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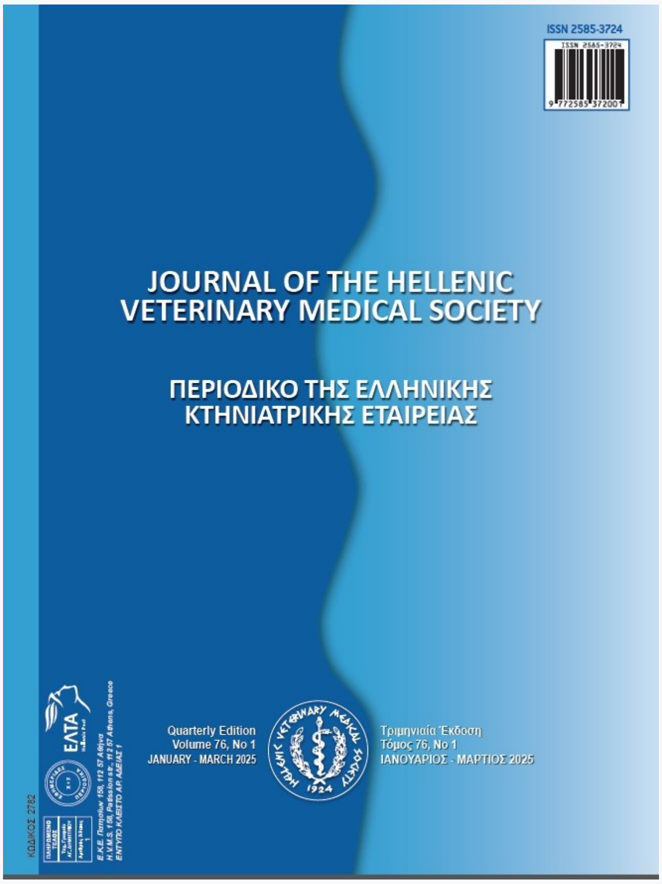

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S Jaberi, A Bani, S Bakhshalizadeh

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Demographic parameters of Caspian trout (*Salmo caspius*) in the southwest Caspian Sea

S. Jaberi[1], A. Bani[1,2], S. Bakhshalizadeh[2,*]

[1]*Department of Marine Biology, Faculty of Science, University of Guilan, Rasht, Iran*

[2]*Department of Marine Science, Caspian Sea Basin Research Center, University of Guilan, Rasht, Iran*

ABSTRACT: *Salmo trutta caspius* is one of the migratory (anadromous) and endemic fish species of the Caspian Sea which exists in the rivers and has great economic and commercial importance to the region. This species lives in the salty and brackish water and returns to freshwater to spawn. In the current study, demographic parameters of *Salmo trutta caspius* are investigated. A total of 104 samples were collected from Anzali to Shafarud in the southwest part of the Caspian Sea in the fall of 2018, using commercial gill-nets. The total length, total weight, and gender of specimens were determined. In terms of sex ratio; the female population was 1.88 times more than the male population. The mean length for males was 67.7±7.8 cm and for females it was 65.6±6.8 cm. The mean weight for males and females was 3.0±0.1 kg and 2.8±0.81 kg, respectively. The correlation coefficient for length-weight relationship was 0.95. The growth rate (K) and asymptotic length (L∞) for both genders were calculated to be 0.37 and 69 cm, respectively. Estimates for natural mortality (M), fishing mortality (F), total mortality (Z), and the exploitation coefficient were 0.3, 1.34, 1.64, and 0.81, respectively. This study showed that the population of this species is young in the southwest Caspian region. With regards to the mortality rate and negative algometric growth, it could be concluded that overfishing of older individuals has caused a reduction in the size of Caspian trout population.

