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Bathymetric Distribution, Seasonal Growth and Mortality of the Deep-Water Rose Shrimp *Parapenaeus longirostris* (Decapoda: Penaeidae) in an Unexploited Stock in Saros Bay, Aegean Sea

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Abstract: To describe the growth, mortality and distribution pattern of the deep-water rose shrimp, *Parapenaeus longirostris* in an unexploited resource, 301 trawl surveys were conducted between 20 and 465 m water depths from February 2005 to September 2008 in Saros Bay, Aegean Sea. *Bathymetrical biomass* distribution of the deep-water rose shrimp shown a clear tendency towards the deeper waters with highest biomass estimations exceeding 50 kg h⁻¹ obtained in water depths between 201 and 300 m. Von Bertalanffy Growth (VBG) parameters were estimated from monthly Carapace Length (CL) frequency distribution data using three different methods: ELEFAN, PROJMAT and SLCA. For the data of this study, the seasonal VBG parameters obtained from ELEFAN was considered to best describe the growth pattern and were estimated as $L_{\infty} = 34.7$ mm, $K = 1.05$ year⁻¹, $t_0 = -0.95$ year, $WP = 0.87$ (i.e., November) and $C = 0.47$ for females and as $L_{\infty} = 27.0$ mm, $K = 1.49$ year⁻¹, $t_0 = -0.88$ year, $WP = 0.35$ (i.e., May), $C = 0.53$ for males. Growth performance index (Φ') was higher in females ($\Phi' = 3.10$) than males ($\Phi' = 3.03$). Instantaneous annual mortality rates (Z), assumed to represent annual natural Mortality rate (M), ranged between 1.19 and 4.73 year⁻¹ for females and between 0.88 and 3.51 year⁻¹ for males, depending on the method used for the estimation. The mortality rates estimated with the Seasonal Length Converted Catch Curve (SLCCC) method was the most appropriate one for the Saros Bay stock and was estimated as 1.72 year⁻¹ for females and as 1.82 year⁻¹ for males.

Key words: Distribution, growth, mortality, *Parapenaeus longirostris*, ELEFAN, PROJMAT, SLCA

INTRODUCTION

The deep-water rose shrimp *Parapenaeus longirostris* is distributed in the West Atlantic, from Massachusetts, USA to French Guiana and in the East Atlantic, from Portugal to Namibia and in the entire Mediterranean including Marmara Sea (Holthuis, 1980; Kocatas, 1981; Bianchi *et al.*, 1999).

The deep-water rose shrimp is a commercially important shrimp species in many countries with total catches for the last decade (1998-2007) of 75926 m in Italy, 37894 m in Spain and about 15000 m in Senagal, Algeria Angola in Turkey, a total catch of 2761 m was reported for 2007. Unexploited shrimp populations are relatively rare but could provide valuable information regarding life history patterns (e.g., migration and distribution) and biological characteristics (e.g., growth and mortality). These information could be then used as reference points for management of the exploited stocks.

Seasonal growth pattern was reported for different shrimp and prawn species (Oh *et al.*, 1999; Cha *et al.*, 2002; Ye *et al.*, 2003; Bilgin *et al.*, 2009a, b). This growth

pattern may differ between species and between sexes. Although, growth of deep-water rose shrimp was investigated for different populations in the Atlantic Ocean (Ribeiro-Cascalho and Arrobas, 1987) and in the Mediterranean Sea (Ardizzone *et al.*, 1990; Garcia-Rodriguez *et al.*, 2009; Guijarro *et al.*, 2009), no seasonal growth pattern was studied for this species for sexes differentiated.

Mortality rate is not only one of the most important parameter for fisheries management but also one of the most difficult one to estimate. Total instantaneous mortality rate for the deep-water rose shrimp was estimated using length converted catch curve analysis without differentiating sexes (Levi *et al.*, 1995; Abello *et al.*, 2002a; Deval *et al.*, 2006). Natural mortality rate for this species was estimated using Pauly (1980) empirical equation for exploited stocks in the South cost of Portugal (Ribeiro-Cascalho and Arrobas, 1987) and Marmara Sea, Turkey (Deval *et al.*, 2006).

The main purpose of this study was threefold: the first one was to analyze Bathymetrical distribution of the deep-water rose shrimp in Saros Bay; the second one was

to investigate and compare seasonal and non-seasonal growth patterns for females and males by using different algorithms namely ELEFAN, PROJMAT and SLCA applied to length frequency data; the third one was to provide reliable natural mortality estimations by using different methods for the unexploited shrimp stock.

MATERIALS AND METHODS

Study area and sampling: Deep-water rose shrimp samples were obtained from a trawl survey conducted between February 2005 and September 2008 in Saros Bay, Aegean Sea (Fig. 1). Although, Saros Bay is closed to commercial trawl fisheries, the survey was conducted with a special permit using a hired commercial trawl boat equipped with a trawl of 44 mm stretched mesh size at the cod-end. A total of 301 surveys were performed in 45 min durations at mean speeds of 2.7 knot. Mean water depths of the surveyed area, measured using an ecosounder, ranged between 20 and 465 m. Starting and ending coordinates of the surveys were recorded by a GPS and the average of the coordinates was assumed to provide the midpoint of the operation. Conductivity and

temperature were recorded at 5 min intervals using a data logger (DST CTD, produced by Star Oddi, Reykjavik, Iceland) attached to the wing of the trawl for the period between November 2006 and March 2008.

Shrimps were weighed on board for biomass estimations and subsamples were taken to the laboratory for length and weight measurements. Carapace Length (CL) was measured as the shortest distance from the orbital edge to the mid-dorsal posterior margin of the carapace using vernier calipers. Total Length (TL) was measured from the tip of the rostrum to the end of telson. The shrimps were sexed based on the presence of the thelycum (female) or petesma (male). Mean CL comparisons between sexes were conducted using t-test and between depth groups using Analysis of Variance (ANOVA). Statistical analysis were considered significantly different at the level of $\alpha = 0.05$.

Density and distribution: The mean depths were calculated by averaging the starting and the ending depths of each sampling operation and were divided into 5 depth zones: 20-50 m (81 hauls), 51-100 m (117 hauls), 101-200 m (38 hauls), 201-300 m (28 hauls) and 301-465 m (37 hauls).

