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Length-weight Relationships of Mediterranean Horse Mackerel *Trachurus mediterraneus* (Steindachner, 1868) (Actinopterygii: Carangidae) from South-Western Shelf of the Crimea, Black Sea

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Abstract: We studied the correlation "weight-length" as well as the standard length on age for the Mediterranean horse mackerel in the bays off Sevastopol and Balaklavskaya Bay. The size of the horse mackerel living in the water area of the Balaklavskaya Bay in the autumn-winter period differed from the horse mackerel living in the bays of the city of Sevastopol, as confirmed by the low correlation coefficient (r = 0.337). Specimens of horse mackerel living in the Balaklavskaya Bay were longer by 10–20% than the ones from the bays of the city of Sevastopol. Analysis of the sexual structure showed that the proportion of males was generally higher than the proportion of females. The growth parameters of horse mackerel caught from the south-western shelf of the Crimea and in the Bulgarian waters of the Black Sea were compared.

Key words: horse mackerel, *Trachurus mediterraneus*, length-weight relationship, Black Sea

Introduction

Mediterranean horse mackerel *Trachurus mediterraneus* (Steindachner, 1868) is widespread along the entire coast of the Black Sea. It is one of the main commercial fish species for the Black Sea countries. Catching of horse-mackerel in the Black Sea varies widely: in 1985 it exceeded 140,000 tons but then the catch decreased sharply (Zuyev et al. 2010). Since 1991, there has been a restoration of the horse mackerel and in the last decade the catch by the Black Sea countries has stabilised in the range of 15,000–20,000 tons, with an upward trend in recent years (Yankova 2014).

Analysis of biometric measurements of horse mackerel from various regions of the Black Sea) showed that there are some differences between the horse mackerel in different parts of the Black Sea (Drenski 1951, Ambroaz 1954, Aleev 1959, Stoyanov et al.1963, Şahin et al. 1997, Zuev et al. 2003, Yankova 2013, Kuzminova et al. 2014, Melnikova & Kuzminova 2018). These differences are related both to the peculiarities of the ecological state of the habitat and to the features of fish development in different periods of their life cycle (Salekhova 2007, Yankova et al. 2010). The publications on this topic do not reveal sufficiently the regional features of the length-weight relationships, which are of great importance in the fishing industry (Raykova-Petrova & Zivkov 1987).

The aim of this work was to make a comparative assessment of the size and weight parameters of horse mackerel living in the area of the Balaklavskaya Bay and the territorial waters of Sevastopol (Karantinnaya, Aleksandrovskaya and Streletskaya bays) in the spring-summer and autumn-winter periods.

Materials and Methods

Specimens of the Mediterranean horse mackerel were collected from the coastal waters of the city of Sevastopol (Alexandrovskaya, Karantinnaya and Streletskaya Bays), from the open water area of the sea opposite Pesochnaya Bay and also in the

Balaklavskaya Bay area (Fig. 1), during 2010–2017.

The processing of the results was carried out separately for the spring-summer period (April-August) and the autumn-winter period (September-March). Fish collected in the coastal zone of the city of Sevastopol and Balaklavskaya Bay were analysed separately. A total of 2,518 specimens of horse mackerel were collected. The number of specimens examined by season and area was distributed as follows: the area of Sevastopol in the spring-summer period – 1154 specimens, autumn-winter period – 583 specimens; the area of the Balaklavskaya Bay in the spring-summer period – 459 specimens, and autumn-winter period – 322 specimens.

The standard length (*SL*) was measured to the nearest 0.1 cm; the body weight was measured with an electronic balance to the nearest 0.1 g. The age of the fish was determined using otoliths; sex and stage of maturity were determined by examination of the state of gonads (Pravdin 1966).

The length-weight relationship of horse mackerel was estimated with the following equation (Ricker 1979):

$$W = a \cdot SL^b, \quad (1)$$

where W was total body weight (g), SL was standard length (cm), a and b are regressive constants.