Keywords: Population Dynamics; Age; Growth; Mortality; Caspian Sea; Trout

Corresponding Author:
Shima Bakhshalizadeh, Department of Marine Science, Caspian Sea Basin Research Center, University of Guilan, Rasht, Iran
E-mail address: sh.bakhshalizadeh@guilan.ac.ir

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INTRODUCTION

Determining the optimal exploitation of aquatic resources in the long term and preserving the exploited species is one of the most important issues of aquatic resource management. Therefore, the first step in preserving and restoring the reserves of an aquatic ecosystem is to study the biology and ecology of fish species in the ecosystem. This leads to better recognition and analysis of the ecology of the food chain of the ecosystem and has many applications in the proper management of fisheries stocks (King 2013). This issue is especially important for economically valuable species such as salmon.

The Caspian Sea salmon is one of the migratory fish (anadromous) native to the Caspian Sea which has great economic and commercial importance. This fish lives in the sea and enters the rivers for spawning (Sarvi *et al*. 2006). The range of distribution of this species in the Caspian Sea is mainly in the western and southwestern coasts, and its distribution is very small in the northern and eastern coasts of the Caspian Sea (Abtahi *et al*. 2007).

Every year, in order to preserve and restore the reserves of this valuable species, hundreds of thousands of salmon fry are released by the Iranian Fisheries Organization into the rivers around the Caspian. According to statistics, during the years 1984 to 2013, 10.8 million salmon fry were released in the Caspian Sea, and in the same years, the catch of this fish was 97.3 tons, including 40% smuggled and unregistered fish. When this includes spawners caught for reproduction, this figure reaches 136.2 tons per year, which shows a return coefficient of about 0.5% compared to the number of released fry (Abdolmalaki 2013).

In recent years, a significant decrease in the number of this fish caught has been observed on the Caspian coast (Abdolmalaki and Sayyad bourani 2004) and Caspian brown trout (Salmo trutta caspius) broodstock supply in south western of the Caspian Sea (Abdolmalaki et al., 2016). The decline of this fish is due to the ecological disturbance in the rivers around the Caspian Sea with the entry of pollutants, toxins and sewage (Sarvi et al. 2006). Also, sand harvesting, urban development and dam construction have reduced the migration and natural reproduction of these fish (Sarvi et al. 2006). However, the overfishing of these fish, especially in the mouths of rivers, is another important factor that aggravates the decline of their population (Tabatabaei et al., 2020). All of these factors have caused the Caspian Sea salmon to be placed on the IUCN endangered species list and in critical condition (Karami et al. 2018; Kiabi et al. 1999; Sarvi et al. 2006). Therefore, a detailed study of the dynamics of the population structure and information on the important parameters of the population structure are required to provide the basis for the preservation and management of this valuable species. In addition, the determination of indicators such as growth and mortality, which are estimated based on the age of fish, is the basis of the population dynamics model (Morales-Nin 1992). This basic information can determine the life of the population and reveal the effect of the environmental factors of the ecosystem of the fish species on its population dynamics (Vicentin et al. 2013). Providing information about the population structure of Caspian salmon and its growth status in the natural ecosystem, considering the lack of this information in the Iranian coasts of the Caspian Sea and the economic importance of this fish, will be a vital step in protecting this valuable species.

MATERIALS AND METHODS

Sampling took place during the months of October to December 2018 from the southwestern shores of the Caspian Sea in the areas of Jafroud, Taleb-Abad, Sangachin, Ghazian, Mojshekan, Bashman, Taze Abad, Pasdaran, Gulogah, Kapurchal, Sahil Gho, Taleb Abad, Haji Bekende and Shafarood (Figure 1). It was a completely random sample from the commercial catch (65) of active fishers from Mashek and Laksh. The spring size of the nets used was 2.5 to 3.5 meters, 4 to 6 meters and 2 to 4 centimeters, and the depth of the nets was 1.5 to 25 meters. The parameters of age, length and weight of 104 fish were bio-measured. A biometric board was used to measure the total length of the fish with an accuracy of 1 mm, and a digital scale was used to measure the weight of the fish with an accuracy of 1 gram (Biswas 1993). After determining the sex of the fish based on macroscopic characteristics, the biometric information of the samples was recorded and their otoliths were extracted to determine the age of each fish (Agger *et al*. 1974).

