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Original research

Reproductive biology of female common sole, *Solea solea* (Linnaeus, 1758) in the southern Aegean Sea

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Abstract: In order to represent reproduction strategy of common sole (*Solea solea*), fishing operations were conducted between October 2013–November 2015 in Güllük Bay and Boğaziçi lagoon which are on the south-west coast of Turkey by using beach seine and trammel nets (52-56-64-80-90 mm mesh sizes). Ovulation type, fecundity and gonadosomatic index were determined. Additionally, gonadal sectioning was performed to determine oocyte development stages, followed by asynchronous ovulation in egg production strategy. Fecundity varied from 13.924 to 341.479. It is observed that a linear correlation between total length and fecundity. Length at first maturity was determined as 15.4 cm.

Keywords: Fecundity, Gonadosomatic index, Aegean Sea, Common sole, Reproduction biology

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Introduction

Soles (*Solea* spp.) are under heavy exploitation all round the world due to their high commercial value (Teixeira, 2007). Among these sole species, common sole *Solea solea* (Linnaeus, 1758) is one of the most valuable commercial species in different parts of the world (Bolle et al., 2012; Seafish, 2013; Diopere et al., 2014; Saleh et al., 2016). Due to its considerably high economic value, common sole is a target species, especially in small-scale and demersal trawl fishery in Turkey (Türkmen, 2003).

Shafi (2012) mentioned the importance of fecundity of fish stocks that affects fish production, stock recruitment and stock management. Beside the fecundity, like in several studies, Gonadosomatic Index (GSI) is a valuable data to make fisheries management strategies or suggestions (in terms of seasonal closures).

Different researchers have determined biological information of many species up to now. But limited knowledge exists on soles biology and the exploitation status of their stocks for different regions (Teixeira, 2007). In Turkey, a few studies were carried out on biology and fishery management but they are not successive or in the same region. Three different water bodies surround Turkey-*Mediterranean, Aegean Sea and Black Sea*- and they have distinctive physical features. So, preliminarily, this variation of distinctive physical features prompts us to learn about reproduction of common sole. This study provides some data about reproduction of common sole in Turkish marine waters and also could be useful for future common sole culture implementations in Turkey.

Materials and Methods

Güllük Bay is an important region for Turkish fishery. Aquaculture systems, industrial and small scale fisheries are present, where many different species are caught from this region. Study area was chosen due to constant small-scale fishery, involving species-specific different fishing nets and being one of the most important common sole fishery area.

Fishing operations were conducted monthly between October 2013-November 2015 in Güllük Bay and Boğaziçi lagoon which are on the south-west coast of Turkey (Fig 1). Beach seine and PA (polyamide) trammel nets with different mesh sizes (52-56-64-80-90 mm) were used to obtain various length classes. Depths changed between 0.5 m and 70 m. Samples were brought to the laboratory in ice. To determine the oocyte diameters and fecundities of females according to total lengths, 30 individuals were chosen among 607 females and measured total lengths to the nearest 0.1 cm. Sex were determined by macroscopic examination of the gonads. Total lengths of our samples were changed between 15.6-30.4 cm (two or three individuals for each examination).

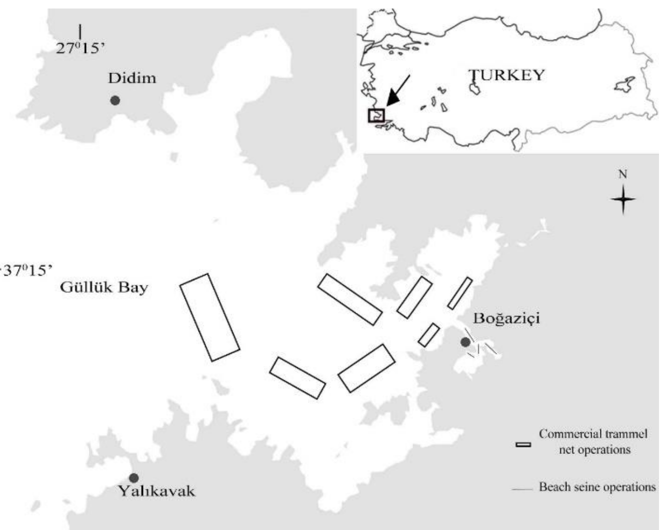

Figure 1. Study area

All female gonads were preserved in *Neutral Buffered Formaldehyde*. This solution was preferred due to its pH (6.8) and to avoid shape deformities of gonads and oocytes while preserving and sectioning processes.

Gonads were subjected to some processes before embedding in paraffin (Culling, 1963). 5 µm sections were taken from paraffin blocks. Sections were stained with hematoxylin and eosin. Samples were scanned under light microscope after staining.