The dependence of the standard length on age was estimated using the von Bertalanffy growth formula (VBGF):

$$L_t = L_\infty \left[1 - e^{-K(t-t_0)}\right], \quad (2)$$

where L_t was the length at time t (cm), L_∞ was the average asymptotic length of fish from the studied population (cm), K was the growth coefficient (year^{-1}), t_0 was the age of fish at zero length (year) and t was the age of the fish. Statistical calculations were carried out using Excel (Microsoft Corporation) and Sigma Plot (Systat Software Inc.).

To quantify the differences in the size distribution of fish from the studied regions in different seasons, the pair correlation coefficient was used (Rokitsky 1961):

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}}, \quad (3)$$

where r was the coefficient of pair correlation, i was the number of the current dimensional group, n was the number of dimensional groups, x_i was the number of fishes of the i^{th} dimensional group for the first of the two compared areas (seasons), $\overline{x}$ was the average number of fishes in the dimensional group for the first of the compared areas (seasons), y_i was the number of fish in the i-i^{th} dimensional group for the second of the two compared areas (seasons) and $\overline{y}$ was the average number of fishes in the dimensional group for the second of the compared areas (seasons).

The Balaklavskaya Bay is not large: its length is only 1.5 km and the largest width is 425 m (Gurov et al. 2015). Its depth varies from 5 to 36 m, with an average of 12.5 m.

The Karantinnaya, Aleksandrovskaya and Streletskaya Bays, which are part of the territorial waters of the city of Sevastopol, are located on the northern slope of the Heraklion Peninsula. They are wide bays that are not deep into the land, with depths up to 20 m. The Streletskaya and Karantinnaya Bays have water exchange with the open sea; however, they are in the territorial waters of the city of Sevastopol, which negatively affects the ecological status of these bays.

On the south-western shelf of the Crimea the horse mackerel is found all year round. It is a fish that prefers warm waters. The most important periods of its life (reproduction and increasing of weight) occur at water temperatures above 15°C. In connection with this, the annual life cycle of the horse mackerel is divided into two periods: 1) spring-summer, characterised by an active state, when there is growth, putting on weight, reproduction; 2) autumn-winter, in connection with the cooling of water this period is characterized by a reduced metabolism, a decrease or even a cessation of feeding, migration to the bottom for wintering.

The places of wintering of horse mackerel are located in the warmest parts of the Black Sea, i.e. off the coast of Georgia, Anatolia and Bulgaria (Ambroaz 1954, Yankova 2013). However, some horse mackerels winter at the southern coast of the Crimea in the area of the Balaklavskaya Bay as well as in the small area from Fiolent to Aya Cape, not far from the coast (from 300–400 m to two miles). In warm winters, they can also be found in the bays off Sevastopol and in the Laspi Bays. The places of wintering of horse mackerel are usually bays protected from winds and strong currents, with depths from 20 to 80 m. In the wintering areas, the horse mackerel gathers into dense jambs, convenient for catches with purse seines or a cone net with the use of electric light.

Results

The standard length of the collected fish in the bays of Sevastopol varied from 6.6 to 19.1 cm (av. 11.2 ± 1.74 cm) during the spring-summer period and from 6.8 to 16.4 cm (av. 10.8 ± 1.58 cm) in the autumn-winter period. In the Balaklavskaya Bay, mostly larger individuals were found: SL varied from 8.1 to 17.5 cm (av. 12.6±1.53 cm) in the spring-summer

