

GROWTH ESTIMATION AND LENGTH–WEIGHT RELATIONSHIPS OF SPOTTAIL MANTIS SHRIMP (*SQUILLA MANTIS*, LINNEAUS 1758) IN THE ALGIERS REGION (SOUTH- WEST OF MEDITERRANEAN SEA)

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Abstract. This study concerns the growth and biometric relations of the mantis shrimp *Squilla mantis* from the region of Algiers. A total of 1064 individuals were sampled from the trawl fishery landings, between December 2016 and December 2017. The results show the different growth parameters, established on cephalothorax measurements ($L_{c\infty} = 48.06$ mm; $K = 0.34$ yr⁻¹; $t_0 = -0.69$ year) and total length values ($L_{t\infty} = 189.9$ mm; $K = 0.48$ yr⁻¹; $t_0 = -0.66$ year). The decomposition of size structures according to the Bhattacharya method yielded four age classes based on the cephalothorax and total length (0⁺-3). The total mortality (Z) calculated from Ricker curve was 1.32 year⁻¹, and the natural mortality coefficient M was calculated at 0.95 year⁻¹ indicating an under-exploitation of the *S. mantis* stock in this area. Different biometric relationships are established of the size-size and size weight type highlighting an allometry coefficient higher than 1 and lower than 3, respectively for the size-size and size-weight relationships, translating a major growth of the total size and a minor growth of the weight. Researchers and decision makers can integrate these results in analytical, bioenergetic and bioeconomic models to better manage the exploitation of the *S. mantis* stock in the western Mediterranean basin.

Keywords: *S. mantis* mortality, population dynamic, age structure, biometric relationship, Algeria, Mediterranean-Western basin

Introduction

Of the nine species of Mediterranean Stomatopods, only the spottail mantis shrimp, *Squilla mantis*, is of appreciable economic importance (Maynou et al., 2004). Its range extends from Angola to the Gulf of Cadiz (Manning, 1977). In the Atlantic, this species seems to be present only in the Gulf of Cadiz (Maynou et al., 2004), while in the Mediterranean, it is reported in Egypt, Syria, Greece, Turkey, Italy, France, Spain, Palestine, Algeria (Schram and Muller, 2004) and on the Tunisian coast (Mili et al., 2011). It is found at sublittoral depths greater than 3 m on sandy and muddy bottoms up to 200 m deep, but generally at less than 50 m (Holthuis, 1987). Its presence is reported on the entire Algerian coast, and studies carried out in the Algerian basin have highlighted its relatively high abundance in the center of the basin, in particular, in the bay of Bou Ismail between 50 and 100 m. *S. mantis* prefers compact and sandy liquid muds and fine sand, and average temperatures of 13.2 to 15.3°C (Campilo, 1982). Its

catch on the Algerian coast in the last five years has recorded a maximum landing rate of 3232.9 Kg in 2016 (Fig. 1; Ministry of Fisheries and Fisheries Production, 2021).

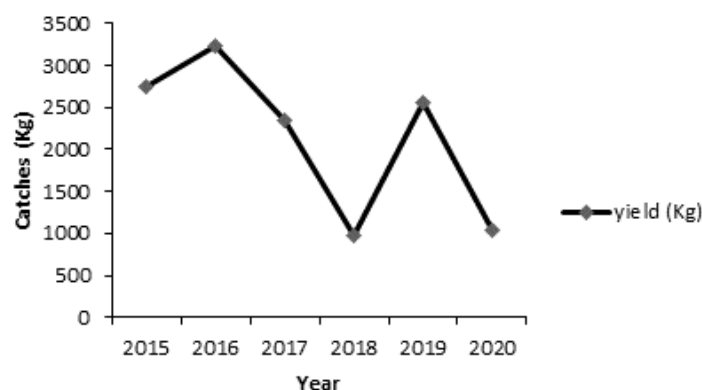


Figure 1. Catch of *S. mantis* in Algeria between 2015 and 2020 (Ministry of Fisheries and Fisheries Production, 2021)

S. mantis has been the subject of numerous research studies in the Mediterranean and Atlantic. Among these works, we mention those of Ragonese et al. (2012) in the southern coast of Sicily, Vasconcelos et al. (2017) in algarve coast, Erdogan-Saglam et al. (2017) in the bay of Izmir, Vila et al. (2013) in the Gulf of Cadiz, Kampouris et al. (2018) in the Thermaikos Gulf, Veneroni and Fernandes (2021) in the northern Adriatic sea; Mili et al. (2008, 2013, 2014) in Tunisia; but no study has been undertaken on this species in Algeria.

S. mantis is caught in limited quantities and essentially on trawlable bottoms by means of demersal trawls. In the past, this species was considered as a fishing product of low market value not appreciated by Algerians for lack of culinary tradition and was consequently rejected at sea after its capture. But given the high price of wild shrimp in recent years, this species has begun to attract interest by the Algerian consumer (Fig. 1). Indeed, *S. mantis* has become popular in fish shops in the central region with prices/kg ranging between 400 and 500 Algerian dinars at retail (about 3 euros). Compared to the numerous investigations undertaken on Peneidae (Derbal and Soltani, 2008; Kennouche, 2009), Aristeidae (Mouffok et al., 2005, 2008; Nouar and Kennouche, 2013) or Pandalidae (Derbal and Kara, 2006) from the Algerian coasts, Stomatopods have not attracted the same scientific interest. Moreover, there is no comprehensive information on the biology, ecology or exploitation level of Stomatopods in Algeria. In order to better understand the available stocks of Stomatopods along the Algerian coasts, this study aims to provide new data on the growth and biometric relationships of *S. mantis* in the Algerian region in a perspective of rational exploitation and valorization of this carcinological resource.

Material and methods

Sampling

Between December 2016 and December 2017, 1064 individuals of *S. mantis* were sampled from the landings of the commercial trawl fishery conducted in the Algiers region (Fig. 2).

