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RESEARCH ARTICLE

Growth of horse mackerel populations in the western parts of the Black, Marmara, and Aegean seas

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Abstract. This study estimated the growth of horse mackerel, *Trachurus mediterraneus* (Steindachner), populations from the western parts of the Black, Marmara, and Aegean seas. Dependencies of individual daily weight gain at age were determined. The calculations showed that in the area studied the highest absolute weight gain was 45.4 mg day^{-1} for fish at the age of 2.46 years from Zonguldak (Black Sea). The relative annual increase in the population biomass of *T. mediterraneus* inhabiting different areas of the Black, Marmara and Aegean seas was determined. It was revealed that the annual relative increase in the biomass of horse mackerel caught in the Black Sea exceeded that in the Marmara and Aegean seas. At the same time, the highest relative annual biomass increase (94.8%) was observed in populations from the Varna-Bourgas region and in the coastal waters of Sevastopol (70.9%) in the Black Sea.

Keywords: horse mackerel, length-weight parameters, weight, growth, Black Sea, Marmara Sea, Aegean Sea

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Introduction

The Mediterranean horse mackerel (*Trachurus mediterraneus* (Steindachner) belongs to the family Carangidae, which includes more than 30 genera and 147 species of marine fish (Nelson et al. 2016). The majority of fish of the family Carangidae are large, important commercial species (Begg et al. 1999, Zuyev et al. 2010, Bat et al. 2011, 2013, Yankova et al. 2014, Şahin et al. 2015). The distribution area of Carangidae is very wide including the Atlantic, Pacific and Indian oceans, the North and Mediterranean seas, and other regions. The most widely distributed genus is *Trachurus*, which includes more than 12 species. Along the eastern shores of the Atlantic Ocean from the Bay of Biscay to Cape Verde, the Mediterranean horse mackerel (*T. mediterraneus*) inhabits the Mediterranean and Black seas. Within its habitat, the Mediterranean horse mackerel forms several stocks in which the size of individuals differs and which are in different locations (Cárdenas et al. 2005, Bat et al. 2011, Kuzminova et al. 2014, Satilmis et al. 2014, Kasapoğlu 2018).

Horse mackerel is distributed widely in the Black Sea along the all its coasts, and it is one of the main commercial fish species in Black Sea countries. Two species are important for fisheries in the Black Sea and the northeastern Mediterranean Sea—the common horse mackerel, *Trachurus trachurus* (L.), and the Atlantic horse mackerel or the Mediterranean or Black Sea horse mackerel, *T. mediterraneus* (Turan 2004, Bektas and Belduz 2008, Bilecenoðlu et al. 2014, Özdemir et al. 2015, Melnikova and Kuz'minova 2018). The horse mackerel is a pelagic schooling fish that inhabits the upper part of the water column. It only inhabits the pelagic layer in the warm seasons, while in winter it moves to the coasts and inhabits the near-bottom water layer at depths of 50-80 m. In winter, the horse mackerel decreases its area of distribution considerably, leaves the open zones of the Black Sea, and gathers in the near-bottom water layer in coastal areas. During the cold period of the year, the life cycle of horse mackerel is characterized by reduced metabolism and decreases in or even the suspension of foraging and growth.

The aim of the study was determine individual weight gain parameters and the relative annual increase of the biomass of horse mackerel populations from coastal waters in the western Black, Marmara, and Aegean seas.

Study area

Our own investigations and literature data on horse mackerel inhabiting the coastal waters of Bulgaria (Yankova et al. 2010) and Turkey (Erdoğan et al. 2016) were used as material for the analysis. The areas of our own studies included the southwestern shelf of the Crimea, specifically the coastal waters of Sevastopol (Aleksandrovskaya, Karantinnaya, Streletskaya Bay, the open sea opposite Pesochnaya Bay (between 44.61° N and 44.63° N; 33.47° E and 33.52° E) and Balaklavskaya Bay (between 44.491° N and 44.496° N; l33.596° E and 33.599° E).

The Karantinnaya, Aleksandrovskaya, and Streletskaya bays are located in the coastal waters of Sevastopol; they are wide water areas that do not cut deeply inland. These are flooded lower reaches of ravines with a submeridional spread that have formed across a network of tectonic cracks (Myslivets et al. 2011). The depths of the Aleksandrovskaya, Streletskaya and Karantinnaya bays do not exceed 20 m. Water is exchanged between the Streletskaya and Karantinnaya bays and the open part of the sea; however, since they are located inside the territorial waters of the city of Sevastopol, this negatively affects the ecological condition of the bays.

