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Determination of some population parameters of the veined rapa whelk (*Rapana venosa*) in the Central Black Sea

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The veined rapa whelk is one of the most important invasive species in the Black Sea ecosystem since the 1940s. Following its introduction to the Black Sea, it destroyed most of the bivalve populations, mainly the Mediterranean mussel and oysters. However, the veined rapa whelk has commercial importance for the Black Sea fisheries as an alternative product. In this study, we aimed to determine some population parameters of the veined rapa whelk based on indirect ageing through length–frequency data by using the Bhattacharya method. We collected 1704 specimens by dredging along the coasts of Samsun Province in the Central Black Sea in 2011 from June to November. The age of the population varied from 0 to 6. Von Bertalanffy growth parameters were estimated as $L_\infty = 112.35$ *mm,* $k = 0.310$, $t_o = -0.486$ *and* $W_\infty = 243.94$ *g. Mean length and weight, length–weight relationship, mortality and exploitation rates were derived as* $L = 56.80 \pm 0.36$ *mm,* $W = 45.67 \pm 0.89$ *g,* $W = 0.0006\ L^{2.719}$, $Z = 0.96$, $M = 0.57$, $F = 0.39$ *and* $E = 0.40$*, respectively.*

Keywords: veined rapa whelk, *Rapana venosa*, population parameters, Central Black Sea

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INTRODUCTION

The veined rapa whelk is originally native to the Sea of Japan, Yellow Sea, Bohai Sea, and the East China Sea to Taiwan (Chung *et al.*, 1993; ICES, 2004). This species was transported to the Black Sea via the ballast waters of merchant ships, and was firstly observed in Novorossiysk Bay in 1947; then in Crimea in 1949, in Batumi in 1950, in Romania in 1955, in the Bosporus in 1960, and in the city of Trabzon in 1962 (Duzgunes *et al.*, 1997). After 1969 they were distributed to the Sea of Marmara and the Aegean Sea via the Bosporus (Bilecik, 1990). They can be found in all coastal waters of the Black Sea, in depths up to 60 m, in sandy, muddy and algal habitats around mussel banks, and feed on shellfish, such as the Mediterranean mussel (*Mytilus galloprovincialis*), oyster (*Crassostrea gigas*) and Venus clam (*Chamelea gallina*) (Duzgunes, 2001).

Whelks are harvested mainly by dredging and to a lesser extent by diving. In recent years, the use of traps has been recommended by scientists instead of dredging, which is very destructive to the sea bottom and demersal flora and fauna (Saglam *et al.*, 2007). The veined rapa whelk is one of the new stocks exploited by Turkish fishermen since 1986. At present, their total production is 6534 t, of which 6348 t were harvested from the Black Sea in 2011 (TUIK, 2012). The majority of production (97%) comes from the Black Sea, with the region east of Sinop city and the Georgian border accounting for 75% of the total (Figure 1) The production of the veined rapa whelk increased to reach a maximum level (14,034 t) in 2004 and gradually decreased to 6534 t in 2011 due to lack of a sufficient food supply from shellfish stocks and an increase in population; it has no conventional predators, such as starfish, in the Black Sea.

According to observations among Riparian countries it is noted that there is a great scientific interest in carrying out research surveys on *Rapana venosa* (Valenciennes, 1846) stocks in the exclusive economic zones of each country to understand the impact of this invasive species on the Black Sea ecosystem. It is one of the most important research fields of interest of the General Fisheries Commission for Mediterranean (GFCM), the Black Sea Environmental Program (BSEP) and the European Union Scientific, Technical and Economical Committee for Fisheries (STECF). The results of this survey may provide information about the recent state of the veined rapa whelk population in order to inform further management decisions in the Black Sea.

