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ABUNDANCE AND SPATIAL DISTRIBUTION OF THE FISH EGGS AND LARVAE OF EUROPEAN SPRAT, *SPRATTUS SPRATTUS* IN THE SEA OF MARMARA, TÜRKİYE

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Abstract
European Sprat, *Sprattus sprattus* (Linnaeus, 1758), is recognized as one of the most representative small pelagic fish species in the Black Sea and the Sea of Marmara (SoM). Scientific data on the early life characteristics of Sprat stocks in the SoM have been insufficient. In the present study, we aimed to elucidate the mean abundance of fish eggs and larvae, as well as their spatial and temporal variations in the SoM. To achieve this, three ichthyoplankton surveys were conducted in December 2021, January 2022, and March 2022 across 32 equally distributed stations covering the entire Marmara Sea. Sprat eggs and larvae were collected using vertical plankton tows with a WP-2 type plankton net equipped with a 300 µm mesh. Among all winter spawners in this study, Sprat was the most abundant fish species for both eggs and larvae, comprising 90.1% and 61.9% of the total abundance, respectively. The mean Sprat abundance per unit area (n/10 m²) was determined to be 713.8 n/10 m², with mean prelarvae abundance at 43.5 n/10 m² and postlarvae at 16.9 n/10 m². A total of 80.3% of the fish eggs, with a mean of 1719.9 n/10 m², and 73.6% of the total larvae abundance, with 133.6 n/10 m², were observed in February. Three primary spawning grounds were identified: the Karacabey Floodplain area (S18), Büyükçekmece shores (S23-S26), and Tekirdağ shores (S8), with larval movement observed from the northern to the southwestern regions and possibly from S18 to the southwestern part.
Keywords: Fish egg, fish larvae, abundance, spawning area, spatial variation

Introduction

European Sprat, *Sprattus sprattus* (Linnaeus, 1758) has a great geographical distribution from Morocco coasts to the North Sea. It is more common around Northeastern Atlantic, but also relatively prevalent around the Black Sea, especially northern part (Whitehead, 1985). European Sprat is a single species represented in the Clupeidae family in Türkiye waters and distributed in the Black Sea, Sea of Marmara, and Aegean Sea (Bilecenoğlu et al., 2014).

European Anchovy, *Engraulis encrasicolus (Linnaeus, 1758),* Sardine, *Sardina pilchardus (Walbaum, 1792),* Round Sardine, *Sardinella aurita* Valenciennes, 1847 and Sprat are the most abundant small pelagic fish species of Mediterranean basin (Lleonart and Maynou, 2003), whereas Sprat and European Anchovy were abundant species in the Black Sea and in the Sea of Marmara. These species are of great ecological importance regarding their position in the food web, which connects the lower and upper levels with their planktivarous feeding against becoming prey by upper carnivarous fish (Curry et al., 2000). In terms of economical importance, Sprat is not as popular as Anchovies and Sardines in the Mediterranean and the Black Sea. In terms of fish landings of Türkiye fisheries in 2024, the European Anchovy has the most catch with 153 175 tonnes and constituted a more than half of the total catch. Anchovy is mostly utilize as food source, whereas the Sprat mostly evaluated as animal food production in the Türkiye waters. Thus, the need for raw protein materials for feed production has become completely dependent on Sprat fishing. According to fish landing statistics of Türkiye, Sprat was caught as 16 067 tonnes in 2024, which constituted a 5.5% of the total landings. Whereas the total catch of Sprat was 77 000 tonnes in 2015, and originated a 22.3% of the total. The amount of catch has been decreasing continuously in the last 10 years (TUIK, 2024).

