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Original Article

Life cycle and otolith morphological parameters of black scorpionfish, *Scorpaena porcus* (Scorpaenidae) in the Crimean waters of the Black Sea

Pavel Donchik*, Kutsyn Dmitry, Irina Chesnokova

A.O. Kovalevsky Institute of Biology of the Southern Seas, Russian Academy of Sciences, Sevastopol, Russia.

Abstract: Sex, size and age structure, growth, mortality, and some of the morphological parameters of the otoliths of the black scorpionfish, *Scorpaena porcus* collected in the south-western Black Sea waters of the Crimea were analyzed. A total of 500 *S. porcus* specimens were examined. The total sex ratio differed (1.00:0.67) with the predominance of females. The maximum total length and age of females were estimated to be 26.9 cm and 12 years old, respectively; for males, they were 21.3 cm and 11 years. The growth rate was determined to be sex-specific. The values of the parameters of the Bertalanffy equation were calculated. For females, the asymptotic total length was estimated to be 28.9, weight – 519.7 g, parameter k = 0.10 year-1, to = -2.90; for males, the asymptotic total length was estimated to be 23.2 cm, weight, 226 g, parameter k = 0.16 year^{-1}, t_o = -2.13. The total, natural, and fishing mortality coefficients for females amount to 0.67, 0.45, and 0.26 year^{-1}, respectively; for males, they are 0.46, 0.30, and 0.13 year^{-1}. The exploitation ratio for females is 0.38, and for males, it is 0.28, corresponding to the low fishing pressure. The relationship between the fish length and the otolith length is isometric, but the relationship between the fish weight and the otolith weight is positively allometric. The Black Sea black scorpionfish differs from the Mediterranean population by their bigger maximum sizes, low growth rate, longer lifespan, and more evident sexual dimorphism.

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Introduction

The black scorpionfish, *Scorpaena porcus* (Linnaeus, 1758), is a demersal species of the family Scorpaenidae. It is distributed in the Eastern Atlantic along the coast from Morocco to Britain, in the Mediterranean basin, including the Sea of Marmara and the Black Sea. Its population among demersal fish is comparatively high. Its role in the fishery is rather insignificant, but it appears to be an object of recreational fishing in the waters of the Crimean region (Svetovidov, 1964).

Within the Mediterranean, black scorpionfish is an important component of marine coastal ecosystems. This fact often makes the given species an object of research. Morphology, distribution, growth, size and age structure, and trophic relationship data of *S. porcus* inhabiting waters along the Croatian coastline are given by Ferri et al. (2010, 2021). The age and growth of black scorpionfish from natural and artificial biotopes of the Adriatic Sea near the Italian coast have also been studied (Mesa et al., 2010). There are also data on size and age, sex composition, growth, nutrition, reproduction, and mortality of black scorpionfish from the Turkish coastal zone of the Black Sea (Başçınar and Sağlam, 2009; Bilgin and Celik, 2009; Şahin et al., 2019). Due to the anthropogenic pollution of the Black Sea distribution, number, population features, growth, and physiological condition are considered in the works of Pashkov et al. (1999), Kutsyn et al. (2019), and Chesnokova et al. (2020). In the works of Kutsyn et al. (2019), some data on the growth, age structure, and maturation of marine black scorpionfish near the Crimean coasts are provided. Thus, the information on mortality of *S. porcus* in the Black Sea waters of the Crimean region remains insufficient. Geographical variability of *S. porcus* from the Adriatic Sea was studied by Ferri et al. (2021). In their work, the

*Correspondence: Pavel Donchik
E-mail: donchik.1997@yandex.ru

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authors indicate that the northern population of black scorpionfish reached great maximum size and showed a higher growth rate and a longer lifespan than the southern population of black scorpionfish. The authors also report that this species largely fed on fish when crustaceans prevailed in the ratio of the black scorpionfish southern population. Ecology-geographical variability of this species' life cycle remains understudied throughout the entire distribution range. Research conducted in this field appears to be of theoretical and practical value since it allows us to determine the nature of adaptive changes in the changing climate conditions (Lindmark et al., 2022).

Molecular analysis and the analysis of the shape of the otoliths of some Scorpaenidae family species inhabiting the coastal area of the Crimea Black Sea waters were carried out in the works of Yedier and Bostanci (2021). Morphology and fluctuating asymmetry of the *S. porcus* otoliths of the Caucasian and Crimean shelves of the Black Sea were analyzed in the work of Polin et al. (2022). Some morphological parameters of *S. porcus* otoliths in the Mediterranean basin were presented in the articles of Trojette et al. (2014). These structures are known to be characterized by enter- and intraspecies variability. Methods to compare the shapes of the otoliths have lately become more and more popular in taxonomic study, which has been testified by a great number of publications. Tuset et al. (2003) described that the otolith shape variability can be connected with genetic, ontogenetic, and ecological factors. Ecological conditions can influence the correlation between the fish and the size of the otoliths (Francis and Campana, 2004; Bostanci et al., 2015; Yedier et al., 2019). In this regard, the morphological features of the otoliths can serve as a marker when studying intraspecies and ecological structures. This research aims to study the sex, size and age, growth, mortality, and morphological features of *S. porcus* otoliths inhabiting the Crimean basin in modern conditions and to analyze the ecology-geographical variability of this species' life cycle.