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MATERIALS AND METHOD

This survey was carried out in the coastal waters of Samsun Province which is the major commercial fishing area for veined rapa whelk dredgers that are widely used to harvest this species. Samples were obtained directly from fishing vessels between June and November 2011 and transferred daily to the laboratory in the Faculty of Marine Sciences,

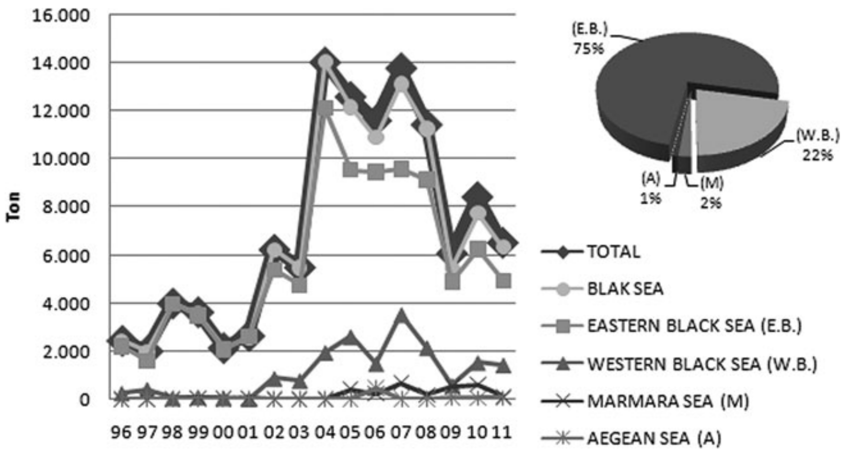

Fig. 1. Catch quantities of the veined rapa whelk in Turkey from 1996 to 2011.

Table 1. Mean total length (mm), weight (g), width (mm) and relationships between length–weight, length–width and width–weight of *Rapana venosa* population in the Central Black Sea in 2011 (±standard error, ranges in parentheses).

	Female (N = 791) **Mean**	**Male (N = 913)** **Mean**	**Total (N = 1704)** **Mean**
Total length (L) minimum–maximum	56.93 ± 0.54 (21.00–107.88)	56.69 ± 0.49 (21.00–102.95)	56.80 ± 0.36 (21.00–107.88)
Witdh (L_w) minimum–maximum	42.49 ± 0.44 (13.00–83.54)	42.44 ± 0.40 (13.00–81.13)	42.47 ± 0.29 (13.00–83.54)
Weight (W) minimum–maximum	45.11 ± 1.34 (1.23–269.20)	45.93 ± 1.20 (1.28–269.20)	45.67 ± 0.89 (1.23–269.20)
$L - L_w$	$L_W = 0.787L - 2.333$	$L_W = 0.799L - 2.851$	$L_W = 0.793L - 2.601$
	$R^2 = 0.943$	$R^2 = 0.947$	$R^2 = 0.945$
$L - W$	$W = 0.0005L^{2.7714}$	$W = 0.0007L^{2.7038}$	$W = 0.0006L^{2.719}$
	$R^2 = 0.8510$	$R^2 = 0.8230$	$R^2 = 0.826$
$L_w - W$	$W = 0.003L_W^{2.484}$	$W = 0.004L_W^{2.397}$	$W = 0.004L_W^{2.437}$
	$R^2 = 0.824$	$R^2 = 0.800$	$R^2 = 0.811$

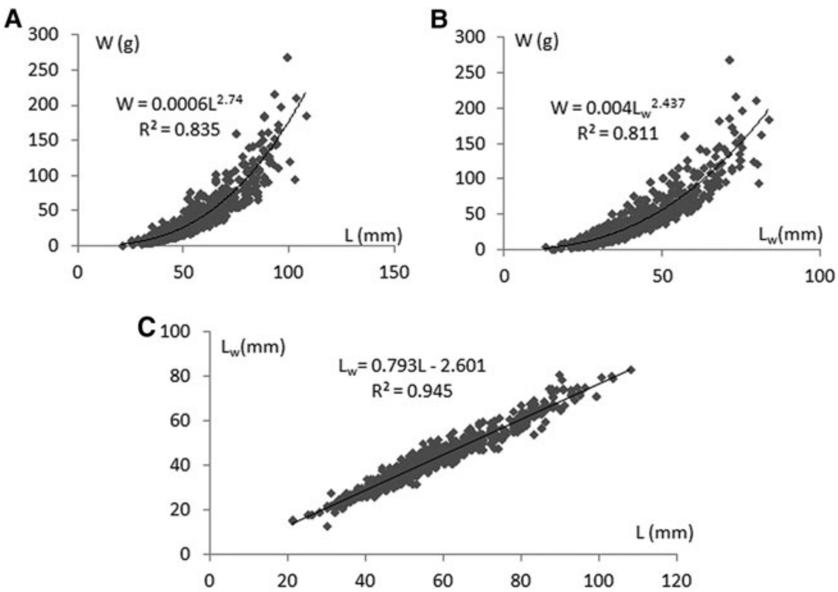

Fig. 2. Length–weight (A), width–weight (B) and length–width (C) relationships in *Rapana venosa* population (both sexes).