The sustainability of small pelagics are closely related understanding of the spawning patterns and overfishing. The temperature and salinity are known as an important environmental factors that effect spawning time and area. Also salinity clearly effect of spawning condition of the Sprat (Elwertowski, 1957, Casini et al., 2006; Ojaveer and Kalejs, 2010). Demirel et al. (2020) analysed stock assesment of 54 fish species distributed in Türkiye waters and stated that the Black Sea Sprat was a single species that stocks seemed sustainable from it's 2017 landing data which the highest catch occurred in the last 6 years. There is no information available about the Marmara stock of Sprat, and it has been found that the stocks of two other small pelagic fish, horse mackerel and sardine, are nearing overfishing levels in the Sea of Marmara (SoM). However, fish landings showed that rapid decline occurred of the Sprat stocks in Türkiye waters especially between 2018 and 2024 (TUİK, 2024).

Small pelagic fish play a crucial role in maintaining the balance of the food web. Sudden changes in their population size can lead to significant ecological issues, such as the overgrowth of certain levels within the food chain (Shannon et al., 2007). In recent years, dense mucilage disasters have been observed in the SoM, which are mostly attributed to global warming and pollution. There is also a potential link between the abundance of planktivorous fish species, such as sprat, and the proliferation of the unicellular organisms causing mucilage (Savun-Hekimoğlu and Gazioğlu, 2021). On the other hand, scientific information such as stock size, feeding, spawning etc. of Sprat is insufficient in the SoM. As a result, there has been great interest in the reproductive success of the sprat stock in the Sea of Marmara during its first spawning period after the massive mucilage event. For this purpose, we tried to reveal fish egg and larvae abundance and it's spatial and temporal variations in the SoM.

Material and Method

Study Area

The surface area of the SoM is approximatelly 11 350 km square meter and the maximum depth is 1 390 m.

The SoM is a is a semi-enclosed sea that constitutes a straits system called as TSS with Bosporus and Dardanelles. Due to the distinct physical and geographical characteristics of the Aegean Sea and the Black Sea, two-layered stratification occurs in the SoM. The colder and less saline (~‰18 ppt) Black Sea water flows upper layer towards Aegean Sea, and the more saline and temperate Aegean Sea water (~‰18 ppt) flows from the lower layer towards the SoM. (Beşiktepe et al., 1995). In addition, the narrowing parts of the SoM such as the exit of the Istanbul Strait and the entrence of Çanakkale Strait (Nara Cape) effect the speed of current flow rate which defined as a jet-like upper current, alongside of cause subsequent mixing and circulation (Özsoy & Altıok, 2016).

Sampling Procedure

Following the initial autumn-winter mucilage event, which occurred between March 2021 and July 2021, three ichthyoplankton surveys were conducted in December 2021, January 2022, and March 2022. These surveys were carried out across 32 evenly distributed stations (Table 1), encompassing the entire Sea of Marmara (SoM) (Figure 1). In order to collect Sprat eggs and larvae, vertical plankton tows were conducted at each station using a WP-2 type plankton net equipped with a 300 µm mesh. Ichthyoplankton tows were performed from the upper layer (approximately from 40 m depth) to the sea surface. All tows were executed during daylight hours, and samples were preserved with a 4% formaldehyde-seawater solution on the vessel.

The determination of fish egg stages was conducted with Dekhnik's (1973) 6-stage development method. The larval stages were determined as prelarvae and postlarvae according to Hubbs (1943). Dead fish eggs were identified by their morphological integrity at the time of capture, and egg mortality was calculated as the ratio of dead to live eggs.

Table 1. The position and the depths of the ichthyoplankton stations located in the SoM.

