

Ichthyoplankton of The Shelf and Deep Water Areas of the North and Northeast of the Black Sea in The Spring Season

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Abstract

This paper is focused on the ichthyoplankton species composition and spatial distribution in the Black sea shelf zone and the deepwater regions off Crimean Peninsula and coast of the Caucasus during the spring hydrological season. Recent changes in the hydrological regime of the Black sea induced by the climate warming have led to an extension of the active and productive spawning of the dominant temperate-water species *Sprattus sprattus* until the end of the spring hydrological season. An intensive spawning of sprat was detected in March, April and May 2016, 2017 and 2019, which was confirmed by a predominance of younger age group larvae. The maximum number of eggs reached 224 ind./m², and the larvae - 116 ind./m². The wide size range of larvae as well as the low proportion of larvae with empty guts evidenced a favorable fodder base for their survival. The reduction in the age and size-weight composition of sprat stock in the Black sea observed since 2016 as a result of an increase in its commercial fishing on the shelf of the Crimean Peninsula, did not affect sprat' spawning activity.

Introduction

Climate change is one of the key factors leading to latitudinal and altitudinal shifts in the spatial distribution of species as a result of changes in environmental conditions and their habitat suitability (Parmesan & Yohe, 2003; Chen, Hill, Ohlemüller, Roy, & Thomas, 2011; Weinert *et al.*, 2016). In marine ecosystems global climate change can affect a variety of physicochemical properties of environment with potentially wide-ranging biological effects on physiology, phenology, adaptation, spatial distribution, changes in species structure, and trophic relationships within the aquatic organisms community (Cushing, 1995; Walther *et al.*, 2002; Brierley & Kingsford, 2009; Hoegh-Guldberg & Bruno, 2010; Doney *et al.*, 2012; Hewitson *et al.*, 2014). Higher temperatures change the time and duration of spawning of both thermophilic and temperate fish

species in the seas with clearly defined seasonality. Shifts in spawning phenology and distribution of some benthic and pelagic fish species were recognized and reported for the North and Irish Seas (Perry, Low, Ellis, & Reynolds, 2005; Engelhard, 2013; Jansen & Gislason, 2011; Fincham, Rijnsdorp, & Kröncke *et al.*, 2011; Weinert *et al.* 2016; McQueen & Marshall, 2017), Western English Channel (Genner *et al.* 2010), northeast Pacific Ocean (Ware & Tanasichuk, 1989; Auth, Daly, Brodeur, & Fisher, 2017;). The increase of the sea surface temperature (SST) of the Black sea, which has been observed since the beginning of the 1990s, contributed to an increase in the heat reserve in the layer 0-100 m (Oguz, Cokacar, Malanotte-Rizzoli, & Ducklow, 2003; Belokopytov, 2017). This likely to have had a positive impact on the plankton community state and contributed to the extension of the spawning season of mass short-cycle fish species, both temperate

and thermophilic, on the autumn hydrological season in the Black Sea (Klimova, Anninskyi, Vdodovich & Podrezova, 2018; Klimova & Podrezova, 2018). Studies on ichthyoplankton were conducted in the southern part of the Black sea as well (Satılmış *et al.*, 2009; Satılmış *et al.*, 2014; Şahin & Duzgunes, 2019).

The most abundant species in ichthyoplankton of the Black Sea are the temperate short-cyclic planktophage *S. sprattus* in winter and the thermophilic *Engraulis encrasicolus* (Linnaeus, 1758) in the summer season. The autumn and spring hydrological seasons belong to the "off-season" period, when the fish eggs are found in single specimens, and the larvae are represented by an older age group. However, in recent years, intensive mass spawning of a temperate-water species *S. sprattus* off the Crimean peninsula begins in November, and the productive spawning of thermophilic *E. encrasicolus* continues in October (Klimova, Vdodovich, & Anninskyi, 2010; Klimova *et al.*, 2018; Klimova & Podrezova, 2018), which has not been reported before in literature for this region (Dekhnik, 1973). The average number of sprat eggs and larvae in November 2017 was comparable to the maximum number of sprat eggs at the peak of the winter spawning season in December-January 1958-59. (Dekhnik, 1973; Klimova *et al.*, 2018).