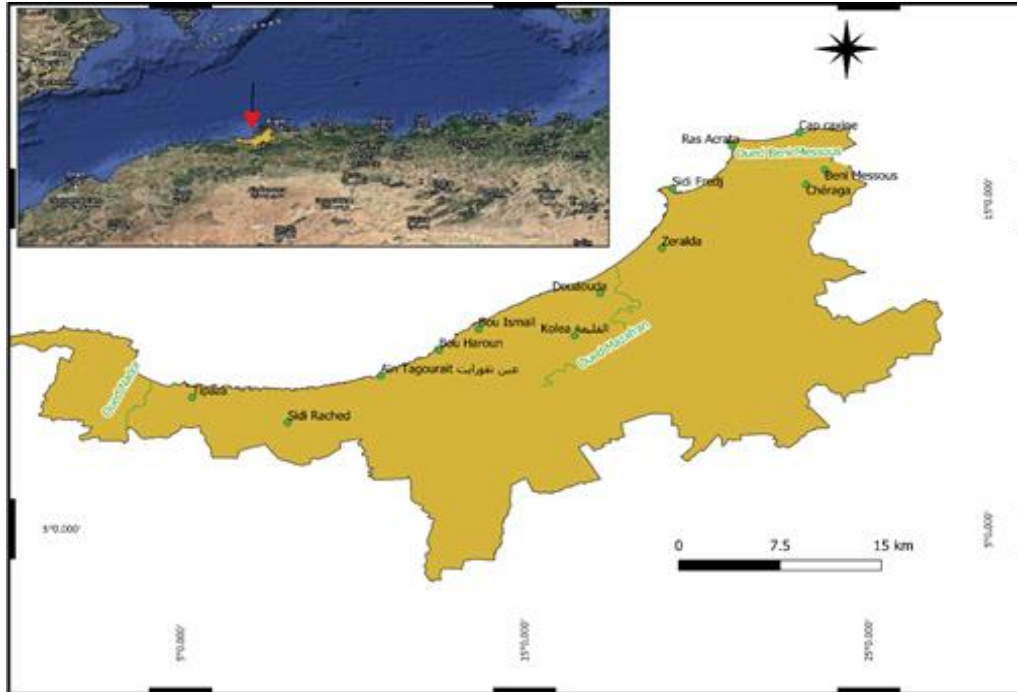


Figure 2. Map of the study area in the central region of the Algerian basin

Measurements were made on each individual using an ichthyometer, for the measurement of total length (L_t) and telson (L_{tel}), and a caliper, for the measurement of cephalothoracic length (L_c). Total weight (W_t) was determined with a 0.01 g precision scale (Fig. 3). The sex of *S. mantis* is easily identified by the presence of a pair of copulatory organs from the base of the third pair of pereopods corresponding to the 8th thoracic segment in males and by the presence of the genital plate on the sternite of the 6th thoracic segment in females (Abelló and Martín, 1993). Also, other individuals (152 specimens) were measured and considered without distinction of sex, because of the deterioration of some frozen individuals.

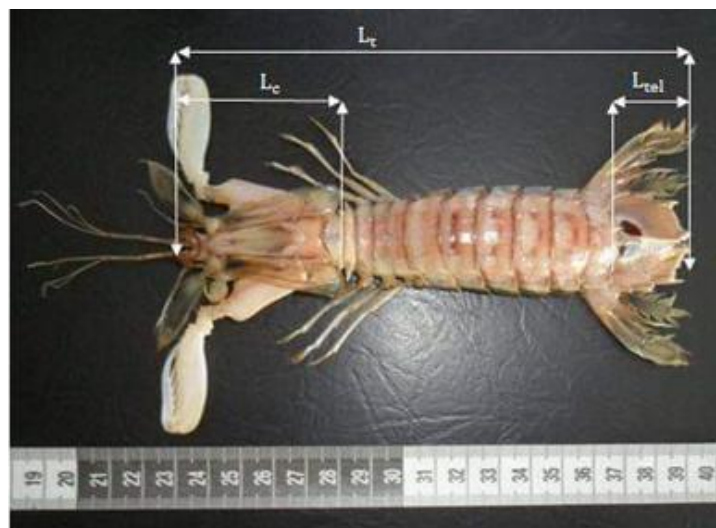


Figure 3. The different measurements made on *S. mantis*

Age and growth

The age of the specimens was determined from length-frequency data analysis using Bhattacharya's method in the FISAT II software. This method, which is based on logarithmic differences, was outlined by Bhattacharya (1967), taken up by Masson (1970) and applied by Gayanilo et al. (2002). The growth in length of this species has been described using the Von Bertalanffy equation (Ricker, 1975; Beverton and Holt, 2012; Eq. 1):

$$L_t = L_\infty (1 - e^{-K(t-t_0)}) \quad (\text{Eq.1})$$

with: L_t : total length at age t (cm), L_∞ : asymptotic length (cm), K : growth coefficient (yr^{-1}), t : age (yr), t_0 : the hypothetical age corresponding to zero theoretical length (Sparre and Venema, 1992; King, 2013). The Von Bertalanffy exponential growth models were evaluated using the root mean square error (RMSE). The RMSE gives an overview of the overall difference between the predicted (VBGE) and observed (Bhattacharya decomposition) values.

The length performance (\emptyset') was estimated using the equation (Eq. 2), given by Moreau et al. (1986):

$$\emptyset' = \log K + 2 \log L_\infty \quad (\text{Eq.2})$$

The asymptotic length L_∞ was estimated from the size frequency distribution by the method of Powell (1979); Wetherall (1986) using the FISAT II software, version 1.2.0 (Gayanilo et al., 2002). This same software also allowed us to estimate the growth rate K by analyzing the age-length key obtained by Bhattacharya (1967) multimodal decomposition. The analysis of this age-length key was performed according to the iterative method of Tomlinson and Abramson (1961), a method based on a "least square" type of adjustment by integrating the L_∞ obtained by Powell (1979) and Wetherall (1986). This method estimates the parameter K so that the sum of the squares of the differences between the model and the observations is minimal (Gayanilo et al., 2002).

The age at time "zero", represented by t_0 is calculated by Pauly (1980) (Eq. 3):

$$\log_{10}(t_0) = -0.3922 - 0.2752 \log_{10} L_\infty - 1.038 \log_{10} K \quad (\text{Eq.3})$$

Biometric relations

For the biometric study of the mantis shrimp, we established the following morphometric relationships: $L_{tel} = F(Lc)$, $L_t = F(L_{tel})$, $L_t = F(Lc)$, $W_t = F(Lc)$, $W_t = F(L_{tel})$ and $W_t = F(L_t)$. With: L_{tel} : telson length, Lc : cephalothoracic length, L_t : total length and W_t : total weight. These relationships were expressed by a linear model of the form $y = a x + b$ for length-length relationships and $\log w = \log a + b \log L$ for length-weight relationships. Where W = total weight, $L = L_t$, Lc , or L_{tel} , a = intercept and b = slope of the regression line for length-weight relationships, these parameters are inverted for length-length relationships (a : slope of the regression line and b : intercept). The exponent b is the allometry coefficient reflecting the proportionality of the growth of a given trait to the reference trait ($b < 3$ negative

allometry, $b = 3$ isometry, $b > 3$ positive allometry). For length-length relationships, the slope coefficient a reflects the nature of the allometry ($a < 1$ minor allometry, $a > 1$ major allometry, $a = 1$ isometry).