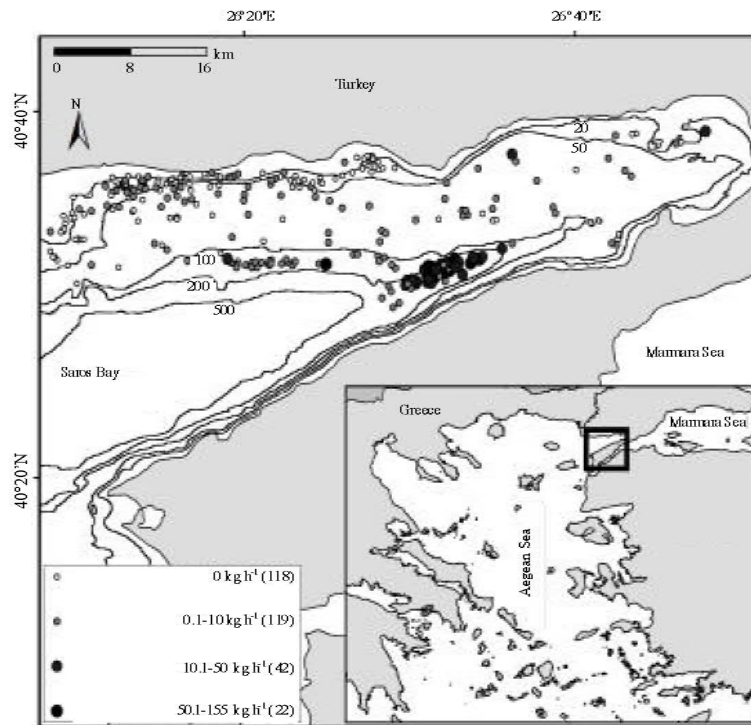


Fig. 1: The sampling locations with 20, 50, 100, 200 and 500 m Bathymetrical contours. Each dot representing a trawl operation with sizes being proportional to the biomass groups (kg h⁻¹) of the deep-water rose shrimp; the numbers of trawl hauls corresponding to the biomass groups are given in parenthesis within the figure legend

Number of individuals for each sampling survey was estimated by dividing the total weight of the haul to the mean weight of an individual of the corresponding sub-sample. Catch weight of an operation was used as a biomass index and calculated as kg/h. Catch Per Unit Effort (CPUE; individuals/h) for the deep-water rose shrimp was used for comparison of the densities among the water depth groups and the seasons. Seasons were grouped as winter (December to February), spring (March to May), summer (June to August) and autumn (September to November). Mean CL was compared between the depth groups for males and females.

Growth: The Von Bertalanffy Growth (VBG) equation estimates length as a function of age and assumes that the growth pattern of a species does not change within a year (e.g., growth rate is constant and independent of season) and is described as:

$$L_t = L_\infty [1 - e^{-K(t-t_0)}] \quad (1)$$

Where,

- L_t = Length at age t
- L_∞ = The asymptotic carapace length (mm) to which the shrimps grow
- K = The growth-rate parameter
- t_0 = The nominal age at which the length is zero

Seasonal growth pattern that incorporates oscillations into the VBG function was described by the Hoenig and Hanumara (1982) as:

$$L_t = L_\infty \left[1 - e^{-\left[K(t-t_0) + \left(C \frac{K}{2\pi} \right) \sin 2\pi(t-t_s) - \left(C \frac{K}{2\pi} \right) \sin 2\pi(t_0-t_s) \right]} \right] \quad (2)$$

Where,

- C = The relative amplitude ($0 \leq C \leq 1$) of the seasonal oscillations
- t_s = The phase of the seasonal oscillations ($-0.5 \leq t_s \leq 0.5$) denoting the time of year corresponding to the start of the convex segment of sinusoidal oscillation

The time of the year when the growth rate is slowest, known as the Winter Point (WP), was calculated as:

$$WP = t_s + 0.5 \quad (3)$$

To estimate growth parameters from length data, monthly length frequency distributions were constructed using 1 mm CL size class intervals. The VBG parameters of the seasonal and non-seasonal versions were estimated

using the Electronic Length Frequency Analysis (ELEFAN) (Pauly, 1987), the Projection Matrix Method (PROJMAT) (Rosenberg *et al.*, 1986) and the Shepherd (1987) Length Composition Analysis (SLCA) with the computer package Length Frequency Distribution Analysis (LFDA). These estimations were conducted for females and males separately. Only monthly distributions for which at least 30 individuals were available were used in the growth analysis.

The ELEFAN procedure first restructures length frequencies and then fits a VBG curve to the restructured data. Seasonal and non-seasonal VBG curves are fitted to the length distributions after providing a range of values for the parameters to be estimated and then iteratively reducing the range until the goodness of fit (R_n) of the curves to the data is maximized. R_n is calculated as:

$$R_n = \frac{10^{\frac{ESP}{ASP}}}{10} \quad (4)$$

Where,

- ASP = The available sum of peaks, computed by adding the best values of the available peaks
- ESP = The explained sum of peaks, computed by summing all the peaks and troughs hit by the VBG curve

Estimation of t_0 from length-frequency data only is not possible using ELEFAN (Pauly, 1987). The computer package LFDA firstly estimates L_∞ and K and then attempts to estimate a value for t_0 relative to the zero sampling timing, expressed as the fraction of the year.

Conceptually, SLCA is rather similar to the ELEFAN procedure in that it attempts to detect peaks and troughs in the length-frequency data. It estimates L_∞ , K and t_0 by maximizing a goodness-of-fit function from time series analysis of diffraction patterns. For given values of L_∞ and K the average age of a length class, T_L , is calculated as:

$$T_L = \frac{\sin \pi(t_{max} - t_{min})}{\pi(t_{max} - t_{min})} \cos 2\pi(\bar{t} - t_p) \quad (5)$$

Where,

- t_p = The proportion of the year that elapsed between recruitment and the time the sample was taken
- t_{max}, t_{min} = The ages corresponding to the lower and upper limits of the length class L
- \bar{t} = The average of t_{max} and t_{min}

A goodness-of-fit or score function, S , is then calculated for each sample distribution, i , by summing over all length classes in the sample as:

$$S = \sum_L \sum_i T_{L,i} \sqrt{N_{L,i}} \quad (6)$$

where, $N_{L,i}$ is the frequency in length class L of the i th sample distribution. If S_a is the value of S when t_0 is set to zero and S_b is the value of S when t_0 is set to 0.25, then the maximum of the score function, S_{max} , over t_0 is given as:

$$S_{max} = \sqrt{S_a^2 + S_b^2} \quad (7)$$

The value of t_0 that maximizes the score function for the given values of the VBG parameters is:

$$t_0 = \frac{1}{2\pi} \arctan\left(\frac{S_b}{S_a}\right) \quad (8)$$

The PROJMAT procedure is based on the Leslie (1945) population projection matrix. However, instead of projecting vectors of proportions in age classes through time (as is the case in Leslie population projection matrix), vectors of proportions in length classes are projected through time. The projection matrix, A , is a lower-triangular matrix of dimension equal to the number of length classes. Each element $a_{i,j}$ of A indicates what proportion in length class i at time t will grow into length class j at time $t + 1$. The vector of proportions in each length class at time $t + 1$, x_{t+1} is then given by:

$$x_{t+1} = A_{j,i} x_{t,i} \quad (9)$$

The projection matrix A depends on the effect of growth and mortality and can be separated, for practical purposes as the products of two terms:

$$A_{j,i} = G_{j,i} S_i \quad (10)$$

Where,

$G_{j,i}$ = The effects of growth in the absence of mortality

S = The effect of mortality and gear selectivity

The projection matrix A can be used with samples of length frequency distributions to estimate parameters of the seasonal or non-seasonal VBG curve. The growth parameters are iteratively estimated by an unweighted least-squares score function for the predicted and observed frequency distributions (Basson *et al.*, 1988). The SLCA procedure is used to obtain an estimate of t_0 corresponding to the values of L_∞ and K estimated by the PROJMAT procedure.