Egg development stages were identified according to Garcia-lopez et al. (2007); 1; Oogonia, 2; Chromatin nucleolar, 3; Early perinucleolus, 4; Late perinucleolus, 5; Cortical alveoli, 6; Early vitellogenic, 7; Late vitellogenic, 8; Early maturation stages.

Among entire female individuals (607), fecundity, oocyte diameter and ovulation type were determined under Olympus szx16 micrometric binocular microscope with 10x zoom. Oocyte diameters were measured within 0.1 mm. Subsamples presents the 10% of total gonad weight. Both whole gonad and subsamples were weighed nearest 0.0001 mg. Oocyte numbers were counted then fecundity was calculated with (Hunter et al.,1985);

$$F = \frac{N \times GW}{SW}$$

Where; F is fecundity, N is total number of oocyte in subsample, GW is gonad weight and SW is sample weight.

Rstudio was used to determine statistical relationship (Pearson's Correlation) between total lengths, mean oocyte diameters, previtellogenic oocyte diameters, vitellogenic oocyte diameters and ripe oocyte diameters. Calculated values were compared with r values; r<2- too low or no correlation, 0.2-0.4- low correlation, 0.4-0.6- moderate correlation, 0.6-0.8- high correlation, 0.8>- too high correlation.

Gonadosomatic Index (GSI) was calculated from gonad and body weights that belong to 607 females. GSI is a ratio between the gonad weights (GW) and body weight (BW) without stomach weight (before weighing of body, stomach and intestines were extracted) (Mehanna, 2014).

$$GSI = \left(GW / BW\right) \times 100$$

Holden and Raitt (1974) maturation scale was used to determine length at maturity (Lm). According to the scale, maturing stages were described as stage 1: immature, stage 2: maturing virgin and recovering spent, stage 3: ripening, stage 4: ripe, stage 5: spent individual.

Results

In analysing of samples, 12 of individuals' oocyte diameters were not determined due to having too small oocytes (<0.1 mm). Total lengths of females (in oocyte diameter examination) varied between 19.7 and 30.4 cm, oocyte diameters were determined between 0.12 and 0.97 mm. Also, fecundities differed between 13.924 and 341.479, in number (Table 1).

In the present case, total length and mean oocyte diameter have high, total length and previtollogenic oocyte have moderate, total length and vitellogenic oocyte diameter have moderate, total length and ripe oocyte diameter have high and total length and fecundity have moderate correlation. Accordingly, it was determined that there is a linear correlation between total length and fecundity (Fig 2). In spite of a continuous egg production strategy, common sole shows asynchronous ovulation. So, oocyte production strategy, which is asynchronous ovulation, is closed by synchronic ovulation. Oocyte development of some females according to different total lengths were given in Fig 3.

Table 1. Values of mean oocyte diameter, previtellogenic oocyte diameter, large oocyte diameter, ripe oocyte diameter and fecundity of *Solea solea*

Total Length (cm)	Mean oocyte dia. (mm)	Previtellogenic oocyte dia. (mm)	Large oocyte dia. (mm)	Ripe oocyte dia. (mm)	Fecundity (Num.)
19.7	0.1224	0.1224	-	-	13924
22.2	0.3716	0.2512	0.5747	-	18085
22.2	0.2022	0.1493	0.5827	-	37421
23.7	0.3746	0.2133	0.5749	-	41490
23.8	0.1497	0.1497	-	-	5929
24.9	0.4864	0.2944	0.5957	0.80	36205
24.9	0.4833	0.3390	0.5575	0.80	22566
25.8	0.3291	0.1965	0.5740	0.80	79014
25.8	0.3196	0.2152	0.5389	-	75812
26.0	0.2969	0.2167	0.5636	0.80	119899
26.1	0.2475	0.1529	0.5493	-	152416
26.5	0.4473	0.2615	0.5781	0.97	59406
27.0	0.2907	0.1869	0.5319	-	104734
28.1	0.5560	0.3591	0.5944	0.82	71245
28.4	0.4384	0.2095	0.5834	0.80	341479
29.3	0.4156	0.2486	0.5693	0.80	119882
29.4	0.4042	0.2625	0.5765	0.80	58958
30.4	0.4741	0.2442	0.5732	0.80	87398
Correlation between Total Length	0.6223	0.4395	0.5214	0.6391	0.5187

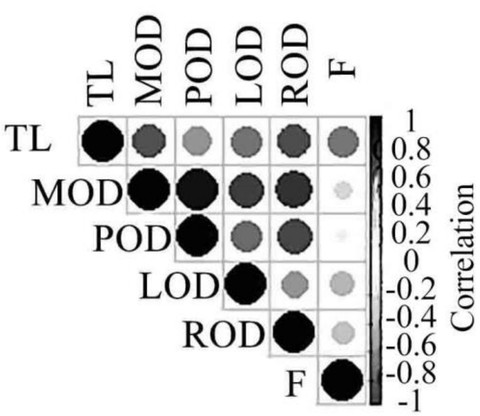

Figure 2. Correlation between; TL; total length, MOD; mean oocyte diameter, POD; previtellogenic oocyte diameter, LOD; Large oocyte diameter, ROD; Ripe oocyte diameter and F; fecundity of *Solea solea*