In addition, t -test for slope conformity was performed to confirm the type of allometry for the length-weight and length-length relationships (Eqs. 4,5) for the size-weight relationships and length-length relationships, respectively:

$$t = \frac{[(b-3)]}{sd(b)} \quad (\text{Eq.4})$$

$$t = \frac{[(b-1)]}{sd(b)} \quad (\text{Eq.5})$$

with:

$$sd(b) = \sqrt{\frac{\frac{\delta y^2}{\delta x^2} (1-R^2)}{n-2}} \quad (\text{Eq.6})$$

with δy^2 : Variance of variable y , δx^2 : variance of variable x , R^2 : coefficient of determination, $n-2$: degree of freedom and $\alpha = 0.05$. If $t < 1.96$ non-significant difference, if $t > 1.96$ significant difference. In addition, statistical analyses were performed to test the significance of the difference between the calculated and observed values. Differences in sex ratios, based on a theoretical ratio of 1:1, were assessed using Chi-square (χ^2) analysis in R (4.0.3). Sample normality was tested by the Kolmogorov Smirnov test and homogeneity of variances with the Levene test using STATISTICA 6.1. ANOVA of the regression models (length-weight and length-length) was used to test the significance of the latter (R 4.0.3).

Mortality

The instantaneous coefficient of total mortality (Z) was calculated by the capture curve given by Ricker (1975); where Z is equal to the slope of the descending part of the curve. Natural mortality (M) was estimated using the empirical equation of Pauly (1983) (Eq. 7):

$$\log M = -0.0066 - 0.279 \log L_{\infty} + 0,6543 \log K + \log T^{\circ} \quad (\text{Eq.7})$$

with T° : temperature of the seawater ($^{\circ}\text{C}$). The mortality coefficient (F) was deduced from the formula $F=Z-M$ (Gulland, 1971). The exploitation rate (E) was estimated according to the ratio: $E=F/Z$ (Gulland, 1971). All statistical analyses were conducted using STATISTICA 6.1, R 4.0.3 and Microsoft Excel® software.

Results

Statistical analysis

The mean total length (L_t), cephalothoracic length (L_c), telson length (L_{tel}), and mean weight of 1064 *Squilla mantis* specimens were 13.39 ± 0.16 (cm), 2.99 ± 0.04 (cm), 2.35 ± 0.03 (cm), and 29.18 ± 0.99 (g), respectively (Table 1). Males were slightly larger

than females, but the difference was statistically insignificant ($P > 0.05$). The sex ratio was 52.82% for females versus 47.18% for males. Chi-square analyses show that the difference between males (47.18%) and females (52.82%) is not statistically significant (Table 2). Males and females were equally represented in the western Mediterranean population of *S. mantis*.

Table 1. Sex, mean total length (cm), carapace length (cm) and weight (g) of *Squilla mantis* from the Mediterranean Sea-Western Basin

Sex	Total length (cm) (min-max)	Carapace length (cm) (min-max)	Telson length (cm) (min-max)	Weight (g) (min-max)
Male N= 422	13.71±0.24 (9.5-17.3)	3.26±0.0.6 (2.35-4.15)	2.42±0.05 (1.6-3.1)	31.56±1.57 (8.88-61.56)
Female N= 490	13.28±0.2 (9.5-16.3)	3.08±0.05 (2.25-3.8)	2.30±0.04 (1.6-2.9)	26.98±1.16 (9.68-50.5)
Total N = 1064	13.39±0.16 (6-18.5)	2.99±0.04 (2.35-4.5)	2.35±0.03 (1.6-3.1)	29.18±0.99 (8.88-61.56)

Table 2. Statistical tests applied on the different measurements of *S.mantis*

Male vs Female	Total length (cm)	Carapace length (cm)	Telson length (cm)	Weight (g)
Levene's Test for Equality of Variances	$P=0.37$	$P=0.01$	$P=0.013$	$P=0.02$
<i>t</i> test for independent samples	$P=0.0052$	$P=10^{-6}$	$P=6.3 \times 10^{-5}$	$P=3 \times 10^{-6}$
Kolmogorov-Smirnov normality test	$P_{\text{male}}=0.119$ $P_{\text{female}}=0.087$	$P_{\text{male}}=0.1$ $P_{\text{female}}=0.092$	$P_{\text{male}}=0.113$ $P_{\text{female}}=0.089$	$P_{\text{male}}=0.052$ $P_{\text{female}}=0.06$
Chi-squared test for sex ratio (F/M)	$P=0.07$			

Significant difference marked at $P < 0.05$. For the Kolmogorov-Smirnov test, the normality of the distribution is accepted at $P > 0.05$

Levene's test of homogeneity of variances, applied between males and females indicates a non-significant difference for total length. However, this same test asserts a heterogeneity of variances for cephalothoracic length, telson length and weight (Table 2). The Kolmogorov-Smirnov normality test shows that the different distributions of size and weight follow a normal distribution. The *t*-test for independent samples shows a significant difference in the growth of male and female *S. mantis* (Table 2), which suggests a sex-dependent growth study.

Linear growth estimation

Figure 4 shows the frequency-size distributions of the sample. The decomposition of these distributions with Bhattacharya's logarithmic difference method, revealed four age groups of 0⁺-3 years for the different measurements *Lt*, *Lc*, *Ltel* (Fig. 4 and Fig. 5).