Balaklavskaya Bay is located on the southern slope of the Heraclean Peninsula. It is 1.5 km in length and 425 m at its widest point. The depth of Balaklavskaya Bay ranges from 5 to 36 m at an average of 12.5 m. In comparison with the coastal waters of Sevastopol, the waters of Balaklavskaya Bay and the adjacent area of the Megalo-Yalo Bay are characterized by higher average wind speeds that cause frequent upwellings, which lead to eutrophication (Gurov et al. 2015).

The areas of the Black, Marmara, and Aegean seas studied are in zones of active anthropogenic loading. This, along with the specificities of the hydrological parameters of these aquatic environments, causes differences in the development and concentration of marine hydrobionts, including phyto- and zooplankton, which are the food base of pelagic fish species.

Material and methods

The fish were caught in from April to August in 2010 to 2015. In total, 1,145 specimens were examined that were obtained from the study area (720 specimens from Sevastopol coastal waters and 425 specimens from Balaklavskaya Bay). Individual production characteristics and the biomass increases of horse mackerel populations were calculated for fish inhabiting the coastal waters of Bulgaria in the Varna and Bourgas region (1,995 fish were caught from April 2007 to October 2008 (Yankova et al. 2010) and the coastal waters of six Turkish regions: Zonguldak (Black Sea), Bandirma (Marmara Sea), Şarköy (Marmara Sea), Edremit (Aegean Sea), Izmir (Aegean Sea), Marmaris (Aegean Sea). Fifty individuals from each region of Turkish waters were analyzed (Erdoğan et al. 2016).

Fish length was measured to the nearest 0.1 cm, and body weight to the nearest 0.01 g. The study results were grouped according to size classes at 1.0 cm intervals. Fish age was determined using otoliths. The age-length dependence of horse mackerel specimens was determined with the von Bertalanffy growth equation:

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

where L_t – is the length of fish at age t; $L\infty$ – is the average maximum possible (asymptotic) length of the fish; K – is the growth coefficient; t_0 – is the coefficient with the dimension of time; t – horse mackerel age.

The length-weight ratios were determined with the formula:

$$W = aL^b, \ (2)$$

where W – is total body weight; L – is fish length in cm; a and b are coefficients.

The individual daily specific production was calculated with the equation:

$$\frac{\Delta W}{W} = \frac{2(W_{t+1} - W_t)}{W_{t+1} + W_t}, \ (3)$$

where W_t and W_{t+1} – fish weight at t and on subsequent days.

The specific daily production of fish of the same age (size) from the entire commercial stock was determined using the specific individual production and the relative numbers of age (size) groups in the commercial stock with the formula:

$$C_i = \frac{\Delta W_i}{W_i} \cdot \frac{n_i}{\sum_{i=1}^{k} n_i}, \ (4)$$

where C_i – is the specific daily production of all the fish of the i-th age (length) group of the commercial stock; $\frac{\Delta W_i}{W_i}$ – is the specific daily production of individuals from the i-th age (length) group; n_i – is the number of horse mackerel individuals in the i-th age (length) group; k – is the number of the i-th age (length) groups in the commercial stock.

The relative annual increase of the biomass of the commercial stock was determined as the sum of the relative specific products of all age (length) groups of the commercial stock.

$$C = 365\sum_{i=1}^{k} C_i \ (5)$$

The results were processed mathematically with Microsoft Excel 5.0, Statistica 6.0, SigmaPlot 12.5, and Surfer 13.0.

Results and Discussion

Catches of horse mackerel from the southwestern shelf of Crimea in 2010-2015 included yearling, two-year-old, three-year-old, and four-year-old fish. Additionally, the majority of the catches (more than 85%) from the coastal waters of Sevastopol consisted of yearling and two-year-old individuals, and the share of four-year-olds did not exceed 2%. In Balaklavskaya Bay, approximately 50% of the catches consisted of two-year-old fish, 2-3% were yearlings, and 8-9% of the catches were four-year-olds.

