on commercial crustaceans in the study area. Uni- and multi variate analysis on the spatio-temporal distributions of the density, biomass, reproduction pattern, age and growth parameters, mortality and the exploitation status of the stock of the species distributed in the area were evaluated. The highest average value of BI (79.9 kg km^{-2}) and D_{TOT} (5105 n km^{-2}), were estimated from the 500 m stratum. Mature individuals distributed in deeper than 400 m, and the recruits were available between 400-699 m depth. The gonadosomatic index of *A. foliacea* females showed a sharp increase between May and August, and the first maturation size (FMS) was estimated ≈ 39 mm (1.8 age). Examining the general pattern of the frequency distributions revealed maximum 3-year modes for males while females displayed 5-year modes. Since current level of fishing mortality (F_{cur}=0.848 year^{-1}) is higher than reference point ($F_{0.1}$=0.540 year^{-1}) and too close to F_{max} (=0.960 year^{-1}), the stock of *A. foliacea females* had a potential for the growth overfishing.

Introduction

Aristaeomorpha foliacea is a deep-water benthopelagic shrimp with a reported depth distribution range of 120-1300 m, population density of the species varies between 500 and 700 m (Politou, Kapiris, Maiorano, Capezzuto & Dokos, 2004). Although the species known to be distributed in the eastern and central Mediterranean basin, it is rarely present in the western Mediterranean (Palmas et al., 2014).

Fishing efforts targeting the red shrimps, *A. foliacea* and *Aristeus antennatus,* have increased in the last two decades in deep-water areas of the Mediterranean coasts of Turkey (Deval, Bök, Ateş & Tosunoğlu, 2009). Annual landings of these species reported to be 1382 tons in 2017 (Anonymous, 2018). According to Turkish Fisheries Regulations, no minimum landing size (MLS) is defined for these crustacean species, accept the annual fishing prohibition period between 15 April and 15 September for bottom trawlers (Anonymous, 2016).

There is quite comprehensive literature available on the *A. foliacea* in the central part of the Mediterranean on distribution, age and growth, (Yahiaoui, 1994; D'Onghia, Maiorano, Matarrese & Tursi, 1998; Cau et al., 2002; Papacostantinou & Kapiris, 2003; Politou et al., 2004), reproduction (Mura, Campisi & Cau, 1992; D'Onghia, Matarrese, Tursi & Maiorano, 1994; Belcari, Viva, Mori & De Ranieri, 2003; Ragonese et al., 2004; Kapiris & Thessalou-Legaki, 2009) and selectivity (Ragonese, Bianchini & Di Stefano, 2002; Carlucci, D'Onghia, Sion, Maiorano & Tursi, 2006). In the north Levant Sea, limited amount of available studies were focused on the morphometric relationship (Can & Aktaş, 2005), trophic ecology (Bayhan, Cartes & Fanelli, 2014) and selectivity (Deval et al., 2009; Deval, Özgen & Özbilgin, 2016)

The Mediterranean Sea is among the best-known seas of the world (Coll et al., 2010), but available knowledge on the biota of the bathyal grounds of its Levantine basin is limited, as only few deep-sea expeditions focused on the region in the past (Deval & Froglia, 2016). Recent scientific surveys on the trawling grounds of the continental slope (between 200 and 900 m) of the Antalya Bay, yielded very detailed information on the deep-sea commercial crustacean species in the Turkish coast of the Mediterranean Sea. Population dynamics of both the deep-water rose shrimp (*Parapenaeus longirostris*) and the blue-red shrimp (*A. antennatus*) have been already reported (Deval & Kapiris, 2016; Deval, Kaya & Olguner, 2019, article in progress). Herein, the population dynamic and pattern of the giant red shrimp *A. foliacea* is reported as the third paper of the series on commercial crustaceans in the area.

Material and Methods

Aristaeomorpha foliacea samples were collected throughout three bottom trawl surveys in the Antalya Bay; *i)* DEEP; conducted between October 2009 and June 2010 at depths of 400-560 m, *ii)* STRATUM; covers eight bathymetric strata between 200 and 900 m and carried out from July 2010 to June 2011, and *iii)* REPR; carried out in summer 2012, as previously described by Deval & Kapiris (2016), Deval, Yılmaz & Kapiris (2017), Deval, Kebapçıoğlu, Güven & Olguner (2018).

To identify the gonad development stages of *A. foliacea*, total weight (TW 0.1 g) and gonad weight (GW, 0.001 g) of 40 female individuals with CL ≥38 mm were evaluated monthly between October 2009 and November 2010 in accordance to the ICES report (2010).

Two different codends in nominal mesh sizes of 44 mm and knotted materials (polyethylene, Ø0.40x10) were used for a total of 16 hauls (9 hauls with 44 diamond mesh (44DM) and 7 hauls with 44 square mesh (44SM)).

Uni-and multi variate analysis on the spatio-temporal distributions of the density, biomass, reproduction pattern, age and growth parameters, mortality and the exploitation status of *A. foliacea* were carried out in concordance to the methodologies described by Deval & Kapiris (2016) and methods of the selectivity, nursery and spawning area mapping as described by Deval et al. (2018).

Results

During the DEEP and STRATUM surveys (two complete years), a total of 33 166 individuals of *A. foliacea* were sampled monthly with hauls carried out 1 to 5 hours (107 trawl operations with a total of 145.2 h) (Table 1). Biomass (BI, kg km^{-2}), catch per unit effort (CPUE, kg h^{-1}) and overall density (D_{TOT}, n km^{-2}) indices of *A. foliacea* were collected through the surveys and reported for every stratum in Table 1.

Monthly carapace length (CL, mm) standardized frequency distributions (SLFD) of both surveys were illustrated separately for each sex in Figure 1. While the CL of males ranged from 12 to 52 mm with a mean of 33.9 ±3.5 mm, females ranged from 13 to 65 mm, with a mean of 37.2 ±8.6 mm in the STRATUM survey. A statistical significant difference was detected for the mean carapace length (t=2.81, P<0.05) and length frequency distributions between sexes (Kolmogorov-Smirnov test, $D_{obs.}$ =6.852 > $D_{crt.}$ =0.0249; P<0.001). For the DEEP survey, the mean CL of males and females were 34.5±3.6 mm and 37.0±8.6 mm respectively. The SLFD's from the STRATUM survey illustrated separately for all depth zones in Figure 2. A statistically significant positive length-depth trend observed in both males (r=0.967, p< 0.01) and females (r=0.971, p< 0.01) (Figure 2).

A. foliacea was present in 53 hauls carried out in deeper than 400 m. D_{TOT} and BI indices fluctuated between 20 and ~11 000 n km^{-2}, and between 0.7 and 206.2 kg km^{-2}, respectively. About 88% of total biomass of *A. foliacea* was found between 500 and 600 m stratums (Table 1). Highest average value of BI (79.9 kg km^{-2}) and D_{TOT} (5105 n km^{-2}) were calculated for the samples collected from the 500 m stratum (Figure 3). Two-way MANOVA analyses revealed a significant effect of only depth on the D_{TOT}, BI and some other fractions (p<0.01, Table 2). However, no significant effect of season was detected on indices and fractions (P>0.05,). The overall average value of D_{TOT} and BI were 3979 n km^{-2} and 69.4 kg km^{-2} for DEEP and 3803 n km^{-2} and 71.5 kg km^{-2} for REEP surveys (Table 1).

