Influence of Climatic Factors on the Interannual Changes of Gonadosomatic Index of the Red Mullet *Mullus barbatus ponticus* in the Coastal Crimean Waters

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Abstract
The analysis of the influence of climatic factors on the interannual changes of the gonadosomatic index (GSI) of the red mullet *Mullus barbatus ponticus*, which inhabits the coastal waters of Crimea, was carried out. The dependence of the development of the reproductive system of the red mullet, determined by the gonadosomatic index, on temperature was revealed. It was found that the correlation coefficient between changes in the average temperature during the spawning and the GSI index is $r = 0.98$ for females and $r = 0.97$ for males. The maximum monthly average GSI values were observed in females and males of the *M. barbatus ponticus*, accordingly, in June, 4.29 and 3.76% and in July – 4.83 and 4.17%. An analysis of the size composition of the fish showed that the females are larger than males. For females, the predominant size group is 10.0–11.0 cm, and for males 9.0–10.0 cm. It was found that the red mullet, living in the coastal waters of the Crimea, has a slight positive allometric growth. A comparison in the developmental features of the red mullet that lives in different regions of the Black Sea-Mediterranean basin was made and the differences in the change in the GSI and other parameters are analyzed.

Key words: *Mullus barbatus ponticus*, the Black Sea, gonadosomatic index (GSI), interannual changes, length distribution.

Introduction
Successful fisheries activity taking into account the impact of changing natural and climatic factors is the most important aspect of exploitation of fish resources. Assessing the level and nature of the impact of climate changes on the abiotic and biotic components of marine ecosystems, including the productivity of populations of economically valuable commercial fish species, is one of the important scientific and practical fishery tasks. With the development of world fisheries in recent decades, one of the main objects of fishing is red mullet *Mullus barbatus ponticus* Essipov, 1927. Specimens of the red mullet family, or Mullidae are characterized by a relatively high abundance, wide geographical distribution, good taste (Boltachev & Karpova, 2012).

*Mullus b.ponticus* is a demersal species that is distributed in the eastern North Atlantic in the Mediterranean and Aegean Seas (Hureau 1986; Özbilgin *et al*. 2004), as well as in the Azov-Black Sea basin (Bat *et al*. 2008; Kozhurin *et al*. 2018; Shlyakhov *et al*. 2018). Mullidae are a small valuable commercial fish having great economic importance in the fisheries of the Mediterranean coastal countries; the annual catch of
the red mullet in this region is an average of 8817 tons. Offshore Turkey, catches ranged between 1281–2790 tonnes per year over the past decade (Tüzün et al. 2019; Fishery Statistics 2018; Yilmaz et al. 2019). In the Gulf of Tunisia, catches are also quite high and reach 2000 tons per year (Cherif et al. 2007). In offshore waters along the Italian coast, catch reaches 5105 tons per year. In recent years, there are positive trends in annual catches in the Black Sea-Crimean region (Kozhurin et al. 2018; Shlyakhov et al. 2018). If from 1992 to 2001 the catches were low and ranged from 4.7 to 22.4 tons per year (Oven et al. 2009), then, from 2001 to 2013 a steady increase was in catches up to almost 100 tons per year. In 2014–2017 red mullet’s catches increased by 3–5 times and, in particular, in 2017 amounted to 571.2 tons per year (Kozhurin et al. 2018).

Temperature of marine water and nature of its changes are one of the important climatic factors that have a direct and indirect effect on the reproductive abilities of fish, the period of the spawning, growth rate, quantity of fish increase within area both in the coldest months of the year (February–March) and in the feeding and reproductive periods.

The spawning of the Mullidae family is portioned and most depends on the hydrological conditions of the year; and is continue, on average, from May to August, when the water temperature fluctuates in relatively small ranges – from 15 to 25 °C (Oven 1961, 1976).

One female spawn to 100 servings of pelagic caviar. Larvae and 0-group fish at the age of 1.5–2 months have a pelagic lifestyle, then, they go down upon reaching a length of 4–6 cm, get the exterior of adult fish. At a length of 7-8 cm, fish of this family become sexually mature. Maturation of red mullet males occurs at the end of the first life year, and of females - at the beginning of the second year of life. At the age of 1+, the red mullet is usually included in the spawning herd (Oven 1961, 1976; Domashenko 1991; Samsun 2017).