These age distributions differed from those Erdoğan et al. (2016) and Yankova et al. (2010) report. The ages of horse mackerel caught in Turkish waters were between I and IV (Erdoğan et al. 2016). Horse mackerel age groups I and II dominated in the whole sample, but age groups III and IV were the most abundant in the fish caught in the Marmaris area (Aegean Sea). Yankova et al. (2010) report that the age group range of horse mackerel stocks from the coastal waters of Bulgaria was from 0+ to 6+. Three-year-old specimens were the most abundant age group (27%) in the whole sample, while 4-5% were yearlings, and 2-3% were six-year-olds. The differences could be related to the interannual features of seasonal migrations, because our studies used average results for a six-year period, while the research by Erdoğan et al. (2016) and Yankova et al. (2010) used results from one year. The analysis of the sex structure showed that the proportion of males in the

Table 1
Parameters of the horse mackerel growth equations used by different researchers

	von Bertalanffy coefficient equation			Coefficient of the length-weight dependence	
Sample station	L_∞	k	t_0	a	b
Sevastopol bays (Black Sea)[1]	22.122	0.2246	-1.302	0.0089	3.107
Balaklavskaya Bay (Black Sea)[1]	22.289	0.2116	-1.439	0.0055	3.318
Varna-Bourgas (Black Sea)[2]	19.725	0.2714	-0.5843	0.0035	3.3046
Zonguldak (Black Sea)[3]	23.47	0.26	-1.61	0.016	2.881
Bandirma (Marmara Sea)[3]	21.63	0.31	-1.62	0.012	2.973
Şarköy (Marmara Sea)[3]	14.73	0.27	-4.48	0.012	3.004
Edremit (Aegean Sea)[3]	15.49	0.29	-3.77	0.007	3.210
Izmir (Aegean Sea)[3]	17.19	0.21	-4.17	0.009	3.121
Marmaris (Aegean Sea)[3]	15.07	0.40	-4.09	0.017	2.820

Note: 1) – own data; 2) – Yankova et al. 2010; 3) – Erdoğan et al. 2016

coastal waters of Sevastopol exceeded that of the females, but the male to female ratio was almost 50% in the waters of Balaklavskaya Bay.

The length of the fish in Sevastopol coastal waters ranged from 6.6 to 19.1 cm (at an average of 11.2 ± 1.74 cm). In Balaklavskaya Bay waters mainly larger specimens were observed, and they ranged from 8.1 to 17.5 cm (at an average of 12.6 ± 1.53 cm). In the coastal waters of Sevastopol there were mostly individuals measuring 10-13 cm (near 75%), about half of the individuals noted had lengths of 11-12 cm, and single specimens exceeded 17 cm. About half of the individuals from Balaklavskaya Bay measured 12-13 cm, more than 80% of the individuals noted were 11-14 cm. Single specimens exceeded 17 cm in length. The length of horse mackerel from Turkish coastal waters ranged from 10.0 to 18.9 cm. Erdoğan et al. (2016) report that the most abundantly captured fish lengths from the Zonguldak area of the Black Sea were 11.0-11.9 cm (36%); from the Black Sea Bandirma and Şarköy areas – 16.0-16.9 cm (36%) and 11.0-11.9 cm (66%), respectively; from the Edremit and Izmir areas of the Aegean Sea – 12.0-12.9 cm (40%), in the Marmaris area – 13.0-13.9 cm (54%). The total length of the horse mackerel inhabiting in the coastal waters of Bulgaria ranged from 10.5 to 17.0 cm (Yankova et al. 2010).

The weight of individuals from the coastal waters of Sevastopol ranged from 3.5 to 100.7 g (at an average of 17.71 ± 9.33 g), and the values of this index for fish caught in Balaklavskaya Bay ranged from 7.2 to 70.2 (at an average of 26.13 ± 10.64 g). The average weight of fish from Balaklavskaya Bay waters was higher by about 40% than that of fish inhabiting the coastal waters of Sevastopol. The weight of mackerel from coastal Turkish waters ranged from 12.81 to 81.71 g. The most abundantly caught specimen weight ranges were from 20.00 to 24.99 g (38%) in the Black Sea (Zonguldak); from 50.00 to 69.99 g (46%) in the Marmara Sea (Bandirma); from 15.00 to 19.99 g (62%) in the Şarköy area; from 20.00 to 29.99 g (80%) in the Aegean Sea (Edremit); from 15.00 to 19.99 g (40%) in the Izmir area; from 10.00 to 19.99 g (40%) in the Marmaris area (Erdoğan et al. 2016). These parameters in our samples differed from those of Erdoğan et al. (2016) and Yankova et al. (2010) because of differences in habitat temperatures, ecological characteristics, food availability, and different ontogenetic development. The results of these analyses permitted determining the coefficients of the von Bertalanffy growth equation and the length-weight dependencies for horse mackerel inhabiting the southwestern shelf of the Crimea. These results are presented in Table 1.