The results obtained in ichthyoplankton studies, it would seem, are not consistent with the data on the sprat fishery in 2016-2017. According to Shlyakhov, Shlyakhova, Nadolinsky, and Perevalov (2018), there was a dramatic decrease in sprat fisheries catches from 25943 tons in 2015 and 2016 down to 14782 tons in 2017, with the fish size and weight characteristics changing in favor of younger age groups. Fishing is known to make populations more sensitive to climate change by reducing abundance, density and truncating the age distribution (Ottersen *et al.*, 2006). Thus, in 2015, the share of younger age group of sprat (age 0+ to 1+) in the Black sea did not exceed 40.1%, whereas in 2016-17 it was about 65%, and sprat fish at the age of 4 years were almost absent in the fisheries catches (Shlyakhov *et al.*, 2018). However, according to the age structure, the sprat population, as well as anchovy, is classified as a type with a pronounced predominance of younger age groups over older ones or "predominance of recruitment over the remainder" (Monastyrsky, 1952). Thus, in the period from 1956 to 1968 off the Romanian coast the younger age group of *S. sprattus* population (aged 0+ to 1+) predominated over the older ones, accounting for 51.3 to 99.9%, average 64% (Ivanov, Kostyuchenko & Kautish, 1979), which is comparable to the data of 2016-17 (Shlyakhov *et al.*, 2018). According to the data of small-cell trawl catches across the entire Black sea, the younger and older age groups of the sprat population in 1974-1975 consisted of equal shares (Ivanov *et al.*, 1979). Sprat reaches sexual maturity by the age of 10 months and under favorable temperature and feeding conditions spawns throughout the year: in winter it spawns across the

entire oxygen layer, and in summer - in the cold intermediate layer under the thermocline (Aleev, 1958; Oven, 1979; Giragosov, Zuev, & Repetin, 2006). The younger age group seemed to provide a high intensity of spawning in November 2017, which was indirectly confirmed by a decrease in the size of the larvae of the younger age groups (Klimova *et al.*, 2018). The eggs of young females are usually smaller, therefore, the size composition of larvae decreases when hatching (Aleev, 1956). On the one hand, the size of the hatching larvae in November 2017 (Klimova, *et al.*, 2018) had been likely to decrease due to a change in the age composition of the spawning individuals in favor of the younger age group. On the other hand, it could have resulted from the reduced period of embryonic and post-embryonic development against the background of a relatively high water temperature in the sea during the spawning period. According to Petereit (2009), the transition to mixed nutrition (pigmentation of the eye and opening of the mouth) of Baltic sprat reduces by ten days with an increase in temperature from 3.8 to 13°C, and for European sprat, with an increase in temperature from 10° to 13°C - by three days.

There is a growing evidence that a number of fish species in different regions may respond to climate change by shifting their distributions to areas with more favorable conditions or by changes in productivity in response to the new conditions (Sabates, Martin, Lloret, & Raya, 2006; Hsieh, Kim, Watson, Di Lorenzo, & Sugihara, 2009; Rijnsdorp, Peck, Engelhard, Möllmann, & Pinnegar, 2009; Auth *et al.*, 2017; Kleisner *et al.*, 2017). The sea water temperature in November 2017 on the shelf of the Crimean Peninsula varied from 12.5° to 14.8°C, which contributed not only to the acceleration of embryonic and post-embryonic development of sprat, but also to the enrichment of the larval fodder base (Finenko, Anninsky, & Datzyk, 2018; Klimova *et al.*, 2018).