The correlation analysis between density values (log X+1) of 116 sampled species from the STRATUM survey with *A. foliacea* indicated a positive correlation only for 12 species (Table 3). These results point out that *A. foliacea* shares its habitat mostly with these species.

The recruitment pattern of *A. foliacea* displayed difference annually for the following two sampling years. In the DEEP survey, first recruits of 2009 cohort (14-19 mm CL) was observed in December (0.6%) and after two months in February 2010 recruit group much more pronounced (3.4%). The mean CL of recruit group of female in February 2010 was 16.0 ±1.4 mm. In the fallowing months CL were 22.3 ±1.8 mm in April, 24.3±2.1 mm in May and 25.7 ±2.3 mm in July. The first recruit of the 2010 cohort observed relatively late in April 2011 (20.7 ±1.8 mm CL) in STRATUM survey. To identify the recruit fraction of the population in each haul, cut-off lengths (CL ≤32 mm for January, ≤30 mm for October and December, ≤28 mm for November and the cut-off length were stable ≤26 mm from February to September) were calculate by the analysis of the mean CL of the first modal groups. During the STRATUM

Table 1. Total density (D_{TOT}, n km^{-2}), biomass (BI, kg km^{-2}), Catch per Unit Effort (CPUE, kg h^{-1}), density of recruit (D_{REC}, n km^{-2}) and mature (D_{MAT}, n km^{-2}) indices with standard deviation (sd), and D_{REC}/D_{TOT} and D_{MAT}/D_{TOT} fractions by surveys for *A. foliacea* in the Antalya Bay. (DR: Depth range, Hn: Number of hauls, OH: Hauls in occurrence, TT: Trawling time, n: number of specimens caught, M: male, F: female, SR: sex ratio).

						Indices					Fractions			Mean CL (mm)	
Surveys	DR (m)	Hn	OH	TT	n	D_{TOT}	BI	CPUE	D_{REC}	D_{MAT}	D_{REC} / D_{TOT}	D_{MAT} / D_{TOT}	SR	M	F
DEEP	400-560	12	100	54.9	17 363	3979±2125	69.4±40.2	5.33±3.02	563±702	2233±1408	0.154	0.529	0.496	34.5±3.6	37.1±8.6
STRATUM	200	12	0	14.6	-	-	-	-	-	-	-	-	-	-	-
	300	12	0	12.6	-	-	-	-	-	-	-	-	-	-	-
	400	15	27	29.0	1 763	535±1017	6.2±11.7	0.46±0.9	119±293	63±174	0.054	0.035	0.500	29.2±2.8	35.1±5.9
	500	14	100	23.6	6 917	5105±4205	79.9±67.1	5.81±4.8	678±871	2583±2392	0.144	0.418	0.459	30.1±3.7	35.8±7.9
	600	14	100	24.8	6 399	3912±2974	72.7±50.5	5.32±3.8	416±881	2519±1808	0.105	0.688	0.464	31.6±3.0	40.6±8.8
	700	12	100	12.6	583	619±751	13.8±14.3	1.04±1.0	-	362±422	-	0.687	0.531	32.9±2.7	45.5±6.3
	800	7	100	7.3	136	267±282	8.6±8.3	0.58±0.6	-	259±281	-	0.848	0.572	34.5±2.5	48.6±5.3
	900	1	100	1.2	5	59	3.0	0.19	-	59	-	1.000	-	34	49.5±6.7
	Mean		83			2279±3180	39±52	2.85±3.8	272±642	1248±1829	0.070	0.495	0.489	33.9 ±4.3	37.2 ±8.7
REPR	450-650	8	100	19.3	5 952	3803±5696	71.5 ±98	-	-	-	-	-	-	34.2±4.3	41.4±9.3
	Σ=	107		145.2	39 118										

Table 2. Results of the two-way MANOVA and non-parametric Spearman's rho correlation analysis for significant testing in all biological indices and fractions (Total density (D_{TOT}, n km^{-2}), biomass (BI, kg km^{-2}), density of recruit (D_{REC}, n km^{-2}), male (D_M, n km^{-2}), female (D_F, n km^{-2}) and mature (D_{MAT}, n km^{-2}) and CPUE (kg h^{-1}) indices, D_{REC}/D_{TOT} and D_{MAT}/D_{TOT} fractions, Sex ratio (SR), mean carapace length (CL, mm) and body weight (TW, g) of *A. foliacea*, between strata and seasons. * are significant at the 0.01 level.

Variables		Two-Way MANOVA		Spearman's rho	
Independent	Dependent	F	p	r	p
Season	SR	1.091	0.303	0.175	0.267
	D_{TOT}	0.089	0.767	0.022	0.865
	BI	0.022	0.883	-0.029	0.819
	CPUE	0.113	0.739	-0.002	0.986
	D_M	0.007	0.933	-0.126	0.405
	D_F	0.232	0.633	-0.061	0.638
	D_{REC}	0.087	0.769	0.163	0.267
	D_{MAT}	0.049	0.826	-0.094	0.539
	D_{REC} / D_{TOT}	0.335	0.566	0.184	0.210
	D_{MAT} / D_{TOT}	2.413	0.129	-0.069	0.651
Stratum	SR	0.868	0.493	0.284	0.068
	D_{TOT}	5.549*	0.001*	0.065	0.614
	BI	4.820*	0.003*	0.134	0.294
	CPUE	4.814*	0.003*	0.127	0.320
	D_M	4.157*	0.007*	-0.596*	0.000*
	D_F	4.766*	0.004*	-0.106	0.409
	D_{REC}	1.671	0.179	-0.618*	0.000*
	D_{MAT}	4.228*	0.007*	-0.243	0.083
	D_{REC} / D_{TOT}	2.102	0.101	-0.655*	0.000*
	D_{MAT} / D_{TOT}	18.089*	0.000*	0.871*	0.000*
	CL_M	-	-	0.943*	0.005*
	CL_F	-	-	1.000*	0.000*