Stations	Latitude	Longitude	Depths	Stations	Latitude	Longitude	Depths
P1	40° 30' 562" N	27° 13' 782" E	63	P17	40° 56' 743" N	28° 04' 594" E	300
P2	40° 37' 451" N	27° 12' 209" E	55	P18	40° 32' 034" N	28°16' 114" E	50
P3	40° 27' 923" N	27° 23' 973" E	53	P19	40° 43' 004" N	28° 11' 890" E	698
P4	40° 42' 963" N	27° 20' 970" E	60	P20	40° 57' 562" N	28° 14' 845" E	130
P5	40° 21' 744" N	27° 35' 362" E	35	P21	40° 34' 694" N	28° 26' 040" E	56
P6	40° 33' 761" N	27° 31' 978" E	64	P22	40° 39' 907" N	28° 29' 322" E	278
P7	40° 39' 806" N	27° 33' 142" E	85	P23	40° 57' 623" N	28° 26' 364" E	65
P8	40° 52' 592" N	27° 29' 308" E	77	P24	40° 34' 019" N	28° 40' 556" E	320
P9	40° 32' 986" N	27° 45' 951" E	64	P25	40° 39' 594" N	28° 37' 191" E	410
P10	40° 40' 951" N	27° 42' 807" E	96	P26	40° 57' 071" N	28° 36' 606" E	42
P11	40° 55' 500" N	27° 42' 167" E	500	P27	40° 41' 180" N	28° 53' 669" E	305
P12	40° 32' 198" N	27° 54' 036" E	53	P28	40° 56' 035" N	28° 45' 255" E	765
P13	40° 42' 757" N	27° 53' 864" E	607	P29	40° 42' 275" N	29° 00' 267" E	1050
P14	40° 55' 528" N	27° 53' 375" E	550	P30	40° 50' 848" N	28° 59' 962" E	156
P15	40° 32' 008" N	28° 05' 053" E	43	P31	40° 43' 051" N	29° 11' 209" E	1000
P16	40° 42' 629" N	28° 04' 762" E	700	P32	40° 46' 331" N	29° 16' 944" E	95

Abundance of fish eggs and larvae from vertical tows standardized in a unit area (n/10 m^2) according to using formula given “Vertical Distribution” part of FAO Fisheries Technical Papers No: 175;
C = Cv x (SR/V) where C is a individual number in a unit area (n/10 m^2), Cv is a individual number in a unit volume (n/1000 m^3), S is a unit of area (10 m^2), R is a depth of sampling (m) and V is a unit of volume (1000 m^3).
Dissolved oxygen, salinity and temperature were measured using a YSI 6600.