Since there are no differences between the left and right otoliths, the left otoliths were used for age determination (Campana and Casselman 1993). Otoliths were prepared for age determination by the 'heating and breaking method' (Winkler et al. 2019) and, the otolith pieces were polished with sandpaper No. 600 after adding a drop of glycerine oil on the cut surface. Using a stereomicroscope (KRUSS, Germany), the age of each fish was determined by counting the dark and light rings (Armiger *et al*. 2009) (Figure 2). Among the extracted otoliths, 25 were suitable for age determination due to the presence of distinct growth rings. After recording the basic information of growth parameters, the length frequency, weight frequency, age and the combination of length and weight were checked. The relationship between length and weight was calculated using equation 1 (Ricker 1975).

$$W = aL^b W = aL^b \tag{1}$$

In this relationship, W is the total weight of the fish in grams, L is the total length of the fish in centimeters, a is the coefficient of the relationship, and b is the parameter of the equation. If b is equal to or close to three, it indicates isometric growth, and if it is smaller than three, it indicates negative allometric growth. If b is greater than three, it indicates positive allometric growth. If the number obtained for b is not significantly different from the number 3, then the fish has homogeneous growth. Therefore, in order to measure this difference, the t-test (Equation 2) was used.

$$t = \frac{s.d.(l)}{s.d.(w)} * \frac{(b-3)\sqrt{n-2}}{\sqrt{1-r^2}} t = \frac{s.d.(l)}{s.d.(w)} * \frac{(b-3)\sqrt{n-2}}{\sqrt{1-r^2}} \tag{2}$$

In this relationship, s.d.(l) is the standard deviation of the logarithm of fork length values, s.d. (w) is the standard deviation of the logarithm of total weight values, r^2 is the regression coefficient of the length-weight relationship and n is the number of samples used. The condition index or fatness coefficient, a

Figure 1. Geographical distribution of sampling stations (blue color and black bold line) of salmon (*Salmo trutta caspius*) in the south-western part of the Caspian Sea.

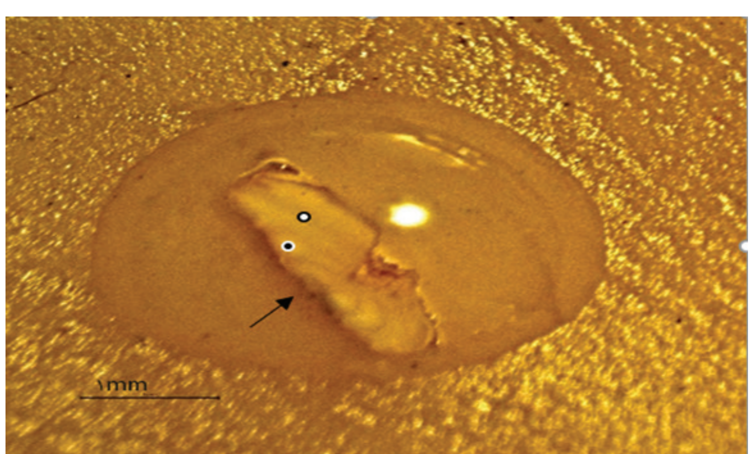

Figure 2. The image of the cross-section of the heated hearing stone, magnification x30 under the stereomicroscope of KRUSS, Germany). In this image, the difference between dark and light circles is shown by empty (white) and filled (black) circles, respectively. The arrow also shows the center of the rings.

suitable representation of the condition of the fish body at a certain length, was obtained using equation 3.