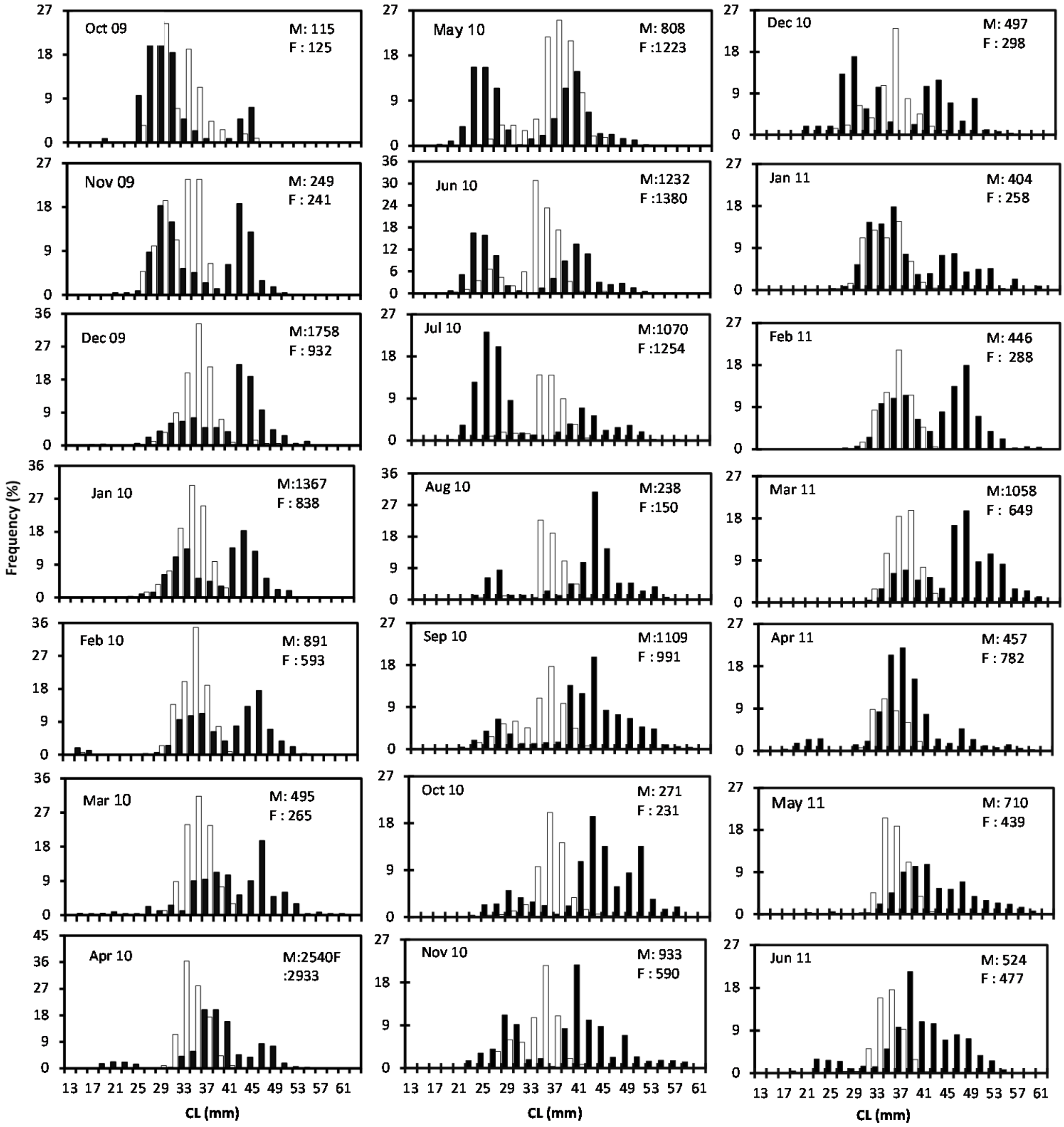

Figure 1. Monthly standardized carapace length-frequency distributions (SLFD) by sex of *A. foliacea* sampled during the DEEP (from October 09 to June 10) and STRATUM (from July 10 to June 11) surveys (Black histograms, female; White histograms, males).

survey, *A. foliacea* juveniles were collected from 26 of the 53 hauls and only 8.1% of the population were identified as juveniles. Density values of the recruits (D_{REC}) were between 13 and 3265 n km^{-2}. The recruits were available between 400-699 m depth, and %85 of them were located only at two stratums (500 and 600 m) (Figure 4a). The lowest mean D_{REC} values observed in March (243 n km^{-2}), highest value was observed in July (1441 n km^{-2}). Only for 5 hauls, D_{REC}/D_{TOT} fraction found to be higher than 0.30. For the DEEP survey, mean D_{REC} value was 563 n km^{-2} and 14.2% of the individuals was recruits (Table 1). While monthly differences found to be a factor impacting both D_{REC} ($F=2.266$, $p=0.038$) index and the D_{REC}/D_{TOT} fraction, season has no impact. Both D_{REC} ($r=-0.618$, $p=0.000$) and D_{REC}/D_{TOT} ($r=-0.655$, $p=0.000$) displayed a negative correlation with the depth stratum (Figure 4b; Table 2).

The mean sex ratios of *A. foliacea* for the DEEP and STRATUM surveys were 0.50 and 0.49, respectively, therefore the hypothesis of a 1:1 was accepted (χ^2= 0.160; $P>0.05$). Season and depth were not significant factors on the SR, and didn't displayed statistically significant correlation at the 0.05 level (Table 2).

The gonadosomatic index (GSI) of 550 *A. foliacea* females (mean CL=43.5 mm; min-max=38-59 mm) was evaluated through 14-month period (Figure 5a). A sharp

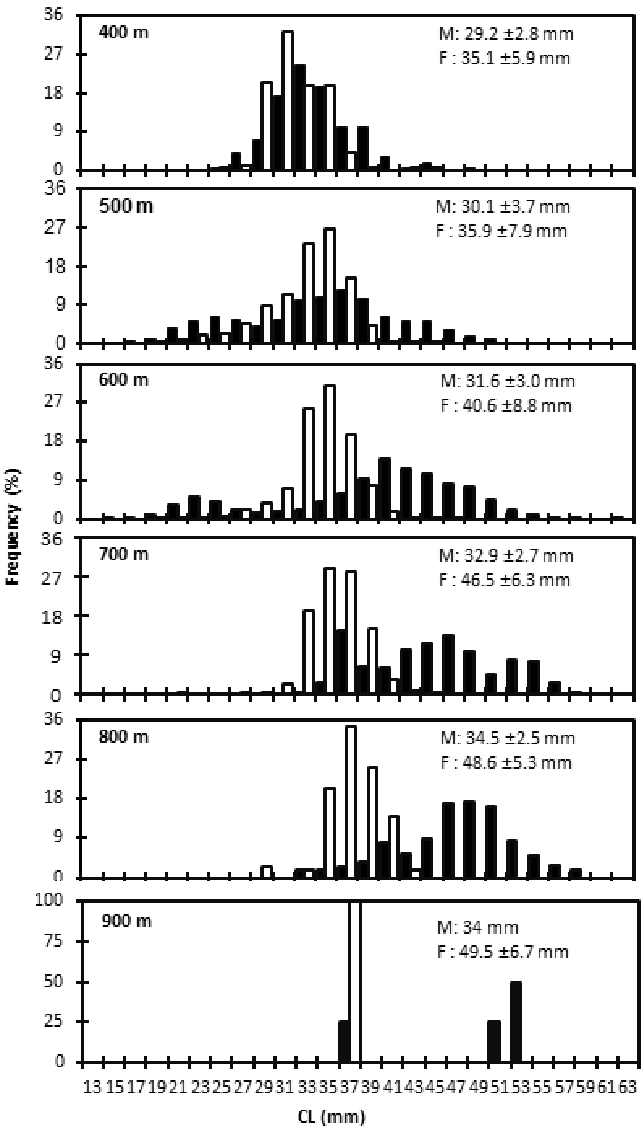

Figure 2. Standardized carapace length-frequency distributions (SLFD) of *A. foliacea* sampled from the STRATUM survey by depth strata (Black histograms, female; White histograms, males).