The start and duration of spawning can be characterized by the gonadosomatic index (GSI) value, which is one of the most available indicators of the dynamics of maturation of sexual products. This parameter illustrates quite well the seasonal and interannual changes in the gonads state at the process of biological maturation, that can be changed at variation of marine environment condition, including influence of climatic factors.

Climate changes observed in recent years lead to interest increased in monitoring studies. Such observations can allow to identify the features of the development of marine organisms and predict trends in their changes. Despite the available publications on this subject, the study of long-term changes in the GSI of the *M. barbatus ponticus* living on the shelf of the southwestern Crimea, taking into account the influence of climatic factors, has not been fully studied and remains actual.

Thus, taking into account the climatic changes observe in recent years, the stock status and level of fishing of the red mullet in the Black Sea should be monitored in order to realize the fisheries management aimed to sustainable economic and social benefits from catch and conserving of fish stock productivity. This study provides some actual information such as the influence of climatic factors on interannual changes in both the gonadosomatic index and some other parameters of the red mullet that lives in the coastal waters of Crimea.

The aim of this research is to identify the features of changes in the gonadosomatic index of the Black Sea red mullet *Mullus barbatus ponticus* with changes in environmental parameters in 2016–2019 in the spring-summer periods in coastal area on the southwestern shelf of Crimea taken into account.

Materials and methods

The study is based on the results of common biological analyzes of the *Mullus barbatus ponticus* Essipov, 1927. The total and standard lengths, weight, weight of fish without viscera were measured, age, sex, maturity stage and weight of sex products were determined. The age of fish was determined by reading the scale (Pravdin 1966). The mass of fish was determined with an accuracy of 0.1 g, the mass of gonads - with an accuracy of 0.01 g.

Adult fish were caught by bottom traps with a mesh of 12 mm on the southwestern shelf of the Crimea in the coastal area of Sevastopol in such coordinates: latitude - from 44.57 ° N up to 44.64 ° N; longitude - from 33.37 ° East up to 33.56 ° east (Fig. 1). Samples were taken in 2016–2019 from April to September. The sample consisted of 10–20 alive individuals different sized and aged. A total of 1,422 individuals were analyzed.
INFLUENCE OF CLIMATIC FACTORS ON THE GONADOSOMATIC INDEX OF THE RED MULLET

The gonadosomatic index was calculated as the ratio of the mass of gonads to the mass of fish without entrails, expressed in a percentage. Maturity stages were determined according to the standard six-point scale (I, II, III, IV, V, VI), taking into account transition stages (II – III, IV – V, VI – II) (Pravdin 1966; Nikolsky 1974).

Size-weight ratios were found by the formula:

\[ W = a \cdot SL^b, \]

where \( W \) is the total body weight, g; \( SL \) – standard fish length, cm; \( a \) – coefficient associated with the shape of the body; \( b \) – growth indicator (indicator of allometric growth).

The parameters «\( a \)» and «\( b \)» of the \( SL-W \) relationship were estimated by the least squares regression method. All of the mean values were given with standard error (±SE).

The null hypothesis of isometric grows (\( H_0: b = 3 \)) was tested by \( t \)-test, using the statistic

\[ t_5 = \frac{b - 3}{S_b} \]

where \( S_b \) is the standard error of the slope for \( \alpha = 0.05 \).

Mathematical processing of the results was done on a personal computer using Microsoft Excel 5.0, Statistica 6.0, SigmaPlot 12.5, Surfer 13.0.

