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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Estimation of spawning stock biomass and spawning areas of sardine, (*Sardina pilchardus*) with winter time ichthyoplankton sampling in the Sea of Marmara, Türkiye

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Abstract: The spawning areas and spawning stock biomass of sardine were studied with ichthyoplankton sampling in the winter period from the 32 stations, in the Marmara Sea. The mean fish egg and larvae biomass in a unit area were calculated as 18.4 ± 5.3 eggs/10 m^2 and 2.5 larvae/10 m^2, respectively. Three main spawning areas were detected as Karacabey Floodplain area, Gönen, and Büyükçekmece estuarine area. The larvae are mostly located in the western part. The batch fecundity of sardine was detected between 2415.9 and 16738.3, with a mean of 6899.8 ± 255.7 eggs. The sex ratio (*R*), spawning fraction (*S*), mortality rate, and daily egg production (*Po*) were calculated as 0.53, 0.098, 0.62, and 9.25 eggs/m^2 in the Marmara Sea. The spawning stock biomass (*B*) is estimated at 2998 tonnes in the Marmara Sea. Both ichthyoplankton biomass and spawning stock biomass were found relatively lower. It is recommended to apply stricter management sanctions for the sustainability of sardine stocks.

Keywords: Fish eggs, fish larvae, small pelagic fish, stock estimation, daily egg production

INTRODUCTION

Sardine, *Sardina pilchardus* (Walbaum, 1792) has a wide geographical distribution from Northeastern Atlantic to Senegal, and the Mediterranean including Adriatic, Marmara Sea, and the Black Sea (Whitehead, 1988). It is mostly found in marine waters, but it can be distributed in brackish and freshwaters (Riede, 2004). The preferred depth range of the sardine occurs between 25 m and 100 m depths (FAO-FIGIS, 2005). It forms a school and shows more coastal distribution between 10 m and 35 m at night. The diet of juvenile and adult sardines differ (Nikolioudakis et al., 2011) and juvenile sardines fed heavily on copepods, whereas diatoms and autotrophic dinoflagellates (Nikolioudakis et al., 2012). The maximum reported length was 27.5 cm SL (Macer, 1974), and the maximum age was 15 (Muus and Nielsen, 1999).

Sardine is a member of Clupeidae, and is one of the most important fish species in both the global fishing industry and Türkiye, due to high supply demand for fresh fish and canned products. The Clupeidae family is represented by 12 species, and between them, *S.pilchardus* and *Sprattus sprattus* are two abundant Clupeidae species in Türkiye waters. *S.sprattus* has a minor commercial interest, it is usually utilized as a fishmeal component. Whereas *S. pilchardus* is evaluated as human consumption in Türkiye, mostly caught in the Marmara Sea and Aegean Sea. In terms of landing data presented by TUIK (2023) sardine ranked third after Anchovy and Bonito, with 825.5 tonnes of catch. When considered small pelagic fish species, its landing was higher than *Pomatomus saltatrix* (618.7 tonnes), *Trachurus trachurus* (751.4 tonnes), *Trachurus mediterraneus* (508.6 tonnes), *Scomber japonicus* (480.9 tonnes), *Sardinella aurita* (26.7 tonnes), and *Scomber scombrus* (3.9 tonnes), but relatively lower than *Engraulis encrasicolus* (13,444.6 tonnes) and *Sarda sarda* (3,113.4 tonnes) catch landings.

Although of great importance for small-scale gillnet fisheries, 85-90% of the total global catch stemmed from seine net fisheries in recent years. According to FAO 2019 fishing reports, a global catch of sardine was reported as 1,499,361 tonnes, whereas 1.4% of the total catch (19,119 tonnes) was caught in Türkiye waters (FAO, 2021). With the increasing industrialization of fishing vessels, the seine net fishery asserted its dominance over commercial catch, and small-scale gillnet fisheries have become able to catch fish only in the summer months when the seine net fishery is under seasonal restriction. This pattern caused a great decline in catchable stocks of sardine in Turkish waters, which was 34,709 tonnes in 2011 and decreased to 16,729 tonnes in the

2022 (TUIK, 2023). The sardine landing constitutes only 5.5% of the total catch (301,747 tonnes) in 2022 fishing season.