increase was observed in May this trend continued until August. The GSI value was decreased sharply in September until to the May. The spawning pattern of the females occurred as unimodal between June and August. Following the detection of first mature female (Stage III and IV) in June, data indicated that only 20% of females were remained immature (Stage I and II) in August. First appearance of the partially spent individuals was also in June (5.2%) and 43% of females were spent in August (Figure 5b). In the REPR survey (July-August), based on the proportion of fully mature gonads (stage III and IV) by every two mm size class in CL (between 22 and 62 mm), the first maturation size (FMS: carapace length at which 50% of the individuals is mature) was estimated 38.7≈ 39 mm (1.8 years old) for females (Figure 5c).

Mature female (CL≥38 mm) and male (CL≥34 mm) individuals of *A. foliacea* constitutes more than half (53%) of the total population in the Antalya Bay. Density of the mature individuals (pooled sex; D_{MAT}) and D_{MAT}/D_{TOT} fraction didn't display a temporal difference, however stratum had impact on both D_{MAT} (p=0.007) and D_{MAT}/D_{TOT} (p=0.000) indices (Table 2). Mature individuals distributed in all the depths ≥400 m with highest availability in both 500 and 600 m stratums (Table 1, Figure 4c). The D_{MAT} value displayed an insignificant negative correlation with depth (r=-0.243). However, a strongly positive correlation between D_{MAT}/D_{TOT} fraction and depth was detected (Table 2) and percentage of the mature reached to 85% at the 800 m depth (Figure 4d; Table 1).

Two methods (ELEFAN and Modal progression Analaysis) and two different computer package (LFDA 5.0: Kirkwood, Aukland & Zara, 2001 and FISAT II: Gayalino, Sparre & Pauly, 2002) were used to estimate the growth parameters and mortality rates (Table 4). According to the reproduction pattern of the *A. foliacea*, 1th of August was adopted conventional birthday in the

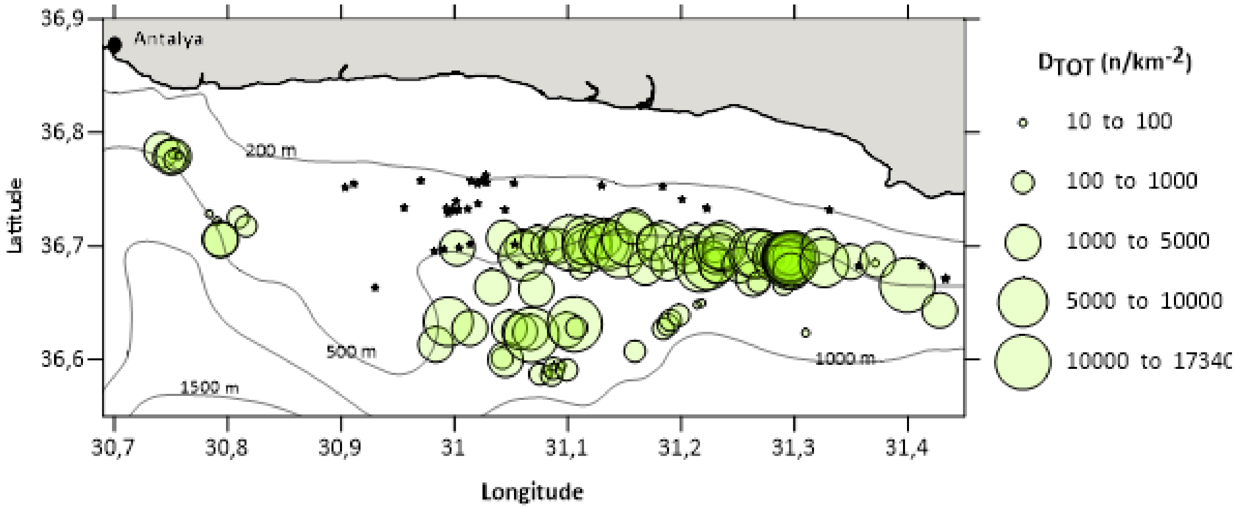

Figure 3. Overall density index of *A.foliacea* from all three surveys in Antalya Bay (*, empty haul).

Table 3. Correlated species with *A.foliacea* and their occurrence in hauls (%). Correlations are statistically significant at the p≤ 0.05 (*) and at the p≤ 0.01 (**) levels.

Class	Family	Species	Oc(%)	r	p
Crustacea	Polychelidae	*Polycheles typhlops* (Heller, 1862)	73	0.546**	0.000
	Aristeidae	*Aristeus antennatus* (Risso, 1816)	65	0.600**	0.000
	Pandalidae	*Plesionika martia* (A. Milne-Edwards, 1883)	56	0.667**	0.000
	Pandalidae	*Plesionika acanthonotus* (Smith, 1882)	25	0.398**	0.001
Actinopterygii	Macrouridae	*Nezumia aequalis* (Günther, 1878)	76	0.620**	0.000
	Trachichthyidae	*Hoplostethus mediterraneus* Cuvier, 1829	75	0.311*	0.013
	Myctophidae	*Lampanyctus crocodilus* (Risso, 1810)	62	0.428**	0.000
	Stomiidae	*Stomias boa* (Risso, 1810)	56	0.408**	0.001
	Nettastomatidae	*Nettastoma melanurum* (Rafinesque, 1810)	49	0.318*	0.011
Chondrichthyes	Etmopteridae	*Etmopterus spinax* (Linnaeus, 1758)	70	0.429**	0.000
	Centrophoridae	*Centrophorus granulosus* (Bloch & Schneider, 1801)	30	0.254*	0.045
Brachiopoda	Terebratulidae	*Gryphus vitreus* (Born, 1778)	71	0.285*	0.024