Results and discussion

Monthly averages GSI values obtained for 2016 to 2019 with differentiation for females and males, both as sea temperature in the location studied for April–August are demonstrated in Figure 2. It can be seen that changes in the GSI during the spawning period for individuals of both sexes have the form of a single-peak curve with a maximum in July. For each of the values in the graphs, their standard deviations are marked. Due to the faster maturation of females during the spawning period (April–May), the GSI values of red mullet females exceeded the gonadosomatic indices of males by about 1.2 times. This demonstrates a greater degree of realization of the reproductive potential of females in comparison with males. In August, with a further increase in temperature, both sexes of the red mullet have a sharp decline in GSI.
Red mullet inhabits a depth of 60–70 m in the winter period. During the period of the temperature minimum (December–March), the intensity of the feeding of red mullet is extremely low (Lipskaya 1959). As the spring warm-up of sea water, the growing of milt and ovaries of *M. b. ponticus* occurs. Our studies have shown that in coastal waters on the southwestern shelf of the Crimea maturation of sexual products of red mullet begins in April at an average temperature of 10–11 °C. During this period fish mainly with III (68%), IV (25%) and V (6%) stages of maturity were found in catches. In the spring, the red mullet is more active, including feeding, and the intensity of its nutrition increases with sea temperature increasing. In May, the percentage of fish with maturity stage III was 20%, the amount of fish with the stages of maturity IV and V increased by 80% on the average. In the summer, Mullidae prefer to live in offshore waters at depths of 10–30 m above the seasonal thermocline, where the temperature of water masses in the spawning is within 15–25 °C (Oven et al. 2009). In June–July, the main part of red mullet in catches were fish with maturity stage V.

Our results obtained in 2016–2019 are in agreement with earlier data of L.S. Oven (Oven et al. 2009): the highest GSI values of *M. b. ponticus* in the Black Sea are observed in June and July, with a significant decline in August. The average monthly water temperature during spawning varies from 15 °C at the beginning to 25 °C at the end. However, if in 2003–2007 the value of the GSI in June exceeded that in July (Oven et al. 2009), then in our studies (2016–2019) the maximum value of the GSI shifted to the July (Fig.2). A comparison of monthly GSI changes showed that in 2003–2007, the average annual GSI of females in May was approximately 10% lower, while in the following months (June–August), GSI values were 1.1–1.6 times higher than in the years of our research.

In the south-eastern part of the Black Sea (Sahin & Akbulut 1997; İşmen et al. 2000), spawning lasts from May to August, which practically coincides with our data obtained for the north-western Black Sea part.

In the warmer seas of the Black Sea-Mediterranean Basin, the increase in GSI and the beginning of the spawning are noticed earlier than in the coastal waters of the southwestern shelf of Crimea. Thus, similar analysis for the Aegean Sea showed that increases in GSI values occur mainly from March when the water temperature reaches 15.0 °C to June (the average monthly temperature is 23.0 °C) (Arslan et. al. 2014), and spawning lasts from April to August (Metin 2005). In the Gulf of Tunisia, males spawn from April at an average monthly temperature of 16.0 °C to July at a temperature of 25.2 °C, while reproductive activity of females starts from late spring (in May at an average temperature of 19.0 °C) to July (Cherif et al. 2007).

Studies of the changes of the GSI of red mullet living in the Mediterranean basin showed that males spawn for almost the entire year. There is a tendency towards an increase in the parameter from November to June and a decrease from July to October for males. Females active spawn from April to July with peaks in May (18.6 °C) and June (22.7 °C) (Carbonara et al. 2015).

It is known that for majority of fish species, the sex ratio is close to 1:1. However, in some species of fish, at phenotypic sex determination, the sex ratio can also be affected in addition to genetic factors, by...
temperature, water salinity, the period of light and dark at which the embryo and 0-age group fish develop, as well as some other factors (Nikolsky 1974).

As it was noted above, puberty of males of the red mullet occurs at the end of the first life year, and for females - at the beginning of the second year of life. Research has established that the sex ratio of the *M. b. ponticus* is affected by the temperature of the water during the spawning. So, in years when the average water temperature in the spawning period (May–July) was not high (20.3 °C in 2017), males (56%) prevailed in catches, while in other years, at temperatures above 21.5 °C females dominated (Fig.3). On average, in years with a higher water temperature, 60.4% of fish were females, and 39.6% – males.

Our results on a dependence of the sex ratio in red mullet population on the changes of the temperature of the sea confirm the results of studies presented in a number of publications. It was noted (Županović 1963; Conover 1984; Larsson 2000; Vrgoč 2000; Joksimović 2005), that the sex ratio is affected by environmental parameters, including temperature at the beginning of spawning, as well as harmful industrial sewage discharges, that pollute the aquatic environment and thereby cause disturbances in the endocrine system of fish in the early stages of life, which changes the sex ratio in the direction of the predominant development of males.

![Figure 3](image-url)  
*Figure 3.* The sex ratio of females and males in the May–August of 2016 – 2019.

