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Length-weight relationships of *Squilla mantis* (Linnaeus, 1758) (Crustacea, Stomatopoda, Squillidae) from Thermaikos Gulf, North-West Aegean Sea, Greece

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Abstract
The length-weight relationships (L-W) and the allometric growth profile of the stomatopod *Squilla mantis* was studied from Thermaikos Gulf, Aegean Sea, Greece. In total, 756 individuals were collected, by artisanal net fishery and log transformed data were used at the (L-W) relationships assessment. Three body parts were measured [carapace length (CL), abdominal length (ABL), and telson width (TW)]. Both females and males demonstrated similarities at their allometric profiles except for CL-W, where females present positive allometric profile and males negative. The present findings are mostly in accordance with earlier studies from Mediterranean.

Keywords: *Squilla mantis*, stomatopoda, allometric growth, fisheries, Aegean Sea, east Mediterranean Sea

1. Introduction
Squilla mantis (Linnaeus, 1758), spot-tail mantis shrimp, belongs to the Order Stomatopoda, generally known as mantis shrimps. Mantis shrimps are ecologically important organisms in tropical and temperate ecosystems around the globe (Antony *et al*. 2010) [1]. Mantis shrimps can be dispensed in two distinct groups based on their external morphology. The group of "smashers" that dwell in hard substrata and the group of "spearers" that dwell in soft substrata (Ahyong 2001) [2]. The latter group is not well studied because of their behaviour and habitat selection (deep and murkier habitats). Most of the "spearers" species constitute a significant bycatch of the prawn fishery and depending on location may be considered as nuisance (e.g. USA, Najiah and Lee 2008) [3] or as an important food resource (e.g. Mediterranean Sea; Maynou *et al*. 2005, Costa Rica, Hernáez *et al.* 2011) [4, 5]. *S. matis* occurs in Mediterranean Sea and the adjacent waters of east Atlantic Ocean (see Maynou *et al.* 2005) [4]. The species inhabits sandy and muddy bottoms at the sublittoral zone, deep as ≈400 m but commonly at 150 m (Abelló *et al.* 2002) [6]. The substrate composition, fine sand and sandy-mud is preferable, is essential for the species behaviour since it burrows U-shaped shelters (Atkinson *et al.* 1997) [7]. Spot-tail mantis shrimps prefer areas where there is a strong river inflow. Such like areas are the Gulf of Cadiz in Atlantic Ocean (Vila *et al.* 2013) [8] while at the Mediterranean basin the species is abundant on the continental shelves of rivers Ebro, Rhone Po and Nile (Lewinsolm and Manning 1980) [9] and at the gulfs of Tunis, Hammamet and Gabes in Tunisia (Mili *et al.* 2011, 2013a) [11, 12]. The spot-tail mantis shrimp is the most economic important mantis shrimp species among Mediterranean countries (Rossetti *et al.* 2005, Mili *et al.* 2011, Ragonese *et al.* 2012, Mili *et al.* 2013a) [11-14]. But, the Lessepsian *Erugosquilla massavensis* (Kossmann, 1880) is also fished in the eastern Mediterranean basin (Maynou *et al.* 2005, Ragonese *et al.* 2012) [4, 14]. In Mediterranean Sea, the spot-tail mantis shrimp is mainly fished with trawling, otter trawls, trammel, gill nets and baited traps (Maynou *et al.* 2005, Mili *et al.* 2013b) [4, 15] targeting prawn and lobster species such as the prawns *Penaeus kerathurus*, *Metapenaeus monoceros*, *Parapenaeus longirostris* and the Norway lobster *Nephrops norvegicus*, or fish species like soles (*Solea sp.*), red mullets (*Mullus sp.*), monkfish (*Lophius sp.*) among others.

Furthermore, in Italian waters the species is caught by a modified beam trawl that is called "rapido". This unique fishing gear is used at flatfish and scallop fishery and it seems to be a very efficient tool, regarding *S. mantis* (Rossetti *et al.* 2005) [13]. In Greece, the species occurs throughout Ionian and Aegean Seas (Lewinsohn and Manning 1980) [9] but its economic importance varies from nothing (e.g. Argolikos Gulf, Kapiris *et al.* 2014) [16] to 7 euros/ kg from Thermaikos Gulf (pers. comm.). The species fishery in Thermaikos Gulf is mainly conducted with bottom trawling, during winter when the species migrates into deeper waters in a depth of 30-40 m. Also, in a smaller percentage spot-tail mantis is fished with trammel nets, usually with mesh size of 20-22 mm from knot to knot during summer -when the species migrates at shallower areas, and during winter by netting and mesh opening of 42-45 mm (pers. comm.).