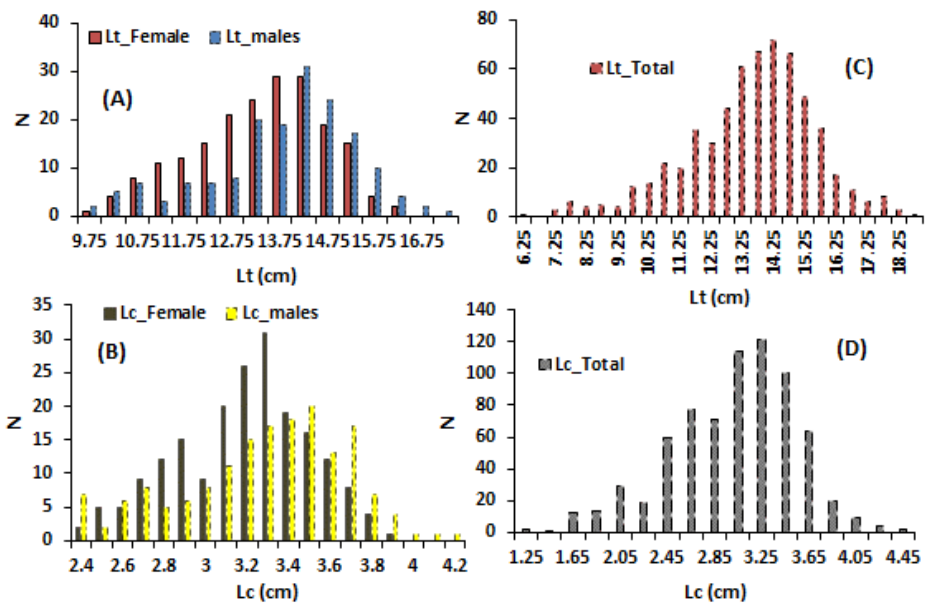


Figure 4. Length frequency distribution for males and females of *S. mantis*, (A): Total length for male and female, (B): Carapace length for male and female, (C): Total length for both sexes, (D): Carapace length for both sexes

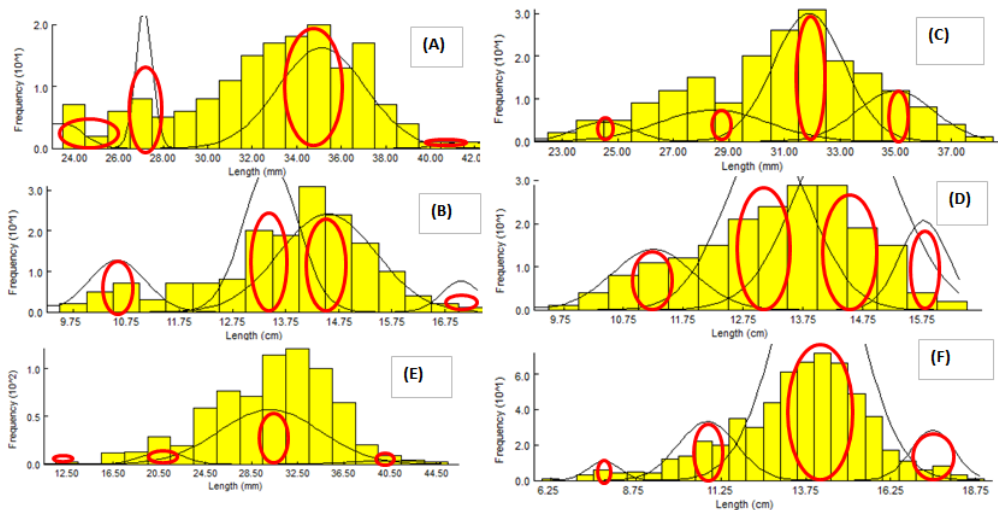


Figure 5. Decomposition of length frequency structures by the Bhattacharya's method in FISAT II. (A): Carapace length for male. (B): Total length for male. (C): Carapace length for females. (D): Total length for females. (E): Carapace length for both sexes. (F): Total length for both sexes. The red circles represent the age groups

These results indicate that *S. mantis* can be considered a fast growing species. The fastest growth occurs mostly in the age interval 0-1.

Bhattacharya's method consists of separating normal components, each representing a cohort of *S. mantis*, from the overall distribution, starting from a left side (Fig. 4). Fig. 5 shows different multimodal distributions with several peaks that can be divided

into four subsamples. These distributions result from a length frequency table with a step of 0.1 cm for cephalothoracic lengths and 0.5 cm for total lengths.

For mean male sizes of 13.71 ± 0.24 , 3.26 ± 0.06 and for mean female sizes of 13.28 ± 0.2 , 3.08 ± 0.05 ; the method of Powell (1979); Wetherall (1986) allowed to estimate asymptotic lengths for males and females: 18.25 cm, 39.40 mm, 18.56 cm, 42.50 cm, respectively for total and cephalothorax lengths. The calculated asymptotic lengths are consistent with the differences in growth observed between males and females of *S. mantis* in the Algerian region, i.e. males show a slightly faster growth than females in this bay (Table 3). The coefficients of catabolism K estimated from total and cephalothorax length are very close to each other, with a slight difference in favor of females, and a slight underestimation when sex is taken together. Calculation of the performance index ϕ' gives an overall view on the rapid growth of *S. mantis* (2.36-3.06); highly similar for both sexes (Table 3). The growth equations as a function of L_t and L_c are: $L_t = 18.25 (1 - e^{-0.69(t+0.56)})$, $L_c = 39.40 (1 - e^{-0.71(t+0.51)})$ for females $L_t = 18.56 (1 - e^{-0.67(t+0.57)})$, $L_c = 42.50 (1 - e^{-0.64(t+0.53)})$ for males, $L_t = 18.99 (1 - e^{-0.48(t+0.66)})$, $L_c = 48.06 (1 - e^{-0.34(t+0.69)})$ for all sexes combined.

Table 3. Growth parameters obtained for the mantis shrimp *S. mantis* from the western Mediterranean basin

Sex	Length measurements (cm)	L_{∞} (Powell, 1979; Wetherall, 1986)	K (year-1) (Tomlinson and Abramson, 1961)	t_0 (Pauly, 1980)	ϕ'
Male N= 422	Lt (cm)	18.25	0.69	-0.56	2.36
	Lc (mm)	39.40	0.71	-0.51	3.04
Female N= 490	Lt (cm)	18.56	0.67	-0.57	2.36
	Lc (mm)	42.50	0.64	-0.53	3.06
Total N = 1064	Lt (cm)	18.99	0.48	-0.66	2.24
	Lc (mm)	48.06	0.34	-0.69	2.9

The age-length key developed for the mantis shrimp *S. mantis* highlighted age groups ranging from 0^+ to 3 regardless of the length used (L_t or L_c) (Table 4). Bhattacharya's multimodal decomposition led to mean lengths of 13.91 cm, 31.88 mm for males and 13.67 cm, 29.96 mm for females; 12.57 cm, 25.76 mm for all sexes combined; which is very close to the means actually sampled in the population.

RMSE values are expressed as the percentage of the mean observed in each sampled length to give more meaning to this statistical estimator. For males, the overall variance of the Von Bertalanffy model was 17.77% for "total length" and 18.70% based on "cephalothorax length"; this means that the two growth models estimated for males explained 82.23%, 81.3% of the observations. The RMSE for females was 20.57%, 21.47%, based on "total" and "cephalothorax length". For all sexes combined, the growth model developed performed well, explaining 87.06%, 87.29% of the average observations. The calculated growth rate indicates rapid growth during early stages, followed by slower growth as the species approaches L_{∞} . The two growth rates estimated for Bhattacharya's age-length key and from Von Bertalanffy's growth equation (Eq.1), show a divergence for the early age groups, suggesting that the size range is not fully sampled due to gear selectivity.