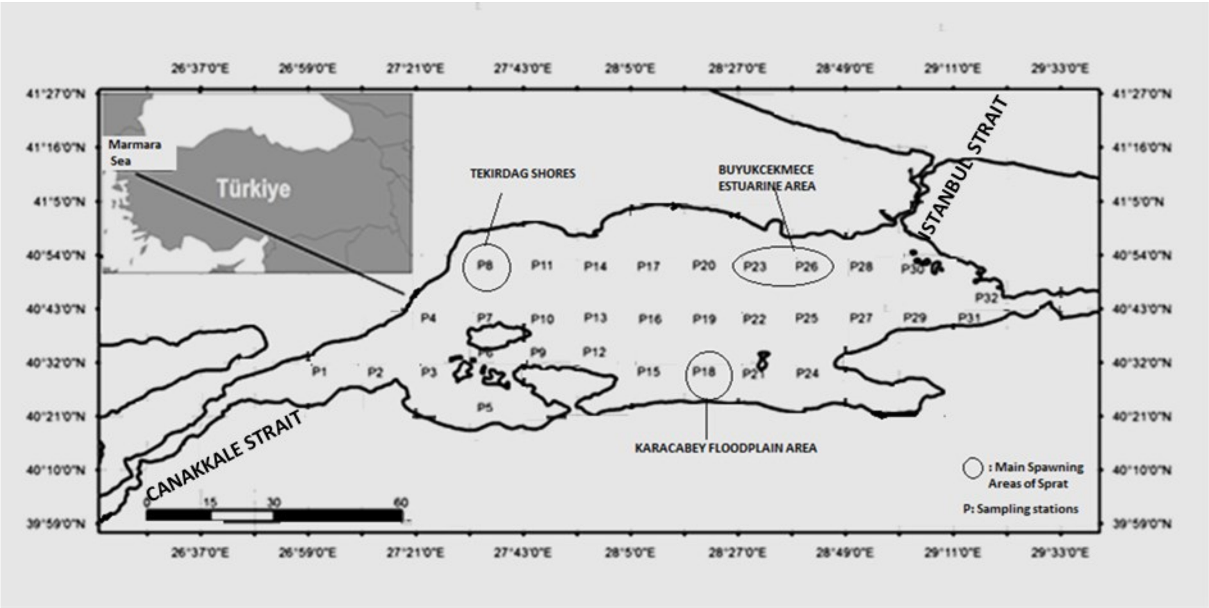

Figure 1. Study area (Sea of Marmara) and the ichthyoplankton sampling stations

Results

The descriptive statistics (mean, minimum, and maximum values) for the measured physical parameters—sea surface temperature, salinity, and dissolved oxygen—are provided in Table 2. Sea surface temperature (SST) reached its highest value in December, decreased sharply in January, and then stabilized through March. The highest SST values were observed in the southern Sea of Marmara across all sampling months. The lowest SST was measured near the Tekirdağ coast in December and January but was found in the central part (P19) in March. Salinity showed a clear spatial trend, with the lowest values occurring at the stations near the İstanbul Strait exit and the highest values in the southwesternmost part. The highest dissolved oxygen values were recorded at the stations situated around the Kapıdağ Peninsula.

Table 2. The descriptive statistics of sea surface temperature, salinity and oxygen

Survey months	Temperature (°C)			Salinity (ppt)			Dissolved oxygen (mg/lt)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
December 2021	12.2 (P7)	13.1 (P15)	12.5±0.03	25.6 (P13)	27.9 (P6)	26.7±0.1	4.0 (P4)	8.8 (P9)	5.9±0.3
January 2022	6.8 (P8)	7.8 (P29)	7.2±0.05	24.4 (P27)	30.7 (P3)	28.8±0.3	8.5 (P4)	9.4 (P15)	8.9±0.04
March 2022	6.4 (P19)	9.1 (P6)	7.3±0.11	22.3 (P28)	28.2 (P1)	25.9±0.3	6.5 (P3)	9.5 (P25)	7.8±0.1

Among all winter-spawning species, Sprat emerged as the most abundant fish species in terms of both eggs and larvae, accounting for 90.1% and 61.9% of the total abundance, respectively. During the total survey interval (December-March), the average abundance of Sprat per unit area was recorded at 713.8 n/10 m^2, while the mean abundance of Sprat prelarvae was 43.5 n/10 m^2 and that of postlarvae was 16.9 n/10 m^2. Consequently, the occurrence-based survival rate of Sprat prelarvae was estimated at 6%, and that of postlarvae at 2.3%. These data indicate high mortality rates during early developmental stages.

In terms of temporal variations of Sprat fish egg and larvae abundance, it was observed that Sprat started to spawn in December. When compared with the other months, the lowest monthly mean fish egg abundance was detected in December (8.6 n/10 m^2; 0.4%). The abundance values were ranged between the stations 0 and 78.4 n/10 m^2.Sprat eggs were detected at only 6 of the 32 stations sampled in December, all of which were situated in the northeastern parts (P21, P22, P27, P28, P30, and P32). In December, sprat prelarvae and postlarvae were not found in any of the stations. Due to the high SST values, it was hypothesized that the Sprat was at the onset of its spawning period.

Sprat spawning peaked in January, with 80.3% of all sprat eggs and 73.6% of all sprat larvae sampled during the study period collected in that month. Sprat eggs showed widespread distribution in January, being detected at 30 of the 32 stations. However, they were not found at the two southwesternmost stations (P3 and P5). The abundance values were distributed from 0 n/10 m^2 (P3 and P5) to 16777.6 n/10 m^2 (P18), with a monthly mean abundance of 1719.9 n/10 m^2. In January, Sprat larvae were found 23 of 32 stations. Sprat larvae were absent in deeper stations located mostly on central area (P9, P10, P12, P13, P17, P24, P25, P27 and P28). The abundance values were ranged between 0 n/10 m^2 and 784 n/10 m^2 (P18), with a monthly mean abundance of 133.6 n/10 m^2.