Considering the possible reasons for the mass spawning of sprats in November 2017 in the Northern sector of the Black sea, it may not be excluded that there may have been latitudinal shifts in the distribution of the southern population of sprat, whose mass spawning off the Turkish coast is usually observed in November (Klimova *et al.*, 2014). The fundamental importance of combined effects of fishing pressure and climate change on distribution patterns of commercially exploited fish were reported for the North Sea, Australia, California, Iceland and Norway (Holst, Dragesund, Hamre, Misund, & Østvedt, 2002, Hsieh, Reiss, Hewitt, & Sugihara, 2008, Last *et al.*, 2011, Engelhard, Righton, & Pinnegar, 2013). The decrease in commercial stocks of sprat off the Crimean Peninsula in 2017 as a result of its intensive fisheries in 2015-2016 (Shlyakhov *et al.*, 2018) and water temperature increase in the layer 0-100 m could have had a positive impact on the abundance of fodder zooplankton in this area (Belokopytov, 2017, Finenko *et al.*, 2018; Klimova *et al.*, 2018) that might have resulted in migration of southern populations of sprat from the

coast of Turkey along the Eastern shelf of the Black sea to the shelf of the Crimean Peninsula.

Currently, regional studies of changes in the spawning phenology of mass short-cycle fish are of great interest in terms of the certain species response to climate warming (Asch, 2015, Auth *et al.*, 2017, Edwards & Richardson, 2004, Genner *et al.*, 2010, Koslow, Goericke, & Watson, 2013). For the reason of the recently observed extension of the mass spawning period of temperate-water fish species to the autumn hydrological season, it is interesting to consider the effectiveness of their spawning during the spring "off-season". The research, carried out during the expedition cruises in 2016, 2017 and 2019 provided the new data for studying and analyzing the state of the ichthyoplankton complexes in the spring hydrological season in shelf and deep waters of the Black sea off the Crimean peninsula and coast of the Caucasus.

Materials and Methods

Ichthyoplankton samples were collected in shelf and deepwater regions of the Black sea off the Crimean Peninsula in April 2016 (latitude 44°19' - 45°42' N, longitude 32°26' - 36°26' E), in March-April 2017 (latitude 43°21' - 45°50' N, longitude 31°37' - 36°55' E),

in April, 2017 (latitude 43°35' - 45°04' N, longitude 31°32' - 36°24' E), in April-May, 2019 (latitude 42°32' - 45°04' N, longitude 31°32' - 39°48' E) in the 84th, 93th, 94th and 106th cruises of R/V "Professor Vodyanitsky" respectively. Samples were collected using a BR-80/113 type plankton net (80 cm diameter, 400 µm mesh size) in vertical fishing mode from the sea floor to the surface in the shallow water regions and from the lower oxygen zone to the sea surface in deepwater regions. Samples were preserved in 4% formalin seawater solution at sea and returned to the laboratory for sorting with a binocular MBS-9. Fish eggs and larvae were counted, measured and identified to the lowest taxonomic level possible based on Russell (1976), Dekhnik (1973), D'Ancona (1933). A total of 213 ichthyoplankton samples were studied.

The study of the fish larvae nutrition was carried out according to the method Duka & Sinyukova (1976). According to Gorbunova (1958), Dekhnik (1973) sprat larvae were divided into two size groups: total length (TL, mm) up to 5.9 mm – the younger age group (I-II), which included larvae on the yolk and mixed types of nutrition and larvae TL more than 6 mm – the older age group (III), which included larvae transitioned to the exogenous type of nutrition. A total of 462 sprat larvae was studied sized 1.9 to 23.0 mm.