$$CF = 100\,\frac{W}{L^b} CF = 100\,\frac{W}{L^b} \qquad (3)$$

In this formula, CF is the obesity coefficient (%), L is the total length of the fish (cm), W is the weight of the fish (grams). In addition, the von Bertalanffy growth parameters were calculated by the least squares method using equation 4, and then the growth curve was drawn based on the data of age, length and growth parameters.

$$Lt = L\infty\left(1 - e^{-K(t-t0)}\right) Lt = L\infty\left(1 - e^{-K(t-t0)}\right) \qquad (4)$$

According to this equation, Lt is the length at age t, L∞ is the length of the eternal tangent, and K is the growth factor that determines how fast the fish reaches L∞. t_0 is the time of fish hatching. Equation 5 was used to calculate t0, Pauly's empirical relationship.

$$-\text{Log}(-t_0) = 1.038\ \text{Log}\ k - L\infty\ \text{Log}0.3992 - 0.2752 \qquad (5)$$

In this equation, t_0 is the age at zero length, L∞ is the asymptotic length in centimeters and k is the growth rate, and equation 6 was used to calculate the life span t_{max} (Pauly 1984).

$$t_{max} = t_0 + 3/k \qquad (6)$$

In this equation, t_{max} is the life span, t_0 is the age at zero length and k is the growth factor. Due to the inverse relationship between the asymptotic length L∞ and the growth factor k, the amount of ϕ will be almost constant for the same species (Pauly and Munro 1984). Therefore, in order to compare and estimate the correctness of the obtained growth parameters L∞ and k, Munro's phi prime test were used in equation 7.

$$\phi = \ln K + 2\ln L\infty \phi = \ln K + 2\ln L\infty \qquad (7)$$

The total mortality rate was obtained from equation 7 (Beverton and Holt 1964).

$$z = k(L\infty - \text{Lmean})/\left(Lmean - \acute{L}\right)$$
$$z = k(L\infty - \text{Lmean})/\left(Lmean - \acute{L}\right) \qquad (8)$$

Here, Lmean is the average length, Ĺ is the lower limit of the first length group that is vulnerable to fishing tools, L∞ is the asymptotic length in centimeters and K is the annual growth factor. To calculate the natural mortality (M), equation 8 was used based on the regression test of growth indices and average water temperature (Pauly 1984).

$$\ln M = -0.0066 - 0.297\ln L\infty + 0.654\ln k + 0.463\ln T$$
$$\ln M = -0.0066 - 0.297\ln L\infty + 0.654\ln k + 0.463\ln T \qquad (9)$$

In this equation, M is the annual natural mortality rate, L∞ is the aymptotic length of the fish in centimeters, K is the von Bertalanffi growth rate, and T is the average temperature of the environment (Sparre 1998). Fishing mortality (F) was calculated based on the relationship F+M=Z (King 2007). In this relationship, F is fishing mortality, M is natural mortality, and Z is total mortality, and total mortality (Z) was calculated using the linear catch method. In order to calculate the exploitation rate, the relationship E=F/Z was estimated, where E is the exploitation rate, F is the fishing mortality and Z is the total mortality. In this situation, the best result is when the value of E is equal to 0.5. Usually, when the stock is under fishing pressure, the value of E is greater than 0.5, and if the stock is under-exploited, the value of E will be less than 0.5 (King 2009).

Before performing all the statistical analyses, the distribution and normality of the data were checked. Due to the small number of samples, the normality of the data was checked using the Shapiro-Wilk test. After determining the length class for both sexes, the similarity or difference in their frequency was measured using a (χ^2) Chi-square test. All calculations were done using Excel (version 2014) and SPSS (version 15) software. A One-sample t-test was used to compare the average height and weight with the data from 2015(Sayyad bourani *et al*. 2015).

RESULTS

Out of 104 salmon samples caught, the largest fish was a male, with a length and weight of 82 cm and 5.2 kg, respectively. In females, the largest fish was 81.5 cm and 5.3 kg, respectively, while the smallest female fish was 45.5 cm and 0.83 kg, and the smallest male was 45 cm and 0.7 kg. There was no significant difference in length, weight and age of the two sexes (Table 1).