The relative size distribution of fish caught, averaged over the time interval from 2016 to 2019, is shown in Fig. 4. It can be seen from the figure that the length distribution of females and males is characterized by a single-peak curve. The modal group (10.0–11.0 cm) is clearly distinguished for females, while the modal group is from 9.0 to 10.0 cm for males. During the period studied, the largest number of females and males with V stage of gonads maturity had an average length of 10.7±0.42 cm and 9.5±0.44 cm, accordingly. The smallest sexually mature female was 7.5 cm long, and the male – 7.0 cm.

As the analysis showed, the nature of the development of sexual products is largely determined by the temperature regime of sea in the coldest period of year (February–March). So, in 2017, the temperature of water in February–March amounted to 8.2 °C on average, which match to the minimum values for the entire period of research (2016–2019). In 2017, during the spawning from May to August, the GSI values were minimal compared to other years and amounted to 3.39 for females and 3.32 for males (Fig.5).

The temperature regime of February–March 2018 (average water temperature was 8.6 °C) can be characterized as warm, the GSI values during the spawning period increased significantly and amounted to 4.69 and 4.33 in females and males, accordingly (Fig.5).
2019 was also a warm year. The average water temperature in February–March was 9.2 °C, which was slightly higher than in 2018. However, in 2019, there was a slight GSI decrease. This can be explained by the fact that the region under study is characterized by coastal upwelling generated by wind-driven effects and north-west coastal winds (Repetin et al. 2003; Mikhailova et al. 2011). Storm wind intensification, the average speed of which in April 2019 was 4.3 m/s with maximum gusts of up to 7.2 m/s at the beginning and 8.6 m/s at the end of April, as well as at the end of May, gusts of wind reached 8–9 m/s (pogoda.365c.ru, ventusky.com) led to the rapid mixing of the upper sea layer, its deepening and cooling, an increase in the vertical gradients of the thermohaline characteristics in the upper part of the seasonal pycnocline and an increase in the upper layers of water masses enriched with nutrients that contribute to the development of the entire food chain and create a better food supply for the fish. Upwellings, which were observed in April–May 2019, led to the fact that the average water temperature in these months was lower than the average annual temperature for period studied by 0.3–0.2 °C. As a result, although during the spawning period of 2019, the water temperature as a whole was slightly lower than in 2018 due to the increase in temperature at the spawning peak (June–July) and the high productivity of seawater in area investigated (possible improvement of the food supply), the GSI values were high – 4.80 and 4.42% in females and males, accordingly (Fig.5).
The calculations showed that for both sexes the interannual GSI has a close correlation with interannual water temperature in the spawning. It was found that the correlation coefficients are \( r = 0.98 \) for females and \( r = 0.97 \) for males.

As a result of the application of regression analysis, the “weight–length” dependences were obtained for red mullet for the whole period 2016–2019 (Fig. 6) and for each year separately in the spawning. The obtained parameters of equation (1) are presented in Table 1.

**Table 1.** The main averaged characteristics and growth parameters of red mullet, caught in 2016–2019 in the coastal waters of Crimea in the spring-summer period.

| years | \( t^\circ C \) | \( n \) | \( Sl \) | \( W \) | \( a \) | \( b \) | \( R^2 \) |
|-------|----------------|-------|--------|------|------|------|-------|
| 2016  | 21.5±4.32      | 307   | 10.1±1.19 | 20.41±8.12 | 0.014 | 3.14±0.035 | 0.97 |
| 2017  | 20.3±4.19      | 654   | 9.7±1.34 | 18.28±8.69 | 0.018 | 3.03±0.021 | 0.97 |
| 2018  | 21.8±3.37      | 241   | 10.0±1.38 | 20.80±10.71 | 0.013 | 3.22±0.012 | 0.97 |
| 2019  | 21.6±4.00      | 220   | 10.5±1.29 | 23.61±9.19 | 0.010 | 3.25±0.0484 | 0.97 |
| Σ     |                 | 1422  |         |      | 0.014 | 3.16±0.029 | 0.95 |

It can be seen (fig. 6) that in the research area there is a slight positive allometric growth (the average value of the parameter of allometric growth is \( b = 3.11 \)) with slight deviations from the average value in some years, that is, a change in length during life cycle of the fish as a whole is accompanied by a slight change in its shape (see Ricker 1973; Bagenal et al 1978).