Lastly, a 19.3% of all Sprat eggs and a 26.4% of all larvae abundance were detected in March. The Sprat eggs abundance were distributed from 0 n/10 m^2 to 2312.8 n/10 m^2 (P29), with a monthly mean abundance of 412.8 n/10 m^2. Sprat eggs were not found in southwesternmost parts (P1, P3, P5, P6, P9, and P12). The Sprat larvae were found 20 of 32 stations in March. The Sprat larvae abundance were ranged between 0 n/10 m^2 and 313.6 n/10 m^2 (P7), with a monthly mean of 47.8 n/10 m^2. The highest larvae abundances were seen between the north of Marmara Island and Tekirdağ.

By means of the spatial variations, the highest mean fish egg abundance was found from Karacabey Floodplain area (S18), with a mean of 5618.7 n/10 m^2 fish eggs and this abundance constituted a 25% of all Sprat egg abundance during study period (Figure 2).

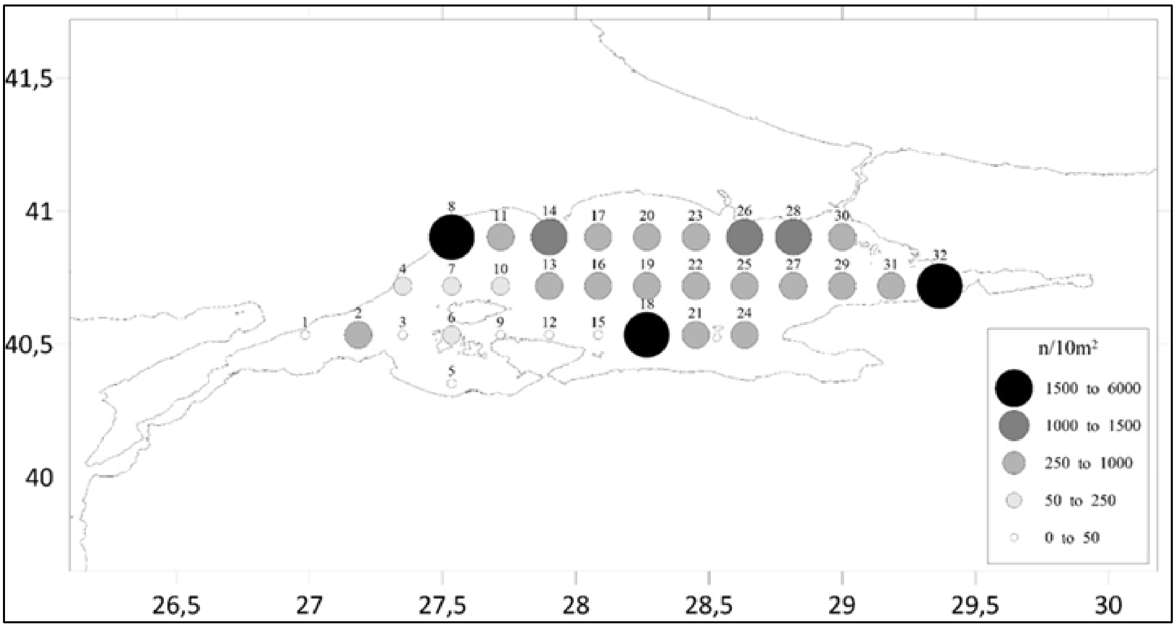

Figure 2. Spatial distribution of Sprat eggs in the SoM.

Also, the area between Tekirdağ and Marmaraereğlisi (S8, S11 and S14) and the area between Büyükçekmece and Pendik (S26, S28, S30 and S32) were the other two abundant areas for Sprat eggs. Sprat eggs were absent at the stations 3 and 5, and the mean abundance of the remaining southwestern stations (P1, P2, P6, P9 and P15) were low (267.9 n/10 m^2). Whereas, the mean Sprat egg abundance of the remaining 25 stations were calculated as 2676.6 n/10 m^2. Similarly, the highest Sprat larvae abundance was detected in S18 with a mean of 261 n/10 m^2, which correspond to 13.5% of the total Sprat larvae abundance during study period. Contrary to fish egg distribution, larvae were distributed more dispersedly. It was detected that the Sprat larvae were not found only 3 of 32 stations (S9, S13 and S27). The shifting of Sprat larvae from spawning areas (Tekirdağ shores and Karacabey Floodplain area) to southwestern part of the Marmara Sea was detected (Figure 3).