Ordu University. When the number of samples was high they were frozen at −35°C to keep samples longer. The length and width of the samples were measured with callipers to the nearest 0.01 mm and weighed with a Prescia balance with 0.001 g sensitivity. Sex determination was done by observing gonads with the naked eye after breaking the shells. The yellow coloured tissue on the terminal of the internal organs is the indicator of a female and a brown colour indicates a male (Erik, 2011). The age of samples was determined by the Bhattacharya method with FISAT software using

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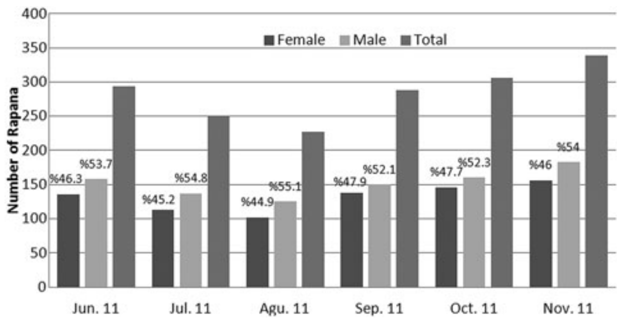

Fig. 3. Frequency distribution of veined rapa whelk by sexes and months in 2011.

Table 2. Mean length, weight, width (± standard error) and sex-ratio of *Rapana venosa* by months.

	N	Length	Weight	Width	Sex-ratio (%)
Female					
June 2011	136	66.48 ± 1.40	61.84 ± 3.83	52.37 ± 1.15	7.98
July 2011	113	58.34 ± 1.47	67.96 ± 4.39	42.56 ± 1.10	6.63
August 2011	102	54.50 ± 0.58	36.91 ± 1.16	43.00 ± 0.49	5.99
September 2011	138	61.50 ± 1.15	42.30 ± 2.23	45.01 ± 0.85	8.10
October 2011	146	46.75 ± 1.00	19.64 ± 1.45	34.06 ± 0.76	8.57
November 2011	156	54.65 ± 1.21	46.93 ± 3.28	39.17 ± 1.00	9.15
Total	791	56.93 ± 0.54	45.36 ± 1.34	42.49 ± 0.44	46.42
Male					
June 2011	158	65.11 ± 1.21	57.60 ± 3.24	51.45 ± 1.03	9.27
July 2011	137	57.28 ± 1.28	69.15 ± 3.72	42.05 ± 1.00	8.04
August 2011	125	54.66 ± 0.52	37.78 ± 1.05	42.82 ± 0.44	7.34
September 2011	150	63.22 ± 1.21	47.48 ± 2.79	46.31 ± 0.93	8.80
October 2011	160	47.79 ± 0.99	21.54 ± 1.64	35.24 ± 0.78	9.39
November 2011	183	52.80 ± 1.04	44.11 ± 2.52	37.84 ± 0.84	10.74
Total	913	56.69 ± 0.49	45.93 ± 1.20	42.44 ± 0.40	53.58
Total					
June 2011	294	65.74 ± 0.91	59.56 ± 2.48	51.87 ± 0.76	17.25
July 2011	250	57.76 ± 0.96	68.61 ± 2.84	42.28 ± 0.74	14.67
August 2011	227	54.59 ± 0.39	37.39 ± 0.78	42.90 ± 0.33	13.32
September 2011	288	62.40 ± 0.84	45.00 ± 1.81	45.69 ± 0.63	16.90
October 2011	306	47.29 ± 0.70	20.63 ± 1.10	34.68 ± 0.55	17.96
November 2011	339	53.65 ± 0.79	45.41 ± 2.03	38.45 ± 0.65	19.89
Total	1704	56.80 ± 0.36	45.67 ± 0.89	42.47 ± 0.29	100.00