The relationship between length and weight of female salmon was $W = 0.0000148L^{2.8999}$and for male fish W = $0.0000059L^{3.1159}$ (Figure 3). Determining the growth pattern of this fish based on the t -test showed negative allometric growth (n=104).

Considering that there was no significant difference in the length, weight and age of the fish, the growth parameters were estimated for the total of the two sexes (Figure 4). The growth factor and the asymptotic length of the fish were calculated as 0.37 and 69 cm, respectively (Table 2; Figure 4). The natural mortality rate was 0.3. The fishing mortality rate, the exploitation rate and total mortality rate were estimated as 1.34, 0.81, and 1.64 respectively (Table 2).

Table 1. One-way analysis of variance test for comparing the length, weight and age of salmon in two sexes in the southwestern part of the Caspian Sea.

Size	Sex	N	Mean	SE of mean	Minimum	Maximum
Length (cm)	Female	68	65.6	6.8	45.5	81.5
	Male	36	67.7	7.8	41.5	82
Age (years)	Female Male	26	3.68	0.825	2	5
Weight (kg)	Female	68	2.8	0.81	0.83	5.3
	Male	35	3	1	0.7	5.2

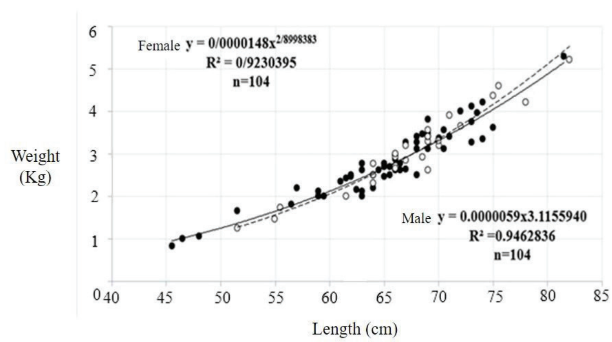

Figure 3. Total length-weight relationship. Male (open circles and dashed line) and female (filled circles and continuous line) Caspian salmon in the southwestern part of the Caspian Sea.

Table 2. Demographic parameters in salmon in the southwest of the Caspian Sea

Growth rate (K)	Asymptotic length ($L\infty$)	Phi Prime Monro φ (ø)´	Natural mortality rate (M)	Fishing mortality rate (F)	Total mortality (Z)	Utilization factor (E)	Catch per unit of effort (CPUE)	Life span (t_{Max})	Age during zero (t_0)
0.37	69	3.33	0.3	1.34	1.64	0.81	1.08	5	-0.136

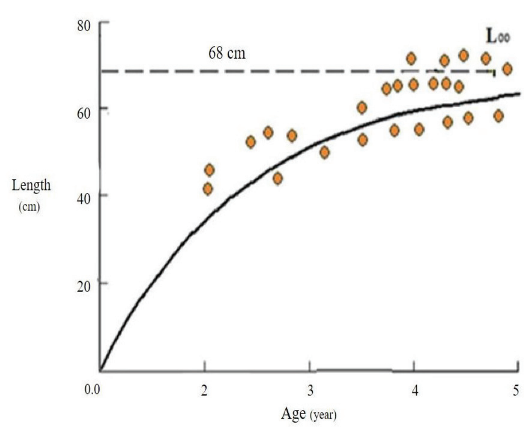

Figure 4. Bertalanffi salmon growth chart in the southwestern part of the Caspian Sea (n=25).