Table 1. Species composition and mean number (ind./m²) of the Black sea ichthyoplankton in the spring season of 2016, 2017 and 2019

Species composition	Dates of sampling			
	19.04.- 25.04. 2016	28.03-13.04. 2017	22.04-06.05. 2017	20.04-11.05. 2019
	<u>Eggs</u> Larvae	<u>Eggs</u> Larvae	<u>Eggs</u> Larvae	<u>Eggs</u> Larvae
Family: Clupeidae	<u>10,0</u>	<u>20,0</u>	<u>12,16</u>	<u>3,77</u>
<i>Sprattus sprattus</i> (Linnaeus, 1758)	2,19	1,5	13,79	0,74
Family: Gadidae	<u>4,09</u>	<u>0,9</u>	<u>1,11</u>	<u>0,07</u>
<i>Merlangius merlangus</i> Linnaeus, 1758	0,66	0	0	0
Gadidae sp		<u>0</u>	<u>0</u>	<u>0</u>
		0,1	0,29	0,04
Family: Lotidae	<u>0</u>			<u>0</u>
<i>Gaidropsarus mediterraneus</i> (Linnaeus, 1758)	0,19			0,02
Family: Syngnathidae			<u>0</u>	<u>0</u>
<i>Syngnathus schmidtii</i> (Popov, 1927)			0,03	0,02
Family: Blenniidae				<u>0</u>
<i>Parablennius tentacularis</i> (Brünnich, 1768)				0,02
Family: Gobiidae	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<i>Pomatoschistus minutus</i> (Pallas, 1770)	0,57	0,1	0,06	0,10
<i>Gobius niger</i> Linnaeus, 1758				<u>0</u>
				0,05
Family: Labridae	<u>0,38</u>			
<i>Ctenolabrus rupestris</i> (Linnaeus, 1758)	0			
Family Scophthalmidae:	<u>1,71</u>		<u>0,43</u>	<u>0,22</u>
<i>Scophthalmus maeoticus</i> (Pallas, 1814)	0		0	0
Total, ind./m ²	<u>16,18</u>	<u>20,9</u>	<u>13,70</u>	<u>4,06</u>
	3,61	1,7	14,17	0,99
Standard deviation	<u>23,95</u>	<u>41,56</u>	<u>29,45</u>	<u>5,77</u>
	6,39	3,03	18,85	2,32
Number of samples	25	47	59	82
Mean sea surface temperature, °C	11,2	9,2	11,5	12,7
Standard deviation	0,67	0,79	2,08	2,37

Dynamics of monthly mean sea surface temperature was calculated using daily maps of sea surface temperature for the period 1982–2017 with a spatial resolution hbc of 0.0417° retrieved from CMEMS website <http://marine.copernicus.eu/> for the region $44^\circ50'–45^\circ00' N$ and $32^\circ70'–33^\circ70' E$. The data are interpolated into nodes regular mesh and have a 4th processing level (Level 4).

Results and Discussions

In ichthyoplankton samples collected in the spring season of 2016, 2017 and 2019 on the shelf and in the deepwater areas of the Black sea, eggs and larvae of 10 fish species from 9 families were detected. Eggs and larvae of temperate-water species *Sprattus sprattus* dominated. The average number of eggs ranged from 4.06 to 20.9 ind./m², and larvae - from 0.99 to 14.17 ind./m² (Table 1, Figure 1).

From April 19 to April 25, 2016, the species composition of ichthyoplankton was represented by 6 species characteristic of the beginning of the spring season (Klimova, Ignat'ev, Vdodovich, & Gubanov, 2016). The average abundance of eggs in a sample was 16.18 ind./m², and the larvae 3.61 ind./m² (Table 1). Thermophilic species (*Ctenolabrus rupestris* and *Pomatoschistus minutus*) were detected only in samples collected in western sector of investigation: on the beam of Sevastopol, in the Karkinitzky and Kalamitsky bays (Table 1; Figure 1). Eggs and larvae of *S. sprattus* dominated in samples comprising 62 and 61% respectively. The maximum number of eggs was 66, and the larvae 14 ind./m². The proportion of dead sprat eggs was 87.6%, *Scophthalmus maeoticus* 88.9%, and the eggs of *Merlangius merlangus* and *C. rupestris* were all dead. The greatest mortality of fish eggs was registered at shallow stations in the Karkinitzky and Kalamitsky bays and coastal stations of the Laspi Bay.