Table 4. Age-length key, growth rate, root mean square error obtained for the mantis-shrimp *S. mantis* from the central Algerian region

Sex	Measurement (cm)	Age group	Bhattacharya	VBGE	RMSE	RMSE/MEAN (%)	Growth rate (Bhattacharya-VBGE)	
Male	Lt (cm)	0	10.58	5.89	2.47	17.77	2.89/6.19 1.07/3.17 2.51/1.62	
		1	13.47	12.08				
		2	14.54	15.24				
		3	17.05	16.86				
	Mean			13.91				
		Lc (mm)	0	23.5	12.23	5.96	18.70	3.64/14.31 7.99/7.55 6.62/3.9
			1	27.14	26.54			
	2		35.13	34.08				
	3	41.75	38.06					
	Female	Lt (cm)	0	11.25	5.85	2.81	20.57	1.9/6.18 1.36/3.10 1.27/1.55
1			13.15	12.03				
2			14.51	15.13				
3			15.78	16.69				
Mean				13.6725				
		Lc (mm)	0	24.5	11.97	6.43	21.47	3.95/13.94 3.43/6.86 3.12/3.37
			1	28.45	25.91			
2			31.88	32.77				
3		35	36.14					
Mean				29.9575				
Combined	Lt (cm)	0	7.82	5.16	1.63	12.94	3.04/5.27 3.26/3.26 3.36/2.02	
		1	10.86	10.43				
		2	14.12	13.69				
		3	17.48	15.71				
	Mean			12.57				
		Lc (mm)	0	11.5	10.05	3.27	12.71	9.31/10.96 9.3/7.80 10.49/5.55
			1	20.81	21.01			
	2		30.11	28.80				
	3	40.6	34.35					
	Mean			25.755				

Biometric relations

From the different measurements, linear relationships were established of the “length-length” and “length-weight” type. *Tables 5 and 6* summarize the equations, the correlation coefficients linking the “length-length” and “length-weight” measurements as well as the different results of the statistical tests applied to each model. These models were obtained using the least squares method which consists of determining the parameters of the intercept and the slope of the regression line so that the sum of the squares of the residual errors is as small as possible.

Table 5. Length-length relationship parameters obtained for the mantis-shrimp *S.mantis* from the Algiers region (R 4.0.3)

Biometric relation	Sex	a	b	Std.Error (a and b)	t value	Pr (> t)	R ²	F-Statistic
Lt _{tel} =a×Lc+b	Female	0.668 (0.608-0.729)	0.24 (0.058-0.43)	0.03	21.96	<2×10 ⁻¹⁶ ***	0.715	482.1
				0.09	2.59	0.0102 *		
	Male	0.6716 (0.61-0.735)	0.23 (0.023-0.437)	0.032	21.070	<2×10 ⁻¹⁶ ***	0.729	444
	Total	0.669 (0.627-0.71)	0.244 (0.11-0.38)	0.02118	31.550	<2×10 ⁻¹⁶ ***	0.735	995.4
				0.06747	3.611	3.49×10 ⁻⁴ ***		
Lt=a×Lt _{el} +b	Female	4.4774 (4.045-4.91)	2.9731 (1.971-3.974)	0.2193	20.417	<2×10 ⁻¹⁶ ***	0.684	416.9
				0.5079	5.845	2.05×10 ⁻⁸ ****		
	Male	4.33 (3.95-4.71)	3.22 (2.29-4.15)	0.1928	22.471	<2×10 ⁻¹⁶ ***	0.754	504.9
	Total	4.36 (4.08-4.64)	3.19 (2.54-3.86)	0.1416	30.796	<2×10 ⁻¹⁶ ***	0.73	948.4
				0.3364	9.506	<2×10 ⁻¹⁶ ***		
Lt=a×Lc+b	Female	3.7953 (3.51-4.077)	1.60 (0.73-2.48)	0.1428	26.573	<2×10 ⁻¹⁶ ***	0.786	706.1
				0.4417	3.637	3.5×10 ⁻⁴ ***		
	Male	3.46 (3.18-3.75)	2.40 (1.47-3.34)	0.1438	24.083	<2×10 ⁻¹⁶ ***	0.779	580
	Total	3.78 (3.63-3.92)	1.70 (1.26-2.15)	0.07226	52.241	<2×10 ⁻¹⁶ ***	0.82	2729
				0.22649	7.519	2.05×10 ⁻¹³ ****		

Significant codes: 0 '****' 0.001 '***' 0.01 '**' 0.05 '.' 0.1 '.' ' ' 1

The linear biometric relationships (Table 5) show a majoring allometry ($a > 1$) for the relationships $Lt = a \times Lt_{el} + b$, $Lt = a \times Lc + b$ and a minoring allometry for relationships of the type $Lt_{el} = a \times Lc + b$ ($a < 1$). The F -test based on Fisher's statistic shows a very high overall significance of all models ($P_{value} < 2 \times 10^{-16}$ and $416.9 \leq F \leq 2729$). Student's t test applied on the regression coefficients a and b (Table 5) indicates a high significance of the slope coefficients a ($Pr (>|t|) < 2 \times 10^{-16}$), which is significant at the error rate $\alpha = 0.001$. The values of the intercept coefficients b are highly significant for all models ($2 \times 10^{-16} \leq Pr \leq 0.0102$), except for the model $Lt = a \times Lc + b$ established for males ($Pr = 0.0296$) (Table 5). The Standard error ranged from 0.03-0.4729, which led to confidence intervals between 0.608-4.71 for the a coefficient and between 0.023-3.94 for the b coefficient (Table 5). This metric of how the values of a and those of b vary under repeated sampling reflects a very high quality of the fitted "length-length" models for *S. mantis*. The estimated coefficient of determination R^2 for all linear models ranged from 0.684-0.82, showing a high degree of linear independence between "total", "cephalothorax" and "telson length" (Table 5). The linear growth model of "telson

length” versus “cephalothorax length” shows slope coefficients *a* less than 1 for both sexes and for the overall population, resulting in a majoring allometry. These results sub-imply that cephalothorax grows faster than telson for *S. mantis* specimens. On the other hand, models that relate “total length” to either “cephalothorax” or “telson” reflect growth with minor allometry (*a* < 1), i.e., “total length” grows faster than both “cephalothorax” and “telson” (Table 5). The observed *a*-slope values were compared to the theoretical value of 1 and the difference was statistically significant (*t*<1.96) for all models developed.