DISCUSSION

This study examined the parameters, including age, growth and mortality of Caspian salmon in the southwestern region of the Caspian Sea. The results showed that the populations of this species are mostly young and the abundance of female salmon in the southwest of the Caspian Sea is 1.88 times that of male fish. In the study of Sayyad bourani *et al*. 2015, the frequency of male salmon in the south of the Caspian in 2016 was reported to be about 27.7% compared to 72.3% of female fish. The Caspian Sea salmon catch in 1984 indicated that 35% of the fish were male and 65% were female. This ratio was 45% male and 55% female in 2007. However, the sexual predominance of females was more prominent in a study conducted in 2014, where 72% of the fish caught were females and 28% were males (Sayyad bourani *et al*. 2015). According to the report (Nikolsky and Birkett 1963), the sex ratio differs from one species to another, but in most species this ratio is approximately equal. However, the discrepancies in the sex ratio may be caused by the difference in habitat preference according to the season and sex, selective mortality, environmental pollution, differences in the time and place of fishing, among other factors that make the female population dominant (Pettersson *et al*. 2004; Head *et al*. 2017).

In this study, the range in the length of the salmon was observed to be between 41.5 and 82 cm. Based on the previous calculations, it was found that the average length of fish under the age of three years was 41.7 cm. At this age they are considered to be under puberty. Therefore, they do not come close to the shore during the spawning season and are not seen in the catch (Sayyad bourani *et al*. 2015 and 2017), but in this research, according to the longitudinal range of sampled fishes, it seems that the adult group existed near the coast and were caught.

The average length and weight of the studied salmon was 66.2 cm and 2.9 kg, while in the previous study, the average weight of salmon in 1947 and 1953 was 4.865 and 3.948 kg, respectively. The average length of fish in those years has been recorded as 78.0 and 67.0 cm respectively (Kiabi *et al*. 1999) and in the present study, a decrease in the length and weight of these fish was observed. The decrease in the average length and weight of the salmon population indicates that the population is getting younger, and the reason for this may be the higher mortality rate and the removal of larger specimens due to fishing (Niksirat and Abdoli 2009; Ohlberger *et al*. 2022). According to the studies of Ghaninejad *et al*. (2009), the average length and weight of salmon from commercial fishing has decreased in recent years compared to the previous decades, and the average weight has decreased from about 5 kg in 1947 to 2 kg in 2001 (Sayyad bourani *et al*. 2015 and 2017). Furthermore, the absence of significant differences in length, weight, and age between male and female salmon in the present study indicate relatively uniform distribution of demographic parameters between two sexes within the sampled population. This highlights the homogeneity of the sample population.

In addition to the decrease in weight, a decrease in free length of fish has also occurred in the past years, such that the average length of this fish was 78 cm in 1947, but it decreased to 67 cm in 1973 (Sayyad bourani *et al*. 2015). The decrease in the average length and weight of Caspian salmon in recent years indicates the pressure on this fish stock and its unprincipled exploitation (Abdolmalaki 2013). This decreasing trend in length and weight has also been reported in other Caspian Sea fishes (Bakhshalizade and Bani 2012; Aminian *et al*. 2017). Sayyad bourani *et al*. (2015) investigated the effects of environmental and biological factors on the catch and migration of white fish in the Caspian Sea in 2014. Their study showed that although white fish stocks have increased quantitatively compared to the past decades, qualitatively they observed changes in the stock, the most important of which was low growth factors such as length, weight and also, the age of the fish caught compared to the previous decades (Aminian *et al*. 2017).

The results of the study of genetic diversity in Caspian Sea salmon indicates that genetic polymorphism is lower in the southwestern Caspian Sea salmon population compared to the Atlantic salmon population (Dysin *et al*. 2022). The lower genetic diversity in the Caspian Sea salmon compared to the free Atlantic fish population may be due to the small size of the population and the lack of genetic mixing between the studied population and other Caspian salmon populations. Environmental changes and overfishing may have caused a decrease in heterozygosity in the Caspian salmon population. Therefore, the wild fish of the southern basin of the Caspian Sea are smaller than its other strains and their weight reaches 2-12 kg (Dysin *et al*. 2022; Abdolmalaki 2013). The salmon population of the southwest region has a higher genetic diversity and abundance than the salmon of the Mazandaran region in the south Caspian sea. Therefore, it is less prone to genetic changes and has the state of a wild population. It is thus less affected by artificial reproduction, so the fish are smaller in terms of length and weight (Abdolmalaki 2013).