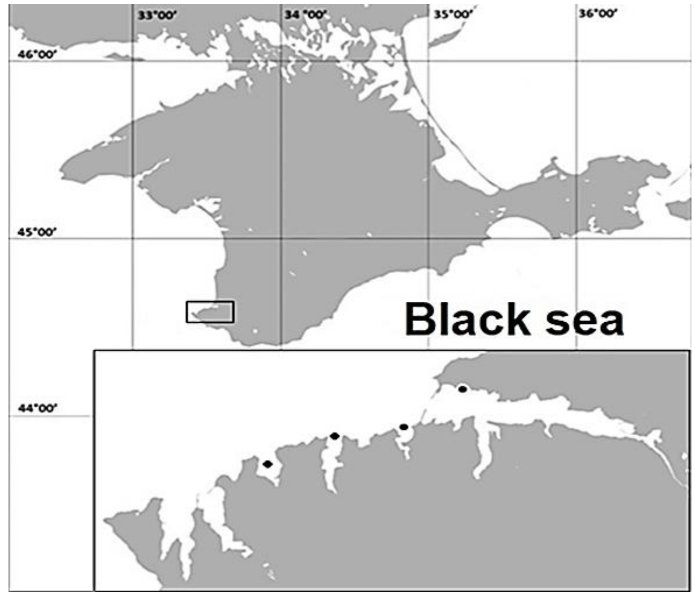

Figure 1. A sketch-map of the area under research: (•) – samples collection areas.

Materials and Methods

The samples were collected in the period of June 2020 through July 2021 in the coastal area of Sevastopol from Omega Bay to Matyushenko Bay (Fig. 1). The fish was caught with bottom trap nets (12 mm mesh) installed at the depth ranging from 2 to 12 m. Overall, 500 specimens were studied, 492 of which were examined with age determination. Biological analysis included the determination of sex, measuring total (*TL*) and standard (*SL*) length to within 0.1 cm and total body weight to within 0.1 g. While examining the sex and age structure, test χ^2 was applied.

To assess the significance of the differences in weight and length distribution between sexes nonparametric Kolmogorov-Smirnov test was applied. The sagittae otoliths were used to determine age. After cleaning and drying, they were examined in reflected light on a dark background at 20x magnification. Borders between the outer edge of the translucent zone (dark) and the inner edge of the opaque zone (light) were taken for annual rings (Mesa et al., 2010). To describe linear growth, the Bertalanffy equation was used (Bertalanffy, 1938; Mina and Klevezal, 1976; Riker, 1979): $L = L_\infty(1-e^{-k(t-t_0)})$ and $W = W_\infty(1-e^{-k(t-t_0)})^b$, where L_∞ is the asymptotic length, W_∞ = the asymptotic weight, k = a growth constant, t_0 = the age of the fish when the length and weight of the model under consideration were 0, and b = the exponent in weight-length relationship ($W=aL^b$). Student t-test was applied to check the isometry of the weight-length relationship the absolute initial growth rate coefficient was calculated (Gallucci and Quinn, 1979): $G_{init} = kL_{\infty}$, the growth performance index for the linear sizes and weight (Pauly et al., 1988): $\varphi' = 1gk+2lgL_{\infty}$ and $\varphi' = 1gk+(2lgW_{\infty})/3$.

Spearman's rank correlation method was applied to assess the possible effect of temperature on the growth rate. As a parameter illustrating the Mediterranean basin temperature conditions, long-time average annual sea surface temperature (SST) calculated based on daily figures in 1982-2012 was used (Shaltout and Omstedt, 2014).

A linear regression was performed to determine the total mortality (Z): $1nN_t = a + bt$, where t = age, and N_t = the number of individuals at the age of t. In this model, $Z = -b$. Natural mortality (M) was determined using the empirical formula (Pauly, 1980): $logM = -0.0066 - 0.279logL_{\infty} + 0.6543logk + 0.463logT$, where T is the average annual sea surface temperature. Fishing mortality (F) was calculated as the difference between the total and the natural mortality: $F = Z - M$ (Ricker, 1979). The exploitation rate was determined as: $E = F/Z$ (Gulland, 1971).

The Kolmogorov-Smirnov test was applied to assess the significance of the differences between the left and right otoliths. The length of the otoliths was determined as a line connecting rostral and postrostral ends (Fig. 2). A regression analysis ($y = ax^b$) was applied to study the relationship of the total length TL of the fish to the length of the otolith, the total weight of the fish W to the weight of the otolith OW, the length of the otolith OL to the age A, the weight of the otolith OW to the age A.