Although, each of the three methods was originally developed to estimate the parameters of a non-seasonal VBG curve, they are also suitable for estimating the seasonal growth parameters. The SLCA procedure,

however, was reported not to perform well when estimating seasonal VBG parameters and therefore, it was not implemented in the LFDA package (Kirkwood and Hoggarth, 2006).

The growth performance index (Φ), preferred to compare growth rather than using L_∞ and K individually was estimated to compare the growth parameters obtained in the present study with those reported in the study, Pauly and Munro (1984). Growth performance index was calculated for each sex, growth pattern and length frequency analysis procedure (ELEFAN, PROJMAT and SLCA) combination as:

$$\Phi = \log(K) + 2 \log(L_\infty) \quad (11)$$

Since Φ from different population follows a Gaussian distribution (Moreau *et al.*, 1986), it was possible to construct a 95% confidence interval for Φ obtain from the different combination estimates and from the study. Growth performance indices that fell outside the interval was assumed to be statistically different at $\alpha = 0.05$.

Mortality: The instantaneous total mortality rate (Z) was assumed to represent instantaneous natural Mortality rate (M) for the deep-water rose shrimp in Saros Bay. To obtain reliable estimates of mortality rates the following different methods were applied:

The Beverton-Holt equation Beverton and Holt (1956) for estimating the instantaneous mortality Z was calculated as:

$$Z = K \left(\frac{L_\infty - \bar{L}}{L - L'} \right) \quad (12)$$

Where,

L' = The length at which shrimps are first fully recruited to the gear

\bar{L} = The mean length of all shrimps longer than L'

Length Converted Catch Curve (LCCC) (Pauly, 1983, 1984a, b) was used to estimate Z as:

$$\ln\left(\frac{N_i}{\Delta t_i}\right) = a + bt_i \quad (13)$$

Where,

N_i = The frequency in length class i

Δt_i = The time needed for fish to grow through that length class

a = The intercept

t_i = The relative age (calculated assuming $t_0 = 0$) of the individuals corresponding to the length class i

b = The slope corresponding to Z with the sign changed

The time needed for fish to grow through length class *i*, Δt_i is calculated as:

$$\Delta t_i = -\frac{1}{K} \ln \left(\frac{L_\infty - L_{i2}}{L_\infty - L_{i1}} \right) \quad (14)$$

where, L_{i1} and L_{i2} are the lower and upper limits of length class *i*, respectively. The relative age t'_i of the individuals corresponding to the length class *i* can be obtained from the inverse of the VBG equation as:

$$t'_i = -\frac{1}{K} \ln \left(1 - \frac{L_t}{L_\infty} \right) \quad (15)$$

Seasonal Length-Converted Catch Curve (SLCCC) (Pauly, 1990; Pauly *et al.*, 1995) was also used to estimate *Z* as:

$$\ln(N) = a + bt' \quad (16)$$

Where,

- N = The number of fish in pseudo-cohorts sliced by means of successive growth curves
- t' = The relative age of the individuals in that pseudo-cohort
- b* = The slope corresponding to *Z* with the sign changed. Relative ages of the SLCCC and LCCC were converted to absolute ages by correcting for t_0

The empirical equation of Pauly (1980) to calculate the instantaneous natural mortality *M* was used as:

$$\log M = -0.0066 + 0.279 \log TL_3 + 0.6543 \log K + 0.4634 \log T \quad (17)$$

Where,

- T* = The mean water temperature in degree centigrade
- TL_∞ = The asymptotic total length (cm) to which the shrimps grow

This empirical equation assumes that the length are measured as Total Length (TL) in cm (Gayaniilo *et al.*, 2005). Therefore, length frequency analyses were reapplied to the length composition data to obtain TL_∞ in cm TL and *K* for employing them in Pauly's empirical equation.

For the purpose of comparing the mortality rates with other studies, the non-seasonal VBG version obtained from ELEFAN, PROJAMT and SLCA procedures were used as the input parameters for the Beverton-Holt *Z*, LCCC and Pauly's *M*. The seasonal VBG parameters obtained from ELEFAN and PROJAMT were used for the SLCCC mortality estimate. All mortality rate estimates were conducted for females and males separately using

FAO-ICLARM Stock Assessment Tools II (FISAT II, version 1.2.2) (Gayaniilo *et al.*, 2005). The instantaneous mortality rates were then converted to annual mortality rates (*A*) as:

$$A = e^{-Z} \quad (18)$$

RESULTS

Density and distribution: From the 301 trawl surveys a total of 2347.4 kg with an estimated 254975 individuals of deep-water rose shrimp were sampled between the depths of 20 and 463.5 m.

The water temperature ranged between 11.70°C in January 2007 and 19.02°C in May 2007, with an overall mean of 14.59±0.10°C. The salinity ranged between 34.74 in October 2007 and 43.87 in February 2008, with a mean of 38.05±0.13.

Carapace length were measured from 3747 individuals and ranged between 9.9 and 36.5 mm (mean 27.3±0.09 mm) for the females (*n* = 2292) and between 12.9 and 34.0 mm (mean 23.0±0.07) for the males (*n* = 1455). The mean CL of females were significantly greater than of males (*t* = 36.84; *p*<0.001).

Overall annual CPUE decreased during the study period; the annual CPUE was 1432.5 individual h^{-1} in 2005 (61 hauls), 1043.7 individual h^{-1} in 2006 (86 hauls), 942.1 individual h^{-1} in 2007 (90 hauls) and 308.3 individual h^{-1} in 2008 (64 hauls). Monthly CPUE fluctuation patterns were similar in all years. Although, the overall annual CPUE varied between the years, the increasing CPUE pattern during spring and summer was evident in all of the years (Fig. 2).

Bathymetrical biomass distribution of the deep-water rose shrimp showed a clear tendency towards the deeper waters in Saros Bay (Fig. 1). Except for only one instance that was observed in the 101-200 m depth contour, all the biomass estimation that exceeded 50 kg h^{-1} were observed in water depths greater than 200 m. Although, 198 surveys were conducted below the 100 m water depth, a biomass >10 kg h^{-1} was never realized.