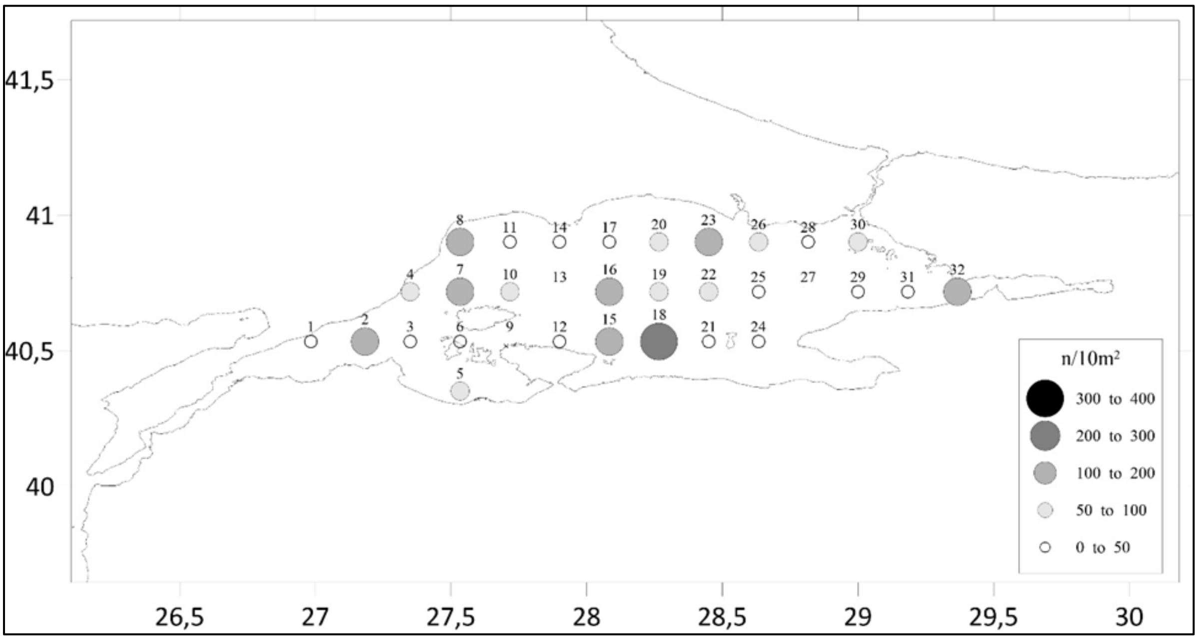

Figure 3. Spatial distribution of Sprat larvae in the SoM.

In this study, 44.8% of the total Sprat eggs were dead. In addition, 64% of the total fish eggs were classified as stage-1, indicating that they were recently spawned and not fully developed. Furthermore, 15% identified as well-developed (stage-5) and 2% of the total eggs were and nearly hatching (stage-6). The highest egg mortality was observed at the 14th station, located in the vicinity of the Marmaraereğlisi - Tekirdağ province. Similarly, relatively high numbers of dead Sprat eggs were detected in nearby areas, specifically at stations 11th and 13th stations. In contrast, the highest rates of live eggs were recorded in the region between Karabiga and Erdek Bay, which is situated in the southwestern part of the Marmara Sea (2nd, 3rd, 5th, and 6th stations). The mortality rate of Sprat eggs was similar across the sampling months of December, January, and March, at 42.9%, 46.9%, and 40.4%, respectively.

Discussion

Sprat is known as a poikilothermic species, and the sea surface temperature and salinity are main boundaries of its distribution and spawning activities. It is more common in the North and Baltic Seas, whereas the Black Sea and SoM set off lower latitudes for its distribution.