Previous studies were realized according to the reproductive biology of adult sardines. The first maturity length (TL, total length) was found as 12 cm in the Aegean Sea (Cihangir, 1995), 12.5 cm in Spain and 13.5 cm in Adriatic (Beverton, 1963), 13.5 cm in the Gulf of Lion (Campillo, 1992), 15 cm in the Gulf of Biscay (Dorel, 1986), and 16 cm in the Madeira (Silva et al., 2006). Also, spawning season occurred between October and April in Portugal (Figueiredo and Santos, 1989), between October and January in Northwest Africa (Delgado and Fernandez, 1985), between January and September in Southwest England (Wirtz et al., 2008), between December and February in the Sığacık Bay (Uygun and Hoşsucu, 2020), and between October and May in the Çanakkale Strait (Daban, 2013). According to Turkish notification on the regulation of commercial fishing, the minimum landing size of sardine is 11 cm in TL. The seasonal restriction application on a species-basis is not available, but the closed season of purse-seining is being implemented between April and September, which is not related to the spawning season of this species.

This declining pattern of sardine stocks may pose a clear threat in the near future in terms of sustainability. A sustainable use of natural resources is known as one of the most important heritage that a nation can leave to future generations. Due to the fisheries stocks being under excessive fishing pressure, lots of stocks become near threatened. Thus, some protective measures should be conducted to prevent sudden collapses of fish stocks. Whereas fisheries managers need accurate information to deal with stock size capacity for stock assessment. Fish stock assessment methods should reveal more robust results by using sufficient observational data obtained from field surveys (Chrysafi and Kuparinen, 2016). Ichthtyoplankton-based data allows estimation independently of occupational fishing (Govoni, 2005) with lower survey costs and in less time (Yüksek, 1993). Besides, ichthyoplanktonic data presents concrete results for estimating stock size and determining stock size-recruitment relationships (Lockwood, 1988). In addition, the most accurate method of the determination of spawning areas and spawning season of fish species was stated as ichthyoplankton studies (Fuiman and Werner, 2002). Although varied stock assessment models have been applied to lots of species such as analysis of length frequency data of catches (Length Cohort Analysis – LCA) and analysis of catch-at-age data (Virtual Population Analysis – VPA), the most appropriate model for small pelagic fish species stated as direct assessment methods based on ichthyoplanktonic data (Oliver, 2002). Among all direct stock assessment methods, the daily egg production method is defined as one of the most important tools, especially for the determination of the stock size of small pelagic fish species. The biomass of fish eggs and prelarvae, sampled with an ichthyoplankton survey constitutes an important part of this method along with fecundity information obtained from adult fish (Alheit, 1993). Among all other species, sprats, anchovies, sardines, and mackerels were the species whose stock size was most frequently calculated with the daily egg production method. Whereas, the previous findings for stock size estimation with daily egg production method were limited only to Taylan and Hoşcucu (2016)'s study in Turkish waters.

After noticing the decrease in catch records, we aimed to reveal the stock size of sardine by applying the daily egg production method. In addition, we tried to ascertain the spawning areas of sardine in the Marmara Sea with a broad-scale geographical sampling strategy.

MATERIALS AND METHODS

To determine stock size with daily egg production method and spawning areas, three ichthyoplankton surveys were conducted in December 2021, February 2022, and March 2022 from 32 stations located at equal distance from each other (10 miles) in the Marmara Sea, Türkiye (Figure 1). The sardine eggs and prelarvae obtained from the vertical hauls of each station were sorted from plankton samples, recorded, and standardized with a unit of individual number/10 m^2.

For the purpose of the stock estimation of sardine based on the daily egg production method, both ichthyoplankton (sardine eggs and prelarvae) and adult sardine individuals were examined. The sexes of the adult individuals were determined and recorded, and all sexed individuals were weighted. Then, the sex ratio for spawning stock biomass (R) was determined from the division of mean female weight to mean total weight of all individuals. For determining batch fecundity (F), the hydrated oocytes of adult females were examined (Hunter et al., 1985). Oocytes were counted and their diameters were measured under a binocular microscope. Oocytes greater than 395 µm diameter were accepted as "large-hydrated" oocytes. The spawning fraction (S) is the fraction of mature females spawning per day (spawning frequency) which is determined by the development stages of oocytes. The total survey area (A) was calculated from the results of ichthyoplankton sampling. In accordance with the method requirement, the stations containing fish eggs and prelarvae were marked as positive, and the positive-coded areas were calculated differently from the total area. The total area of the Marmara Sea was accepted as 11500 km^2. The total survey area (A) in the spawning stock biomass equation is estimated from the fraction of positive stations to all stations, due to all stations being located at equal distances. To calculate the daily egg production (P_0), initially, the ages of eggs need to be determined. The aging of fish eggs was determined according to the temperature-dependent model of sardine developmental rate (Miranda et al., 1990),

$$Y = 17.52 * e^{-0.136T-0.173i} * i^{2.222} \quad (1)$$

where T is the sea surface temperature of the station (5 m), Y is the sampling hour of the fish egg, i is the development stage of the fish egg (stage 1-10), and peak spawning time is 20.00 (Ganias et al., 2003).