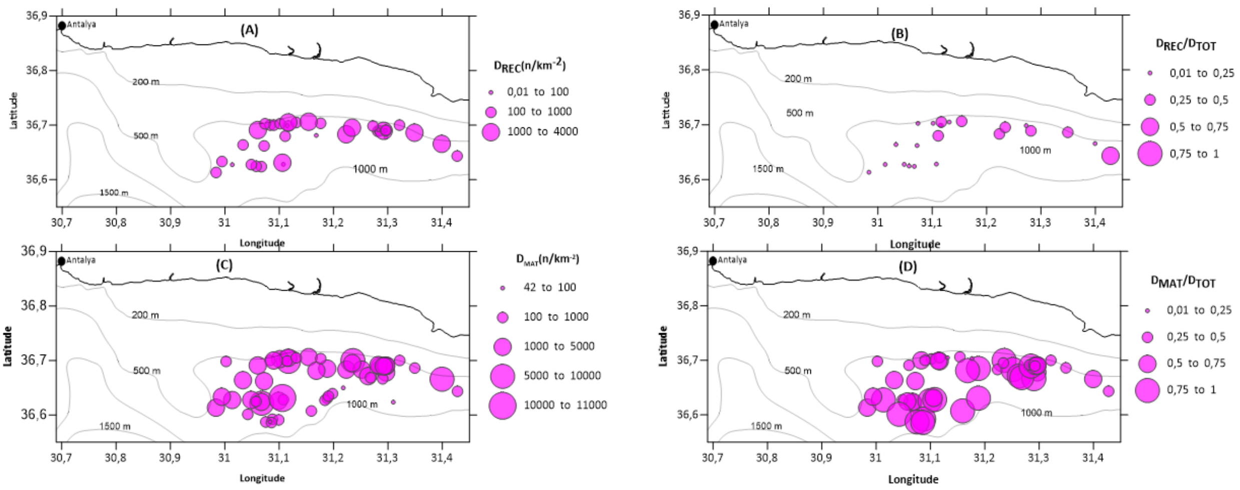

Figure 4. a) The recruit (D_{REC}) and (b) mature (D_{MAT}) indices, (c) recruitment (D_{REC}/D_{TOT}) and (d) mature (D_{REC}/D_{TOT}) fractions of *A. foliacea* from the STRATUM survey.

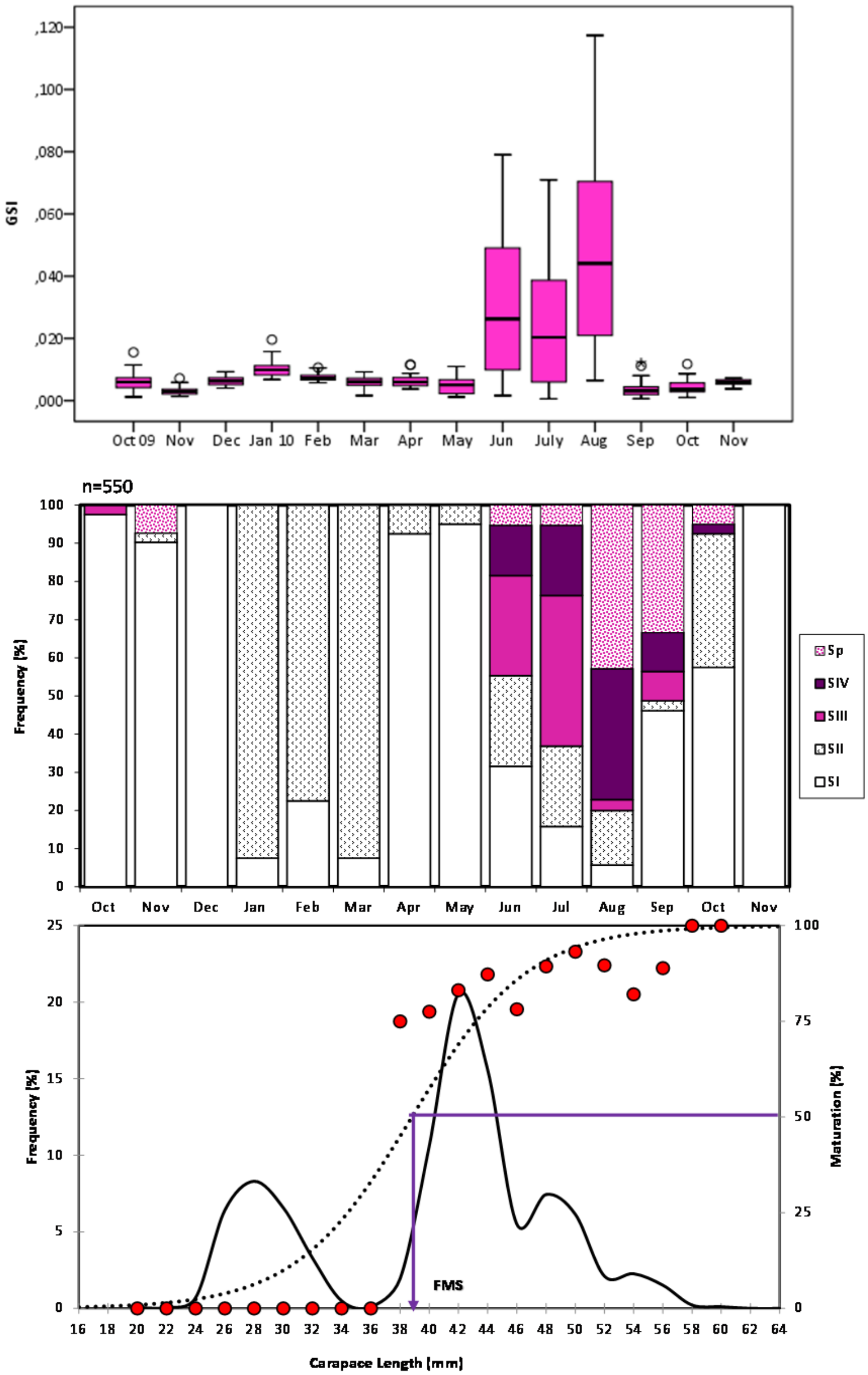

Figure 5. a)-Changes in GSI of standard size (CL ≥40 mm length) of female *A.foliacea*, **b)**-Monthly development in relative frequency of *A.foliacea* maturity stages, **c)**-The first maturation ($CL_{50\%}$) sizes for female specimens.

length-at-age key. Identification of the modal groups for females was easier than males. Examining the general pattern revealed maximum 3-year modes for males and 5-year modes for females displayed. As a result of low number of identifiable cohorts of males, exploitation and mortality were analyzed only for females. Mean CLs of the modal group of 5 cohorts of female *A. foliacea* were represented in Figure 6. Employing the parameters of growth functions, the CL attained by the female red shrimps at years 1-5 of its life span works out to be 28, 41, 49, 55 and 58 mm, respectively. The growth performance index ϕ of *A. foliacea* was calculated as

Table 4. The seasonal and non-seasonal growth curve parameters obtained for female *A. foliacea* by using ELEFAN and Modal progression Analysis (MPA) in two different software FISAT II and LFDA 5.0. (Parameters in the Von Bertalanffy growth equations (VBGF), **L_∞**: asymptotic length, K: curvature parameter, **t_0**: the "age" fish would have had at length zero if they had always grown according to the VBGF, **C**: parameter expressing the amplitude of seasonal growth oscillation in the VBGF, **t_s**: parameter of the seasonally oscillating version of the VBGF, **WP**: the time of the year when growth rate is slowest; equivalent to t_s + 0.5 year)

Software	FISAT II			LFDA 5.0		
Model	ELEFAN		MPA	ELEFAN		
Growth curve	Non-seasonal			Seasonal		
Survey	Deep	Stratum	Both	Deep	Stratum	Mean
L_∞	66.2	66.2	65.4	63.9	64.3	65.2
K	0.45	0.45	0.47	0.45	0.49	0.46
t_0	-	-	-0.10	-0.25	-0.23	-0.19
C	-	-	-	0.40	0.32	0.36
t_s	-	-	-	0.46	0.48	0.47