The highest mean CPUE was observed in the 201-300 m water depth group in all the seasons (Fig. 3). Compared to spring and summer, an increase in the mean CPUE of was evident at lower depths (20-50 and 51-100 m) in Winter and Autumn seasons.

Significant differences of mean CL between depth groups were evident for females (*F* = 69.76; *p*<0.001) and for males (*F* = 65.06; *p*<0.001) (Fig. 4). However, the mean CL did not differ between the 201-300 and the 301-465 m depth groups for either sex. Interestingly, at shallow waters (20-50 m) the mean CL were significantly greater than the deeper 51-100 m depth group.

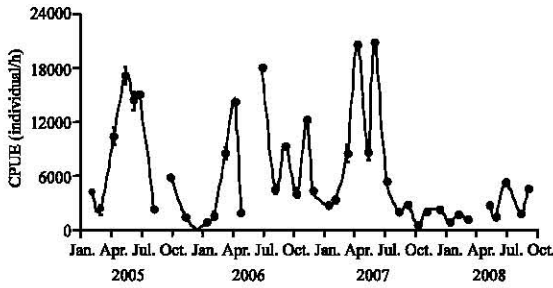


Fig. 2: Monthly catch per unit effort (CPUE; individuals/h) with standard error bars of the deep-water rose shrimp

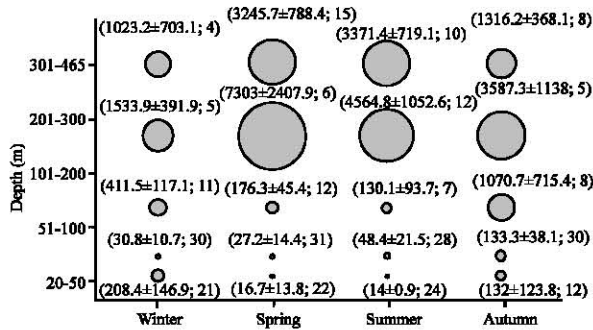


Fig. 3: Seasonal mean catch per unit effort (CPUE; individuals/h) of the deep-water rose shrimp at different depth groups. Sizes of the dots are proportional to CPUE (mean CPUE±SE; number of sampling)

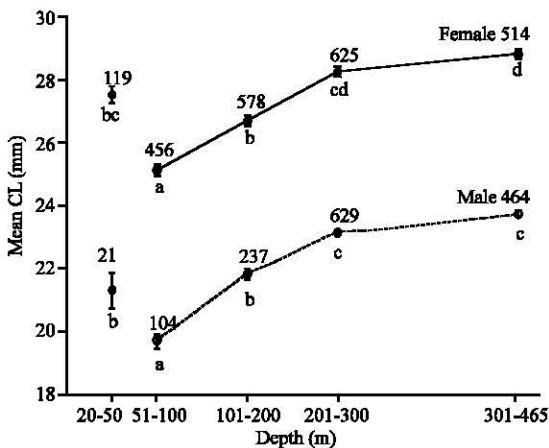


Fig. 4: Mean carapace length (CL) of males and females across depth groups. Within each sex group, CL means with different letters are significantly different at $\alpha = 0.05$. Numbers of individuals given above the dots

Growth: Growth parameter estimations for the seasonal and non-seasonal VBG versions varied between the different estimation methods in both sexes (Table 1). Compared to PROJMAT and SLCA, ELEFAN estimated higher values of L_{∞} and lower values of K in both the seasonal and the non-seasonal versions of the VBG curves of females. Similar results for males from ELEFAN were obtained, except for the non-seasonal growth curve in which SLCA estimated a higher L_{∞} and lower K compared to the other two methods.

Based on the scores, the seasonal VBG curves yielded better fits than the non-seasonal in females and males by both ELEFAN and PROJMAT (Table 1). Note that five parameters are estimated in the seasonal VBG curve and always will produce a better fit than the non-seasonal VBG curve which has only three parameters to be estimated. Conflicting results between ELEFAN and PROJMAT were obtained in the estimation of the seasonal oscillation amplitude, C. In females, PROJMAT estimated a higher C than ELEFAN, whereas in males the estimated oscillation was greater in ELEFAN (Table 1). The slowest growth period, WP in females was estimated as November (WP = 0.87) by ELEFAN and as January (WP = 0.01) by PROJMAT. In males, WP corresponded to May in both ELEFAN (WP = 0.35) and PROJMAT (WP = 0.39).

Visual inspection of the growth curves superimposed on the length frequency histograms shown that for both sexes, the seasonal VBG curves provided by ELEFAN had a better fit to the length frequency distributions than the curves produced by PROJMAT (Fig. 5 and 6). The relatively low estimation of L_{∞} by the PROJMAT resulted in growth curves that did not pass through the larger length groups in females (i.e., 30 mm CL and over; Fig. 5a) and in males (i.e., 20 mm CL and over; Fig. 6a).

Growth performance indices, Φ' for the deep-water rose shrimp derived from different methods and from the other studies ranged between 2.99 and 3.28 and had a mean of 3.14 ± 0.029 for females (Table 1). For males Φ' ranged between 2.80 and 3.08 and had a mean of 3.00 ± 0.027 . The 95% confidence interval was 3.07-3.20 ($t_{0.05(2),8} = 2.262$) for females and 2.94-3.06 ($t_{0.05(2),8} = 2.262$) for males. For the deep-water rose shrimp from Saros Bay, as opposed to the Φ' estimates derived from PROJMAT and SLCA, only ELEFAN results provided Φ' estimates that were within the 95% confidence limits for both sexes.

Mortality: Instantaneous annual mortality rates estimated with different combinations of methods ranged between 1.19 and 4.73 year⁻¹ for females and between 0.88 and 3.51 year⁻¹ for males (Table 2).