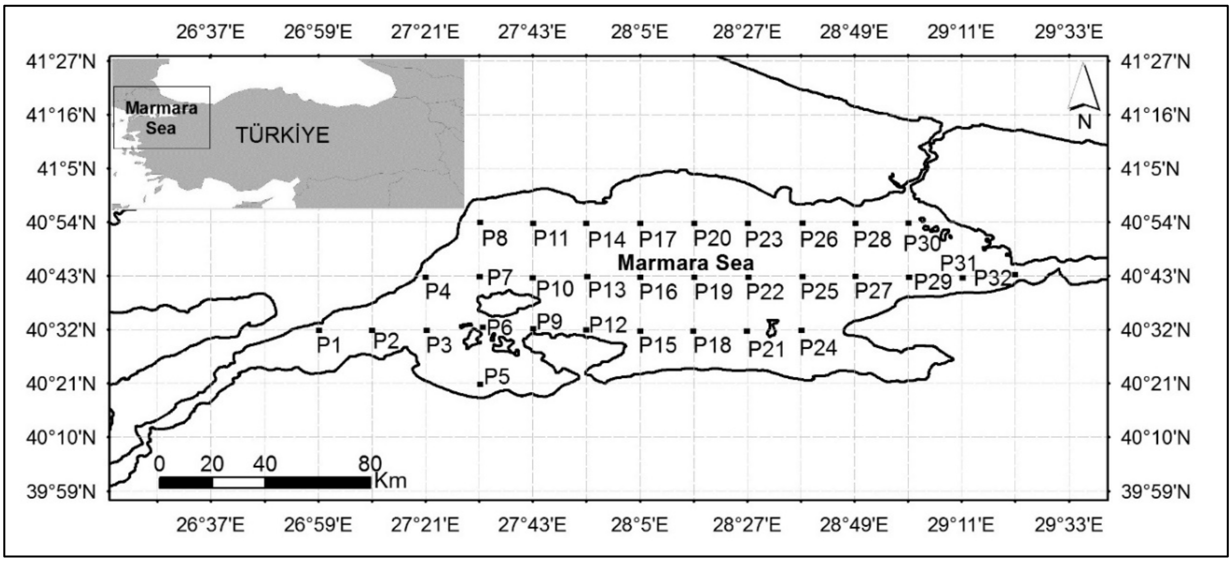

Figure 1. Study area and equally-spaced ichthyoplankton sampling stations in the Marmara Sea, Türkiye

The age of the egg was accepted as “zero” when the development stage was between 1st and 6th, whereas accepted as “one” when the development phase was ranged from the 7th to 12th stage. Due to zero-age development being completed in less than 24 hours, the zero-age stage revealed an estimated spawning time. When the estimated spawning time was subtracted from the sampling time, if the duration was higher than 48 hours, the age of the egg was determined as 2. Somarakis (2005) stated that the mortality rate calculation did not show differences from 0 when the mortality curve was constituted only from fish eggs and advised that the mortality curve should be plotted using both fish eggs and prelarvae count. The aging of prelarvae is determined according to eye pigmentation, where age accepted 1 when pigmentation has not started yet, and 2 when brown pigmentation occurred (Somarakis, 2005). After all age classes were determined, a single mortality curve was constructed for both eggs and prelarvae. The slope of the curve reveals the daily instantaneous mortality rate (Z). Thus, daily egg production (P_0) is estimated according to the given equation:

$$P_{\mathrm{t}} = P_{\mathrm{o}} e^{-zt} \qquad (2)$$

where e is the number of eggs or yolk-sac larvae produced per day per unit area at age t days; Po is daily egg production at age zero; and Z is the daily instantaneous mortality rate (Lo, 1986).

The spawning stock biomass (B) was estimated according to the given equation of Stauffer and Picquelle (1980);

$$\mathrm{B} = (\mathrm{k} * \mathrm{P} * \mathrm{A} * \mathrm{W})/(\mathrm{R} * \mathrm{F} * \mathrm{S}) \quad (3)$$

where k defines the conversion factor from grams to metric tons, P_0 is the daily egg production (the number of eggs and prelarvae per sampling unit (m²)), A the total survey area, W is the mean weight of mature females (g), R the sex ratio, F the batch fecundity and S the fraction of mature females spawning per day.

Non-parametric Kruskal–Wallis test was used to compare the spatial variation of physico-chemical parameters rather than parametric tests because the data was limited due to 3-month sampling and did not show a normal distribution.