The relationship between length and weight in the present study showed that the numerical value b of the females was less than 3 and they had negative allometric growth, which was similar to the results obtained on Caspian salmon (Sayyad bourani *et al*. 2015). In the studies conducted on the brown trout of the northeastern Anatolian River of Turkey (Arsalan 2007), they reported the value of b to be less than 3. In the research conducted by Salvatian *et al*. (2015) on the red spotted trout of Lar Dam Lake, the growth pattern of the red spotted trout was also reported as of the negative allometric type. In other fish whose growth rate is negative allometric, we can refer to the research on the population of Kilka fish (*Clupeonella sp.*) in the southern basin of the Caspian Sea (Ghninezhad *et al*. 2007). Previous research showed that factors such as geographical areas, environmental conditions such as water temperature, feeding capacity, season, date and time of fishing, stomach fullness and diseases can affect the changes in the numerical value of b (Arsalan 2007). In addition to biotic factors, abiotic parameters such as water temperature, salinity, diet, food consumption and density also affect fish growth (Tsoumani *et al*. 2006). The obtained b value of the length-weight relationship shows the shape of the fish body and the direct effect of the fish biological ecosystem (Stergiou and Moutopoulos 2001).

The growth factor and length average of Caspian Sea salmon indicate the proper growth of this fish in sea water. Previous studies showed that the growth of this fish during its young life is much lower in fresh water (rivers) (Sayyad bourani *et al*. 2015).

Comparison of L_∞ in this study with other salmon trutta L_∞ in other regions shows that this index is optimal for Caspian Sea Caspian salmon in the southwest of Caspian Sea (Guilan region). The rate of growth (K) indicates the speed of growth towards asymptotic length, and its highest value is close to 1 in fish species that have a short life, and its lowest value (close to zero) is seen in those that have a longer life. In addition, the values of L_∞ and K have an inverse relationship with each other, and with the decrease of the asymptotic length, the growth rate increases (Charnov 2008).

The natural mortality rate in this study was estimated at 0.3, which indicates a significant rate of mortality. The value of phi-prime Munro obtained in this research was 3.33, which was equal to the report published (Thorpe 1974) for brown trout in the Baltic Sea, and it was proof of the correctness of the growth and asymptotic length of this research, and also the value of the phi-prime for brown trout in Russia in the Caspian Sea is reported to be equal to 3.68, which is slightly higher than the phi-prime value obtained in this research (Anonymous 2022).The pressure of on fish stocks can be attributed to environmental factors such as the loss of fish habitat which affects their survival. By comparing the data and results of growth and mortality parameters in the current study with previous studies, the results of the current study are largely confirmed, (Froese et al. 2014). The results of Turan and Engin (2009) also confirms the results of the current study.

CONCLUSIONS

In this study, the three branches of the studied parameters, including age, growth and mortality of Caspian salmon in the southwest of Caspian Sea, showed that the populations of this species are mostly young fish. In terms of gender distribution, for every male there are on average 1.88 females. According to the mortality rate and negative allometric growth of this population, it can be concluded that overfishing and the death of older fish in the population have caused their numbers to decrease and the population of this fish stock has been put at risk. Considering the fact that the situation varies between different salmon populations in different regions of the Caspian Sea, for the sustainable management of salmon stocks, it should be taken into account that such fishes form multiple different ecological units in the entire southern basin of the Caspian Sea. Therefore, from the point of view of management and exploitation aspects, Caspian salmon with considerable geographic distribution in the Caspian Sea should be considered as relatively independent units.

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CONFLICT OF INTEREST

None declared

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