Table 2. The results of trophological studies

Values	Dates of sampling			
	19.04.-25.04. 2016	28.03-13.04. 2017	22.04-06.05. 2017	20.04-11.05. 2019
Larvae TL, mm: min.-max.	<u>4,1-20</u>	<u>2,5-17,8</u>	<u>2,5-23</u>	<u>1,9-21</u>
Average	11	7	7	8
Number of copepod consumed, ind.	1-4	1-3	1-21	1-2
Length of copepod consumed, mm	0,1-0,9	0,15-0,275	0,15-0,925	0,15-0,35
The proportion of larvae (TL >4,3 mm) with food in guts, %	26	41	25	33

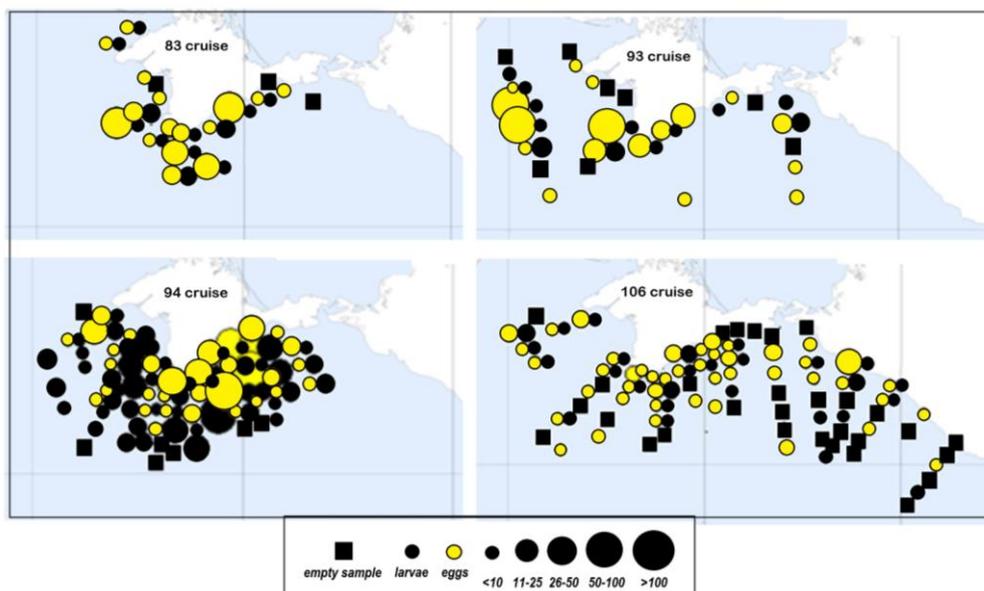


Figure 1. Schematic maps of the spatial distribution of fish eggs and larvae (ind./m²) in the 84th, 93rd, 94th and 106th cruises of the R / V "Professor Vodyanitsky"