Besides, Kruskal–Wallis test is preferred due to this distribution-free test proved to be more robust than its parametric counterpart in the case of non-normal distribution of sample data, and it is a viable alternative to parametric statistics (Potvin and Roff 1993). The variations in abundance and physico-chemical parameters based on sampling months and stations were tested with the non-parametric Kruskal-Wallis test. Then, the Mann-Whitney U post-hoc test was applied to understand where differences occurred within these variables. Significant differences were established at 0.05 significance level.

RESULTS

Spawning area estimation

Mean sea surface temperature, salinity, and dissolved oxygen values of 32 ichthyoplankton stations were measured. The temperature values ranged from 11.2ºC (P7) to 12.1ºC (P15) (mean: 11.5 ± 0.03ºC) in December 2022, ranged between 6.8ºC (P8) and 7.8ºC (P5) (mean: 7.2 ± 0.05ºC) in February 2023 and distributed from 6.4ºC (P19) to 9.1ºC (P6) (mean: 7.4 ± 0.1ºC) in March 2023. The temporal variation of sea surface temperature (SST) showed statistically important variations. The SST in December was statistically different from the SST of February and March (K-W test; H=63.39; P≤0.05). The salinity values ranged from 25.6 ppt (P13) to 26.9 ppt (P6) (mean: 26.7 ± 0.6 ppt) in December, ranged between 24.4 ppt (P27) and 30.7 ppt (P3) (mean: 28.8 ± 0.3 ppt) in February and distributed from 22.3 ppt (P28) to 28.3 ppt (P1) (mean: 25.9 ± 0.3 ppt) in March. The dissolved oxygen values were ranged from 7.6 mg/l (P3) to 9.3 mg/l (P25) (mean: 8.4 ± 0.07 mg/l) in December, ranged between 8.4 mg/l and 9.4 mg/l (mean: 8.9 ± 0.04 mg/l) in February, and distributed from 6.9 mg/l to 9.5 mg/l (mean: 7.8 ± 0.14 mg/l) in March. The salinity values were statistically differ between December and February (K-W test; H=35.56; P≤0.05) and between February and March (K-W test; H=35.56; P≤0.05). The dissolved oxygen values were statistically different between December and February (K-W test; H=35.56; P≤0.05), between December and March (K-W test; H=35.56; P≤0.05), and between February and March (K-W test; H=35.56; P≤0.05). Whereas SST did not differ statistically between the stations (K-W test; H=9.71; P≥0.05). Similarly, the sea surface salinity (K-W test; H=35.98; P≥0.05) and dissolved oxygen (K-W test; H=36.26; P≥0.05) values did not differ statistically between stations.

The mean sardine egg biomass in a unit area was calculated as 18.4 ± 5.3 eggs/10 m^2 in the Marmara Sea. 15 of 32 stations contained sardine eggs. The dead fish egg ratio was detected as 5.5%. Using spatial variation of sardine eggs, the highest biomass was observed in station 18 where under the influence of Karacabey Floodplain area with a 130.7 eggs/10 m^2 mean biomass (22.2% of the total biomass). The area between Karabiga and Gönen Stream was found the second most abundant area with a mean of 58.8 eggs/10 m^2. The other abundant area was detected as between Büyükçekmece and İstanbul Strait, with a 43.6 eggs/10 m^2 mean biomass. A common feature of all 3 areas is their proximity to freshwater input.

Between all sites, the prelarvae of sardine were only detected in station 18 (Karacabey Floodplain area). Postlarvae of sardine were observed in 6 of 32 stations, with a relatively low mean biomass (2.5 postlarvae/10 m^2). Postlarave distribution was also supported by the fish egg distribution data, which was closer to the shores of the freshwater input. When all 3 life phases were considered together, the main spawning area was seen as Karacabey Floodplain area, and Gönen Estuarine and Büyükçekmece estuarine areas were the other spawning sites of sardine in the Marmara Sea (Figure 2)