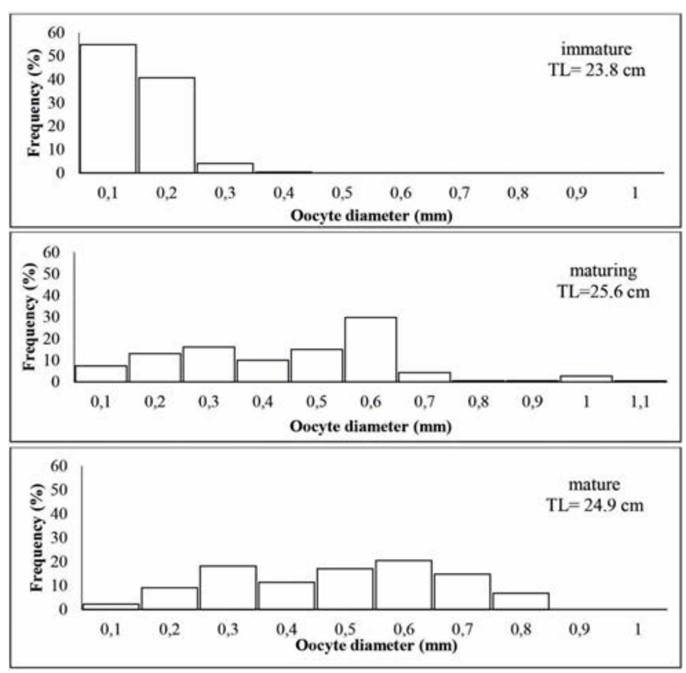

Figure 3. Oocyte diameter-frequency distribution of *Solea solea* (TL; Total length)

Also, different oocyte development stages were observed in common sole gonads (Fig 4). This shows indeterminate spawning in common sole and GSI values prove prolonged spawning season in one year (Fig 5). Length at first maturity (L_m) was determined as 15.4 cm for females.

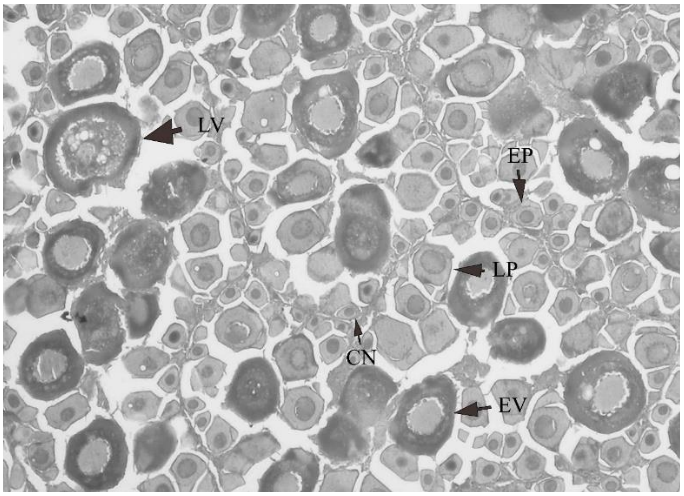

Figure 4. Egg development phases of *Solea solea*; EP: Early perinucleolar, LV: Late vitellogenic, CN; Chromatin nucleolar, LP: Late perinukleolus, EV: Early vitellogenic

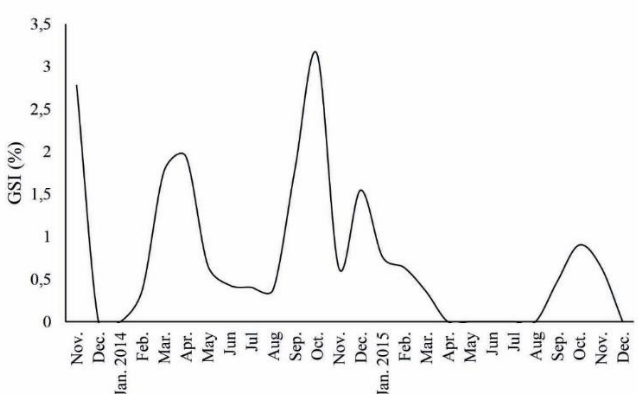

Figure 5. Monthly variation of GSI in female *Solea solea*

Discussion

Having information about reproductive features of a commercial species is crucial for sustainable fish stock management or aquaculture implementations. Reproduction data of a fish species is very useful to sustain fish stocks or to use as an alternative to available aquaculture species.