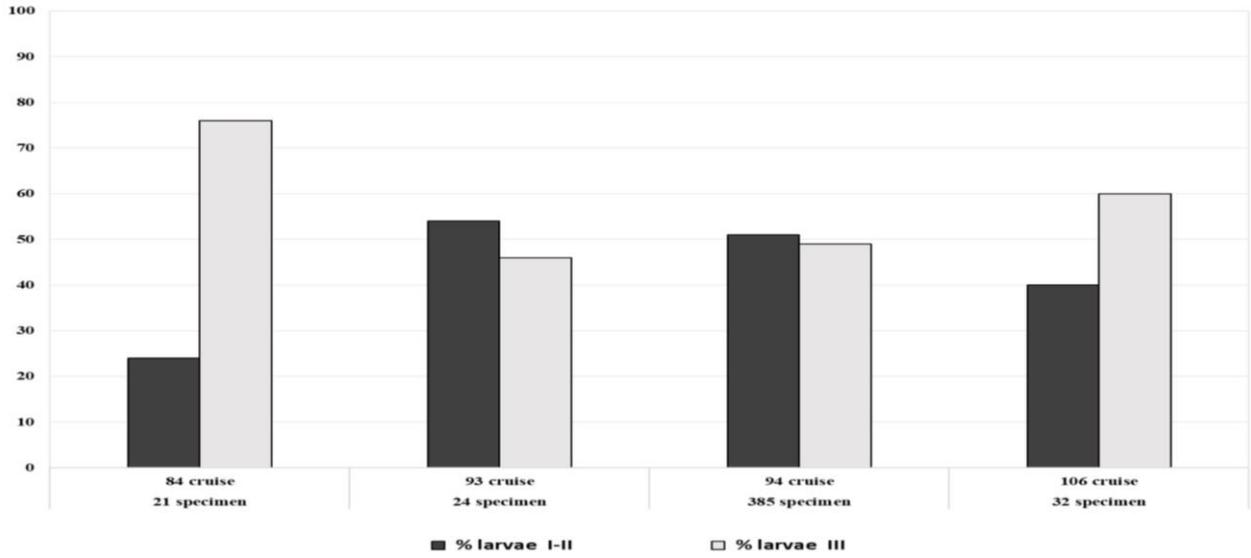


Figure 2. The proportion of *Sprattus sprattus* larvae on yolk and mixed types of nutrition (I-II) and exogenous type of nutrition (III) in the 84th, 93rd, 94th and 106th cruises of the R / V "Professor Vodyanitsky"