Student t-test was applied to check the statistical significance of parameter differences b to 1. If the value of the exponent was equal to 1, the relationship was considered to be isometric. Otherwise, it was considered to be allometric. A total of 90 pairs of otoliths of *S. porcus* were studied, 69 of which belonged to female individuals with body lengths ranging from 9.1 to 26.9 cm and weights ranging from 12.89 to 432.58 g at the age of 3 to 12 years old and 21 individuals were males ranging 9.2-18.6 cm in total length, 13.72-151.47 g in body weight, aged 4-8 years old. Statistical analysis was performed using MS Excel and Statistica 12 software.

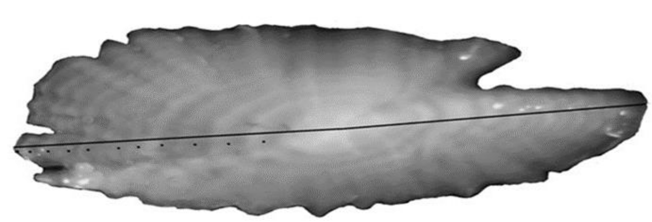

Figure 2. An otolith of a twelve-year-old female individual of *Scorpaena porcus* (TL 26.1 cm), caught in April 2021: annual rings are marked with dots, (-) the otolith length (OL).

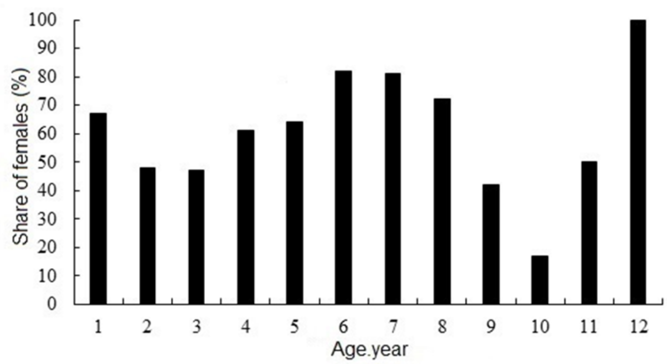

Figure 3. The portion of females (■) in different age groups of black scorpionfish *Scorpaena porcus*.

Results

Sex, size, and age structure: The sex ratio of *S. porcus* in the catches differed (1.00:0.67) with the predominance of the female individuals and had statistically significant difference from being equal (χ^2=33.3, P<0.05) (Fig. 3). The sex ratio in the younger age groups was close to equal. However, females predominated in the middle age groups (Table 1). In the older age groups (9-11 years old), the proportion of males increased, but the difference from equal balance was insignificant due to the small number of individuals.

In the catches, the length of the females (TL) varied from 9.1 to 26.9 (16.0±0.18 cm on average), and the length of males varied from 8.4 to 21.3 (14.7±0.2 cm) (Fig. 4). The sex differences in length distribution were statistically significant (Kolmogorov-Smirnov

Table 1. Linear and weight growth for females and males of black scorpionfish, *Scorpaena porcus*.

Age, years	Females			Males			
	Length (*TL*), cm	Weight (W), g	n, spec	Length (*TL*), cm	Weight (W), g	n, spec	χ^2 df=1
1	10.2±0.35	22.5±5	2	8.4	10.5	1	χ^2=0.33, p=0.6
2	11.3±0.27	28.3±2.07	14	11.0±0.27	25.4±.2.57	15	χ^2=0.34, p=0.8
3	13.3±0.24	45.3±2.83	37	12.8±0.25	41.8±2.86	42	χ^2=0.32, p=0.6
4	14.8±0.26	67.0±3.53	64	14.4±0.20	57.6±3	41	χ^2=5, p=0.24
5	16.1±0.24	84.9±4.37	66	15.3±0.23	68.3±3.25	36	χ^2=9, p=0.002
6	17.0±0.25	100.6±5.67	53	16.8±0.29	92.1±6.89	11	χ^2=28, p=0
7	19.0±0.36	139.9±8.64	39	17.8±0.21	103.6±5.57	9	χ^2=19, p=0
8	19.5±0.52	154.5±13.5	16	18.4±0.32	119.3±7.82	6	χ^2=0.33, p=0.6
9	20.3±1.18	195.8±33	5	18.6±0.31	120.2±8.4	7	χ^2=1.28, p=0.26
10	22.0±4.85	233.0±119.5	2	20.0±0.42	144.2±10.45	5	χ^2=0.33, p=0.6
11	22.6	247.5	1	21.3	206.5	1	
12	22.4±3.7	279.1±153.4	2	-	-		

test, *nf* =n301, *nm* = 174, *P*<0.001). For both sexes, the average length was 15.6±0.24 cm (n = 475).