Table 1: Comparison of von Bertalanffy growth parameters

Methods	Parameters					Score	Φ'	Locality	Study
	L_{∞}	K	t_0	WP	C				
Female									
Ford-Walford plot	44.0	0.70	-0.30	-	-	-	3.13	South cost of Portugal	Ribeiro-Cascalho and Arrobas (1987)
MLA*	44.4	0.74	-0.13	-	-	-	3.16	Tyrrhenian Sea, Italy	Ardizzone <i>et al.</i> (1990)
ELEFAN	47.0	0.44	0.13	-	-	-	2.99*	Gulf of Alicante, Spain	Garcia-Rodriguez <i>et al.</i> (2009)
ELEFAN	41.0	0.65	-0.16	-	-	0.295	3.04*	Southern Mallorca	Guijarro <i>et al.</i> (2009)
ELEFAN	45.0	0.66	-0.24	-	-	0.379	3.13	North-western Mallorca	Guijarro <i>et al.</i> (2009)
ELEFAN	34.9	1.02	-0.03	-	-	0.321	3.09	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
PROJMAT	31.3	1.78	-0.68	-	-	-1.083	3.24*	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
SLCA	33.5	1.69	-0.60	-	-	165.125	3.28*	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
ELEFAN-Seasonal	34.7	1.05	-0.95	0.87	0.47	0.378	3.10	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
PROJMAT-Seasonal	31.3	1.71	-0.46	0.01	0.86	-0.975	3.22*	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
Male									
Ford-Walford plot	36.0	0.90	-0.30	-	-	-	3.07*	South cost of Portugal	Ribeiro-Cascalho and Arrobas (1987)
MLA*	33.1	0.93	-0.05	-	-	-	3.01	Tyrrhenian Sea, Italy	Ardizzone <i>et al.</i> (1990)
ELEFAN	36.0	0.49	0.08	-	-	-	2.80*	Gulf of Alicante, Spain	Garcia-Rodriguez <i>et al.</i> (2009)
ELEFAN	33.5	0.97	-0.10	-	-	0.486	3.04	Southern Mallorca	Guijarro <i>et al.</i> (2009)
ELEFAN	30.1	0.99	-0.79	-	-	0.706	2.95	North-western Mallorca	Guijarro <i>et al.</i> (2009)
ELEFAN	27.0	1.49	-0.87	-	-	0.511	3.04	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
PROJMAT	24.5	2.00	-0.78	-	-	-1.170	3.08*	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
SLCA	32.3	0.83	-0.05	-	-	73.232	2.93*	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
ELEFAN-Seasonal	27.0	1.49	-0.88	0.35	0.53	0.528	3.03	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)
PROJMAT-Seasonal	24.4	1.94	-0.86	0.39	0.21	-1.153	3.06*	Saros Bay, Aegean Sea	Ribeiro-Cascalho and Arrobas (1987)

*MLA: Mean Length at Age obtained from ordination model; (L_{∞} : Asymptotic carapace length (mm); K: Growth coefficient (yr^{-1}); t_0 : Age at zero length (yr); WP: Winter Point; C: Amplitude of growth oscillation) and growth performance index (Φ') of *Parapenaeus longirostris*. Scores for different methods are not comparable. Von Bertalanffy Growth (VBG) parameters estimated from ELEFAN, PROJMAT and SLCA procedures. For the studies 1, 2, 3 and 4 Φ' was calculated from the provided L_{∞} and K. The 95% confidence interval of Φ' was 3.07-3.20 for females and 2.94-3.06 for males; *Values outside the confidence limits

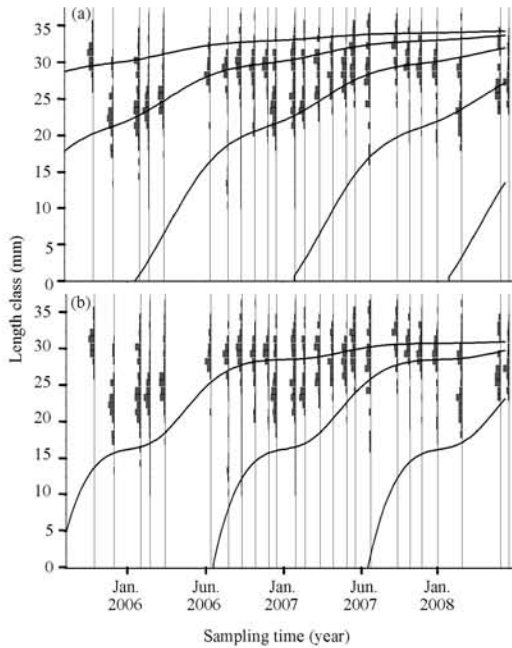


Fig. 5: Carapace length frequency distribution with seasonal von Bertalanffy growth curves obtained from ELEFAN (a) and PROJMAT (b) for females

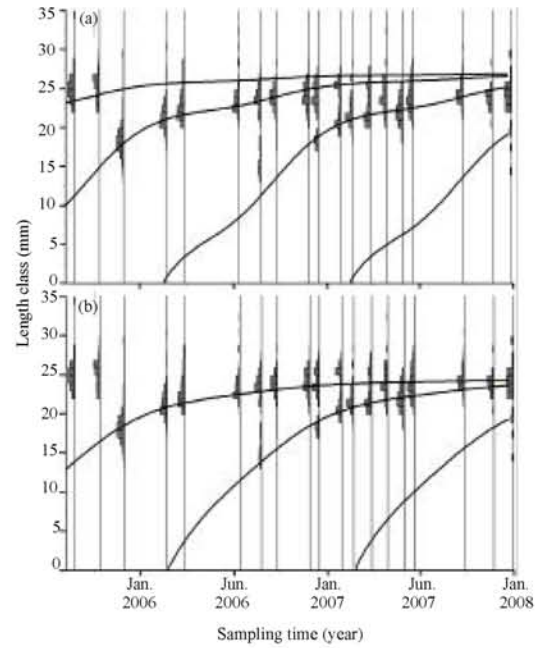


Fig. 6: Carapace length frequency distribution with seasonal von Bertalanffy growth curves obtained from ELEFAN (a) and PROJMAT (b) for males

Beverton and Holt (1956) Z estimates ranged between 1.58 and 166 year^{-1} for females and between 1.50 and 3.37 year^{-1} for males. However, no mortality estimation was possible with the VBG input parameters obtained from

PROJMAT for both sexes, because \bar{L} exceeded the estimated value of L_{∞} . Compared to LCCC, mortality rates obtained from SLCCC were about 11% lower with the input parameters from ELEFAN for females and 27%

Table 2: Instantaneous annual mortality rates (Z) with Confidence Intervals (CI_Z) and annual mortality rates (A) for females and males of *Parapenaeus longirostris*