The calculation of the significance level of differences between the coefficient \( b \) from \( b = 3 \), which accords to allometric growth, showed that with a significance level of \( \alpha < 0.05 \) in 2016, 2018 and 2019, the values obtained significantly differ from \( b = 3 \) and during these years positive allometric growth was reliably observed. In 2017, the probability of the difference between the obtained coefficient \( b \) and \( b = 3 \) is \( p = 0.85 \).

A comparison of the allometric growth coefficients for red *M. b. ponticus* living in the coastal waters of Crimea and those caught in the Sinop area (Yilmaz *et al.* 2019) shows some differences. In our studies, based on a regression analysis of all individuals for the study period (fig. 6), a small positive allometric growth is observed (\( b = 3.1 \)), and a small negative allometric growth for red mullet from the coastal Sinop waters. Probably, this is due to differences in the ecological status of the compared marine areas.

![Figure 6](image-url)  
**Figure 6.** The average weight – length relationship for the red mullet that lived in the coastal waters of Crimea in the spring and summer of 2016–2019.

We have demonstrated (fig. 5) that in the study area the red mullet grows almost isometrically (the average value of the allometric growth parameter is close to three (\( b = 3.11 \)) with small deviations in some years, i.e., a change in length during the development of the fish as a whole is practically not accompanied by a change its forms (Ricker, 1973; Bagenal *et al.*, 1978).
An analysis of interannual changes in coefficient \( b \) showed that a close correlation was observed between fluctuations in interannual temperature in the period studied and changes in the coefficient of allometric growth \( b \) (\( r = 0.91 \)). In this case, parameter \( b \) varies from 3.03 (the lowest value) in 2017 at a water temperature at spawning of 18.2 °C to the highest value 3.25 at a water temperature at spawning of 2019 – 19.5 °C (table 1).

As it was noted above, the coefficient \( b \) in the spawning period of 2017 was close to three (\( b = 3.03 \)); this indicates that in 2017 there was an almost isometric growth of the red mullet. However, in 2016, 2018, and 2019 the average water temperature was higher than in 2017, and, in addition, the parameter \( b \) was also high (\( b = 3.14–3.25 \)). Taking into account, that there is relationship between parameter \( b \) and condition factor (Ricker, 1973; Bagenal et al., 1978), it can be stated that the condition factor of the red mullet in these years was higher than in 2017.

The study has established that interannual changes in parameter \( b \) in equation (1) and changes of the gonadosomatic index have a rather high correlation. Calculations showed that the correlation coefficient between changes in these parameters for females is \( r = 0.93 \) and \( r = 0.97 \) for males.

It is revealed, that in years with an average temperature in the spawning period above 21 °C, an increase in the average length and weight of the fish is observed.

On the one hand, the results of our study confirmed the data previously obtained (Owen et al. 2009) on the parameters of the red mullet spawning period, which continue about 4 months at an average temperature of 21.5 °C, with a maximum spawning intensity in June–July. On the other hand, it should be noted that the size and weight characteristics of the \textit{M. b. ponticus} during earlier the period (2003–2007) (Owen et al. 2009) were slightly higher (average length of females – 11.1±1.25 cm, males – 9.8±0.95 cm) than in the period of our work (2016–2019), when the average length of females was 10.7±0.42 cm, males – 9.5±0.44 cm. This indicates a decrease in the growth rate of the red mullet in 2016–2019. This conclusion is confirmed by the data on the biomass decreased and abundance of the red mullets’ food objects (polychaetes and mollusks) during this period, and, as a result, a decrease in the value of another morphophysiological index - the hepatosomatic index, as well as an increase in the resorption of \textit{M. b. ponticus’} scales in the period 2016–2018 explained by increasing of toxicants concentrations in the environment (Kuzminova et al. 2019).

Conclusions

1. A dependence of the development of the red mullet reproductive organs, determined by the gonadosomatic index, on temperature was revealed. It was found that the correlation coefficient between changes in the average temperature during the spawning period and the GSI is \( r = 0.98 \) for females and \( r = 0.97 \) for males.

2. Analysis of the size composition of the \textit{Mullus barbatus ponticus} showed that the size of the females as a whole exceeds the size of the males in spawning. In females, the predominant size group is 10.0–11.0 cm, and in males 9.0–10.0 cm.