Data from the present study and reported by Yankova et al. (2010) and Erdoğan et al. (2016) were used to determine the character of the weight gain of individuals and the relative biomass increases of horse mackerel populations from the coastal waters of the western Black, Marmara, and Aegean seas.

Table 2
Maximal daily horse mackerel weight gain

Sample station	Maximal daily weight gain (mg)	Age (Years)
Sevastopol bays (Black Sea)	39.9	3.75
Balaklavskaya Bay (Black Sea)	41.3	4.25
Varna-Bourgas (Black Sea)	23.4	3.82
Zonguldak (Black Sea)	45.4	2.46
Bandirma (Marmara Sea)	42.27	1.89
Şarköy (Marmara Sea)	11.7	< 1
Edremit (Aegean Sea)	15.63	< 1
Izmir (Aegean Sea)	16.35	1.25
Marmaris (Aegean Sea)	11.2	< 1

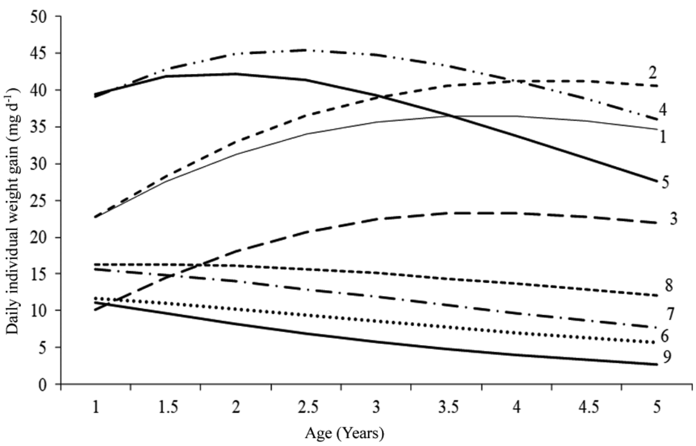

Figure 1. Daily horse mackerel weight gain: 1 – Sevastopol Bay (Black Sea); 2 – Balaklavskaya Bay (Black Sea); 3 – Varna-Bourgas (Black Sea); 4 – Zonguldak (Black Sea); 5 – Bandirma (Marmara Sea); 6 – Şarköy (Marmara Sea); 7 – Edremit (Aegean Sea); 8 – Izmir (Aegean Sea); 9 – Marmara (Aegean Sea).

The results used in further analyses are presented in Table. 1. Based on the coefficients in Table 1, weight gain equations were calculated, and the daily weight gain of *T. mediterraneus* individuals caught in different regions of the Black, Marmara, and Aegean seas was calculated. The resulting curves are presented in Fig. 1.

The results indicate that the daily weight gain of *T. mediterraneus* depended on fish age and area inhabited. The highest daily individual weight gain of 45.4 mg was noted at the age of 3.82 years in horse mackerel from the Zonguldak area of the Black Sea. Horse mackerel inhabiting the Black Sea areas studied had a maximum daily weight gain that ranged from 23.4 mg day^{-1} (Varna-Bourgas) to 45.4 mg day^{-1} (Zonguldak). On the southwestern shelf of the Crimea, the maximum daily weight gain was 41.3 mg day^{-1} (Balaklavskaya Bay) and 39.9 mg day^{-1} (Sevastopolskaya Bay). High rates of daily weight gain (42.27 mg day^{-1}) were also observed in horse mackerel from the Bandirma area of the Marmara Sea. The daily weight gain of horse mackerel caught in other areas of the Marmara and Aegean seas was much lower and did not exceed 16.35 mg day^{-1} Izmir (Table 2).