Mortality method	VBG procedure	A	Z ^a	CI _Z	Absolute ages	Input parameters
Female						
SLCCC	ELEFAN	0.82	1.72	1.58 - 1.86	1.45 - 3.72	L _∞ = 34.66, K = 1.05, t ₀ = -0.95, C = 0.47, WP = 0.87
SLCCC	PROJMAT	0.99	4.73	2.80 - 6.67	0.28 - 0.59	L _∞ = 31.31, K = 1.71, t ₀ = -0.46, C = 0.86, WP = 0.01
LCCC	ELEFAN	0.86	1.94	1.77 - 2.12	1.77 - 3.63	L _∞ = 34.89, K = 1.02, t ₀ = -0.03
LCCC	PROJMAT	0.70	1.19	0.54 - 1.83	1.58 - 2.48	L _∞ = 31.28, K = 1.78, t ₀ = -0.68
LCCC	SLCA	0.95	2.93	2.65 - 3.22	1.79 - 2.45	L _∞ = 33.47, K = 1.69, t ₀ = -0.60
Beverton and Holt (1956)	ELEFAN	0.81	1.66	-	-	L _∞ = 34.89, K = 1.02, L' = 29.5, L = 31.55
Beverton and Holt (1956)	PROJMAT	NE ^b	NE ^b	-	-	L _∞ = 31.28, K = 1.78, L' = 29.5, L = 31.55
Beverton and Holt (1956)	SLCA	0.79	1.58	-	-	L _∞ = 33.47, K = 1.69, L' = 29.5, L = 31.55
Pauly (1980)	ELEFAN	0.78	1.51	-	-	TL _∞ = 15.86 ^c , K = 0.94, T = 14.59°C
Pauly (1980)	PROJMAT	0.91	2.36	-	-	TL _∞ = 14.31 ^c , K = 1.78, T = 14.59°C
Pauly (1980)	SLCA	0.90	2.26	-	-	TL _∞ = 15.17 ^c , K = 1.70, T = 14.59°C
Male						
SLCCC	ELEFAN	0.84	1.82	1.09 - 2.55	1.03 - 1.96	L _∞ = 26.95, K = 1.49, t ₀ = -0.88, C = 0.53, WP = 0.35
SLCCC	PROJMAT	0.62	0.97	-0.99 ^d - 2.92	0.28 - 0.50	L _∞ = 24.39, K = 1.94, t ₀ = -1.15, C = 0.21, WP = 0.39
LCCC	ELEFAN	0.92	2.50	2.44 - 2.55	2.16 - 3.10	L _∞ = 26.97, K = 1.49, t ₀ = -0.87
LCCC	PROJMAT	0.59	0.88	-0.36 ^d - 2.12	1.76 - 2.19	L _∞ = 24.45, K = 2.00, t ₀ = -0.78
LCCC	SLCA	0.97	3.51	2.47 - 4.55	1.69 - 3.24	L _∞ = 32.28, K = 0.83, t ₀ = -0.05
Beverton and Holt (1956)	ELEFAN	0.78	1.50	-	-	L _∞ = 26.97, K = 1.49, L' = 23.5, L = 25.23
Beverton and Holt (1956)	PROJMAT	NE ^b	NE ^b	-	-	L _∞ = 24.45, K = 2.00, L' = 23.5, L = 25.23
Beverton and Holt (1956)	SLCA	0.97	3.37	-	-	L _∞ = 32.28, K = 0.83, L' = 23.5, L = 25.23
Pauly (1980)	ELEFAN	0.88	2.12	-	-	TL _∞ = 12.83 ^c , K = 1.44, T = 14.59°C
Pauly (1980)	PROJMAT	0.91	2.38	-	-	TL _∞ = 11.84 ^c , K = 1.66, T = 14.59°C
Pauly (1980)	SLCA	0.76	1.42	-	-	TL _∞ = 14.96 ^c , K = 0.83, T = 14.59°C

^aZ assumed to be equal to instantaneous natural mortality rate (M); ^bNE, not estimatable because $L > L_{\infty}$; ^cTL_∞, total length unit in cm; ^dlower bound of the confidence intervals estimated as negative values; Seasonal Length Converted Catch Curve (SLCCC), Length Converted Catch Curve (LCCC), Von Bertalanffy Growth (VBG); parameters estimated from ELEFAN, PROJMAT and SLCA procedures. Absolute ages: corresponding ages

lower for males. By using the input parameters from PROJMAT, compared to LCCC, SLCCC yielded a four fold estimate of Z for females. With inputs from PROJMAT VBG for males, the SLCCC estimation of Z (0.97 year⁻¹) was somewhat higher than the LCCC estimation (Z = 0.88 year⁻¹). Within the LCCC estimations, SLCA VBG parameters provided the highest estimates of Z for both females (Z = 2.93 year⁻¹) and males (Z = 3.51 year⁻¹). Also note that in males, with VBG input parameters obtained from PROJMAT, the mortality rates estimated with SLCCC and LCCC resulted in awkward low confidence limits (i.e., negative value of Z).

Instantaneous annual natural mortality rate (M, assumed to be equal to Z in this study), estimated from the empirical equation of Pauly (1980), ranged between 1.51 and 2.36 year⁻¹ for females and between 1.42 and 2.38 year⁻¹ for males, with the highest values obtained with input parameters from PROJMAT for both sexes.

DISCUSSION

Density and distribution: Density distribution of the deep-water rose shrimp was related to several physical environmental parameters. The deep-water rose shrimp was found to live primarily on mud or sandy mud grounds (Ribeiro-Cascalho and Arrobas 1987) and at water temperatures between 13.5 and 15.5°C (Ungaro and Gramolini, 2006). Besides the bottom sediment and water temperature, salinity was found to be significantly

related to the density of the deep-water rose shrimp (Benchoucha *et al.*, 2008; Guijarro *et al.*, 2009). However, water depth appears the most important factor affecting the density and size distribution this shrimp species in the Mediterranean (Guijarro *et al.*, 2009).

The bathymetric distribution of the deep-water rose shrimp was studied in many areas and reported to range between 20 and 700 m (Sobrinho *et al.*, 2005; Guijarro *et al.*, 2009). Biomass were higher in the 200-500 m depth stratum along the European Mediterranean coasts (Abello *et al.*, 2002a). For the unexploited stock in Saros Bay, the highest biomass was observed in the 201-300 m depth group. Similarly, highest occurrence rates were observed between 201 and 300 m in the Mediterranean coasts of the Iberian Peninsula (Abello *et al.*, 2002b). In the Northern Tyrrhenian Sea, highest yields were obtained at depths ranging between 180 and 300 m (Sbrana *et al.*, 2006). Highest abundances were in the depth range of 100-400 m in Aegean Sea, Ionian Sea (Politou *et al.*, 2008) and the southern Adriatic Sea, Greece (Ungaro and Gramolini, 2006). The adults were reported to live mainly between 150 and 350 m in Latium, Italy (Ardizzone *et al.*, 1990).

Smaller individuals of the deep-water rose shrimp inhabit shallower water depths and the larger individuals are observed in deeper waters (Ribeiro-Cascalho and Arrobas, 1987; Ardizzone *et al.*, 1990; Sbrana *et al.*, 2006; Politou *et al.*, 2008). Similar results were obtained for the Saros Bay stock with larger mean CL observed in deeper waters (Fig. 4).