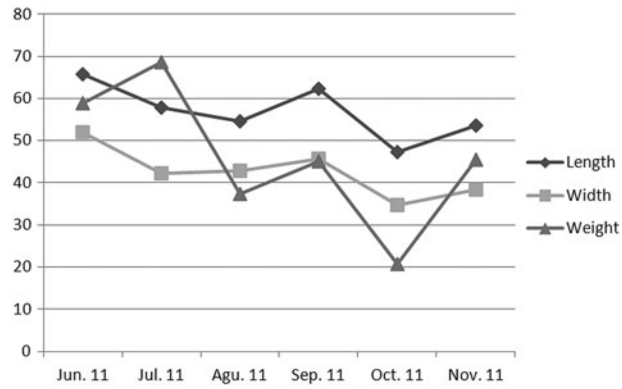

Fig. 4. Mean length, width and weight of *Rapana venosa* by months.

length–frequency data (Bhattacharya, 1967). Length–weight, width–weight and length–width relationships were derived as $W = aL^b$, $W = aL_w^b$ and $L = bL_w - a$, respectively, in which the parameters of '*a*' and '*b*' were calculated by the least squares method (Schaeperclaus, 1967; Lagler, 1969; Ricker, 1975). In these equations W is total weight, L is total length and L_w is width.

Von Bertalanffy growth equations of age–length and age–weight were derived as:

$$L_t = L_\infty[1 - e^{-k(t-t_o)}]$$

$$W_t = W_\infty[1 - e^{-k(t-t_o)}]^b$$

where L_t is length at any age t, L_∞ is asymptotic length, k is Brody growth coefficient, t is age, t_o is theoretical age when length of shellfish is zero, W_t is weight at any age t, W_∞ is asymptotic weight and b is a regression coefficient for the length–weight relationship (Ricker, 1975).

Instantaneous total mortality rate (Z) was calculated from the slope (opposite sign) of the linear relationship between age converted length data ($t_1 = t_o - 1/k \times \ln(1 - L/L_\infty)$ and frequencies ($\mathrm{Ln}N/\Delta t$) of each length group (Sparre & Venema,

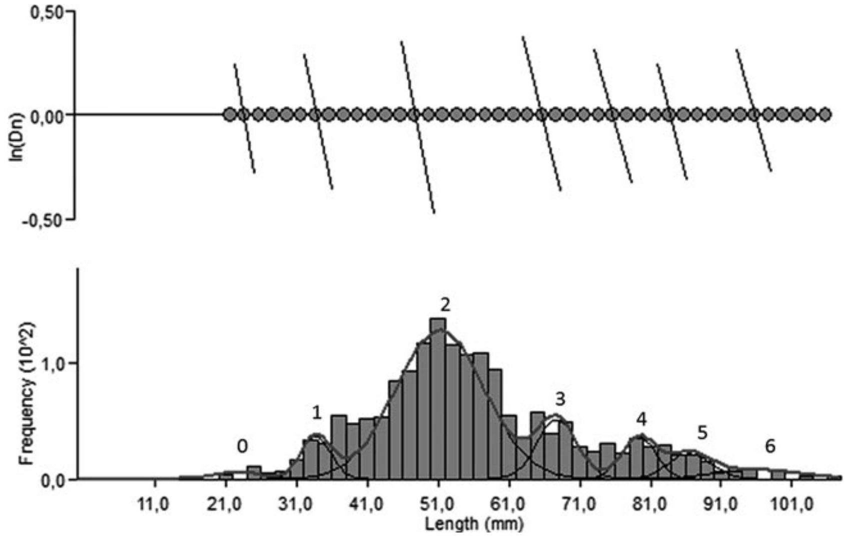

Fig. 5. Composite distributions of the pooled length–frequency composition of veined rapa whelk identified by the Bhattacharya (1967) method.

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Table 3. Mean length (cm) of *Rapana venosa* computed from Bhattacharya method and Von Bertalannfy growth equation (VBGE) at corresponding ages.