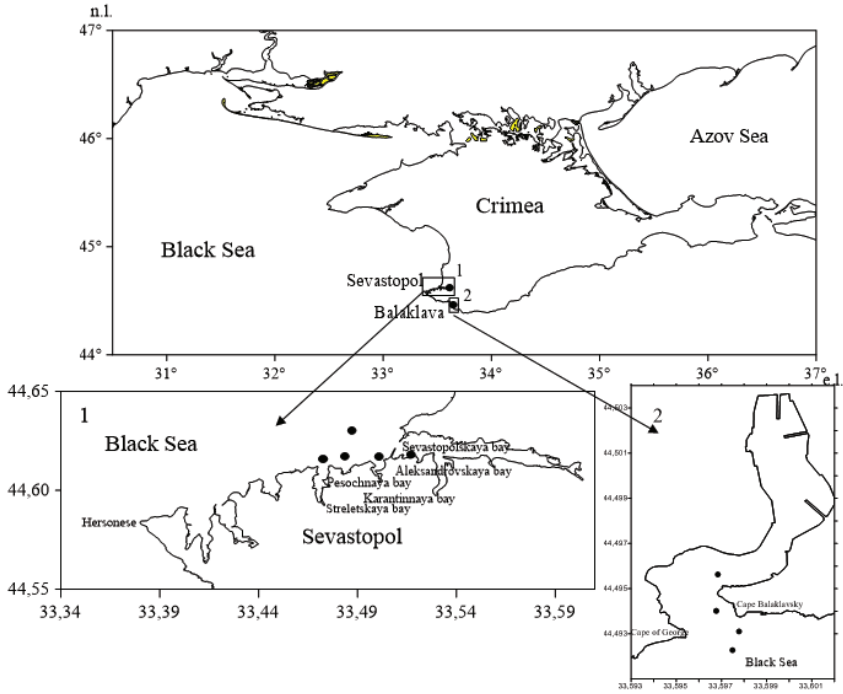

Fig. 1. Scheme of the study area and location of the sampling points.

Table 1. Average values of main biological characteristics of horse mackerel from the area of the Sevastopol Bays and the Balaklavskaya Bay between 2010 and 2017.

Parameters	Bays of Sevastopol		Balaklavskaya Bay	
	spring-summer	autumn-winter	spring-summer	autumn-winter
Number of specimens	1154	583	459	322
Average standard length, cm	11.2 ± 1.74	10.8 ± 1.58	12.6 ± 1.53	12.5 ± 1.11
	11.07 ± 1.69		12.56 ± 1.36	
Average total length, cm	13.3 ± 2.02	13.06 ± 1.85	15.0 ± 1.80	14.8 ± 1.31
	13.22 ± 1.96		14.91 ± 1.60	
Average body weight, g	17.71 ± 9.33	18.56 ± 8.83	26.13 ± 10.64	25.69 ± 7.05
	17.99 ± 1.96		25.96 ± 9.16	
Males, %	54.09	54.89	50.33	54.04
Females, %	43.68	43.57	49.67	43.48
Unsexed, %	2.26	1.54	0	2.48

period and from 8.8 to 15.4 cm (av. 12.5±1.11 cm) in the autumn-winter period of 2010-2017 (Table 1).

The curves of the length distribution of the horse mackerel averaged over the interval from 2010 to 2017 from the water area of the Sevastopol Bays and the Balaklavskaya Bay calculated in 0.5 cm increments are shown in Figure 2.

In the spring-summer and autumn-winter periods in the Balaklavskaya Bay, there were individuals mainly over 10 cm in length (single smaller specimens were found). More than 50% of the studied individuals had a length of 12–14 cm. The comparison showed that the length distribution of fish inhabiting the water area of the Balaklavskaya Bay during the spring-summer and autumn-winter periods was almost the same (correlation coefficient $r = 0.96$). This was not the case for the bays near the Sevastopol City. In the spring-summer period predominated individuals with length 11–13 cm; single specimens 6–7 cm long as well as 18–19 cm long were also found. In the autumn-winter period, the difference in the size distribution of fish was smaller and mainly fishes with a length of 8–14 cm were found, while the number of fish for each of the length groups was approximately the same (Table 1). The coefficient of correlation of the length distribution of fish in the seasons for the bays of Sevastopol was $r = 0.71$.

The average weight of the horse mackerel from the bays of Sevastopol was 17.99±9.16 g and from the Balaklavskaya Bay it was higher, 25.95±9.16 g (Table 1).