Kutsyn (2025) stated that its northern and southern latitude stocks show varied growth, life span, and reproduction parameters. With lower temperatures and salinity values at higher latitudes, it has larger length distributions, larger sexual maturities, and a longer spawning season. In addition, global warming and overfishing are the causes of reduction in the lifespan and size of Sprat in the Black Sea. Petereid et al. (2008) revealed the effects of temperature on the development of S. sprattus eggs and prelarvae. They found that no hatching occurred below 3.4°C and over 14.7°C in the Baltic Sea. They also stated that the mouth gape opening duration and larval yolk sac phase development time decreased with increasing temperature. In addition, the optimal survival temperature for Sprat was determined as 8.4°C (Petereid et al., 2008) and within the range of 5 °C to 13°C (Nissling, 2004). In addition, Wahl and Alheit (1988) reported that the peak spawning of Sprat occurred within the range of 9.1°C and 12.1°C. The temperature during peak spawning in the present study was determined as 7.2 °C. It was stated that the spawning duration, spawning peak time, embryonic, and larval development showed some variations between Baltic, North Sea, and English Channel Sprat. These variations are associated with varied salinity ranges and thermal adaptations. Although the mean abundance of fish eggs of the Sprat in a unit area in the SoM were detected as high within the range of 11.3°C and 7.2°C interval, the simultaneous high fish egg mortalities and low prelarvae and postlarvae abundances could be explained by lower temperature values for development and potentially lower food supply for development of the Sprat in the SoM.

Klimova et al. (2021) stated that the abundant ichthyoplankton species Sprat's spawning season extention occurred in the Black Sea due to climate changes. The winter spawner Sprat was detected as dominant between ichthyoplankton in March, April, and May, when the sea surface temperature varied between 9°C and 15°C. Also, this pattern supported with the finding's of Uygun and Üstün (2024) in the Southern Black Sea. According to the recent multivariate analyses, authors stated that *S. sprattus* eggs and larvae exhibits a negative relationship with temperature during winter months, with peak densities (382 ind./10 m²; 7.7%) observed between December and April (8.4-12.6°C). Dembek et al. (2019) found that Sprat dominated ichthyoplankton of Baltic Sea between May and June, when temperature was detected between 9 and 14°C, whereas salinity was 7 ppt. In the SoM, the spawning activity was deteceted as low in December, when the temperature was measured as 11.5°C, peaked in February (7.2°C) and relatively active in March (7.4°C). Salinity was measured between 25 and 28 ppt during the spawning season. Because the sampling surveys in the present study were carried out between December and March, the extension of the spawning season towards spring could not be evaluated in the SoM. Sprat can tolerate temperatures up to 15°C and uses this increase positively for rapid growth, whereas salinity can be a major restrictive parameter, especially around southern latitudes such as the SoM, which may be a reason for the high mortality rates observed in the present study.

The distribution pattern of vertical fish eggs in Sprat showed three main spawning areas in the SoM. The major spawning area, the Karacabey Flood Plain, is one of the most pristine areas in SoM. This area is not affected by any industrial facilities or human population. In addition, it constitutes brackish water owing to freshwater input. In addition, Büyükçekmece and Küçükçekmece are estuarine areas with similar brackish waters. Thus, these areas were not surprising for Sprat spawning because of the need for lower salinities for spawning. The third spawning area of Sprat in SoM was detected around Tekirdağ (S8), where there was no valid freshwater input. Among the stations, S8 had the highest zooplankton displacement value (ZDV). The high zooplankton availability may explain why this location was chosen as the spawning ground. The spatial variations of immotile fish eggs and pre-larvae reveal spawning areas of a given species, whereas fish larvae distribution exhibits favorable growth and recruitment areas, especially for small pelagic fish (Palomera et al., 2007). In the present study, the highest fish larvae abundance was found in the Karacabey Floodplain area (S18), where ZDV was also relatively high. In addition, the southwestern part of the SoM, Gönen Estuarine area, and Karabiga region had the highest ZDV values. In this area, relatively few Sprat eggs were found, but high Sprat larvae were detected. It was observed that Sprat larvae drift from S8 to these favorable areas after hatching.