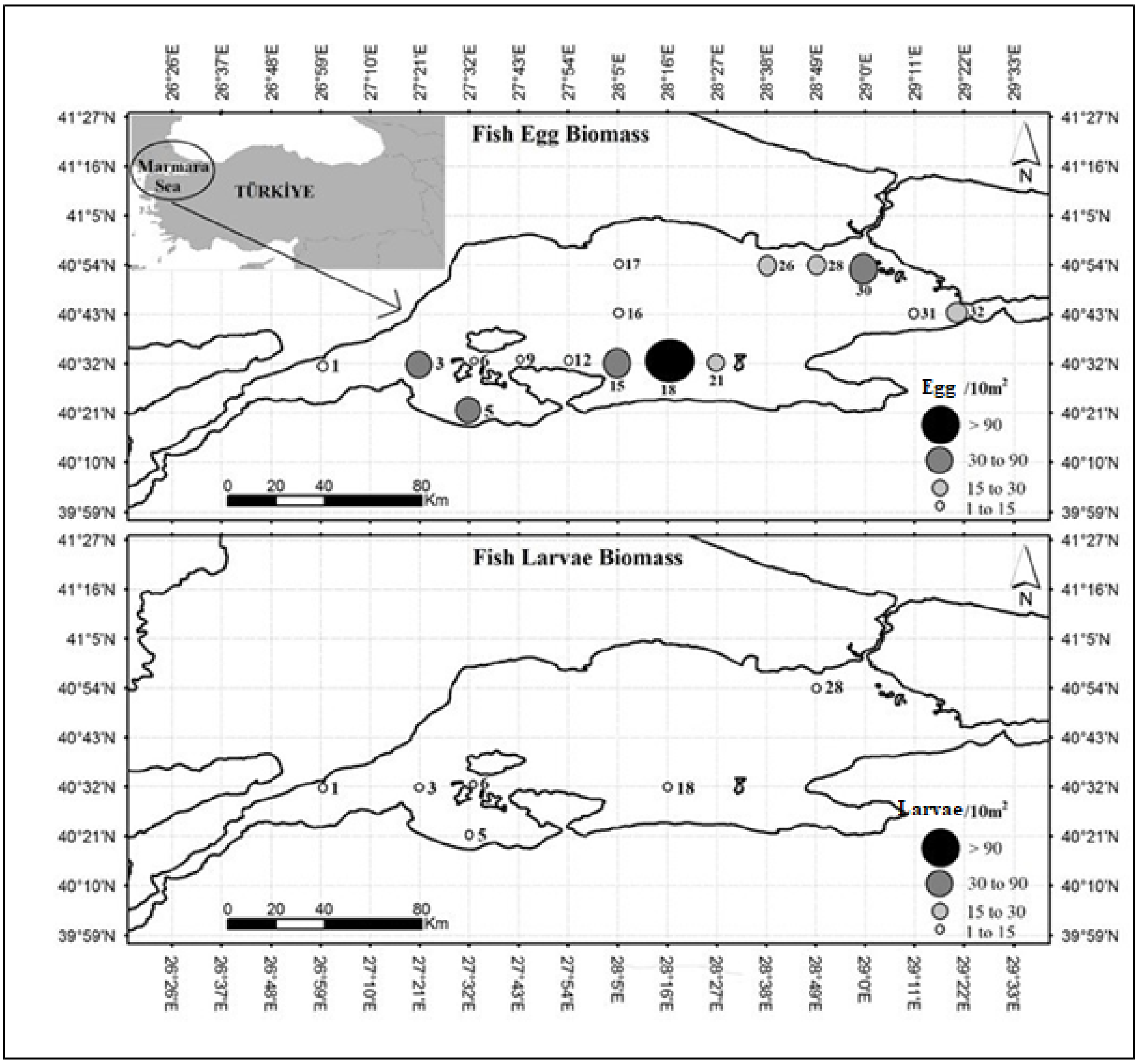

Figure 2. The spatial variation of sardine, *Sardina pilchardus* eggs, and larvae in the Marmara Sea, Türkiye

Stock size estimation

The parameters used for estimating spawning stock biomass such as mean female weight (W), batch fecundity (F), and sex ratio (R) were determined from the examination of adult sardine individuals. For this purpose, a total of 257 individuals were examined, and 114 of 257 individuals was detected as female. The remaining 128 individuals were male and 15 were not sexed due to damaged reproduction organs. The mean gonad-free body weight of mature females was calculated as 21.49 g. The sex ratio (R) in this study was calculated as 0.53. Yolk compact mass diameters in hydrated oocytes ranged between 395 µm and 935 µm with a mean of 695 ± 11 µm. The batch fecundity ranged between 2415.9 and 16738.3, with a mean of 6899.8 ± 255.7 eggs. The fish length-batch fecundity relationship was shown in Figure 3, and a linear relationship was detected.