The length-weight relationships averaged over the period of research (from 2010 to 2017) for horse mackerel caught in the bays of Sevastopol

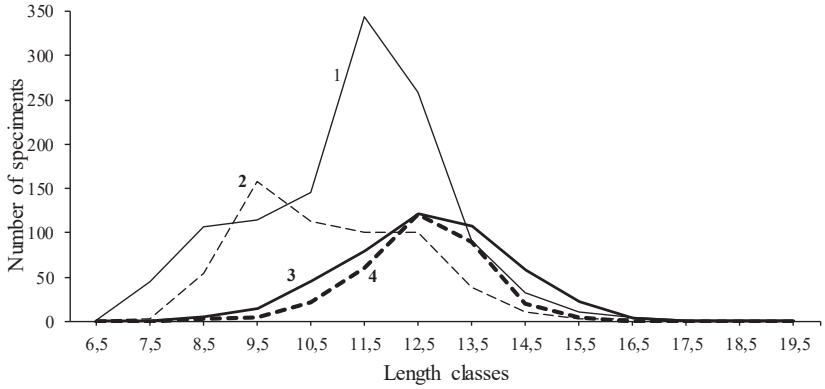

Fig. 2. Dimensional distribution of horse mackerel from: (1) – the bays of Sevastopol, spring-summer period; (2) – the bays of Sevastopol, autumn-winter period; (3) – Balaklavskaya Bay, spring-summer period; (4) – Balaklavskaya Bay, autumn-winter period.

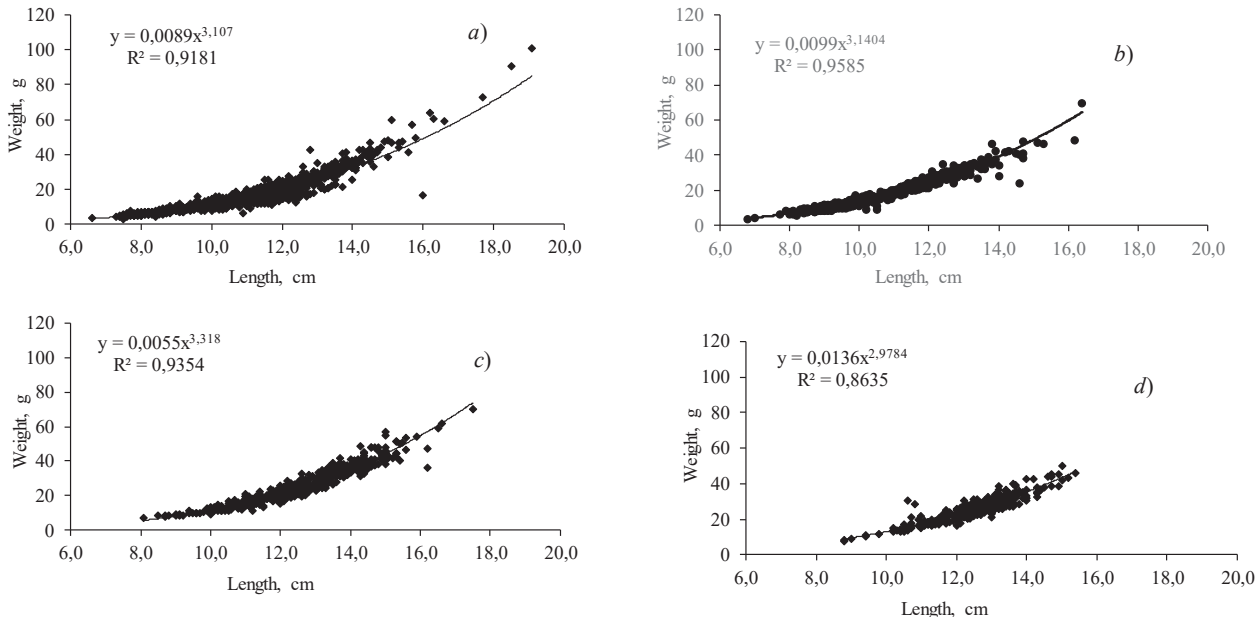

Fig. 3. Length-weight relationships for horse mackerel, averaged over the period 2010 – 2017. *a*) the bays of Sevastopol, spring-summer; *b*) the bays of Sevastopol, autumn-winter; *c*) Balaklavskaya Bay, spring-summer; *d*) Balaklavskaya Bay, autumn-winter.

and Balaklavskaya Bay in the spring-summer and autumn-winter periods are presented in Fig. 3.