Table 6. Size-weight relationship parameters obtained for the mantis-shrimp *S.mantis* from the Algiers region (R 4.0.3)

Biometric relation	Sex	log a	b	Std.Error	t value	Pr (> t)	R ²	F-Statistic
Log Wt = log a + b log Lc	F	0.056 (-0.045- 0.158)	2.78	0.05153 0.10547	1.092 26.367	0.276 <2×10 ⁻¹⁶ ***	0.79	695.2
	M	0.084 (-0.034- 0.204)	2.7 (2.47- 2.93)	0.06 0.117	1.4 23.01	0.163 <2×10 ⁻¹⁶ ***	0.77	529.6
	Total	0.075 (0.029- 0.12)	2.77 (2.67- 2.86)	0.023 0.047	3.20 58.21	0.00145 <2×10 ⁻¹⁶ ***	0.853	3388
Log Wt= log a + b log Lt _{el}	F	0.50 (0.42- 0.59)	2.52 (2.29- 2.75)	0.04297 0.11831	11.69 21.29	<2×10 ⁻¹⁶ *** <2×10 ⁻¹⁶ ***	0.71	453.1
	M	0.51 (0.42- 0.61)	2.50 (2.26- 2.74)	0.04699 0.12123	10.95 20.60	<2×10 ⁻¹⁶ *** <2×10 ⁻¹⁶ ***	0.73	424.3
	Total	0.51 (0.44- 0.57)	2.52 (2.35- 2.67)	0.031 0.082	16.41 30.62	<2×10 ⁻¹⁶ *** <2×10 ⁻¹⁶ ***	0.73	937.6
Log Wt= log a + b log Lt	F	-1.83 (-2.05,- 1.62)	2.89 (2.7- 3.079)	0.10781 0.09602	-17 30.09	<2×10 ⁻¹⁶ *** <2×10 ⁻¹⁶ ***	0.83	905.6
	M	-2.16 (-2.31,- 2.003)	3.19 (3.06- 3.33)	0.07811 0.06865	-27.62 46.51	<2×10 ⁻¹⁶ *** <2×10 ⁻¹⁶ ***	0.93	2163
	Total	-1.92 (-1.99,- 1.84)	2.97 (2.91- 3.05)	0.03962 0.03524	-48.50 84.45	<2×10 ⁻¹⁶ *** <2×10 ⁻¹⁶ ***	0.92	7132

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Log transformation of the data for the length-weight relationships linearizes the relationship and erases problems of heteroscedasticity (Table 6). Fisher's *F* statistic applied on the “log-log” models shows a very high overall significance of the models with varying values between 424.3-7132 and a *P*_{value} <2.2×10⁻¹⁶, which is significant at $\alpha = 0.001$. Student's *t*-test shows high significance of the slope coefficients *b* at the 99.9% confidence level (*Pr* (>|*t*|< 2×10⁻¹⁶) (Table 6). The values of the intercept *a* are significant for all models except for the model log Wt = log a + b log Lc. The value of this parameter for the total weight-cephalothoracic height relationship being: *a* = 1. The standard error calculated for each of the models indicates confidence interval values

ranging from 2.26-3.33 and -2.31-0.57 for the parameters b and $\log a$ respectively (Table 6).

The estimated R^2 for each model is very close to 1 (0.71-0.93) indicating a very good fit and a strong linear relationship between the logarithm of weight and the logarithm of length (Table 6). The set of tests applied show a very good fit of the length-weight relationships. The slope coefficients b of the models of the length-weight relationship indicates a negative allometry ($b < 3$) and a positive allometry for males of the total weight-total length relationship. This results in a relatively lower weight growth than the “total”, “cephalothorax” and “telson length” for both sexes and for the whole population. However, *S. mantis* males show faster growth in “total length” than weight ($b > 3$) (Table 6). The calculated reduced difference t -test indicates a significant difference between the observed slope values and the theoretical value of 3 for the length-weight relationships ($t < 1.96$, $\alpha = 0.05$), except for the two “total length-total weight” relationships for females and combined sex ($t = 1.15$, $0.83 < 1.96$). This result suggests that “total weight” growth is proportional to the cube of “total length” growth for females and for the sex-mixed *S. mantis* population (isometry).

Mortality

The instantaneous total mortality coefficient (Z) for *S. mantis* was 1.32/year. According to Pauly (1983) (Eq. 3), natural mortality (M) was calculated as 0.95/year using $L_\infty = 18.99$ cm and $K = 0.48$ yr⁻¹ and a water temperature (T°) of 15.3°C (Shaltout and Omstedt, 2014). Fishing mortality (F) was 0.37/year (Fig. 6). Exploitation rate (E) indicates whether a stock is overfished based on the fishing mortality rate (F), while assuming that the optimal value of E is approximately equal to 0.5 (Gulland, 1971). The value of E obtained in the present study (0.28) was lower than the optimal value, which is in line with the catches actually observed in the field (under-exploited stock).

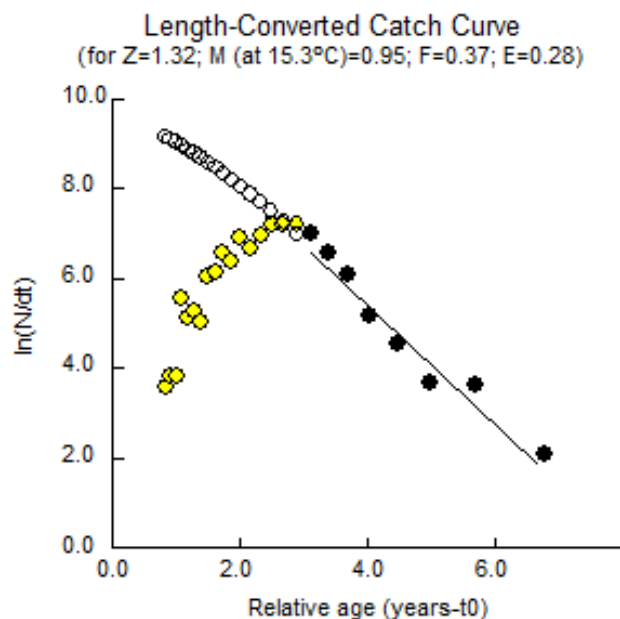


Figure 6. Length-converted catch curve of mantis shrimp from the Mediterranean-Western basin. (Yellow represents points on the ascending part of the catch curve that were not included in the regression analysis to estimate total mortality Z . The black dots represent the descending part used in the estimation of Z .)