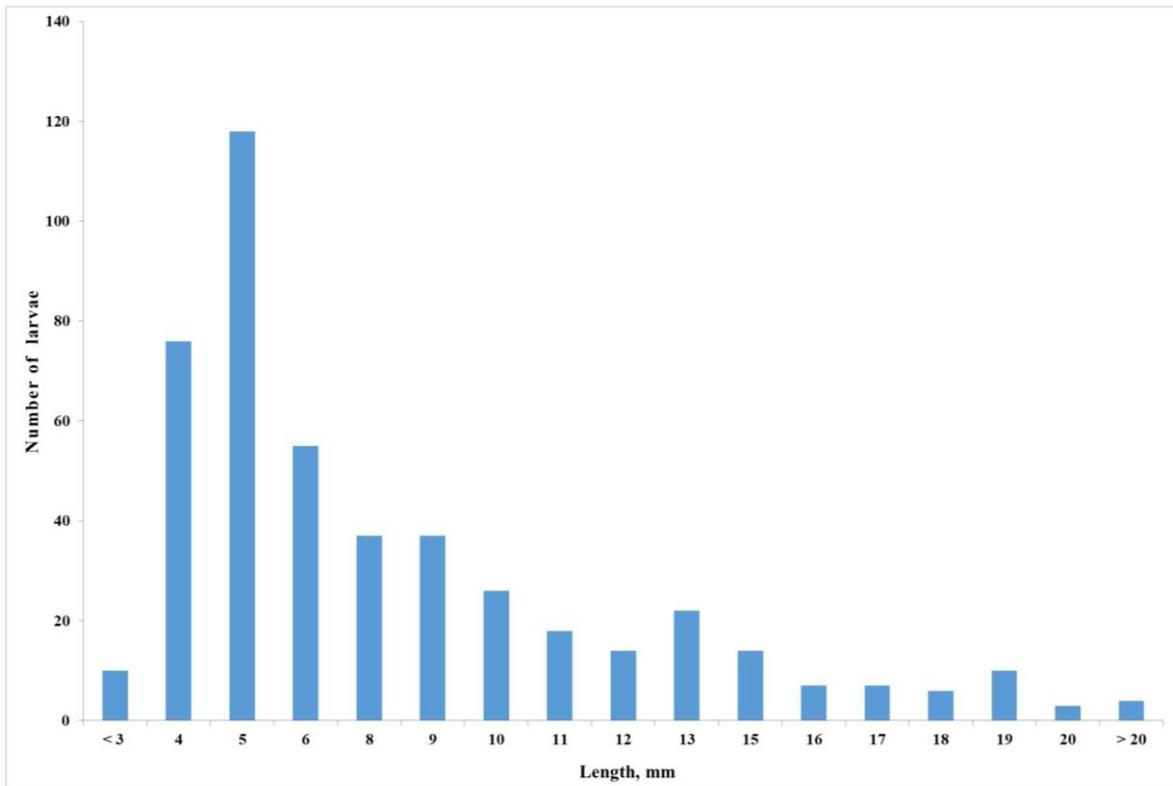


Figure 3. Size-frequency distribution of the variational series of sprat larvae lengths in spring research cruises of 2016, 2017 and 2019.

The nutrition patterns are studied and presented for sprat larvae, as the most prevailing in ichthyoplankton (Table 2). In the samples collected from April 19 to 25, 2016, the older age group of sprat larvae prevailed, the proportion of larvae of the younger age group (mean length 5 mm) was 24% (Figure 2).

In 2017, ichthyoplankton was collected from March 28 to April 13 and from April 22 to May 6. In samples collected in March-April, only 4 species of fish eggs and larvae were detected on the beam of the Crimean peninsula (Table 1, Figure 1). The average number of eggs was 20.9, and the larvae -1.7 ind./m². Eggs (95.7%) and larvae (88.2%) of sprat were dominant; their maximum abundance was 224 and 20 ind./m², respectively. The high abundance of sprat eggs and larvae, as well as the predominance of larvae of the younger age group in the samples, indicated an intensive spawning of sprat. Thermophilic species were observed only in the western sector of research: on the beam of Sevastopol, in the Karkinitsky and Kalamitsky bays.

In samples collected from the last decade of April to the 6th of May ichthyoplankton off the Crimean peninsula was represented by 6 fish species. Eggs and larvae of thermophilic fish species in ichthyoplankton were detected only in the western sector of research, where the temperature of the water surface in the sea reached 14 °C and therefore was favorable for the start of their spawning. (Table 1, Figure 1). The average number of eggs was 13.7, and the larvae - 14.17 ind./m². Along the coast of Crimea from the Kerch Peninsula to the Cape Sarych, the water temperature was 8.4-8.5°C (Artamonov *et al.*, 2019) and therefore was favorable for spawning of temperate-water species *S. sprattus*. The maximum number of sprat eggs was 162.8 ind./m², and the larvae -116 ind./m². Thus the maximum number of sprat larvae four times exceeded that at the peak of the sprat spawning season in December-January 1958-1959 (Dekhnik, 1973).

The high abundance of wide size range sprat larvae (2.5–23.0 mm) with the prevalence of younger age groups in the spring season of 2017 evidenced the massive effective spawning of *S. sprattus* and a favorable food supply for the survival of its larvae (Figure 2).

From April 20 to May 11, 2019 the average surface water temperature in the sea was 12.7°C. At the beginning of the survey the temperature was about 9°C and by the end of the sampling, it already exceeded 15°C, which was the highest value comparing to sea surface temperatures in previous studies (Table 1). In the samples, 9 species of fish eggs and larvae from 7 families were identified. The average number of eggs and larvae was 4.06 and 0.99 ind./m², respectively. Moderate-water fish species were represented by eggs and larvae of *S. sprattus*, eggs of *M. merlangus*, Gadidae sp. larvae and juvenile *Gaidropsarus mediterraneus*; thermophilic species were represented by eggs of spring spawning *S. maeoticus*, larvae of *Parablennius*

tentacularis, 2 species of gobies and *Syngnathus schmidtii* (Table 1). The larvae of thermophilic species amounted to 19.2% in total. Eggs (93%) and larvae (74.7%) of moderate-water *S. sprattus* dominated in samples.