Growth: Non-seasonal VBG parameters for the deep-water rose shrimp, *Parapenaeus longirostris*, were estimated for several different stocks (Ribeiro-Cascalho and Arrobas, 1987; Ardizzone *et al.*, 1990; Garcia-Rodriguez *et al.*, 2009; Guijarro *et al.*, 2009) (Table 1). Unexpectedly, the unexploited stock in the Saros Bay achieved a lower L_{∞} and a higher K for both sexes when compared to other estimates. Similar growth results for an unexploited stock for the giant red shrimp, *Aristaeomorpha foliacea* in the Greek Ionian Sea, was reported to achieve lower L_{∞} and higher K, when compared to other exploited Mediterranean stocks (Papaconstantinou and Kapiris, 2003). Besides exploitation pressure, variations in the growth rates of the deep-water rose shrimp for different areas may be the result of external factors such as temperature, food availability, competition (Hartnoll, 2001; Abello *et al.*, 2002a; Sobrino *et al.*, 2005). In addition to the differences of growth rates observed between stocks, variations may be observed between years within a stock. Moreover, even for the same years, different estimations of growth rates can be obtained from the different methods used for the estimations.

Analyses of repeated length frequency samples, assuming that the size frequencies represent the true population are more apt for populations with short recruitment patterns, with rapid growth that assure annual cohorts to be easily separated and with short live span in which the older ages do not pile up into a single broad mode (Hilborn and Walters, 1992). The reliability of the VBG estimations from ELEFAN, PROJMAT and SLCA is discussed controversially for different fish and Crustacea species in the study. Leonce-Valencia and Defeo (1997) suggested to abandon the use of ELEFAN in favor of SLCA and PROJMAT because ELEFAN estimated L_{∞} and K-values of the red snapper, *Lutjanus campechanus* that were not in agreement with other studies that estimated these parameters from age and length data and because of the imprecise results obtained from jackknife iterations. However, red snapper has a life span over 52 years and grows up to 1040 mm TL (Wilson and Nieland, 2001) and may not be apt to apply length frequency analysis at all. Rueda and Santos-Martinez (1999) reported that similar and reliable growth parameter estimates were obtained by SLCA and ELEFAN, with estimates from PROJMAT being less plausible for the striped mojarra, *Eugerres plumieri*, population from the Ciénaga Grande de Santa Marta, Colombia. Defeo *et al.* (1992) found that as opposed to SLCA and PROJMAT, ELEFAN gave estimations that were similar to those previously obtained from analysis of growth rings for yellow clam, *Mesodesma mactroides*. This species grows up to a size of 82 mm length and has a life span up to 8 years in Isla del Jabali, Argentina

(Fiori and Defeo, 2006). Simpfendorfer *et al.* (2008) stated that, compared to ELEFAN, PROJMAT provided more accurate estimates of size at birth and concluded that PROJMAT probably better represented the non-seasonal VBG for juvenile smalltooth sawfish, *Pristis pectinata*, in the western Atlantic. The controversial suggestions for the appropriate growth estimation methods from length frequency distributions may be explained to some extent by the magnitudes of the growth rate, K and the highest mean length achievable, L_{∞} , for the species in question. Simulation analyses revealed that ELEFAN was more appropriate for populations of small fishes with faster growth and shorter life span and that SLCA provided smaller bias for fishes with slow growth rates (Issac, 1990).

The deep-water rose shrimp is described as a short living and fast growing species (Abello *et al.*, 2002a; Sobrino *et al.*, 2005). If the true population of this species is assumed representative by the samples, length frequency analysis could provide reliable results of the growth parameters. For both sexes of the deep-water rose shrimp from Saros Bay, the ELEFAN L_{∞} estimation were higher than the estimates obtained from the other two methods. In addition the estimates were relatively closer to the estimates from studies. Compared to the other two methods, PROJMAT resulted always in a lower estimate of L_{∞} and a relatively higher K for both sexes in the Saros Bay stock. Moreover, the L_{∞} obtained from PROJMAT was below the mean length, \bar{L} of all shrimps longer than the length at which shrimps are first fully recruited to the gear, L' (Table 2, Beverton and Holt (1956) mortality method input parameters). SLCA provided a relatively higher estimation of L_{∞} for males, but an intermediate estimation for females. Thus, for the non-seasonal growth pattern, ELEFAN provided biologically rational and comparable results for the fast growing deep-water rose shrimp population.

For the seasonal growth pattern, simulation analysis revealed that ELEFAN gave better estimates of L_{∞} and K within 20% of the true values whereas PROJMAT has done much better with C, t_0 and WP. Simpfendorfer *et al.* (2008) stated that the seasonal growth for the juvenile smalltooth sawfish was better represented by ELEFAN, by judging on the improved model fit compared to the non-seasonal growth fit and on the coincidence of the faster growth period estimation with the high water temperature period. An attempt was made to estimate seasonal growth of the deep-water rose shrimp by Levi *et al.* (1995) for a population in the Sicilian Channel. However, they estimated WP as 0.1 and a seasonality oscillation, C, of 1 which actually were the starting seed values they provided as inputs for the iteration process.

Moreover, the length frequency analysis they conducted were for both sexes combined which may have resulted in biased estimation of the parameters due to clear sexual dimorphism in length for this species. Seasonal oscillation estimates from ELEFAN were relatively similar between females ($C = 0.47$) and males ($C = 0.53$), whereas the estimates from PROJMAT were much more pronounced for females ($C = 0.86$ vs. 0.21). However, visual examination of the pronounced seasonal oscillation show that the VBG curve produced by PROJMAT does not fit the length frequency data well (Fig. 5b). Thus, the seasonal growth pattern of the deep-water rose shrimp for the Saros Bay stock is probably more appropriately described by the seasonalized ELEFAN model.

Although, the WP for the females in Saros Bay were estimated by ELEFAN and PROJMAT with a high difference in terms of value (0.87 vs. 0.01), when converted to months the estimates represent periods (November vs. January) with relatively lower water temperature. Levi *et al.* (1995) reported a peak period of maturity between November and February for females in the Sicilian Chanel. Other studies reported that more than one spawning period for the deep-water rose shrimp; one occurring in spring and the other one in autumn (Bayhan *et al.*, 2005; Sobrino and García, 2007). Thus, the slow growth period of females may not be directly related to the spawning period, but could be a result of the relatively lower temperature between November and January. For males, both methods estimated the slowest growth period as May. The growth rate of shrimps depends on the period of the intermolt period, the water temperatures and food availability (Hartnoll, 2001). On the other hand, the predicted slow growth periods for both sexes may not be a result of the growth pattern but rather a reflection of sampling bias.

The growth performance index, Φ' , can be used for averaging growth parameters of a particular species and markedly differences of Φ' would imply erroneous estimates of L_∞ and K (Sparre and Venema, 1998). For both the females and males in Saros Bay, only the Φ' estimates calculated from the ELEFAN results were not significantly different from the other studies estimates. In a simulation study for fast vs. slow growing species, ELEFAN always overestimated L_∞ and underestimated K , but the combination of these two (Φ') was affected <1% for the fast growing species; the bias of Φ' calculated from SLCA results was much higher (Issac, 1990).