Length-weight (L-W) and/or length-length (L-L) relationships are often used to study population characteristics of many crustacean species (e.g. *Aristaeomorpha foliacea*, Ragonese *et al.* 1997, *Palinurus elephas*, Tidu *et al.* 2004, *Harpiosquilla raphidea*, Antony *et al.* 2014, *Astacus astacus,* Duretanović *et al.* 2016, *Parapenaeus longirostris,* Chatzispyrou *et al.* 2018) [17-21]. Moreover, these equations contribute at the species' life history understanding (Josillen, 2011) [22] such as changes during growth (Radhakrishnan *et al.* 2015, Martínez-Calderón *et al.* 2018) [23, 24] or variability amongst populations of the same species (e.g. Maguire *et al.* 2017) [25], that may hide genetic diversity. Morphometrics are quite important when examining populations of alien or invasive species (e.g. *Ruditapes philippinarum*, Nerlović *et al.* 2016) [26]. For instance, the alien prawn *Penaeus aztecus* (Ives, 1891) grows larger in Mediterranean Sea (Deval *et al.* 2010) [27]. Also, these relationships set the basis at population modelling (e.g. Zheng *et al.* 1995) [28], therefore are quite useful at studies of fisheries biology (e.g. Herter *et al.* 2011) [29]. Furthermore, biometric studies are useful in ecological studies since populations of the same species may exhibit morphological differences that reflect adaptations to the local environmental conditions (Debuse *et al.* 2001; Brash *et al.* 2017) [30, 31].

The species is far from well-studied in Greek waters and east Mediterranean Sea, with only two published studies being available (Kapiris *et al.* 2015; Erdoğan Sağlam *et al.* 2018) [32, 33]. Kapiris *et al.* (2015) [32] presents some relative preliminary data from Greece and highlights the necessity for further research like ours. This study presents new data on the morphology and growth patterns of the spot-tail mantis shrimp from Thermaikos Gulf for the first time. Moreover, we compare our data with earlier studies with comparable data.

2. Materials and Methods

2.1 Study area

Thermaikos Gulf is at the north-western Aegean Sea. It is the largest gulf (5,100 km^2) in the area and is one of the most productive parts of the eastern Mediterranean basin (Sakellariou and Alexandri 2007) [34], that supports the most important fishing activity in the Hellenic waters (Stergiou *et al.* 1997) [35]. The gulf's physical characteristics demonstrate seasonality with deviations from an average pattern. Furthermore, significant forces forming the *status quo* are the inflows/outflows from/to Aegean Sea and the riverine fluxes of freshwater from several large or smaller rivers (Krestenitis *et al*. 2012) [36]. With an extensive shelf, little depth variation and dominated by soft sediments -that are amplified by the heavy trawling activity (Dimitriadis *et al.* 2014) [37] and which are influence the resuspension generally (Tragou *et al.* 2005) [38] and are several times higher in comparison with the contribution from the major rivers in the area (Kombiadou and Krestenitis, 2011) [39], Thermaikos Gulf supports more than 80% of the Hellenic mussel production. Thermaikos Gulf also receives about 120,000 m^3/ day of sewage from the city of Thessaloniki and 25,000 m^3/ day of industrial discharges (Katsikatsou *et al.* 2011) [40]. The caramote prawn *Penaeus kerathurus* and the pink shrimp *Parapenaeus longirostris* were the main two decapod species that was believed to be exploited in Thermaikos Gulf (Thessalou-Legaki, 2007) [41]. Also, some fishing activity regarding *Palinurus elephas* (Fabricius, 1787) was described by Kampouris *et al.* (2018) [42].

2.2 Sampling methodology

The *S. mantis* samples were collected with the artisanal fishing vessel "Kronos" (9.2m long, 115 HP) and by using tangle nets. The mesh size was 20-22 mm from knot to knot during summer, and 42-45 mm during winter. The sampling period was one year (December 2014-December 2015). Nets were soaked for 10-14 hours.

2.3 Morphometric measurements

The *S. mantis* specimens' measurements regard CL= Carapace length, ABL= Abdominal length, TW= Telson width and W= Weight (wet), following the description by Antony *et al.* (2014) [19] and Kapiris and Conides (2009) [43]. Sex identification was based on the external morphological differences (Erdoğan Sağlam *et al.* 2018) [33].

Length-Weight relationships were expressed by the logarithmic form $logW = loga + blogL$. Where W= wet weight, L = ABL or CL or TW or BL, a = intercept and b = slope. The constants a and b were estimated by the linear regression from logarithmically transform data. The degree of association between length- weight variables was determined by coefficient (r^2). The types of allometric growth are determined by the values of constant b (b < 3 negative allometry, b = 3 isometry, b > 3 positive allometry (Zhang *et al.* 2017) [44].

2.4. Statistical analyses

GraphPad Prism 6.0. software was used to conduct the Length/weight relationships and the Student's t-test, to assess potential differences between sexes. Spatial and distributional differences were determined by the abundance and the biomass of the species. The sexes ratio differences, based on a theoretical 1:1, were assessed with Chi-square (χ^2) analysis. ANOVA used to assess the significance of linear regression.