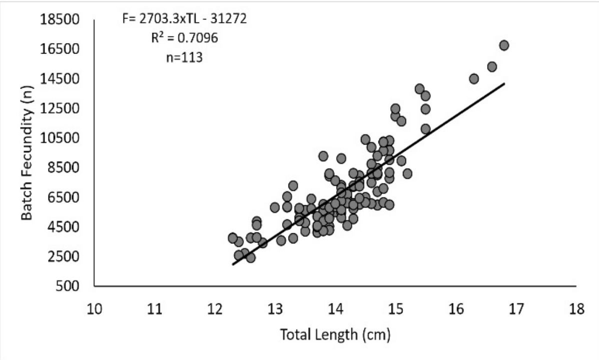

Figure 3. The fish length (TL) – batch fecundity (F) relationship of sardine, *Sardina pilchardus* in the Marmara Sea, Türkiye

15 of the 32 stations contained fish eggs and/or prelarvae, and were codded as positive areas. Thus, the total survey area (A) which is also referred to as the spawning area was detected as 5405 km^2. The spawning fraction (S) was calculated as 0.098.

The mortality rate is estimated from the slope of the mortality curve as 0.62 (Figure 4). Thus, the daily egg production (P_0) was estimated as 9.25 eggs/m^2 in the Marmara Sea. When the calculated R, A, W, F, S, and P_0 variables were substituted into the equation, the spawning stock biomass (B) was estimated as 2998 tonnes in the Marmara Sea.

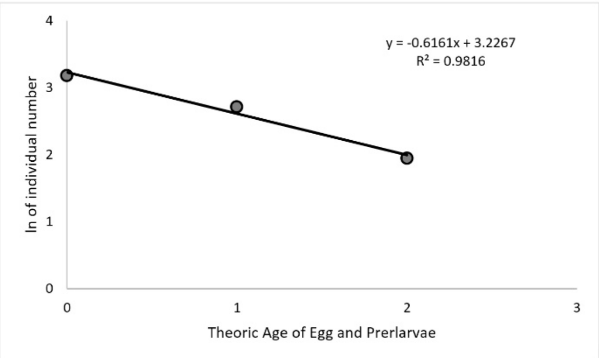

Figure 4. The mortality curve of sardine, *Sardina pilchardus*

DISCUSSION

The mean fish egg (18.4 ± 5.3 eggs/10 m^2) and larvae (2.5 larvae/10 m^2) biomass of sardine were detected relatively lower than the results of the previous studies. Kara (2015) found that the mean egg biomass in Erdek Bay was 166 eggs/10 m^2, and the highest mean egg biomass was calculated in October as 600 eggs/10 m^2. Daban (2013) stated that the mean sardine egg biomass was 118 eggs/10 m^2, with the highest mean egg biomass at 326 eggs/10 m^2 in February in the Çanakale Strait, Marmara Sea. Yüksek (1993) found only a single fish egg individual in the northeastern Marmara Sea (Büyükçekmece) and stated that this egg drifted with currents from the southwestern part to this area and was sampled accidentally. In the present study, it can be seen in Figure 2, except from Büyükçekmece and nearby areas, fish eggs and larvae of sardine were not found in the Northern part of the Marmara Sea. We detected both early life phases (egg, prelarvae, and postlarvae) of sardine in Büyükçekmece region. In addition, Daban et al. (2023) detected juvenile individuals of sardine around Büyükçekmece coasts with beach seine samplings. Thus, we thought that, Büyükçekmece region is one of the local spawning areas for sardine in the Sea of Marmara. According to our results, this situation was not related to sea water physico-chemical properties. As explained in the results section, the temperature, salinity, and dissolved oxygen values did not show statistical variations between the North and South parts of the Marmara Sea. Thus, the absence of Sardine in the northern part (except Büyükçekmece) could not be explained by physico-chemical properties. It may be associated with the spawning area selection of adults such as vicinity of estuarine areas.

In the same area, Alimoğlu (2002) detected the highest mean egg biomass of sardines in October as 180 eggs/10 m^2. In our study, although Büyükçekmece was the 3rd abundant area for sardine egg biomass, the mean value was determined as 43.6 eggs/10 m^2. As well, Karacabey Floodplain area, the most abundant area for sardine eggs in this study, had a lower mean value (130.7 eggs/10 m^2) than in previous studies. Also, relatively higher mean fish egg and larvae biomass values were reported from the Aegean Sea and Mediterranean Sea. The mean fish egg biomass in a unit area was found as 607 eggs/10 m^2 in Edremit Bay (Türker Çakır, 2004; Türker Çakır et al., 2008), as a 49 eggs/10 m^2 in the Sığacık Bay (Uygun and Hoşsucu, 2020), and as 40 eggs/10 m^2 in the Mersin Bay (Ak, 2004). It can be seen that the mean biomass was found lowest in the present study. Several parameters may have caused to occur these differences. In addition, a dense fishing effort by purse seiners on small pelagic fish species in the semi-enclosed basin, Marmara Sea can play a major role. As a result of the high fishing pressure, species become mature earlier than they should be. Thus, younger females generate smaller eggs and embryos, and the survival rate of these larvae faces trouble due to inadequate development in unfavorable conditions. Besides, the increasing pollution and resulting decreases in dissolved oxygen, and the changes in water temperatures due to global warming may cause changes in spawning areas.