Age	Mean length (Bhattacharya method)	Mean length from VBGE
0^+	22.67 ± 0.67	15.71
1^+	33.72 ± 0.22	41.47
2^+	51.30 ± 0.20	60.36
3^+	67.75 ± 0.21	74.22
4^+	79.37 ± 0.23	84.38
5^+	86.53 ± 0.34	91.84
6^+	96.00 ± 0.78	97.31

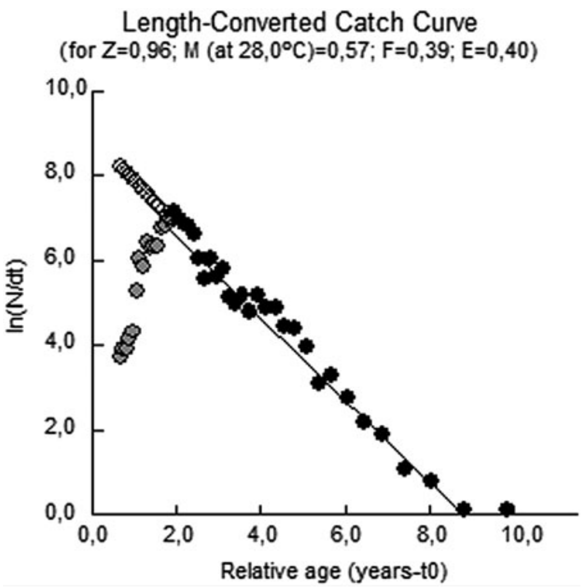

Fig. 6. Length converted catch curve of veined rapa whelk from the Central Black Sea.

1992) where L is length, t_1 is calculated age from mean of each length group, L is mean length, N is frequency and Δt are differences between adjacent two ages. Natural mortality rate was calculated by Pauly's (1980) equation:

$$\text{Ln}M = -0.0152 - 0.279 \times \text{Ln}L_\infty + 0.6543 \times \text{Ln}K + 0.463 \times \text{Ln}T$$

where M is natural mortality rate, L_∞ and K are Von Bertalanffy growth parameters and T is mean water temperature at the bottom in the *Rapana* habitat (15°C) (Sahin *et al.*, 2005).

The fishing mortality and exploitation rates were calculated as $F = Z - M$ and $E = F/Z$, respectively (Gulland, 1988; King, 1995; Avsar, 1997; FAO, 2000).

Statistical analyses were done where necessary, i.e. the Chi square test for testing the differences between sex rates and the Student's *t*-test for comparing mean lengths of sex-ratios on different ages and time (Sokal & Rohlf, 1995).

RESULTS

The mean length, weight and width of 1704 specimens of *Rapana venosa* were calculated as 56.8 ± 0.36 mm, 45.7 ± 0.89 g and 42.5 ± 0.29 mm, respectively (Table 1; Figure 2). Females have slightly higher values than males but the difference is statistically insignificant. Minimum and maximum values of each parameter were also given in parentheses. The length–weight relationship was derived as $W = 0.0006\ L^{2.719}$ for both sexes (N = 1704, $R^2 = 0.826$). According to the statistical analyses there is no difference between the regression coefficient of males and females. The relationship between length–width was found as $L_W = 0.793L - 2.601$ ($R^2 = 0.945$). There is also a strong correlation between the weight and width of *Rapana* as $R^2 = 0.811$ in the equation of $W = 0.004{L_W}^{2.437}$.

The sex-ratio was found as (F:M) 1:1.15. Chi square analyses show that the difference between females (46.42%) and males (53.58%) is not statistically significant. So, it can be said that male and female were equally represented in the *R. venosa* population in the Black Sea. The rates of females to males in the sampling period were derived as 1:1.16 in June, 1:1.21 in July, 1:1.23 in August, 1:1.09 in September, 1:1.10 in October and 1:1.17 in November. The total male to female ratio for 2011 was 1:1.15 (Figure 3). These monthly figures showed that the ratio of females is also less than males in monthly samplings but the differences were also found to be statistically insignificant.