The maximum number of sprat eggs and larvae was an order of magnitude lower than in the spring of 2017. A decrease in the number of sprat eggs and larvae, as well as the predominance of older age group larvae in samples are known to be markers of the finishing of the spawning season. However, the proportion of larvae of the younger age group in 2019 was still quite significant and amounted to 40%. The minimum size of the larvae of the younger age group was only 1.9 mm, and their average length (LT) was 3.65 mm. A reduction of a hatching larvae size is typical under increasing water temperature conditions during embryonic and postembryonic development (Petereit, 2009).

The latest data on ichthyoplankton studies in the spring hydrological season in this research area were obtained in March 1986 (Tkach, *et al.*, 1991). Ichthyoplankton was represented by eggs and larvae of *S. sprattus* and *M. merlangus*. Sprat had already completed its winter spawning season. The average number of its eggs did not exceed 1.9 ind./m², and the larvae - 4.4 ind./m², and the maximum number of eggs and larva were 20 and 26 ind./m² respectively. Only 5% of 360 larvae collected in vertical and horizontal catches were less than 10 mm in size (Tkach, *et al.*, 1991).

The data on the size range of sprat larvae obtained in spring 2016, 2017 and 2019 differed significantly from those in March-April 1986. A high proportion of sprat larvae of a younger age group (up to 6 mm TL) was observed in all ichthyoplankton samples, indicating the continuation of its effective spawning (Figure 3).

The positive temperature anomalies are known to contribute to improving the food supply of fish larvae and consequently affect the recruitment success of natural fish populations (Fromentin & Planque, 1996). And contrary, under adverse hydrological conditions, the development of fodder zooplankton may be delayed, the species composition or the size of prey can change, and according to the match/mismatch hypothesis, cause mortality of the larvae when transiting from yolk to exogenous nutrition (Dekhnik *et al.*, 1970; O'Connell & Raymond, 1970; Cushing, 1990; Fuiman & Werner, 2002). Compared to 1986, in our studies the proportion of larvae with food objects in the guts increased, indirectly indicating a favorable food supply for fish larvae. In samples, collected in research cruises in spring 2016, 2017, 2019, the larvae of the younger age group sized from 4 to 6 mm prevailed in total. It could have indicated the match between the maximum development of the consumed forms and larvae hatching and development, as the larvae at the stage of transition to active exogenous nutrition appeared to have been provided with a sufficient food supply, which contributed to a greater possibility of their survival.

Conclusions

Climate warming induced changes in the hydrological regime of the Black sea favorably affect the spawning activity of the sprat, resulting in the extension of the terms of its mass productive spawning for the autumn and spring hydrological seasons. The fact of the mass productive spawning of sprat in the spring season of 2016, 2017 and 2019 is confirmed by the high number of sprat eggs and larvae (the maximum number of eggs reached 224 ind./m², and larvae-116 ind./m²), and by the prevalence of larvae of the younger age group in the ichthyoplankton samples as well.

The reduction in the age and size-weight composition of sprat in the Black sea, which has been observed since 2016 as a result of an increase in its commercial fishing on the shelf of the Crimean Peninsula, did not affect its spawning activity. We believe this to be derived from the wide range of the sprat's habitat distribution area (both the shelf and deep-water areas of the entire Black sea), its early puberty (at age of 10 months) and multiportion spawning. Different age sprat individuals are able to begin spawning simultaneously under favorable temperature conditions due to year-round reproduction of sprat in the Black sea.

Ethic statement

Specific permission was not required to conduct sampling for this research. No experiments have been carried out using living organisms. The authors confirm that the field studies did not involve any endangered or protected species.

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Author Contributions

Klimova T. contributed substantially to the conception and design of the study. Klimova T., Vdodovich I. and Podrezova P. studied ichthyoplankton samples, worked on the analysis and interpretation of the data, wrote and reviewed the manuscript.

Identification of ichthyoplankton was made by Klimova T. and Podrezova P., larval fish nutrition was studied by Vdodovich I.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All listed co-authors declare that the present study was conducted in an ethical, professional and responsible manner.

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