The results of this study and previous ichthyoplankton studies from the Marmara Sea showed that the *S.pilchardus* spawning peaked in specific temperature intervals between 11°C and 16°C, and mostly centered upon 12-13°C. According to monthly sampling intervals, Daban (2013) detected that the spawning peaked at 11.8°C in February in the Dardanelles, whereas Kara (2015) found that it peaked at 12.3°C in October in the Erdek Bay. In the present study, the fish egg and larvae biomass decreased with the decrease of the sea surface temperature (SST) from 11.5°C in December to 7–8°C in February and March. Also, similar temperature intervals and spawning seasons were stated in the Aegean Sea. Sardine spawning peaked between 13-15°C in İzmir Bay (Hoşsucu, 1992), and 12.5-15.3°C in February in the Sığacık Bay (Uygun and Hoşsucu, 2020). Similar SST ranges were revealed also for the Bay of Biscay as between 12.5 and 15°C according to Sola et al. (1990) and 10-16°C according to Arbault and Lacroix (1977). The main factor that controls the spawning density was explained as SST for small pelagic fish species (Maynou et al., 2020; Peck et al., 2012). The results of sardine spawning pattern confirm this hypothesis. Whereas, more frequent sampling intervals should be applied for understanding temporal changes (Daban and İşmen, 2020).

The present study revealed the first results related to spatial variation of sardine eggs and larvae on a scale covering the entire Marmara Sea. Three main spawning areas were detected explicitly such as Karacabey Floodplain area, Büyükçekmece area, and the Gönen estuarine area, where all these are close to brackish waters. Whereas larvae of Sardine increased in Gönen estuarine area, Karabiga and Mürefte, where located western part of the Marmara Sea. In addition, both Daban et al. (2023) identified early juveniles of sardine as a school with beach seine in the Büyükçekmece and high fish egg and larvae biomass in the present study in this area supported the hypothesis that this area is a spawning location. Palomera et al. (2007) stated that estuarine areas are favorable for the growth of planktivorous small pelagic fish species due to carrying high nutrients through streams. Some authors stated that sardine avoid cloudy waters and lower saline waters and distributed off-shore areas rather than coastal areas (Olivar et al., 2003; Coombs et al., 2004; Santos et al., 2004). Conversely, Ramos et al. (2009) found relatively high sardine eggs and larvae around the Lima estuary during 2-year ichthyoplankton sampling and stated that the total ichthyoplankton biomass was dominated by sardine. When the results were compared, the outputs coincided with the findings of Palomera et al. (2007) and Ramos et al. (2009). As can be seen in Figure 2, the fish egg and larvae biomass is mostly concentrated around shallower areas rather than deeper waters. This may be a result of the instinct to be close to river input, accordingly nutrient and food. Somarakis et al. (2006) stated that sardines mostly prefer depths between 40 m and 90 m for spawn, and biomass is concentrated especially in zooplankton-rich areas in open water conditions in the Aegean Sea. Also, Zwolinski et al. (2006) determined the dense fish egg biomass around 40-60 meter depths between the Gulf of Cadiz and Algarve, Portugal, and stated the eggs distributed between 25 and 75 meters in the Sığacık Bay (Uygun and Hoşsucu, 2020). In the present study, the stations in which sardine fish egg and larvae biomass was higher (3, 5, 15, 18, and 30) were mostly located between 35 and 53 m depths. The depths deeper than 60 meters had relatively lower biomass values and the deepest center channel had not any sardine eggs and larvae. The results show similarities with the findings of Somarakis et al. (2006), Zwolinski et al. (2006), and Uygun and Hoşsucu (2020).

Roy et al. (1989) stated that sardine adapted their reproductive strategy to the coastal upwelling ecosystem of the Portuguese West coast to minimize Ekman offshore transport effects. Due to the two-layered stratification of the Marmara Sea, the Black Sea water flow discharges via the upper thermocline. It was thought that immobile and semi-mobile fish eggs and larvae could be transported from one place to another by this strong current. However the results of the spatial variation of sardine egg and larvae biomass did not reflect this situation and it was seen to be concentrated in 3 main regions, especially close to freshwater inlets. The absence of biomass in the middle deep water channel strengthened this finding. The coastal distribution of the sardine has aroused curiosity as to whether it is a strategy developed to be less affected by the Marmara Sea surface current. This issue generates another study issue, which should be considered together with physical oceanographers.