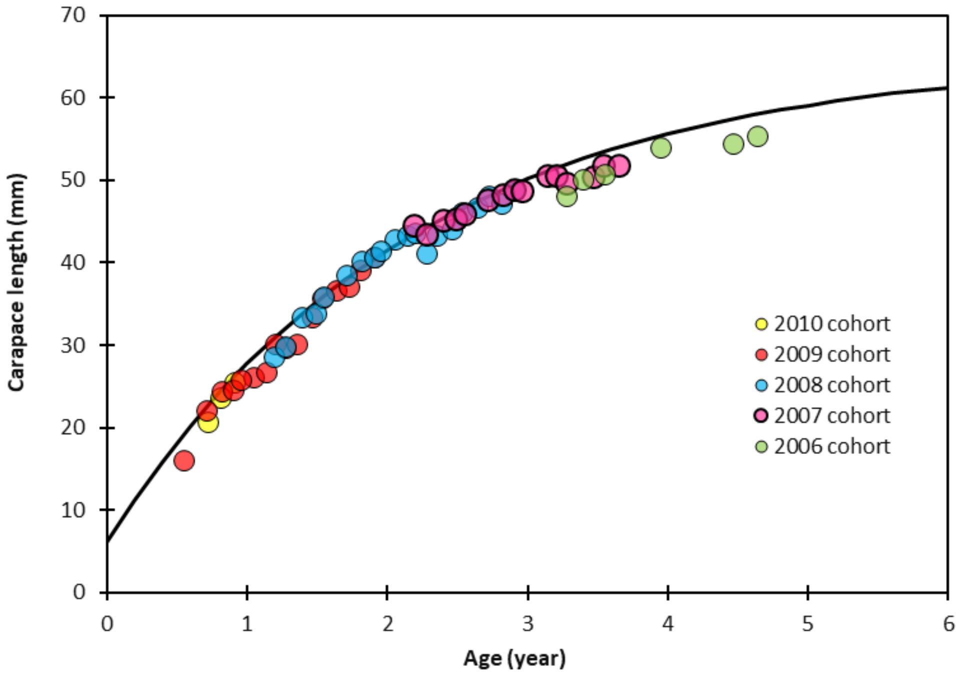

Figure 6. Five identified cohorts based on modal progression analysis and non-seasonal growth model for *A.foliacea* in the Antalya Bay.

3.299. Using the pooled data sets, males (t=14.91) and females (t=47.869) of *A. foliacea* exhibited a strong negative allometric growth:

Male: TW (g) =0.0014*CL (mm)$^{2.615}$ r^2=0.95

Female: TW (g) =0.0014*CL (mm)$^{2.583}$ r^2=0.95

Commercially available 44DM codend, retention was almost full (98.4%) and 78% of retained individuals were smaller than FMS (first maturity size) (Figure 7a). Even though retention of *A. foliacea* decreased from 98.4% to 86% after changing the diamond shaped codend with square shaped codend (44SM), most of the retained individuals (77%) were still smaller than FMS (Figure 7b). Moreover, an increase in CL_{50} (carapace length at which 50% of the catch is retained in the codend) from 18.8 to 22.2 mm. CL_{50} values estimated for both codends were much lower than first maturity size for *A. foliacea*. According to estimated CL_{50} and FMS values, the exploitation of the giant red shrimp begins in the first juvenile stage.

The total mortality (Z) was calculated as; 1.484 year^{-1} from Length Converted Catch Curve method (Pauly, 1984), 1.440 year^{-1} from Beverton-Holt method (Beverton & Holt, 1956) and 1.394 year^{-1} from Powell-Wetherall method (Powell, 1979) the with the algorithms integrated LFDA5.0 software. The natural mortality (M) (Pauly, 1980) calculated as 0.591 year^{-1}. An average Z value (1.439 year^{-1}) used for the further computations. The fishing mortality (F_{curr}=Z-M) and the exploitation ratio (E=F/Z) was estimated as 0.848 year^{-1}

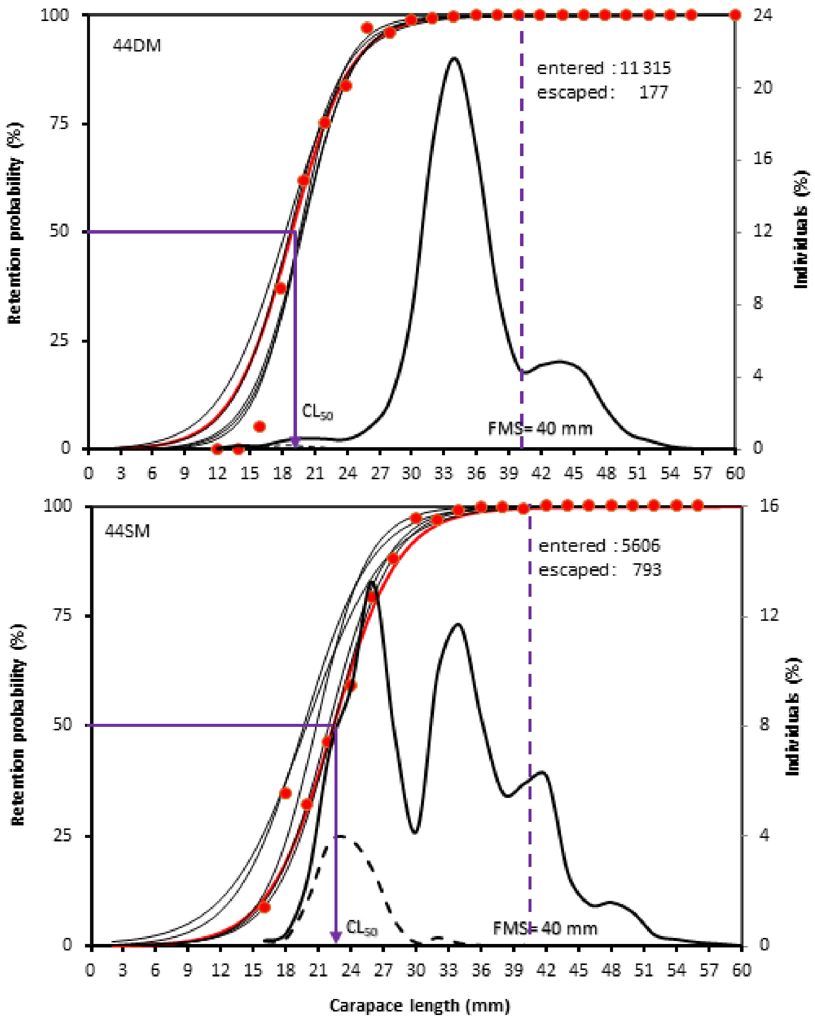

Figure 7. Selection curves with CL_{50} values for two codends, and carapace length frequency distributions of *A. foliacea* that entered (thick line) and escaped (broken line).

and 0.589 year^{-1} respectively. The coefficient of reference points of the fishing mortality was calculated as 0.540 year^{-1} for $F_{0.1}$, while the value was calculated as 0.960 year^{-1} for F_{max}, with the Yield software (Branch, Kirkwood, Nicholson, Lawlor & Zara, 2000). Since current level of fishing mortality (F_{cur}=0.848 year^{-1}) is higher than $F_{0.1}$ and too close to F_{max}, the stock of *A. foliacea females* was considered in fully exploited status in the Antalya Bay, and stock had a potential for the growth overfishing.