Discussion

The average lengths obtained by the different measurements considered as well as the average total weight are compared with the results of other authors. The average total length (*Lt*) of males (13.7 cm) is the same as that obtained by Ragonese et al. (2012) and is very close to that observed by Mili et al. (2013) in the Tunis area (13.92 cm). For females, the average cephalothoracic length (*Lc*) (3.08 cm) is comparable with those of Mili et al. (2013) in the Gabes area (3.089 cm) (*Table 1*). The average total weight (29.18 g) remains between the values of Erdoğan Sağlam et al. (2017): 22.14 g and Torres et al. (2017): 35.3 g.

For each growth parameter (L_{∞} , K , and t_0) obtained, the calculation was performed using “total length” and “cephalothoracic length”. The asymptotic “total length” of females (18.25 cm) is lower than those of other Mediterranean authors, whereas for males this parameter is very close to that found by Erdoğan Sağlam et al. (2017). The asymptotic “cephalothoracic” length of females (39.4 cm) is identical to that obtained by Abelló and Martín (1993) (*Table 7*). For all sexes combined, the present results of growth parameters are very similar than those noted by Erdoğan Sağlam et al. (2017) and Ragonese et al. (2012) (*Table 7*). The coefficients of catabolism K estimated from “total” and “cephalothoracic lengths” are very similar, with a slight difference in favor of females. These estimated coefficients are consistent with the more or less low longevity character of the squilla *S. mantis* (Maynou et al., 2004).

Table 7. Growth parameters obtained by different authors in the Mediterranean Sea

Authors	Region	Length measurement	Sexe	N	L_{∞} (mm)	K (y ⁻¹)	t_0 (y)	ϕ'
Froggia (1996)	Central Adriatic Sea	Lc	F		41.88	0.448	-0.038	2.90
			M		41.18	0.532	-0.059	2.96
			F+M		41.53	0.49	-0.010	2.93
Righini & Baino (1996)	Ligurian Sea	Lt	F		220	1.45		4.85
			M		225	1.3		4.82
Ragonese et al (2012)	Southern coasts of Sicily	Lt	F+M	484	190	0.41	-0.52	4.17
Mili et al. 2013	Gulf of Tunis	Lt	F	1564	179.1	1.44	-0.57	4.66
			M	1726	188.3	1.400	-0.39	4.70
	Gulf of Hammamet		F	1404	187.1	1.430	-0.24	4.70
			M	1620	198.2	1.330	-0.26	4.72
	Gulf of Gabes		F	7799	188.4	1.560	-0.31	4.74
M	8770	204.6	1.330	-0.3	4.75			
Erdoğan Sağlam et al. (2017)	Izmir Bay (Aegean Sea)	Lt	F	549	192.8	0.510	-0.36	4.28
			M	387	183.43	0.420	-0.45	4.15
			F+M	936	196.9	0.500	-0.37	4.29
		Lc	F	549	46.3			
			M	387	45.7			
			F+M	936	47.4			
Present study	Algiers region (SW Medit.)	Lt	F	490	182.5	0.69	-0.56	4.36
			M	422	185.6	0.67	-0.57	4.36
			F+M	1064	189.9	0.48	-0.66	4.24
		Lc	F	490	39.40	0.71	-0.51	3.04
			M	422	42.50	0.64	-0.53	3.06
			F+M	1064	48.06	0.34	-0.69	2.90

The determination of the age-length key, established from the method of Bhattacharya (1967) and the Von Bertalanffy curve (Eq. 1), has given satisfactory results. Indeed, between three and four age classes are observed in most Mediterranean authors (Figs. 4,5); the studies carried out in the Bay of Cadiz (northeastern Atlantic Ocean), based on the length of the carapace, have determined two age groups in females and males (Vila et al., 2013); this same result was also observed by Mili et al. (2013) on the Tunisian coast. On the southern coasts of Sicily, three age groups are observed (1-3) (Ragonese et al., 2012). Erdoğan Sağlam et al. (2017) note four age groups in Izmir Bay (Aegean Sea), a result similar to this work (Figs. 4,5). The differences found with previous authors may be due to the methods used for size structure decomposition or simply the vagaries of sampling. The difference between the study areas where the samples were taken could be the first source of variability in the results.

The length versus age correspondence presented by Bhattacharya's method of total length in males and females shows very similar lengths with Ragonese et al. (2012) and the same size of 15.7 cm obtained at age 3 in females with Erdoğan Sağlam et al. (2017) (Table 4).

The growth parameters given by this study are very comparable with other Mediterranean research (Table 7). Indeed, Mili et al. (2013) presented very similar values in the Gulf of Tunis, Hammamet and Gabes. This emphasizes the current results given the proximity of the two study regions. For all sexes, the asymptotic total length is identical to that found by Ragonese et al. (2012). As for the results based on "cephalothorax length", the asymptotic length of males ($L_{c\infty}$) is close to that obtained by Froglija (1996) in the central Adriatic Sea. The growth rate K is between 0.41/year and 1.56/year for *S. mantis*, the results obtained in this study are within this range except for both sexes combined considering "cephalothorax length" (0.34/year) (Table 7).

This difference found with other authors who determined the growth parameters of *S. mantis* can likely be attributed to the environmental conditions (temperature, salinity, nutrients) or to the fishing pressure exerted on the stock of this species which differs according to the region. According to the growth performance estimated in this study (Table 7), the values of Φ' are greater in the Ligurian Sea (Righini and Baino, 1996) and in the Gulfs of Tunis, Hammamet, and Gabes (Mili et al., 2013) but are highly similar compared to those in the central Adriatic Sea and Izmir Bay (Froglija, 1996; Erdoğan Sağlam et al., 2017) (Table 7).

Concerning the biometric relationships, the "length-length" relationships are strong ($R^2 = 0.68-0.82$), with a slope a for both sexes between 0.67 and 4.88: for females ($0.67 < a < 4.88$) and males ($0.67 < a < 4.33$) indicating a growth with minoring allometry ($a < 1$) for telson size versus cephalothorax. A growth with majoring allometry ($a > 1$) was recorded for the "total-length-cephalothorax" and "total-length-telson" relationships for both sexes, reflecting a higher total growth than both sizes; cephalothorax and that of telson (Table 5). As for the "total weight-cephalothorax length", "total weight-telson length" and "total weight-total length" relationships, the coefficient of determination R^2 is very high (0.71-0.93), reflecting a strong body response of weight to length changes in the *S. mantis* population (Table 6). Erdoğan Sağlam et al. (2017) found isometry in the "total length-weight" relationship for males and females, with slope values equal to 2.95 and 3.02, respectively, reflecting isometry (Table 8).