As a result of applying the regression analysis, the following length-weight relationships were obtained:

- bays of Sevastopol, spring-summer period

$$W = 0{,}0089 \cdot SL^{3{,}107} \quad ; \qquad (4)$$

- bays of Sevastopol, autumn-winter period

$$W = 0{,}0099 \cdot SL^{3{,}1404} \quad ; \qquad (5)$$

- Balaklavskaya Bay, spring-summer period

$$W = 0{,}0055 \cdot SL^{3{,}318} \quad ; \qquad (6)$$

- Balaklavskaya Bay, autumn-winter period

$$W = 0{,}0136 \cdot SL^{2{,}978} \quad ; \qquad (7)$$

Our results showed that the body weight of fish from the bays of Sevastopol varied from 3.5 to 100.67 g (av. 17.71 ± 9.33 g) in spring-summer and from 3.87 to 69.78 g (av. 18.56 ± 8.83 g) in autumn-winter. The body weight of fish from the Balaklavskaya Bay varied from 7.22 to 70.22 g (av. 26.13 ± 10.64 g) in spring-summer and from 7.49 to 50.25 g (av. 25.69 ± 7.05 g) in autumn-winter. The overall average weight of fish living in the water area of the Balaklavskaya Bay was approximately 40% higher than that from the bays of the city of Sevastopol.

Analysis of the age composition showed that there were fish of five age classes (0+, 1+, 2+, 3+ and 4+) in the autumn-winter period and four age classes (1, 2, 3 and 4) in the spring-summer period. The prevalent age classes were 1 and 1+. The dependence of the standard length of the horse mackerel from the age was compiled and was for:

- bays of Sevastopol, spring-summer pe

$$L_t = 22.122\left[1 - e^{-0.2246(t+1.302)}\right]; \quad (8)$$

- bays of Sevastopol, autumn-winter period

$$L_t = 21.28\left[1 - e^{-0.1962(t+1.853)}\right]; \quad (9)$$

- Balaklavskaya Bay, spring-summer period

$$L_t = 22.289\left[1 - e^{-0.2116(t+1.439)}\right]; \quad (10)$$

- Balaklavskaya Bay, autumn-winter period

$$L_t = 20.777\left[1 - e^{-0.2078(t+2.334)}\right]. \quad (11)$$

Based on equations (8)–(11), we concluded that the average asymptotic length of horse mackerel from the south-western shelf of the Crimea ranged from 20.77 cm to 22.29 cm. Dependences of the standard length of the mackerel from the age of the bays of the city of Sevastopol and the Balaklavskaya Bay are presented in Fig. 4.

Specimens of horse mackerel living in the water area of the Balaklavskaya Bay were longer by 10–20% as compared to the ones from the bays of the city of Sevastopol. In the spring-summer period, SL of fish of different ages, living both in the bays of Sevastopol and in the Balaklavskaya Bay, practically coincided (Fig. 4).

The proportion of males was generally higher than the proportion of females (Table 1). Only in the water area of the Balaklava Bay in the spring-summer period the ratio of males and females was almost 50%.

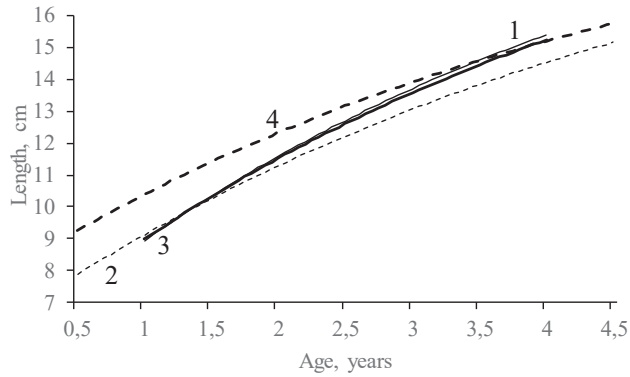

Fig. 4. Relation between standard length and age of horse mackerel from: 1 – the bays of Sevastopol, spring-summer period; 2 – the bays of Sevastopol, autumn-winter period; 3 – Balaklavskaya Bay, spring-summer period; 4 – Balaklavskaya Bay, autumn-winter period.