Discussion

Although stock status is well known for the giant red shrimp *A. foliacea* in western and central Mediterranean areas, there is a data gap in the Eastern Mediterranean. This study delivered detailed information on the biological patterns of the species from the most eastern part of the Mediterranean, and it provided data for a better comparison status of the stocks in the different parts of the Mediterranean.

The maximum CL of the giant red shrimp's females in the Mediterranean Sae reported as 74 mm at the Strait of Sicily and that of males 58 mm at Tyrrhenian and Aegean Seas (Cau et al., 2002), individuals sampled from the study area with in the current study were bigger than 66 mm and 52 mm (Table 5). Although in most of the studies carried out in the western and central Mediterranean, *A. foliacea* was reported to distribute intensely between 500 and 800 m (Table 5), moreover the species found also at the upper parts of the slope (201-500 m) (D'Onghia et al., 1994; Yahiaoui, 1994). In the present study the species was mostly caught in depth of 500-600 m. According to the Rinelli et al. (2013), based on the analysis of MEDITS surveys in seven Mediterranean Geographical Sub-Areas, the mean BI and D_{TOT} indices recorded for *A. foliacea* show the highest values in southern Sicily-Maltese Islands (24.5 kg km^{-2}), eastern Ionian Sea (20.1 kg km^{-2}) and the southern Tyrrhenian Sea (17.3 kg km^{-2}). The highest D_{TOT} value was recorded in the eastern Ionian Sea, (1408 n km^{-2}), followed by the southern Tyrrhenian Sea (1222 n km^{-2}) and southern Sicily-Maltese Islands (1021 n km^{-2}). A surprisingly high D_{TOT} and BI values (5000 n km^{-2} and 95 kg km^{-2} at 600 m depth stratum) were reported in the Eastern Ionian Sea (in null exploitation condition)

(Politou et al., 2004). Rinelli et al. (2013) indicated that "the results of MEDIT surveys allowed to conclude that there are no clear, evident gradients for the distribution and abundance of *A. foliacea* species". On the contrary, Cau et al. (2002) and Politou et al. (2004) observed "a longitudinal gradient of the space distribution of the *A. foliacea* was relatively more abundant in the central and easternmost part than the westernmost Mediterranean Sea". The estimated BI and D_{TOT} values (80 kg km^{-2} and 5100 n km^{-2}) indicated that there was an increasing abundance gradient at 500 m stratum, from the western to the eastern Mediterranean, of the species was confirmed with the present study.

In different parts of the Mediterranean Sea, the SR can vary between areas, depth and season, and have been reported between 0.73 in North Ligurian Sea (AAVV, 2008) and 0.46 in the South Aegean Sea (Cau et al., 2002). The SR value in Antalya Bay was 1:1 and within these limits.

Several species (Table 3) were identified as "plausible indicator species" of the giant-red shrimp habitat in the present study. Previously *A. antennatus*, *Polycheles typhlops*, *Hymenocephalus italicus* and *Etmopterus spinax* were also reported as a companion species to the *A. foliacea* within other studies (De Santis, S., Labate, Tursi, D'Onghia, & Maiorano, 1999; Righini & Abella, 1994; Sardà & Demestre, 1989) .

The reproductive period of female *A. foliacea* in the Antalya Bay (Figure 5a-b) was similar with available information on the species (Table 6), and in general, mature females can be found between May and September in different part of Mediterranean (Mura et al., 1992; Papaconstantinou & Kapiris, 2003). Mature specimens have been caught at depths between 440 to 800 m (Kapiris & Thessalou-Legaki, 2009; Palmas et al., 2014) in the Mediterranean Sea. The smallest mature female and first maturity size measured 33 mm (D'Onghia et al., 1998) and 36 mm (Mura et al., 1992), respectively. The estimated first maturity size (39 mm CL) in the Antalya Bay (Figure 5c) was very similar with D'Onghia et al. (1994) and Kapiris & Thessalou-Legaki (2009) (Table 6).

The recruitment of juveniles of *A. foliacea* occurs mostly between 400 and 600 m depth range in western and central Mediterranean (Mura et al., 1992; Ragoneze & Bianchini, 1995; Belcari et al., 2003; Ragonese et al., 2004) in spring when individuals have reached a carapace length between 8 mm (D'Onghia et al., 1998) and 31 mm (Ragonese et al., 1994). The recruits can be found in earlier months, as in the Tyrrhenian Sea and in Ionian Sea from January to March (D'Onghia et al., 1998). Based on MEDITS and GRUND surveys, the highest D_{REC} value was recorded in the Central Tyrrhenian Sea (1979 n km^{-2}) in while the lower values (1-91 n km^{-2}) was reporter from the northern Ligurian Sea. A positive trend was only observed in the Western Ionian Sea (37-870 n km^{-2}) (AAVV, 2008). In the Eastern Ionian Sea, the recruit juveniles were found during only six years (11-294 n km^{-2}). Most of the *A. foliacea* recruitment was found to be take placed from April to the August and more than 90% of recruits dwell at 500-600 stratums and undertake ontogenetic migrations to lower grounds (700-800 m) in the Antalya Bay. Recruit juveniles were never found areas deeper than 700 m.

Estimated Von Bertalanffy parameters of female *A. foliacea* (Figure 6) in the present study were generally similar to those presented previously in the literature in the Mediterranean Sea (Table 6). The highest CL_∞ was recorded in eastern Ionian Sea (74 mm, D'Onghia et al., 1994) and in the south Tyrrhenian Sea (73 mm; AAVV, 2008). In the south Aegean (Cau et al., 2002) and in the eastern Aegean Seas (AAVV, 2008) was reported smallest CL_∞ (62 mm) value. Generally, four and five age groups were identified (Table 6), with the exception of in Ionian Sea (AAVV, 2008; Papaconstantinou & Kapiris, 2003) where three age groups were detected. However, six age groups also reported in Algerian (Yahiaoui, 1994) and Sicilian waters (Cau et al., 2002).

The observed $CL_{\%50}$ values of both the commercial (19 mm) and alternative square mesh (22 mm) codends were smaller than first maturity size (39 mm) of the species (Figure 7a-b). FMS of the species known to range between 36 mm (Mura et al., 1992) and 43 mm (D'Onghia et al., 1998). Our results indicate that similar to the estimations of other studies, 16 mm (Carlucci et al., 2006) and 23.2 (Deval et al., 2016), carried out in the Mediterranean Sea, large amounts of juveniles were retained in codends.