The weight of the females varied between 12.9 and 432.6 (90.2±3.34 g), and of the males, it varied between 10.6 and 206.5 (65.5±2.7 g) (Fig. 4). The sex differences in weight distribution were statistically significant (Kolmogorov-Smirnov test, *nf* =n301, *nm* = 174, *P*<0.001). For both sexes, the average length was 81.0±4.3 g (n = 475). The minimum age of the females was 12 years old, and the maximum age of the males was 11 years old. Among males, age 3 or 4 were predominated, and females were mostly 4 or 5 years old. The maximum size of black scorpionfish in the coastal area of Crimea can, apparently, reach high values. Thus, in 2011 in Karantinnaya Bay, a black scorpionfish female individual with a total length of 30.7 cm, a total weight of 623 g, and an age of over 11 years old was registered.

Growth and weight-length relationship: The highest growth rate of black scorpionfish is observed in the first year of life at 10.2 cm with an increase in weight of 22.5 g for females and 8.4 cm with an increase in weight of 10.5g for males (Table 1). In the third year of life, while gaining sexual maturity, the total length is 13.3±1.5 on average, with a weight of 45.3±2.83 g for females. Males gain sexual maturity earlier, in the second year of life, reaching 11.0±2.6 cm in length and 25.4 g in weight. Both female and male individuals' growth slows down during the entire life cycle. Nevertheless, the size of females is bigger in all age groups. The weight-length relationship for female and male individuals is described with an equation $W = 0.013TL^{3.15}$ (R^2 = 0.95), $W = 0.017TL^{3.02}$ (R^2 = 0.94). According to the equation, it becomes clear that the weight gain for both males and females is marked by positive allometry as b = 3.19 (t = 4.06 at *P*<0.05) and b = 3.15 (t = 3.75 at *P*<0.05), respectively.

Growth modeling: The following Bertalanffy equations describe black scorpionfish's linear and weight growth. For females, *TL* was $28.9[1\text{-}e^{-0.1(t+2.9)}]$ and *W* was $519.7[1\text{-}e^{-0.1(t+2.9)}]^{3.15}$. The growth indexes were as follows: $k = 0.1$, $\varphi = 0.82$ and $G_{init} = 2.96$, and $k = 0.16$, $\varphi = 0.78$ and $G_{init} = 3.63$ for females and males, respectively. According to the models, *S. porcus* growth in the studied area is marked by sexual dimorphism (Fig. 5). The growth rate of females was higher, though males reached the asymptotic length faster.

Mortality: The total mortality rate, *Z*, of females and males of *S. porcus*, were 0.67 and 0.46 year^{-1}, respectively. At the same time, the natural mortality rate for females was higher than for males, 0.45 versus 0.30 year^{-1}. The total fishing mortality rate, *F,* for females and males, is moderate and accounts for 0.26 and 0.13 year^{-1}, respectively. The exploitation rate *E* for females and males was 0.38 and 0.28, corresponding to low fishing pressure (*E*<0.50). Sex differences for *S. porcus* in the mortality rates can occur due to the growth rate differences. Apparently,