Mortality: The mortality rate estimates for the deep-water rose shrimp in Saros Bay represent the first mortality estimates for an unexploited stock and therefore these estimates could be regarded as to represent natural

Mortality rate (M) for this species. The decrease in CPUE during the study period could be to some extent a result of the mortality of the stock by the trawling samples from this study. Therefore, the mortality rates presented here could be regarded as overestimated. For example Oh *et al.* (1999) estimated a total mortality of 3.96 and a fishing mortality that was assumed as sampling mortality of 0.36 for the period between April 1995 and July 1998 for an unexploited common shrimp, Crangon crangon, stock in Port Erin Bay, Isle of Man, Irish Sea.

The broad range of the Z estimates obtained from different methods made it difficult to decide on a reliable single value of mortality rate. The differences of the estimates may arise either from the violation of the assumptions of the methods (e.g., stock being at equilibrium and constant mortality for different sizes) or from the data it self (e.g., the data does not represent the true population).

The Beverton and Holt (1956) Z estimation method can provide reliable results if the assumptions behind the method are met and if L' is well-estimated (Kirkwood and Hoggarth, 2006). The method depends critically on the stock being at steady state (equilibrium), on representative length frequency sampling of all fish sizes above L' and on having a good independent estimate of L_∞ (Hilborn and Walters, 1992). Hilborn and Walters (1992) cautioned that very few populations are at equilibrium and sampling bias is unavoidable and therefore only the most naive biologist would use the Beverton-Holt method with any confidence. Ralston (1989) shown that due to seasonal recruitment, the time of sampling had a major effect on the relative bias of the Beverton-Holt's Z when estimated from a single sampling event, whereas relatively little bias was evident in multiple length-frequency samples. Beverton-Holt's Z equation was not used by any other study for the mortality estimation of the deep-water rose shrimp. For the Saros Bay stock, Beverton-Holt's Z mortality estimates calculated from the VBG outputs of SLCA and ELEFAN were similar for the females. A relatively higher estimate was evident for males when the VBG results from SLCA were used. To obtain a result from the Beverton-Holt's Z equation, L_∞ must be $> \bar{L}$, which was not the case for the PROJMAT obtained results (Table 2).

Using LCCC, several researchers estimated mortality rates for the deep-water rose shrimp for different regions without differentiating sexes (Levi *et al.*, 1995; Abello *et al.*, 2002a; Deval *et al.*, 2006). Levi *et al.* (1995) calculated the growth parameters from the seasonal VBG curve, but estimated the mortality rates from the regular (non-seasonal version) LCCC and obtained estimates between 0.705 and 1.239 year^{-1} for different regions in the

Sicilian Channel. An example of sampling bias for estimating total mortality rate for the deep-water rose shrimp was provided by Deval *et al.* (2006), who found that the estimate increased from 1.57 year⁻¹ when shrimps were sampled with a 36 mm cod end mesh size trawl to 2.13 year⁻¹ when sampled with a 32 mm cod end mesh size in the Marmara Sea, Turkey. Abello *et al.* (2002a) estimated mean total mortality rates of the deep-water rose shrimp as 2.41 year⁻¹ for the North Aegean Sea and as 3.22 year⁻¹ for the south Aegean Sea between 1994 and 1999. Abello *et al.* (2002a) estimated *Z* without distinction of sex and claimed that this may result in an overestimation of the *Z* values. Length converted catch curve is obtained by converting the frequencies at length to frequencies at relative age and then the *Z* value is obtained by estimating the slope of the regression line that is fitted to the descending right side of the natural logarithmic converted frequencies at the relative age groups. Thus, the bias of *Z* for sexes combined depends on the ratio of the frequencies at the relative ages of a given sex and therefore a sex combined analysis can result in either over- or underestimation of *Z*. Since sex differentiated growth pattern is evident in the deep-water rose shrimp, LCCC analysis with sexes combined is probably not appropriate for this species.

Length converted catch curve analysis for the deep-water rose shrimp in Saros Bay, revealed that males had a higher mortality rate than females with the VBG outputs from ELEFAN and SLCA. On the other hand, the LCCC mortality estimates were higher in females when the VBG outputs from PROMAT were used (please note that the lower limit of CI_L was negative, Table 2).

Seasonal length converted catch curves provide less biased estimates of mortality rate than regular LCCC estimates when a species shows a seasonal growth pattern (Pauly, 1990). This bias is more pronounced for small short-lived species exhibiting a seasonal growth pattern (Sparre, 1990), which is the case in the deep-water rose shrimp. Provided that the deep-water rose shrimp lives up to 3 years old (Sobrino *et al.*, 2005), the upper limit of the absolute ages used in the descending side of SLCC were markedly low for both sexes (0.59 year for females and 0.50 year for males) when the VBG results from PROJMAT were used. Moreover, unreasonable results were obtained for the SLCCC estimates when the outputs of the seasonal VBG curve from PROJMAT were used; the estimates resulted in an upper limit of the CI_L as 6.67 year⁻¹ for females and in a lower limit of the CI_L as -0.99 year⁻¹ for males.

Pauly's empirical natural mortality rate estimate is valid only if L_∞ refers to Total Length (TL) and the units are in

cm (Gayaniilo *et al.*, 2005). This natural mortality estimation method has been erroneously applied to many crustacean species such as the spiny lobster, *Palinurus delagoae* (Groeneveld, 2000), the green tiger prawn, *Penaeus semisulcatus* (Niamaimandi *et al.*, 2007) and the cut trough shell *Spisula subtruncata* (Deval and Gokturk, 2008). Correctly applying this method to the deep-water rose shrimp, Ribeiro-Cascalho and Arrobas (1987) estimated higher natural mortality rates for males ($M = 1.44$ year⁻¹) than for females ($M = 1.17$ year⁻¹) using Pauly's empirical equation with TL (cm) measurements for the deep-water rose shrimp population in the Atlantic, south coast of Portugal. The natural mortality estimates were relatively higher in both sexes for the unexploited stock in Saros Bay. For sexes combined, natural mortality was estimated as 0.97 year⁻¹ for the stock in the Marmara Sea, Turkey (Deval *et al.*, 2006).

CONCLUSION

Since the results of the unexploited stock in Saros Bay are in concordance with the exploited stocks from other areas, the distribution pattern of the deep-water rose shrimp does not seem to be shaped by fishing pressure. In this study, different procedures and methods were applied to obtain reliable estimates of growth and mortality rates for the unexploited deep-water rose shrimp stock in Saros Bay. For the aforementioned conditions, the ELEFAN procedure with a seasonal growth pattern can be considered to be the most appropriate method among the ones that were applied to the data of this study. Using the outputs from this procedure, the mortality rates estimated with the SLCCC method can be considered as the most appropriate ones for the Saros Bay stock.

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