3. The average annual values of the coefficients \( a \) and \( b \) of the equation of the dependence “weight–length” are found. It was obtained that for the research period (2016–2019), there is a close correlation between changes in interannual temperature and variations in the coefficient of allometric growth \( b \); correlation coefficient \( r = 0.91 \).

4. The maximum monthly average GSI values were calculated for females and males of red mullet for June (4.294 and 3.76% accordingly) and for July – 4.826 and 4.167%.

5. It was found that in years when the average water temperature during the spawning (May–July) was not high, males prevailed in catches, and in years when the average water temperature during the spawning season was higher than 21.5 °C, females dominated in catches.

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Ecologica Montenegrina, 31, 2020, 10-19
References

Arslan, M. & İşmen, A. (2014) Age, growth, reproduction and feeding of Mullus barbatus in Saros Bay (North Aegean Sea). J. Black Sea/Mediterranean Environment, 20(3), 184–199.

Bagenal, T.B. & Tesch, F.W. (1978) Age and growth. In: T. Bagenal (Editor). Methods for Assessment of Fish Production in Fresh Waters. IBP Handbook No. 3, 3rd ed. Blackwell Sci. Publ., 101–136.

Bat, L., Erdem Y., Ustaoglu, Tiril S. & Yardim, O. (2008) Systematics of fish. Nobel Publication. 270 p.

Boltachev, A.R. & Karpova, E.P. (2012) Sea fish of the Crimean peninsula. Simferopol: Business Inform. 224 p.

Bougis, P. (1952) Recherches biométriques sur les rougets (M. barbatus L., M. surmuletus L.) (Biometric research on goat fish (M. barbatus L., M. surmuletus L.). Archs. Zool. Exp. Gén., 89(2), 57–174.

Carbonara, P., Intini, S., Modugno, E., Maradonna, F., Spedicato, M. T., Lembo, G., Zapa, W. & Carnevali, O. (2015) Reproductive biology characteristics of red mullet (Mullus barbatus L., 1758) in Southern Adriatic Sea and management implications. Aquat. Living Resour. 28, 21–31.

Cherif, M., Zarrad, R., Gharbi, H, Missaoui, H. & Jarboui, O. (2007) Some biological parameters of the red mullet, Mullus barbatus L., 1758, from the Gulf of Tunis. Acta Adriatica, 48(2), 131–144.

Conover, D.O. (1984) Adaptive significance of temperature-dependent sex determination in a fish. American Natural, 123(3) 297–313.

Domashenko, Yu.G. (1991) Biology, prospects for red mullet in the Black Sea. Abstract. dis... cand. biol. sciences. M.: Moscow State University, 21 p.

Fishery Statistics, Turkish Statistical Institute. http://www.tuik.gov.tr. Accessed April 16, 2018.

Hureau, J.C. (1986) Mullidae. In: Fishes of the North shelf tepes, (eds., P.J.P. Whitehead, M.L. Bauchot, J.C. Hureau, J. Nielsen, E. Tortonese), UNESCO, Paris, pp. 877–882.

İşmen, A., Yıldırım, Y. & İşmen, P. (2000) Growth characteristics and reproductive biology of red mullet (Mullus barbatus, L. 1758) in the eastern Black Sea. Fisheries Symposium 342–356.

Joksimović, A. (2005) Population dynamic of red mullet Mullus barbatus, Linnaeus, 1758 in the Montenegro shelf. Ph. D. Thesis. Faculty of Biology, University of Belgrade, 93 pp.

Kozhurin, E.A., Shlyakhov, V.A. & Gubanov, E.P. (2018) The dynamics of catches of commercial fish of the Crimea in the Black Sea. Trudi VNIRO, 171, 157–169.

Kuzminova, N.S., Alemov, S.V., Viter, T.V., & Novoselsky, V.Yu. (2019) Interannual fluctuations in the main population and morphophysiological parameters of the red mullet and its food objects in the coastal zone of the Sevastopol. Ecosystemi, 20, 117–124.

Larsson, J.D.G., Hallman, H. & Forlin, L. (2000) More male fish embryos near a pulp mill. Environmental Toxicology and Chemistry, 19, 2911–2917.