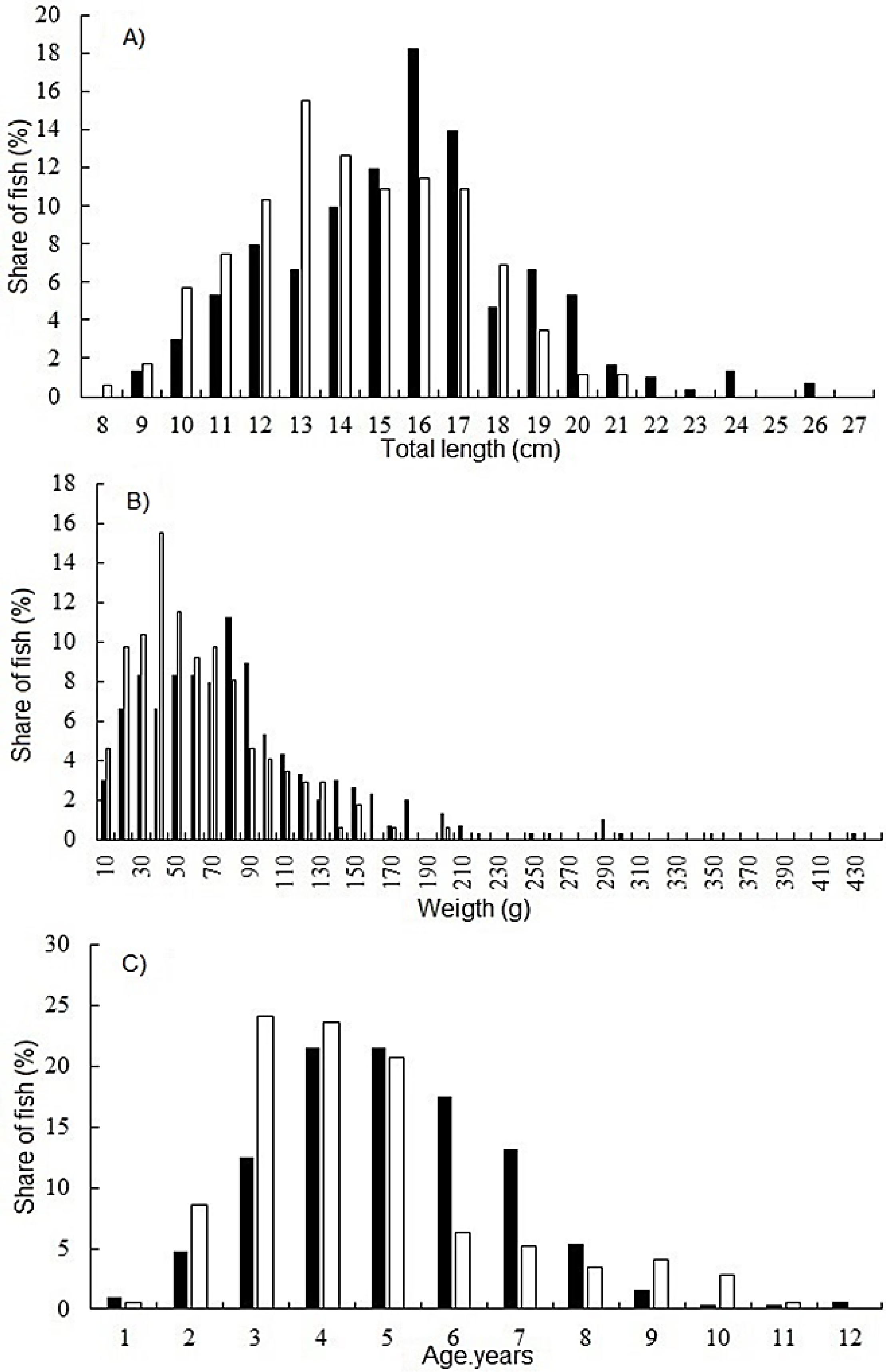

Figure 4. Length (A), weight (B) and age (C) distribution of females (■) and of males (□) in different age groups of black scorpionfish *Scorpaena porcus*.