Table 2 and Figure 4 show variations of length, width, weight and sex-ratios by months. The bigger sized individuals were observed in June, then gradually decreased till November. Similar evaluations can be done for mean weight and mean width values for both sexes. The reason for this reduction can be explained by the recruitment of the population after spawning (which starts in May and peaks in June to August) and the addition of younger cohorts to the population. The

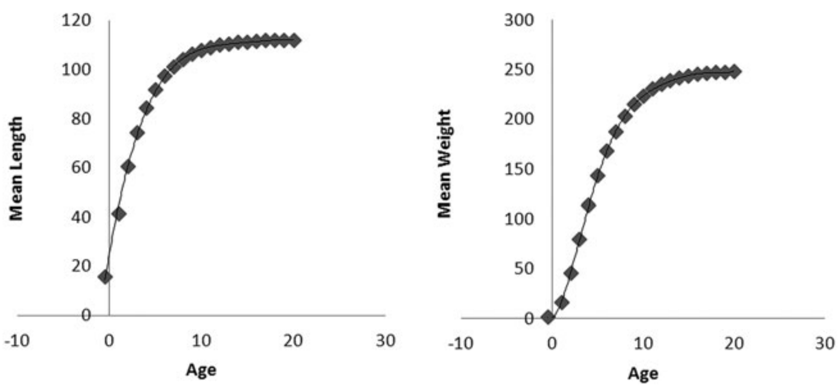

Fig. 7. Age–length and age–weight relationship of *Rapana venosa* population in the Central Black Sea.

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age of *R. venosa* was determined by the Bhattacharya method based on length–frequency distribution of the samples. Figure 5 shows seven age groups derived by this method. The first year-class is the age of 0^+ with a mean length of 22.67 ± 0.66 mm. Other mean lengths for successive ages are given in Table 3. These data were also used in order to estimate Von Bertalanffy growth parameters; L_∞, k and t_o with the Ford–Walford method which were also used to compute calculated lengths. According to the regression between L_t and L_{t+1} the Ford–Walford method gives the estimation of L_∞ and k as, 112.35 mm and 0.310, respectively. The parameter of t_o is −0.486 computed from the length converted catch curve (Pauly, 1979) (Figure 6). The differences between lengths derived by two methods were found to be statistically insignificant. Asymptotic length was also estimated as 243.94 g from the length–weight relationship using the asymptotic length computed. Age–length and age–weight equations can be summarized as follows (Figure 7):

$$L_t = 112.35(1 - e^{0.310(t-(-0.486))})$$

$$W_t = 243.94(1 - e^{0.310(t-(-0.486))})^{2.7354}$$

Mortality rates (Z, M, F) and the exploitation rate were all derived by the catch curve method as $Z = 0.96$, $M = 0.57$ and $F = 0.39$. Annual mortality and survival rates were calculated as 62 and 38% in relation to Z, respectively. The exploitation rate (E) was 0.40 for the 2011 fishing season.

DISCUSSION

In this study, the sex-ratio in the *Rapana venosa* population was found to be 1:1.15; the number of males in the samples was slightly higher than females, though this difference is not statistically important. Saglam (2003) reported the F:M ratio as 1:1.6 for the samples obtained from the Eastern Black Sea; mainly in the length groups of 50–60 and 60–70 mm males were dominant. There are also regional differences in the sex composition of the samples taken from Samsun (Central Black Sea), Ordu and Trabzon (both in the Eastern Black Sea) which were 1:1, 1:1.4 and 1:1.6, respectively, in the surveys carried out between April 2006 and February 2007 (Saglam *et al.*, 2008). A similar slight difference was reported by Samsun *et al.* (2008) in Sinop (Central Black Sea) as 1.15:1. Major differences were reported by Erik (2011) in the same area as 1:1.8 which is significantly different from the previous findings. All these figures on slight abundance on behalf of males may be the indication of possible imposex, as reported by Micu *et al.* (2009) in Romanian Black Sea costs. However, more scientific research is needed in the survey area for imposex.

The size of *R. venosa* in Chesapeake Bay, which is the most recently invaded area, is between 102.7–149.0 mm (Harding & Mann, 1999) while the size range is reported as 67–136.7 mm in the Adriatic Sea (Savini *et al.*, 2004). In the case of the Black Sea, Prodanov *et al.* (1995) reported that the size range of the samples showed a variation between 70–92 mm and 80–172 g off the Bulgarian coast. The mean length and weight of *R. venosa* in the Eastern Black Sea (Trabzon) was reported as 62.25 ± 0.19 mm and 47.22 ± 0.45 g (Duzgunes *et al.*, 1992), and 55.96 ± 0.41 mm and

Table 4. Mean length, width, weight, sex-ratio and length–weight parameters of *Rapana venosa* populations in previous studies.