The "length-length" relationship (L_t-L_c) gives values close to those of Mili et al. (2008) in the Gabes region (Table 8). This author is the only one who considered the

length of the telson and their results are very comparable to this study (Tables 5,8). Indeed, the calculated *Ltel-Lc* relationship gives an "a" in males and females (0.67 and 0.66, respectively) close to the one obtained by Mili et al (2008) in Gabes (0.73 and 0.70). The "length-weight" relationship (*Wt-Lt*) of our results, showing an isometry between length growth and weight growth, are also very comparable to those of Ragonese et al. (2012) and Erdoğan Sağlam et al. (2017) for females, males and for both sexes combined. As for the *Wt-Lc* relationship, the results are supported by those reported by Righini and Baino (1996), Abelló (1989), Mili et al. (2008) (Hammamet), Vila et al. (2013) and Erdoğan Sağlam et al. (2017).

Table 8. Length-weight and length-length relationship parameters obtained by different authors in the Mediterranean

Authors	Region	Relation	Male		Female		Combined	
			a	b	a	b	a	b
Giovanardi and Piccinetti Manfrin (1984)	Adriatic Sea	Lc-Wt	0.0116	3.0431	0.0138	2.9168		
Abello and Sarda (1989)	Ebro delta (NW Mediterranean)	Lc-Wt	0.0026	2.8305	0.0020	2.9026		
		Lc-Lt	0.7637	0.8937	0.6164	0.9523		
Frogli (1996)	Adriatic Sea	Lc-Wt	0.0014	3.0425	0.0014	3.0419		
Righini and Baino (1996)	Ligurian Sea	Lc-Wt	0.0356	2.6100	0.0526	2.4100		
Mili et al.(2008)	Tunisian water (Tunis)	Ltel-Lc	0.786	1.0135	0.8592	0.99	0.821	1.0021
		Lc-Lt	5.4649	0.9374	4.8955	0.9712	5.2613	0.9526
		Lc-Wt	0.0008	3.026	0.0006	3.11	0.0007	3.0673
	Tunisian water (Hammamet)	Ltel-Lc	0.9387	0.9644	0.9168	0.972	0.9269	0.9684
		Lc-Lt	5.5116	0.9389	5.1155	0.6909	5.299	0.9505
		Lc-Wt	0.0013	2.8864	0.0011	2.9165	0.0012	2.9019
	Tunisian water (Gabes)	Ltel-Lc	0.7302	1.0414	0.7087	1.0624	0.7211	1.0461
		Lc-Lt	4.9131	0.9776	4.494	1.0553	4.7074	0.9909
		Lc-Wt	0.0006	3.1279	0.0006	3.1555	0.0006	3.1431
Ragonese et al. (2012)	South of Sicily	Lt-Wt	-11.561	3.031	-11.534	3.027		
Vila et al. (2013)	Gulf of Cadiz (E-C Atlantic)	Lc-Lt	6.8589	0.8879	7.2757	0.8766	7.3949	0.8693
		Lc-Wt	0.00677	2.5465	0.004347	2.6725	0.005118	2.6263
Erdogan Saglam et al. (2017)	Izmir Bay	Lc-Lt	0.2317	0.1087	0.2410	0.0117	0.2373	0.0378
		Lc-Wt	0.7733	2.92	0.8670	2.87	0.8046	2.91
		Lt-Wt	0.0111	2.95	0.0098	3.02	0.0098	3.02
Torres et al. (2017)	Gulf of Cadiz	Lc-Wt					1.709	2.842
Kampouris et al. (2018)	Gulf of Thermaikos Aegean Sae	Lc-Wt	2.670	2.737	2.941	3.189	2.881	3.087
Present study	Algiers region (SW Medit.)	Lc-Wt	1.0876	2.7	1.0575	2.78	1.0778	2.77
		Ltel-Wt	1.6652	2.50	1.6487	2.52	1.6652	2.52
		Lt-Wt	0.1153	3.19	0.1604	2.89	0.1466	2.97
		Ltel-Lc	0.67	0.23	0.668	0.24	0.669	0.24
		Ltel- Lt	3.33	3.22	4.477	2.973	4.36	3.19
		Lc-Lt	3.46	2.40	3.795	1.60	3.78	1.70

The calculation of exploitation indices provided insight into the status of the stock. Fishing mortality F is 0.95/year, a value very close to that recorded in southern Sicily by Ragonese et al. (2012), but still lower than that found by Erdoğan Sağlam et al. (2017) in Izmir Bay in 2017 (1.16/year). The latter Mediterranean region exploits mantis shrimp weakly with an exploitation rate of 0.39. In the central Algerian region, this exploitation is even lower; E is equal to 0.28 because the fishery does not target this species (Fig. 6).

Conclusion

This study is the first of its kind to give results on the growth parameters and mortality of *S. mantis* from Algeria. It was based on length-frequency data which can provide valuable information on the life history of the mantis shrimp in this country.

Overall, the study contributed to the knowledge of the population dynamics of *S. mantis* exploited in the central region of Algeria and provided basic parameters essential for the management of the stock of this species in this area. We showed that the spottail mantis shrimp has a rapid growth in this area and a low longevity. The study of biometric relationships revealed the following findings: a) growth in "total weight" is proportional to the cube of growth in "total length" for females and for the mixed-sex population of *S. mantis* (isometry) and b) growth with a major allometry for males. For growth in length, cephalothorax grows faster than telson for all *S. mantis* specimens and "total length" grows faster than "cephalothorax" and "telson".

This study carried out from the catches of the commercial fishery in the central region of Algeria shows an under-exploitation of the *S. mantis* stock. Nevertheless, the fishing statistics of this species show an evolution of the catches in 2016. This limited fishing pressure may be considered as an important issue to protect the *S. mantis* population in this region. In this study, it is noted that the fishery is carried out by trawls with a large horizontal opening, but it is discarded at sea. In our country, the discarding of this species, which is beginning to attract consumers, represents a loss for the national economy and the regional fishery.

In other countries such as Italy, Spain, France and Slovenia, this species is economically valued. As a result of this study, the population parameters of *S. mantis* are similar to those of the European countries that fish this species economically. It could be exported to European countries or fished as a target species instead of being discarded in Algeria. The lack of knowledge concerning the biology of *S. mantis* is evident and further research is needed. The present study is the first one carried out in Bou-Ismaïl Bay (central region of Algeria). Future studies should focus more on this species in order to enhance its value.

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