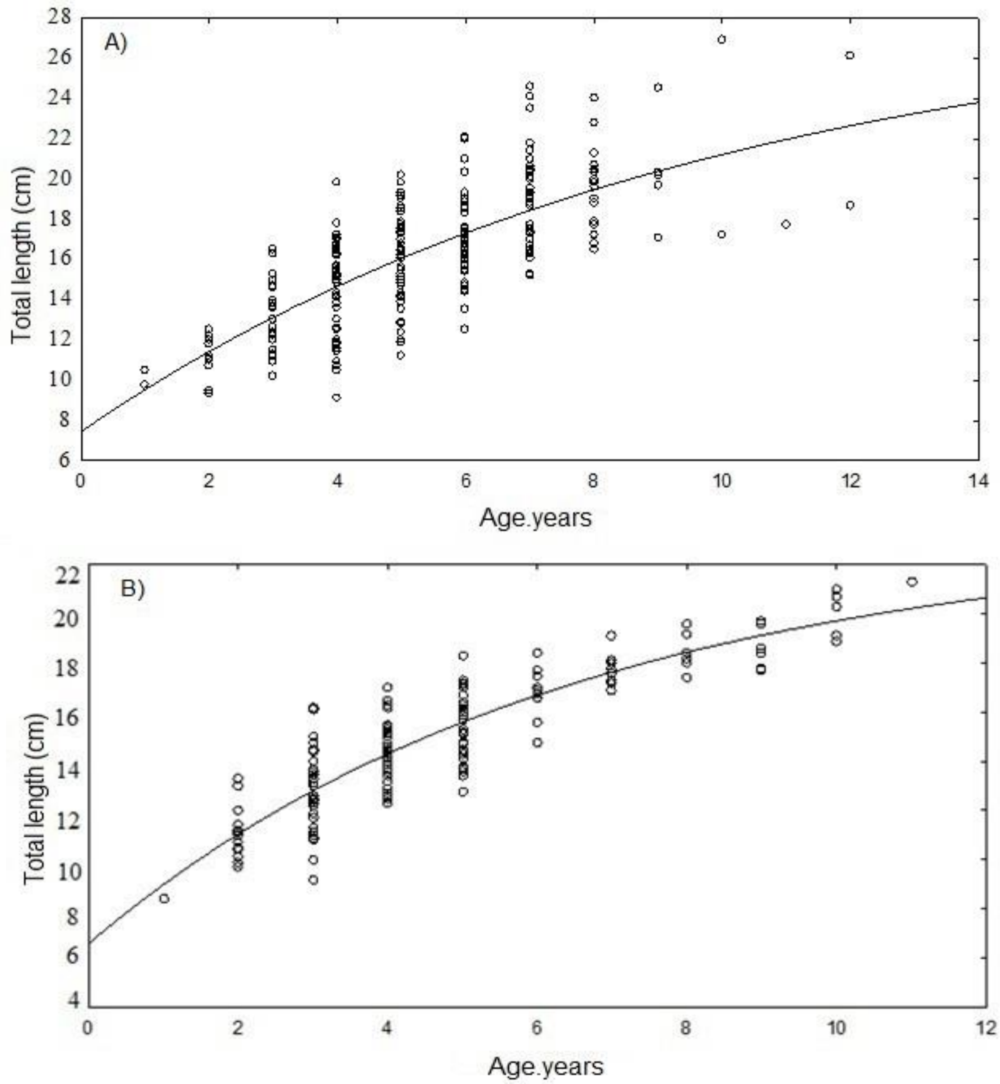

Figure 5. Linear growth curves for black scorpionfish Scorpaena porcus at the south-eastern coast of the Crimea, approximated with the Bertalanffy equation: A – females, B – males: (○) – empirical points, (--) – growth curve.

females more often appear to become the objects of fishery because of their bigger sizes.

Morphological parameters of *S. porcus* otoliths: The otoliths are oblong, thin, and transparent. Their edges are wave-shaped, with pointed ledges. The rostrum is short and wide with rounded peaks. Antirostrum is visible (Fig. 6). There were no significant differences between the left and the right otoliths (P>10). Other works also pointed out this pattern (Mesa et al., 2010; Bostanci et al., 2012; Basusta et al., 2020; Yedier et al., 2021). For this reason, only the left otolith parameters were used for regression analysis.

The relationship of the fish size to the size and age of the otoliths was as follows (Fig. 3); for females, $TL = 1.96OL^{1.08}$ ($R^2 = 0.82$, the relation is isometric, $t = 1.17$, $P<0.05$), and for males, $TL = 1.76OL^{1.10}$ ($R^2 = 0.95$, the relationship is isometric, $t = 1.66$, $P<0.05$). The relationship of the body weight, W, to the weight of the otoliths, OW, for females was $W = 13OW^{1.27}$ ($R^2 = 0.84$, the relationship is positive allometric, $t = 4$, $P<0.05$) and for males, $W = 95.6OW^{1.23}$ ($R^2 = 0.95$, the relationship is positive allometric, $t = 1.91$, $P<0.05$). The relationship of age, A, to the length of the otoliths, OL, for females is described by the equation of $A = 0.82OL^{1.01}$ ($R^2 = 0.61$), and for males, $A = 1.4OL^{0.7}$ ($R^2 = 0.68$). The relationship of age, A, to the weight of the otoliths OW, for females is described by the equation of $A = 23.7OW^{0.35}$($R^2 = 0.6$), and for males, $A = 20.1OW^{0.28}$ ($R^2 = 0.82$).