References	Length	Width	Weight	R^2	*a*	*b*	Sex	Survey area	Catch method
Wu (1988)				0.93	0.0001	2.933			
Duzgunes *et al.* (1992)	62.15	45.44	47.22	0.93	0.0005	2.7716		Trabzon 91–92	Dredge
Prodanov *et al.* (1995)	70–92		80–172					Bulgarian coast	
Harding & Mann (1999)	102.7–149.0							Chesapeake Bay	
Saglam (2003)							1:1.6		
Savini *et al.* (2004)	67–136.7						1:1	North Adriatic	
Saglam (2004)	52.85 ± 0.234	36.60 ± 0.312	27.72 ± 0.403		0.00009	3.1459	1:1.6	In tanks	Mesocosm
Sahin *et al.* (2005)	44.61 ± 0.883		27.22 ± 1.145	0.989	0. 00009	3.1585		Rize	Trap and diving
Erik (2005)				0.92	0.0008	2.6023		Sinop, Fatsa (Ordu)	
Samsun *et al.* (2008)	55.96 ± 0.41		32.01 ± 0.9	0.96	0.0008	2.6277	1.15:1	Sinop	Collected from beach
Saglam *et al.* (2008) Samsun	75.5 ± 0.64		65.9 ± 1.84		0.0006	2.712	1:1		
Saglam *et al.* (2008) Ordu	48.7 ± 1.93		36.4 ± 6.33		0.0011	2.256	1:1.4		
Saglam *et al.* (2008) Trabzon	61.5 ± 0.45		48.2 ± 1.61		0.0002	2.933	1:1.6		
Erik (2011)	64.9 ± 0.23		46.1 ± 0.51	0.98	0.0002	2.8775	1:1.8	Sinop	Trap
This study	56.80 ± 0.36	42.47 ± 0.29	45.67 ± 0.89	0.84	0.0006	2.7354	1:1.15	Terme (Samsun)	Dredge

Table 5. Some population parameters of *Rapana venosa*.

	L_∞	W_∞	*K*	*R*	*a*	*b*	t_o	*E*	*F*	*M*	*Z*
Sahin *et al.* (2005)	103.97	213.52	0.345	0.989	0.000091	3.1585	−0.310	0.32	0.36	0.78	0.96
This research	112.35	243.94	0.310	0.84	0.0006	2.7354	−0.486	0.4	0.39	0.57	0.96

32.01 ± 0.9 g in the Western Black Sea (Sinop) (Samsun *et al.*, 2008). In the same period, Saglam *et al.* (2008) reported the mean length and weight of the samples collected from Samsun, Ordu and Trabzon as 75.5 ± 0.64 mm, 65.9 ± 1.84 g; 48.7 ± 1.93 mm, 36.4 ± 6.33 g and 61.5 ± 0.45 mm, 48.2 ± 1.61 g, respectively. In the recent survey carried out by Erik (2011) in Sinop the calculated mean length and weight of *R. venosa* was 64.9 ± 0.23 mm and 46.1 ± 0.51 g. Finally, in the present study, we found that the mean size of *R. venosa* was 56.80 ± 0.36 mm and 45.55 ± 0.89 g in the Central Black Sea area in 2011. All these figures show that the mean sizes of *R. venosa* are similar in the Black Sea countries. The size of the individual is strongly influenced by environmental conditions, such as temperature and food supply (Yankova *et al.*, 2013). The reason for these variations can be explained by the changes in demand from importing countries, reduction in prey quantities in some locations and different exploitation levels performed in certain locations.

There was a slight increase in mean values of all three parameters in September due to growth. In this period, trawling is legally permitted after mid-September and the majority of *R. venosa* fishermen use trawl nets to catch demersal fish species outside of a 3 mile zone, which causes a decrease in fishing efforts with regards to *R. venosa*. Thus, small scale dredgers are able to find large-sized *R. venosa* in this area in even smaller quantities, although they command higher prices.