Turkey is a sub-tropic region, where common sole behaviours could be different rather than northern populations. Ganias et al. (2015) mentioned that to know about phenotypic plasticity in fecundity type, relationship of oocyte growth rate and duration of spawning season is crucial. According to their study, sub-polar populations show slow oocyte growth and determinate fecundity, Sub-tropic and tropic populations show high oocyte growth and indeterminate fecundity. On the other hand, Miller et al. (1991) mentioned that flatfish species which have a distribution on high latitudes, have long growth period and low *k* growth parameter but at lower latitudes have a reverse situation. On this subject, Abookire and Macewicz (2003) found that dover sole (*Microstomus pacificus*) populations from northern latitudes become mature at larger sizes than southern. This is a clear evidence of effect of latitudinal changes on maturation size. In this study, correlation between total length and fecundity was found positive with each other i.e. increasing in total length means increasing in fecundity. According to the latitudinal changes, fecundity in our study and other studies seems to be a little different. However, this situation may be associated with differences between total lengths (Table 2).

Table 2. Changes in *Solea solea* fecundities according to latitudinal changes

Region	Latitude	Longitude	Total Length (cm)	Fecundity	Author/s
German Bight	54 N	5 E	35	440.000	Witthames et al. (1995)
Bristol Channel (England)	51 N	5 W	35	221.000	Horwood and Greer-Walker (1990)
Diouarnenez Bay (France)	48 N	4 W	35	218.000	Deniel (1981)
Portugal	38 N	9 W	35	205.000	Witthames et al. (1995)
Güllük Bay	37 N	27 W	30.4	87.000	This study

Observed female gonads of common sole didn't show a strong asynchronous ovulation. But, in view of eggs with different diameters in mature individuals' gonads, spawning of common sole can be thought as it has several batches in spawning season. Besides, in relation to prolonged spawning season, recent climatic changes may affect the duration of the spawning season. So, spawning seasons should be monitored in every fishing season to maintain the sustainable common sole stocks.

Moreover, there is considerable study about flatfish spawning in different times of a year. Anguis and Canavate (2005) controlled the spawning period of captive Senegal sole (*Solea senegalensis*) in facilities. In this experiment, they made a fluctuation in temperature regime and as a consequence the Senegal sole spawned in two different periods in a year. Similarly, these experiments could be implemented on common sole and this species may be used for alternative species in aquaculture.

All region is affected with starting of tropicalisation in Mediterranean (Zaitsev and Öztürk 2001). As is known, water temperature is one of the most important parameters in marine species. With shift in climate and in parallel with changes in other environmental parameters, organisms respond with physiologic and behavioural adaptations. Thus, they may adapt or acclimatize to new conditions. Effects of temperature could be observed as earlier spawning period than normal in many species (Otero et al., 2013). In flatfishes, spawning or feeding are arranged by water temperature like spawning migration (Sims et al., 2004; Rijnsdorp et al., 2015; Gibson et al., 2015). In this study, GSI values differ year by year. Turkish State Meteorological Service (2018) analysed the changes in Aegean Sea water temperature from 1970 to 2017. Water temperature was 18.2 ˚C in 1970 and it raised up to 19 ˚C in 2017. Although 0.8 ˚C seems to be a low value, differentiation in GSI values may be the effect of this warming.

On the Turkish coasts of Mediterranean Sea, different length at first maturity (Lm) values were presented by some researchers (Table 3). Length at first maturity values of Türkmen (2003) and the present study are close to each other. Similarly, these values were found as 15.87 and 15.31 cm for females and males by Mehanna (2015), respectively. As it is known, *Solea solea* is a partial spawner. Ersönmez and Özyurt (2018) separated their common sole individuals as “mature” and “immature”. In Türkmen (2003), gonad stages were classified in 6 stages (stage 0, immature; stage 1, resting; stage 2, developing; stage 3, ripe; stage 4, running; stage 5, spent; stage 6, recovering). In this study, gonad stages were determined with fivefold scale. Differences in length at first maturity values may be methodology originated.

Consequently, especially reproduction biology of commercial species and climatic changes should be monitored. In the light of these observations, species behaviours may be guessed (like spawning season etc.). Thus, we can implement proper fishery management.

Table 3. Length at first maturity (Lm) values of *Solea solea* on the Mediterranean coasts

Region	Length at First Maturity (cm)		Author/s
	♀	♂	
Iskenderun Bay, Turkey	15.87	15.31	Türkmen (2003)
Bardawil lagoon, Egypt	15.2	14.8	Mehenna et al. (2015)
Iskenderun Bay, Turkey	26.37	19.77	Ersönmez and Özyurt (2018)
Güllük Bay	15.4		Present Study

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