Due to the buoyancy of fish eggs, the egg diameters of Sprat showed great variation between different geographical areas. It was ranged from 1.23 to 1.58 mm (Horbowa and Fey, 2013) and from 1.20 to 1.60 mm (Dembek et al., 2019) in the Baltic Sea, from 0.8 to 1.3 mm in the North Sea (Munk and Nielsen, 2005). Whereas, the egg size was detected as 0.78 to 1.05, respectively). The higher salinities in the SoM caused the smallest egg size of Sprat. The negative effects of salinity variations on fish egg diameters was previously stated by Demir (1961) with comparison of the pelagic fish eggs collected from the Black Sea and Marmara Sea. Our findings related egg size coincided with the findings of the author. Owing to the two-layer stratification, less saline and temperate Black Sea waters flow from the Black Sea via the İstanbul Strait to the SoM in the upper layer. Thus, pelagic non-motile organisms drifted from the northern part towards the southwesterntern part of the SoM. Non-motile and/or semi-motile eggs and prelarvae of sprat drift are possible. The results of the spatial distribution of fish larvae reflects this pattern especially from Tekirdağ region (S8) towards Karabiga shores. The high abundance of Sprat eggs around the northwestern part may be related to the flow of Sprat eggs from the southwestern part of the Black Sea to the Northeastern part of the SoM. However, the high abundance of early egg development stages in the present study proved that Sprat spawns in the SoM and that only a limited part of it may drift with the currents to the SoM.

Conclusion

The Sprat defined as a forage fish, which is characterized a key role in the ecosystem with linking upper and lower food web (Frisk et al., 2015). Due to this pattern, it has a great importance for balancing food web of SoM. Due to the SoM defined as a semi-enclosed basin, it is sensitive to sudden environmental changes with it's high pollution load. In recent years, the dense mucilage events has been occurred in the SoM. The formation mechanism of mucilage is associated mostly global warming and pollution (Danovaro et al., 2009; Boero, 2016; Malone and Newton, 2020). The SoM is defined as large drainage basin (Akoğlu, 2021) and polluted by industrial facilities, domestic wastes, marine traffic and fisheries. Whereas, the other potential effect on mucilage formation, "over-fishing" of small-pelagic planktivarous fish species is overlooked. The huge fishing effort by active fishing gears such as a purse-seiners and mid-water trawls (Avşar, 1995; Totoiu et al., 2016; Akoğlu, 2021; Zuev and Skuratovskaya, 2022) on Sprat was explained from the Black Sea and the SoM. The fisheries landings of Türkiye in the last decade proved this decline of the Sprat. Due to it's low economical value, the Sprat target by purse-seiners as fish meal production raw-material in Türkiye. Harmful algal blooms has been reported (Taş et al., 2016; Ergül et al., 2018) in the SoM. After algal blooms, primer and seconder planktivore species has vital role in the pelagic ecosystem by means of balance with consuming them rapidly. Thus, the stock status of primer planktivors such as Sprat become important in this pattern. If the density of these species is not sufficient, the seconder planktivors such as jellyfish multiply rapidly due to favorable conditions. It was stated that the jellyfish blooms during a living or dead life cycle may have triggered the mucilage formation due to release of dissolved organic load (Isinibilir, 2014). Due to the Sprat is the most abundant small pelagic fish species in the Black Sea and in the SoM, the proper fisheries regulations should be applied by fisheries management authority in order to prevent environmental disasters such as mucilage.

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Ethical approval
Not applicable

Informed consent
Not available

Data availability statement
The author declares that data can be provided by the corresponding author upon reasonable request.

Conflicts of interest
There is no conflict of interests for publishing this study.

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Contribution of authors
Author 1: Conceptualization, Data curation, Formal analysis, Writing original draft
Author 2: Conceptualization, Data curation, Formal analysis,
Author 3: Field work, software
Author 4: Field work
Author 5: Field work
Author 6: Field work
Author 7: Field work
Author 8: Field work
"All authors have read and agreed to the published version of the manuscript."

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