Length–weight relationship parameters also show spatial and temporal variations according to the results of the surveys carried out on *R. venosa* populations (Table 4). Saglam *et al.* (2008) derived length–weight equations in Trabzon, Samsun and Ordu provinces as $W = 0.0006 \times L^{2.712}$, $W = 0.0011 \times L^{2.2560}$, $W = 0.0002 \times L^{2.933}$, respectively, while Duzgunes *et al.* (1992) reported the relationship 20 years ago as $W = 0.0004 \times L^{2.7716}$ ($R^2 = 0.93$). Both of the parameters of '*a*' and '*b*' are bigger than in the study carried out by Saglam *et al.* (2008). A similar trend can be seen in the previous studies of Saglam (2004), Sahin *et al.* (2005) and later in Saglam *et al.* (2008) by comparing the '*b*' coefficient calculated in the surveys. It shows that *R. venosa* had a higher growth rate in the past. The relationship between a specimen length and its weight varies too over time and between locations, depending on the abundance of food, competitors and reproductive activity (Yankova *et al.*, 2013).

The findings of Wu (1988) in Laizhou Bay ($W = 0.0001 \times L^{2.933}$) have shown that the '*b*' coefficient is rather high compared to the Black Sea. The parameters in Table 4 indicate that the '*b*' values of the samples from the west–east direction in the Black Sea are decreasing spatially. The minimum determination coefficient (R^2) was observed in our present study as 0.84 (Table 4).

In the present study, seven age groups were identified in the samples. In the previous study of Sahin *et al.* (2005) 0–5-year age groups were reported with population parameters of $L_\infty = 103.97$ mm, $k = 0.345$, $t_o = -0.310$ and $W_\infty = 213.52$ g. In the present study, the same parameters were derived as $L_\infty = 112.35$ mm, $k = 0.310$, $t_o = -0.486$ and $W_\infty = 243.94$ g although the growth rate is decreasing by years. A comparison of the condition coefficient '*K*' also shows a slight decrease in *R. venosa* growth performance. Exploitation rate and fishing mortality are also in a decreasing trend in the region. Natural mortality is decreasing while total mortality rate seems stable over years (Table 5).

This study contains findings about the recent population parameters in the Black Sea. It is the second survey giving age, length and weight data for *R. venosa* populations after 2005. From this point of view it is very important for the scientists working on *R. venosa* not only in the Black Sea but also in other locations in the world.

Rapana venosa is one of the important invasive species in the Black Sea. It became a dominant mollusc widely distributed all over the Black Sea due to a lack of natural predators such as starfish in the Black Sea ecosystem (Thomas & Himmelman, 1988; Bilecik, 1990; Harding & Mann, 1999). The fecundity of *R. venosa* is very high and their egg capsules are very resistant to all negative environmental conditions. As a result of these facts, all the coastal waters in the Black Sea were invaded by this species with a high growth rate at the beginning. Following this, the population biomass reached a maximum level in 2007 in line with the prey abundance in its habitat, but later the growth rate started to decrease, with specimens having smaller length and weight. At present, stocks in the Eastern Black Sea are smaller in size than in the Central and Western Black Sea. This is why the main commercial fishing effort is concentrated in a very limited area in the Central and Western Black Sea. This species is still threatening the existence of mollusc stocks in the Black Sea, i.e. the Mediterranean mussel (*Mytilus galloprovincialis*), oyster (*Crassostrea gigas*) and Venus clam (*Chamelea galin*). Also, the harvesting method of *R. venosa* by dredges is very harmful for the bottom substrate in the locations where bottom trawling is forbidden due to a narrow continental shelf area in the Eastern Black Sea. It would be useful to change the harvesting method to traps and pots, allowing *R. venosa* fishermen to catch throughout the whole year in order to reduce the population. By this measure, fishermen may benefit more from the *R. venosa* by catching bigger sized whelks which can grow better by utilizing the existing prey due to a reduced population in the sea.

More scientific surveys on *R. venosa* population are needed for assessment of the stock size, reproduction physiology (mainly imposex) and behaviour, and prey–predator relations in the whole Black Sea area.

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