The maximum daily weight gain of horse mackerel from the coastal waters of Sevastopol, Balaklava, Varna-Bourgas, Zonguldak, Bandirma, and Izmir was observed in fish over one year of age, so the weight gain curves appeared convex, and the maximum was observed within the age range of 1-4 years. The maximum weight gain of fish inhabiting Şarköy, Edremit, and Marmaris was observed at the age of under one year; therefore, the weight growth curves assumed the form of falling exponents. The relative annual growth curves of horse mackerel inhabiting the western part of the Black, Marmara, and Aegean seas is presented in Fig. 2. The highest, relative annual individual weight gain was observed for *T. mediterraneus* that were caught in the Varna-Bourgas region (167.2%), in Balaklavskaya Bay (103.9%) and in coastal Sevastopol waters (103%). Population biomass increase is determined by individual weight gain in fish of different ages and population age distributions. Accordingly, relative increases in population biomasses are determined as the sum of the products of relative daily individual weight gain in age groups and the numbers in the age groups. The results obtained on relative population biomass increases are presented in Table 3. The largest population biomass increase was in *T. mediterraneus* from the Varna-Bourgas region (94.8%), followed by that from the coastal waters of Sevastopol (70.9%). Generally, relative biomass increases of horse mackerel

Table 3
Relative annual (%) individual weight gain and horse mackerel population biomass increases

Sample station	Age (Years) 1	2	3	4	Population biomass increase %
Sevastopol bays (Black Sea)	103.0	63.5	42.9	30.5	70.9
Balaklavskaya Bay (Black Sea)	103.9	65.6	45.1	32.5	55.9
Varna-Bourgas (Black Sea)	167.2	88.3	54.5	36.3	94.8
Zonguldak (Black Sea)	77.2	48.1	32.3	22.7	57.4
Bandirma (Marmara Sea)	73.6	44.5	28.9	19.6	38.8
Şarköy (Marmara Sea)	23.9	17.1	12.4	9.1	20.7
Edremit (Aegean Sea)	31.2	21.5	15.2	10.9	21.6
Izmir (Aegean Sea)	33.4	24.7	18.7	14.4	27.7
Marmaris (Aegean Sea)	16.9	10.8	7.0	4.6	11.9

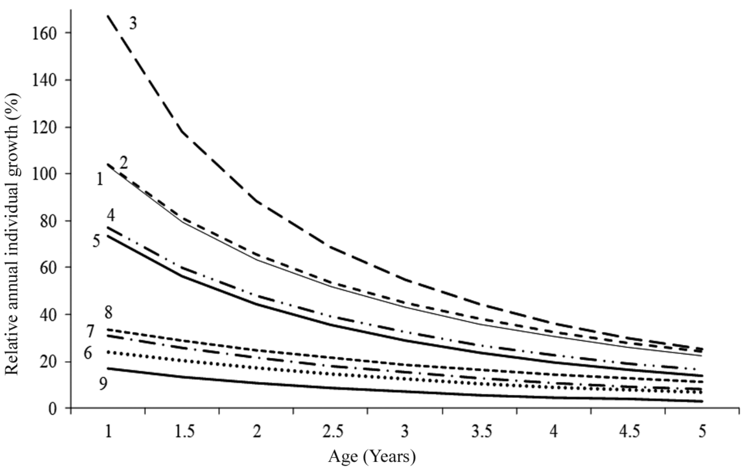

Figure 2. Relative annual horse mackerel growth (%): 1 – Sevastopol Bay (Black Sea); 2 – Balaklavskaya Bay (Black Sea); 3 – Varna-Bourgas (Black Sea); 4 – Zonguldak (Black Sea); 5 – Bandirma (Marmara Sea); 6 – Şarköy (Marmara Sea); 7 – Edremit (Aegean Sea); 8 – Izmir (Aegean Sea); 9 – Marmaris (Aegean Sea).

populations inhabiting the Black Sea ranged from 55.9 to 94.8%, which exceeded the relative biomass increases in populations from the Marmara (20.7-38.8%) and Aegean (11.9-27.7%) seas.

Conclusions

Horse mackerel weight gain depends on habitat. The highest absolute weight gain was 45.4 mg/day noted in *T. mediterraneus* aged 2.46 years from the Zonguldak region of the Black Sea. Horse mackerel yearlings from the Varna-Bourgas area of the Black Sea attained the largest relative weight gain (167.2% annually). The horse mackerel inhabiting the southwestern shelf of Crimea had the largest relative weight gain at 1 year of 103.9% (Sevastopol bays) and 103% (Balaklavskaya Bay). The annual relative biomass increase in fish populations inhabiting the Black Sea (55.9-94.8%) exceeded that of populations inhabiting the Marmara (20.7-38.8%) and Aegean (11.9-27.7%) seas. Simultaneously, the highest relative annual biomass increase (94.8%) was observed in the population from the Varna-Bourgas region of the Black Sea.

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