Lipskaya, N.Ya. (1959) Dependence of the intensity of the nutrition of red mullet (Mullus barbatus ponticus) Essipov on temperature at experimental conditions. Tr. Sevastopol. Biol. St., XII, 328–337.

Metin, G. (2005) Reproduction characteristics of red mullet (Mullus barbatus L. 1758) in İzmir Bay. EU Journal of Fisheries and Aquatic Sciences, 22(1-2), 225–228.

Mikhailova, E.N., Polonsky, A.B., & Muzyleva, M.A. (2011) About the water surface temperatures drops in the Karkinitsky Gulf of the Black Sea. Mor. hydrophysis. zhurn., 6, 28–35.

Nikolsky, G.V. (1974) Dependance of the intensity of the nutrition of red mullet (M. barbatus ponticus) Essipov on temperature at experimental conditions. Tr. Sevastopol. Biol. St., XII, 328–337.

Oven, L.S. (1961). On the specifics of portioned spawning and on the fecundity of the Black Sea red mullet Mullus barbatus ponticus Essipov. Journal of Ichthyology, 17 (1), 33–38.

Oven, L.S. (1976) Features of oogenesis and the nature of spawning of marine fish. Kiev: Nauk. Dumka, 131 p.

Oven, L.S., Salekhoa, L.P. & Kuzminova, N.S. (2009) Current status of the population of the Black Sea red mullet Mullus barbatus ponticus, which lives in the coastal area near Sevastopol. Journal of Ichthyology, 49 (2), 214–224.

Özbilgin, H., Tosunoğlu, Z., Bilecengolu M. & Tokaç A. (2004) Population parameters of Mullus barbatus in İzmir Bay (Aegean Sea), using length frequency analysis. Journal of Applied Ichthyology, 20(4), 231–233.

Pavlov, I.F. (1966) Guide to the study of fish. M.: Pishev.prom., 376 pp.

Repelin, L.N., Belokopytov, V.N. & Lipchenko, M.M. (2003) Winds and waves in the coastal zone of the southwestern part of Crimea. Ecolological safety of coastal and shelf zones and integrated use of shelf resources, 9, 13–21.
Ricker, W.E. (1973) Linear regressions in fishery research. Journal of Fisheries Research Board of Canada, 30, 409–434.

Sahin, T. & Akbulut, B. (1997) Some biological characteristics of Mullus barbatus ponticus Essipov, 1927 in the Eastern Black Sea Coast of Turkey. Turkish Journal of Zoology, 21 (2), 179–185.

Samsun, O. (2017) Length-Weight Relationship and Mortalities of Mullus barbatus ponticus Essipov, 1927 in the Central Black Sea, Turkey. Turkish Journal of Maritime and Marine Sciences, 3(2), 75–80.

Shlyakhov, V.A., Shlyakhova, O.V., Nadolinsky, V.P. & Perevalov, O.A. (2018) Commercial and biological indicators of fisheries for the most important distributed reserves of aquatic biological resources of the Black Sea as the basis for their regional estimation. Vodnie biorersursi i sreda obitania, 1 (1), 86–103.

Tesch, F.W. (1971) Age and growth. In: Methods for assessment of fish production in fresh waters. W. E. Ricker (Ed). Blackwell Scientific Publications, Oxford, pp. 98–130.

Tüzün, S., Dalyan, C. & Eryilmaz, L. (2019) Age and Growth of the Red Mullet Mullus barbatus in the North Aegean Sea. Journal of Ichthyology, 59(4), 572–582.

Vrgoč, N. (2000) Struktura i dinamika pridnenih zajednica riba Jadran skog mora (Structure and dynamics of demersal fish communities in the Adriatic Sea). Ph. D. Thesis. University of Zagreb, 198 pp.

Yılmaz, B., Samsun, O., Akyol, O., Erdem, Y. & Ceyhan, T. (2019) Age, growth, reproduction and mortality of Red Mullet (Mullus barbatus ponticus Essipov, 1927) from the Turkish coasts of the Black Sea. Ege Journal of Fisheries and Aquatic Sciences, 36(1), 41–47.

Županović, S. (1963) Contribution a la croissance de la biologie du Mullus barbatus L. dans l’Adriatique moyene (Contribution to the knowledge on Mullus barbatus L. biology in the middle Adriatic). Rapp. Com. int. Mer Medit., 17(2), 346–362.