By means of the reproductive biology of sardine, several valuable works were realized in the Marmara Sea and the Aegean Sea. Taylan et al. (2019) were detected that the fecundity of sardine ranged between 4.600 and 9.800 eggs, with a mean of 6.110 ± 1.755, which closely similar to the findings of the presented study which fecundity estimated between 2.416 and 16.738, with a mean of 6.899 ± 255.7 eggs. A slightly higher fecundity in the present study may be a result of the higher length distribution of the adult females in the present study. Similarly, linear length-fecundity relationships were found in both two studies. Also, Cihangir (1995) stated that the lengths at first maturity of sardine were to be 12.0 cm for females and 12.7 cm for males in the Aegean Sea. As can be seen in Figure 3, all mature females examined for fecundity ranged between 12.4 and 16.8 cm in TL in the present study. This coincides with the findings of the authors. Also, the gonadosomatic index, which shows the spawning period of fish, peaked between December and February in İzmir Bay, when the STT values were lowest (Cihangir, 1996). Thus, it was understood that the adult reproductive characteristics coincide with the results of ichthyoplankton studies.

The estimation of spawning stock biomass by daily egg production method has been applied to lots of small pelagic fish stocks up to date, but it has not been applied sufficiently in Turkish waters. In a single study, the spawning stock biomass of anchovy, *Engraulis encrasicolus* estimated as 403.9 metric tonnes (mt) in the Edremit Bay, Aegean Sea by Taylan and Hoşsucu (2016).

The estimated value is relatively higher than our findings which calculated for sardine as 2998 tonnes (~3 mt). In terms of previous findings related sardine spawning stock biomass from adjacent seas or other seas, it was estimated as 134195 tonnes in Galicia, 33503 tonnes in western Cantabrian, and 12467 tonnes in the eastern Cantabrian (Garcia et al., 1992), 14196 tonnes in the Adriatic (Casavola et al., 1996), 5149 tonnes in the Ionian Sea (Somarakis et al., 2006), 16174 tonnes in the Aegean Sea (Somarakis et al., 2006). In both studies, the highest egg production took place between 20:00 and 24:00, during the day. When all previous findings were compared, the estimation of spawning stock size was close to the estimation of the Ionian Sea, and lower stock size was detected against all other areas. These differences may have arisen due to the long passage of time since previous studies were conducted. Besides, the increased fishing pressure in all these areas from the past to date may reveal variations in the spawning stock size of sardine in these areas.

The comparison with current studies may provide an opportunity to make more accurate comparisons. Nevertheless, it was stated that the spawning stock biomass showed variations among each survey area and over the years in the same areas. The fishing pressure on demersal fish stocks of the Marmara Sea has increased within the last 20 years (Daban et al., 2021). For these reasons, fisheries efforts verge upon the fisheries of small pelagic fish species in the Marmara Sea. In terms of fisheries of sardine in the Türkiye Seas, the highest pressure stemmed from purse seine net boats, which are fishing intensively in the winter period, when the sardine spawning occurs.

Sardine spawning occurs from October to May, and peaks in December and January. In Greece, sardine fishing in the North Aegean Sea with purse seining is banned between mid-December and the end of February (Stergiou et al., 1997). A similar short intermediate fishing ban should also be conducted by the Fisheries Management Authority of Türkiye.

CONCLUSION

The sustainability of these species becomes even more important for eutrophic seas such as the Marmara Sea due to they act as a bridge between the lower and upper food web. Hence, the studies related estimation of spawning stock size should be supported permanently and more efforts should be realised in varied local seas and varied small pelagic fish species such as *E. encrasicolus, S. pilchardus,* and *S. sprattus.* Additionally, the spawning season of these species should be monitored more closely, and seasonal fishing restrictions related to these should be revised more frequently by the fisheries management authority. Once continuous stock size information is obtained, quota application can be initiated on these species when necessary.

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AUTHOR CONTRIBUTIONS

İsmail Burak Daban: Writing-Original draft, data analyses, sampling. Yusuf Şen: Sampling, laboratory works, visualization, investigation. Ali İşmen, Ahsen Yüksek: Supervision, data-analyses. Uğur Özekinci, Fikret Çakır: Laboratuary works, visualization, investigation. Alkan Öztekin, Adnan Ayaz, Uğur Altınağaç, Tekin Demirkıran, Gençtan Erman Uğur, Oğuzhan Ayaz, Buminhan Burkay Selçuk: Sampling, laboratuary Works.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest or competing interests.

ETHICS APPROVAL

No specific ethical approval was necessary for this study.

DATA AVAILABILITY

For questions regarding datasets, the corresponding author should be contacted.

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