According to the GRUND and MEDIT surveys (AAVV, 2008), Z values was fluctuated between 0.43 year^{-1} and 2.83 year^{-1} for different regions and annually. Observations indicated over exploitation of the stocks (E>0.5) in Tyrrhenian and in Sardinian Seas. With an exception of eastern Ionian Sea, status change from the full exploited to an overexploitation of the *A. foliacea* stocks is evident for the areas evaluated (the Western Ionian Sea, the South Sicily and Maltase islands) by similar studies. In the Eastern Ionian Sea, status of the *A. foliace* was reported as underexploited, since the fishing pressure was almost zero in the area (AAVV, 2008). In Mersin Bay, Demirci (2006) suggested a higher M and a lower exploitation (E) values probably using the higher surface water temperature (21 ^{0}C) instead of lover bottom temperature (14 ^{0}C).

In concussion, juvenile individuals of *A. foliacea* with no economic value in the Antalya Bay "is caught before reaching the maximum reproductive potential, similar with other regions of Mediterranean" (Belcari et al., 2003). The exploitation of the juvenile part of the stock before it has reached its full biological and economic potential, defined as growth overfishing (Diekert, 2015). Enforcing the increased legal mesh size (at present, 44 mm diamond) should be the first step of controlling the overfishing, for the benefit of both the fishermen and the marine environment. Also the results of previous selectivity study on *A. foliacea* carried out in the Antalya Bay indicated that, $\%_{50}$ retention CL were 22 and 23 mm for 50 mm diamond and 90^0 turned codends

MDD: depth of maximum density, SR: Sex ratio, M-CL: Maximum Carapace Length, AG: Age groups (M: natural mortality, Z: total mortality, E: Exploitation level, TS: Tyrrhenian Sea, SS: Sardinian Sea, SSMI: South Sicily and Maltese Island, IS: Ionian Sea, S-AS: South Aegean Sea, MB: Mersin Bay, AB: Antalya Bay)

Area	SD	MDD	D_{TOT}	BI	SR	Sex	M-CL	CL_∞	*K*(year)	t_0	ϕ'	AG	M	Z	E	a	b	References
Algeria	1979-88	400-600	-	-	-	♀	67	73	0.56	-	3.47	6	-	0.91	0.6-0.7	-	-	Yahiaoui, 1994
						♂	45	45	0.66	-	3.13	5	-	0.79	-	-	-	
TS	1994-04	500-800	1644	27.8	0.50	♀	71	72	0.44	-0.10	3.36	4	0.50	0.83-2.16	0.52-0.68	0.002	2.502	AAVV, 2008
						♂		45	0.66	-0.25	3.13		-	-	-	-	-	
SS	1994-99	500-800	-	20.9	0.66	♀	70	71	0.54	0.27	3.43	-	-	-	-	-	-	Cau et al., 2002
	1994-04	500-800	2359	37.8	0.53	♀	79	72	0.50	0.00	3.42	5	0.50	0.86-2.44	0.39-0.83	0.002	2.546	AAVV, 2008
SSMI	1990-93	500-700	-	-	-	♀	57	65	0.67	0.28	3.45	4	0.42	0.65-0.79	0.38	0.003	2.437	Ragonese et al. 1994b
					-	♂	39	41	0.96	0.28	3.21	5				0.001	2.948	
				21.1	0.55	♀	74	65	0.67	-	3.45	6	-	-	-	-	-	Cau et al., 2002
	1994-04	500-800	535	12.9	0.51	♀	74	62	0.65	0.05	3.40	5	0.50	0.47-1.24	0.02-0.56	0.002	2.507	AAVV, 2008
						♂	-	40	0.79	-0.44	3.11	4	-	-	-	-	-	
IS	-	-	-		-	♀	72	74	0.50	0.09	3.44	-	-	-	-	-	-	D'Onghia et al., 1994
	-	500-600	-	-	-	♀	62	64	0.46	-	3.27	3	-	-	-	-	-	Papaconstantinou and Kapiris, 2003
					-	♂	40	47	0.56	-	3.09	2	-	-	-	-	-	
	2001	600-800	1694	54.9	0.57	♀	62	67	0.37	-0.11	3.21	5	-	-	-	-	-	Politou et al. 2004
					0.43	♂	49	47	0.45	-0.42	3.00	3	-	-	-	-	-	
	1994-04	500-800	1051	13.5	0.54	♀	69	71	0.49	0.00	3.38	3	0.50	0.46-1.53	0.10-0.67	0.001	2.646	AAVV, 2008
			1408	20.1	0.52	♀	58	62	0.56	0.16	3.33	4	0.50	0.43-0.72	0.12-0.31	-	-	
					0.48	♂	-	46	0.34	-1.22	2.86	3	-	-	-	-	-	
S-AS	1994-99	500-800	451	12.7	0.46	♀	-	62	0.60	-0.34	3.36	-	-	-	-	-	-	Cau et al., 2002
MB	2005	400-800	-	67.3	0.67	♀	-	63	0.66	-0.47	3.42	4	0.94	1.373	0.31	1.039	2.330	Demirci, 2006
					0.33	♂	-	48	0.33	-0.59	2.88	3				1.378	2.022	
AB	2009-12	500-600	4508	76.3	0.49	♀	66	65	0.46	-0.19	3.29	5	0.59	1.439	0.59	0.0014	2.615	Present study
					0.51	♂	52	-	-	-	-	3	-	-	-	0.0014	2.583	

Table 6. Results of the two-way MANOVA and non-parametric Spearman's rho correlation analysis for significant testing in all biological indices and fractions (Total density (D_{TOT}, n km^{-2}), biomass (BI, kg km^{-2}), density of recruit (D_{REC}, n km^{-2}), male (D_M, n km^{-2}), female (D_F, n km^{-2}) and mature (D_{MAT}, n km^{-2}) and CPUE (kg h^{-1}) indices, D_{REC}/D_{TOT} and D_{MAT}/D_{TOT} fractions, Sex ratio (SR), mean carapace length (CL, mm) and body weight (TW, g) of *A. foliacea*, between strata and seasons. * are significant at the 0.01 level.

Area	References	Spawning season	SMF (mm)	CL_{50}	Recruitment
Sardinia waters	Mura et al., 1992	-	-	36	Spring
Central Tyrrhenian Sea	Belcari et al., 2003	July-September	-	41	Spring
Strait of Sicily	Ragoneze and Bianchini,1995	Spring-Summer	-	40	Spring
Strait of Sicily	Ragonese et al., 2004	-	-	42	Spring
Western Ionian Sea	D'Onghia et al., 1998	-	33	43	Spring
Ionian Sea	D'Onghia et al., 1994	-	35	39	-
Eastern Ionian Sea	Kapiris and Thessalou-Legaki, 2009	June-August	-	39	-
Antalya Bay	This study	June-August		39	April-July

and they were also lower than FMS (Deval et al., 2016). Since codend selectivity could not be the solution, my recommendation is to combine three types of control measures (effort controls, catch quotas and area closures) proposed by Stefansson & Rosenberg (2005) for the deep-water fisheries management.

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