Discussion

The comparison of biometric measurements of horse mackerel from the Bulgarian Black Sea coast (Yankova 2015) shows that the standard (*SL* = 13.50 ± 2.42 cm) and the total lengths (*TL* = 15.60 ± 1.74 cm) of the Bulgarian specimens are generally longer than the specimens collected from the waters area of the Sevastopol and the Balaklavskaya Bay (Table 1).

In the bays of Sevastopol in the spring-summer period, the size distribution of horse mackerel was somewhat different from the autumn-winter period, when the difference in the size distribution was smaller. The coefficient of correlation of the length distribution of fish in the bays of Sevastopol during the different seasons likely indicated that there were differences associated with seasonal migrations and feeding and reproduction characteristics. The comparison showed that the length distribution of fish inhabiting the water area of the Balaklavskaya Bay during the spring-summer and during the autumn-winter periods was almost the same. This indicated a stable seasonal composition of fish in the annual cycle of growth in this region. However, the absence of fish of small size groups (younger ages) does not give grounds for asserting the isolated location of the Balaklava herd with a full cycle of growth, including reproductive and putting on weight periods of fish life.

The length distribution in the spring-summer season in the water area of the Sevastopol Bays and the water area of the Balaklavskaya Bay had similar dimensional distribution (correlation coefficient r = 0.707), which indicated a uniform spreading of fish in when gaining weight and during the reproductive period in the large water area (including Sevastopol and Balaklavskaya Bays).

In the autumn-winter period, the length distribution of fish in the water area of the Balaklavskaya Bay and Sevastopol Bays differed from each other, which was confirmed by a low correlation coefficient (r = 0.337). This could be due to the peculiarities of wintering fish and the temperature characteristics of the winter season. E. g., in the Balaklavskaya Bay area, the horse mackerel winters annually and in the area of the Sevastopol bays only in warm winters.

On average, the Bulgarian specimens of the horse mackerel (W = 24.75 ± 2.47 g; Yankova 2015) were heavier that the specimens from the bays of Sevastopol but lighter than the average weight of the horse mackerel inhabiting the Balaklavskaya Bay. As demonstrated by our results, the average asymptotic length of horse mackerel from the south-western shelf of the Crimea was above from those reported by Yankova et al. (2010) for the horse mackerel populations from the Bulgarian Black Sea coast (L_∞ = 19.725 cm). But the growth coefficient K (K = 0.19 – 0.22 year^{-1}) of the studied populations was smaller than the one for the population from Bulgaria (K = 0.302 year^{-1}, see Yankova et al. 2010).

A comparison of the growth curves showed that during the first two years of life horse mack-

erel from south-western shelf of Crimea was longer than the Bulgarian specimens but when older than 3–3.5 years – it was shorter than horse mackerel from Bulgarian waters. The obtained equations for the dependence of fish size on age (8)–(11), together with equation (4)–(7) could be used to calculate the relative daily weight increase, as well as to determine the biomass increment of the commercial herd depending on the catch area and season.

The length-weight relationship for horse mackerel from the Balaklavskaya Bay in spring-summer differed slightly from those from Bulgarian waters (a = 0.0035, b = 3.305; see Yankova et al. 2010). These relationships for horse mackerel from the bays of Sevastopol and Balaklavskaya Bay in autumn-winter (see equation (4), (5) and (7)) were different from those presented by Yankova et al. (2010).

We found that the proportion of males was generally higher than the proportion of females and only in the spring-summer period in the area of the Balaklavskaya Bay, the shares of males and females were almost equal.

Conclusions

The size of the horse mackerel living in the water area of the Balaklavskaya Bay in the autumn-winter period differs from the horse mackerel living in the bays of the city of Sevastopol, which is confirmed by the low correlation coefficient. The size of the horse mackerel from the bays of Sevastopol and the water area of the Balaklavskaya Bay in the spring-summer period are less different than in the autumn-winter period. This indicates the expansion of the area of distribution of this fish during the feeding and reproductive period in comparison with the winter period.

The comparison showed that the average length of the horse mackerel which have been collected from commercial net catches from the south-western shelf of the Crimea tend to be smaller than those caught in the Bulgarian Black Sea waters.

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