3. Results

During this study, a total of 756 spot-tail mantis shrimps were sampled, of which 429 (56.7%) were females and 327 (43.3%) were males. The population significantly ($\chi^2 = 13.7$; $P < 0.05$) diverts from the theoretical 1:1, and females are dominant in 1.31:1 ratio. Significant differences between sexes were observed regarding the CL. In contrary, no significant differences, regarding ABL, TW and W were observed.

The mean carapace length (CL) for females, was 38.25 ± 6.43 mm with maximum and minimum value of 54.98 and 20.73 mm respectively. The mean CL for male mantis shrimps was 40.67 ± 5.39 mm with maximum and minimum values 56.77 and 22.26 mm respectively. The abdominal length (ABL) for females ranged from 35.18 mm (min) to 153.42 mm (max), while mean ABL was 107.33 ± 17.57 mm. Also, males had a mean ABL of 111.13 ± 14.76 mm with maximum and minimum values of 166.07 and 65.24 respectively. The mean telson width (TW) for females 22.53 ± 4.54 and ranged from 10.05 (min) to 32.22 (max). The mean (TW) for males was 23.99 ± 3.72 with minimum 7.14 mm and maximum 31.61 mm. Moreover, weight (W) measurements demonstrated that the mean weight of females was 32.47 ± 15.65 g with maximum and minimum values of 78 and 3.5 g respectively. In males the mean (W) was 38.62 ± 14.28 g with maximum and minimum values of 86 and 5 g respectively (Table 1). When merging sexes, the mean CL was 40.67 ± 5.39 mm, the mean ABL was111.13 ± 14.76 mm, the mean TW 23.99 ± 3.72 mm and the mean W 38.62 ± 14.28 g (Table1).

Table 1: Mean and Standard Deviation of CL, ABL, TW and W regarding the mantis shrimp measurements

		Carapace Length (CL)	**Abdominal Length (ABL)**	**Telson Width (TW)**	**Weight (W)**
Females (n = 429)	Mean ± SD	38.25 ± 6.43	107.33 ± 17.57	22.53 ± 4.54	32.47 ± 15.66
	Minimum	20. 73	35.18	10.05	3.5
	Maximum	54.98	153.42	32.22	78
Males (n = 327)	Mean ± SD	40.67 ± 5.39	111.13 ± 14.76	23.99 ± 3.72	38.62 ± 14.28
	Minimum	22.26	65.24	7.14	5
	Maximum	56.77	166.07	31.61	86
Merged (n= 756)	Mean ± SD	39.3± 6.12	108.97 ± 16.51	23.16 ± 4.26	35.13 ± 15.37
	Minimum	20.73	35.18	7.14	3.5
	Maximum	56.77	166.07	32.22	86
SD: standard deviation, CL, ABL, TW: measured in mm, W: refers to wet weight, measured in g					

The parameters of CL-W, ABL-W and TW-W relationships are presented in Table 2. The CL-W relationships for females, males and merged sexes, are illustrated at Fig. 1. Females as well as merged sexes showed positive allometric growth and male individuals negative allometric. The ABL-W relationships for females, males and merged sexes, are illustrated at Fig. 2. Females, males and merged sexes showed positive allometric growth. The TW-W relationships for females, males and merged sexes, are illustrated at Fig. 3. Both female and male individuals, and merged sexes showed negative allometric growth.

Table 2: The parameters of CL-W, ABL-W and TW-W relationships, of *S.mantis* from Thermaikos Gulf.

Sex	**CL-W**			
	a	**b**	**SE(b)**	**r^2**
Female	2.941	3.189	0.1323	0.7424
Male	2.670	2.737	0.1594	0.6901
Merged	2.881	3.087	0.0999	0.7359
	ABL-W			
	a	**b**	**SE(b)**	**r^2**
Female	2.899	4.424	0.1903	0.6904
Male	2.729	4.025	0.2103	0.6839
Merged	2.892	4.386	0.1435	0.6901
	TW-W			
	a	**b**	**SE(b)**	**r^2**
Female	2.315	1.663	0.0919	0.7293
Male	2.178	1.445	0.1043	0.7179
Merged	2.301	1.632	0.0687	0.7334

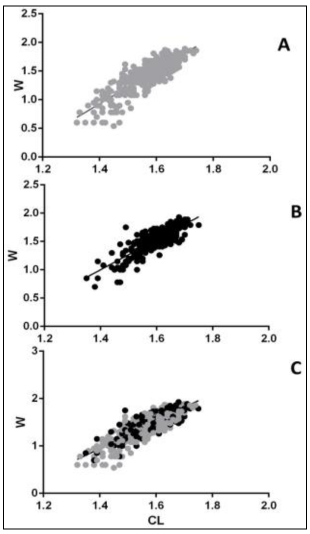

Fig 1: CL-W relationships. (A) females, (B) males, (C) merged sexes.