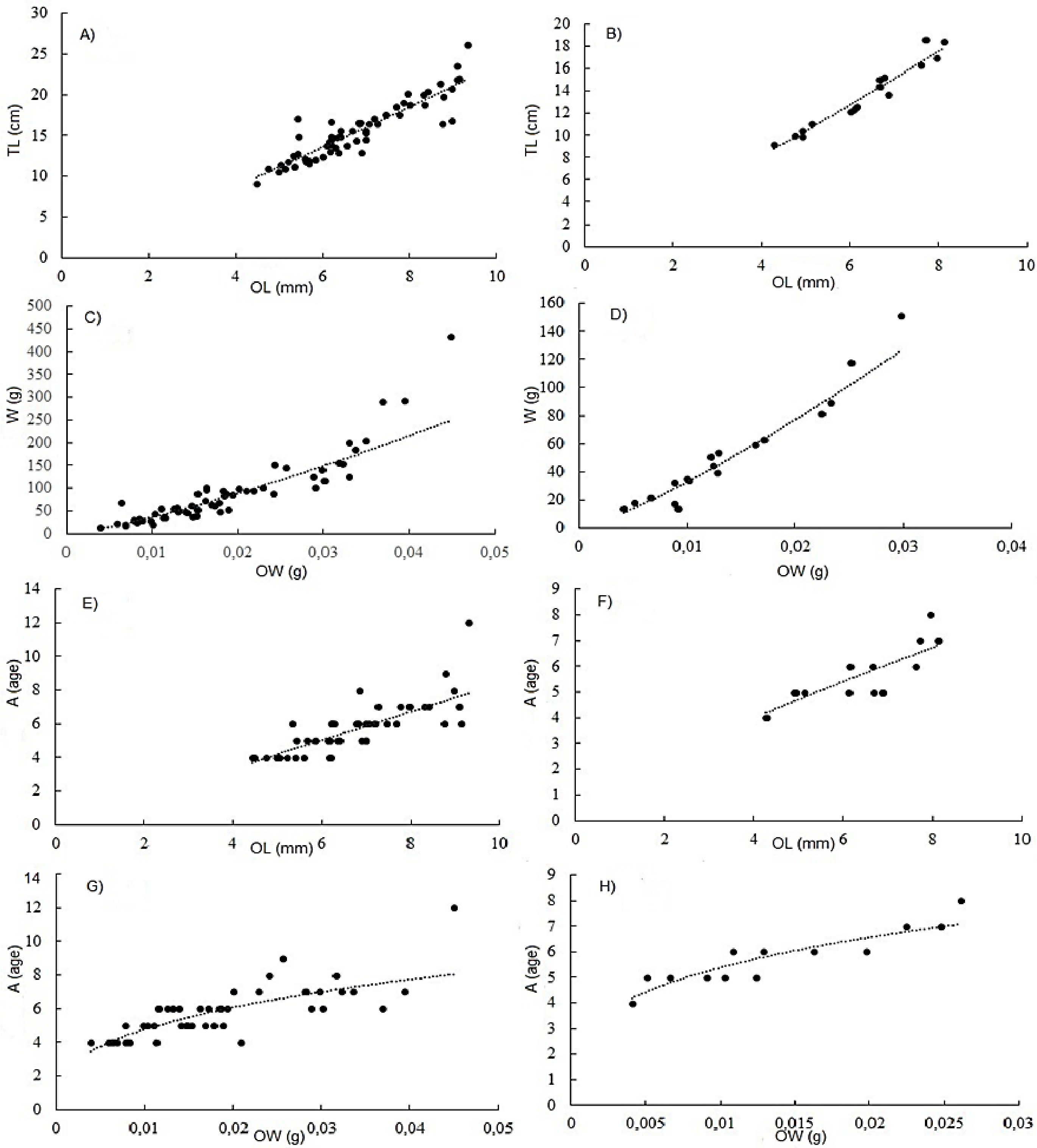

Figure 5. *TL-OL* relationship for females (A) and males (B), *W-OW* relationship for females (C) and males (D), A-OL relationship for females (E) and males (F), A-OW relationship for females (G) and males (H) of *Scorpaena porcus*.

Discussions

Sex structure and sexual dimorphism: The sex structure and the sexual dimorphism are closely connected with the habitat conditions (Nikolskii, 1969). Temperature and genetic factors are some of the most important factors in the environment that can influence sex formation (Geffroy and Wedekind, 2020). In the *S. porcus*, the share of males decreases

Table 2. Bertalanffy equation parameters and growth indexes for *Scorpaena porcus* from different parts of the area.

Region	Sex	L_∞, cm	*k*, year^{-1}	t_0, year	*b*	G_{init}, cm/year	φ′	L_{max}, cm	A_{max}, year	Information source
Channel England, England	–	–	–	–	–	–	–	31.6	9	Mahe et al. (2014)
Black Sea, Crimea	♀	28.9	0.10	-2.90	3.15	2.96	1.93	30.7	12	Own data
	♂	23.1	0.16	-2.13	3.02	3.63	1.92	21.3	11	
Black Sea, Crimea	♀	24.2	.24	-0.72	3.13	5.81	2.15	28.7	11	Kutsyn et al. (2019)
	♂	17.1	0.47	-0.24	2.88	8.04	2.14	21.4	12	
Black Sea, Turkey	♀	29.7	0.18	-1.5	3.20	5.35	2.21	25.5	8	Şahin et al. (2019)
(Trabzon and Rize)	♂	21.9	0.24	-2.28	3.23	5.26	2.07	22.8	7	
Black Sea, Turkey, Sinop (peninsula)	♀	111.9	0.04	-1.43	3.06	3.92	2.64	31.7	8	Bilgin and Celik (2009)
	♂	74.6	0.05	-1.50	3.08	4.03	2.49	23.6	–	
Adriatic Sea, Croatia	♀/♂	41.9	0.06	-3.54	3.12	2.52	2.02	28.1	11	Ferri et al. (2021)
	♀/♂	60.9	0.03	-5.18	3.03	1.83	2.05	25.9	12	
Adriatic Sea, Croatia	♀/♂	28.2	0.18	-0.80	3.03	5.08	2.16	30.0	11	Jardas and Pallaoro (1992)
Ligurian Sea, Italy	♀/♂	32.4	0.18	--	–	5.83	2.28	–	–	Silvestri et al. (2002)
Balearic sea, Algeria	♀/♂	29.4	0.16	-0.97	–	4.76	2.15	–	–	Siblot-Bouteflik (1976)
Marmara Sea, Turkey	♀	22.2	0.20	-0.83	–	4.44	1.99	23.9	8	Unsal and Oral (1996)
	♂	17.2	0.26	-0.88	–	4.47	1.82	20.4	8	
Gulf of Gabes, Tunisia	♀	21.9	0.17	–	–	3.72	1.91	23.0	6	Bradai and Bouain (1988)
	♂	18.2	0.20	–	–	3.64	1.82	18.0	6	

in the direction of higher latitudes, which is caused by sex differences in the life cycle strategies. Thus, in Crimean waters, males dominate in the younger age groups as they reach sexual maturity earlier and have a shorter lifespan than females. In the age groups of 4 to 6 years old, the share of females increases consistently. A similar pattern is typical for *S. porcus* found near the Turkish coast (Bilgin and Celik, 2009), while for the Mediterranean populations, the equal sex ratio and a moderate sexual dimorphism during the entire life cycle are typical (Jardas and Pallaoro, 1992; Mesa et al., 2010; Ferri et al., 2021). The development of sexual dimorphism in the direction of higher latitudes allows for the reduction of intraspecies competition and, in this way, increases food supply. It can be suggested that this strategy allows for accumulating resources for wintering and breeding more effectively under seasonal conditions.