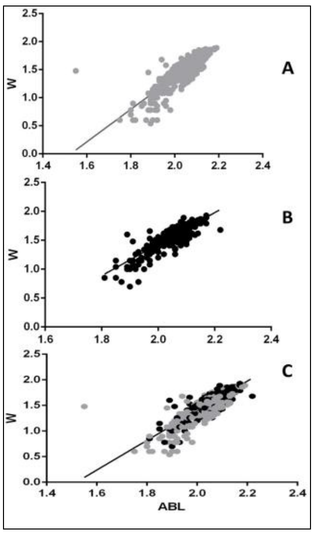

Fig 2: ABL-W relationships. (A) females, (B) males, (C) merged sexes.

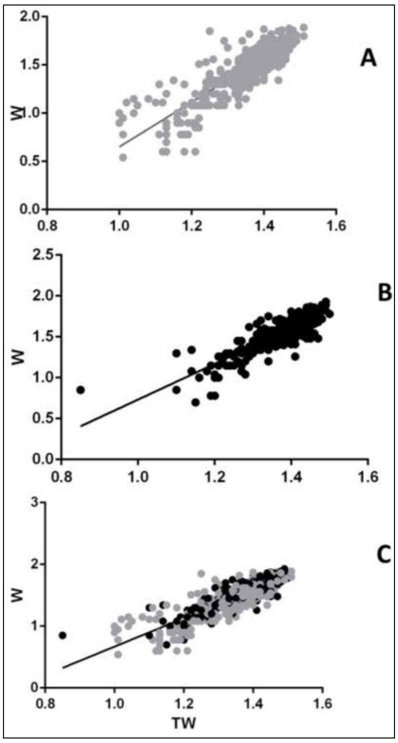

Fig 3: TW-W relationships. (A) females, (B) males, (C) merged sexes.

4. Discussion

The species is far from well-studied, and most of the relative data regard west Mediterranean Sea. Consequently, relative quantitate data from eastern basin are missing and studies like the present are essential. The sampling size (n=756) and the size range-weight wise and lengthwise, covers different size classes. For instance, the minimum weight is 3.5 g and the maximum is 86 g -approximately 24 times more than minimum, while the minimum CL value (20.73 mm) is roughly the 1/3 of the maximum value (56.77 mm). The coefficient determination (r^2) were not high (≤0.74) and not significant indicating distant relations. Meaning, that as mantis shrimps grow, other dimensions of the body are not changing significantly, in relation to the abdominal length and carapace length. The CL-W, in males, showed a positive allometric growth. Perhaps that could be explained by the fact that the carapace bears the raptorial claws, but further data are needed to support this hypothesis. Although, that the abdomen growth pattern seems to be distinct in mantis shrimps (Antony *et al.* 2014) [19], our results are not indicating suchlike dimorphism, since all (females, males, and merged sexes) demonstrated positive allometry. Males seem being larger and heavier at the study area, but females have a wider telson.

Regarding the morphometric relationships and the allometric growth of the mantis shrimps at Thermaikos Gulf the present results are partially in accordance with the earlier studies, comparisons among CL-W. Female individuals have a positive allometric pattern that is in contrast with all previous studies (Vila *et al.* 2013; Kapiris *et al.* 2015; Erdoğan Sağlam *et al.* 2018) [8, 32, 33]. This disparity could be affected by either the sampling size (n=321, Vila *et al.* 2013, n= 152, Kapiris *et al.* 2015) [8, 32] or the sampling methodology (trawlers, Vila *et al.* 2013, Kapiris *et al.* 2015) [8, 32]. Remarkably, the present data are in contrast with the study of Erdoğan Sağlam *et al.* (2018) [33], where the sampling size is similar n= 936 and the sampling methodology involved the use of nets. Males demonstrated a negative allometric growth pattern and is in accordance with all abovementioned studies. Further comparisons were avoided since our methodologies and measured characters are different.

5. Conclusions

Although that most preferable fishing gear is the use of trawling nets, it seems that this gear might affect the catchability between sexes (Ragonese *et al.* 2012) [14], resulting in potential biases. Thus, for scientific purposes netting or modified trawlers (heavier) -digging deeper into the sediment, should be preferable sampling methodologies.

The relatively low economic species' value did not trigger any systematic population monitoring, therefore a monitoring scheme along with a specific protocol regarding length-weight measurements that would allow systematic populations comparisons and contrasts is essential.

The lack of knowledge regarding the biology of *S. mantis* is apparent and further research is required. The present study is the first from Thermaikos Gulf, the second regarding Greek seas and the third published from east Mediterranean.

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