Ecology-geographical variability of some life cycle parameters: Lifespan, growth, and size are connected to environmental conditions (Nikolskii, 1969). Temperature, salinity, and food supply differ within the Eastern Atlantic and the Mediterranean basin. This fact determines the differences in the life cycle parameters of the black scorpionfish in various parts of the area. The increase in the lifespan, maximum size, and growth rate decrease in the direction of higher latitudes (TSR – temperature-size rule) are common for ectothermic animals. It is connected with lowering the water temperature, which controls the metabolic rate and redistribution of the consumed energy (Pauly, 1998; Verberk et al., 2020). Other environmental factors such as salinity, photoperiod, predator-prey relationship, intraspecific and interspecific competition, and food availability can exert a complex influence on the formation of the life cycle strategy. Thus, geographical variability of size, age, and growth do not always match the above rule and will depend on the selection results.

In the case of black scorpionfish, the observed variability of the life cycle parameters corresponds to the TSR on the whole (Table 2). For example, on the southern border of the areal, on the coast of Tunisia, the maximum age of black scorpionfish registered is 6 years old (Bradai and Bouain, 1988). In the more northern and colder Marmara Sea, it is 8 years old

(Ünsal and Oral, 1996). At the northern borders of the areal, in the Adriatic and Black Seas, and the English Channel, it varies from 9 to 12 years old (Mahe et al., 2014; Ferri et al., 2021). The Black Sea *S. porcus* has a lower growth rate (according to parameters *k, φ'*, and G_{init}) and bigger maximum sizes than the Mediterranean Sea representatives, especially in its southern part (Table 2). The correlation analysis of some *S. porcus* life cycle parameters with the temperature conditions confirms the above observations. A strong negative correlation is observed between the maximum age and average annual sea surface temperature (SST) (r = -0.89). A less marked negative correlation is observed between the maximum size, and a positive correlation is observed between the parameters describing the growth rate (G_{init} and *φ*') and average annual sea surface temperature with SST: r = 0.23 and r = 0.24, respectively.

Mortality: Low mortality rates are typical for black scorpionfish due to its long lifespan and low fishing pressure. Data on the mortality of black scorpionfish is low. The mortality rate of *S. porcus* found on the Turkish coasts of the Black Sea is given in the research of Şahin et al. (2019). The rates between *S. porcus* belonging to the Turkish and the Crimean coasts are comparable. Thus, the total mortality rate for females and males at the Crimean coast is 0.67 and 0.46 year^{-1}, while this parameter for the Turkish coast equals 0.50 year^{-1} for combined samples; for natural mortality, it is 0.45 and 0.30 year^{-1} to 0.37 year^{-1}; for fishing mortality, it is 0.26 and 0.13 year^{-1} to 0.13 year^{-1}. The exploitation rate E is close to 0.26 for the Turkish coast. The comparability of the mortality parameters in the Black Sea boundaries can be explained by the similarity in the habitat conditions.

The morphology of the otoliths: For the regressions describing the Black Sea basin scorpionfish body size and otolith size relationship, the determination coefficient R^2 of high value is typical. It proves the strong correlation between the parameters. The determination coefficient R^2 of high value was also seen at the Turkish coast of the Black Sea (Bostanci et al., 2012). The size of the otolith can be considered a reliable predictor of the fish's length, weight, and age. According to the data obtained, the relationship between the fish length and the otolith length is isometric, whereas the relationship between the fish weight and the otolith weight is positively allometric (weight gaining of the otolith slows down as the weight of the fish grows). Similar results were shown in *Umbrina cirrosa* (Sciaenidae) belonging to the eastern part of the Mediterranean Sea (Basusta et al., 2020). The positive allometry of the otolith weight and fish weight relationship can be explained by the density loss of the otolith in the course of ontogeny.

The Crimean Basin black scorpionfish is distinguished by evident sexual dimorphism, high lifespan, and asymptotic sizes. According to the currently available data, the variability of this species' life cycle in the boundaries of the entire range favorably compares to TSR. Following this, in the condition of further climate warming, the biological peculiarities of black scorpionfish are likely to change: the shortening of lifespan, the increase in growth rate at the beginning of the life cycle, and the size shrinking. Further studies of the geographical variability of *S. porcus* and monitoring of the life cycle parameters will allow us to understand the species' evolutionary-ecological peculiarities better and test the above-mentioned hypothesis.

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