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Growth pattern, mortality and reproductive biology of common sole, *Solea solea* (Linneaus, 1758), in the Sea of Marmara, Turkey

by

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Abstract

The study deals with the growth pattern, mortality, and reproduction of common sole, *Solea solea* (Linneaus, 1758), from the Sea of Marmara (Turkey). A total of 580 fish specimens were sampled monthly from October 2017 to September 2018. The total length of all sampled individuals ranged from 11.1 to 29.5 cm, corresponding to ages from 1 to 3 years. The length–weight relationship was expressed as $W = 0.022\ TL^{2.6838}$, where the slope indicated negative allometric growth. Growth parameters were $L_{\infty} = 33.7$ cm, $k = 0.48$, and $t_0 = -0.18$ for all samples. A seasonally oscillating growth model, indicating the amplitude of oscillations, revealed an important seasonal growth pattern. Total, natural, and fishing mortality rates were calculated as 1.42, 0.47, and 1.01, respectively. The exploitation ratio (E = 0.68) indicates that the fishing pressure on the common sole in the Sea of Marmara was high. The sex ratio (♀/♂) was 1.18. The gonadosomatic index (GSI) for females showed that two main spawning seasons were observed: one in spring (May) and one in autumn (September–October). Sizes at the onset of sexual maturity were estimated for both females and males at 21.6 and 18.6 cm, respectively.

Key words: *Solea solea*, growth, mortality, reproductive biology, Sea of Marmara

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1. Introduction

The common sole, *Solea solea* (Linnaeus, 1758), is a commercially important benthic species that occurs commonly in the eastern Atlantic, from southern Norway to Senegal, and in the Mediterranean Sea, including the Sea of Marmara and the southwestern Black Sea (Carpentier et al. 2009). *S. solea* is a strongly compressed flatfish with eyes and snout on the right side of the body. It is oval with a rounded head and can grow up to 70 cm in length, but usually reaches 30–40 cm. Depending on the substrate, the color of the sole can vary between gray, reddish brown and gray-brown with dark blotches (Reeve 2007).

The global capture production of common sole in 2016 was about 32 057 t (FAO 2020). Common sole landings in the Mediterranean Basin amounted to 5227.5 t in 2018 (GFCM 2020). Total landings of common sole in Turkey have dramatically declined in recent years from approximately 1000 t in 2010 to < 500 t in 2019 (TÜİK 2020). Knowledge of the age, growth and reproduction of any species is of great importance for achieving good environmental status and management strategies. Several studies on the age–growth and spawning characteristics of the common sole have been conducted in different regions in recent years (Slastenenko 1956; Nielsen 1972; Quéro et al. 1986; Hoşsucu et al. 1999; Muus & Nielsen 1999; Vallisneri et al. 2000; Cerim & Ateş 2019). On the other hand, there is only one not very recent PhD study on the general biological characteristics of this species in the Sea of Marmara (Oral 1996).

In the Sea of Marmara, the common sole is primarily caught by beam trawls and set gillnets, because bottom trawling has been completely banned for a long time. On the other hand, it is obvious that the existing management policies and strategies (seasonal closures and minimum landing size) have failed to protect critical nursery and spawning areas for many fish species, including the common sole. In addition, these management practices are outdated and ignore region-specific details regarding sexual maturity and reproductive patterns of this species. Estimation of demographic parameters of fish populations, particularly their growth, mortality and spawning rates, is essential for assessing population dynamics and management of fishery resources (Newman & Dunk 2003). After a comprehensive review of the relevant literature, it can be concluded that the material available for this study is extremely scarce. The declining trend in landings further indicates the urgency and necessity for research on common sole. Therefore, the objective of this study was to determine the growth characteristics of the common sole in the Sea of Marmara based on sagittal otolith readings, fish length at the onset of sexual maturity (L_m) and spawning season.

2. Materials and methods

Common sole specimens were randomly collected monthly from the Sea of Marmara by commercial fishermen using beam trawls and trammel nets between October 2017 and September 2018. Total length (TL, cm) and total wet weight (TW, g) were recorded for each specimen. Sex was determined macroscopically as male, female and immature (or unidentified). Pairs of "sagittal" otoliths were extracted for age assessment and ground on both sides with two abrasive papers of 35.0 µm and 25.8 µm, respectively. They were then cleaned in distilled water and immersed in glycerin for the age estimation process and viewed using an image analysis system with a circular reflected light source (Leica DFC295 stereomicroscope). For age estimation, annual growth rings on otoliths were evaluated by three experienced age readers, and agreement rates between them were 90–95%. Annuli were counted from the core outward. Each annulus was defined as the location where the opaque zone meets the translucent zone.

The length–weight relationship was determined using the equation $TW = a\ TL^b$ (Ricker, 1973). In addition, the parameter *b* was compared for significant differences between sexes using analysis of covariance, ANCOVA (Zar 1999). Growth was analyzed by fitting the typical parameterization of the von Bertalanffy (1938) growth equation, $L_t = L_\infty [1 - e^{-k(t - t0)}]$ (Sparre & Venema 1992), where L_t is the total length at age *t*, *k* is the growth coefficient, L_∞ is the asymptotic length, and t_0 is the theoretical age at length zero. Electronic Length Frequency Analysis (ELEFAN) with a genetic algorithm was also used to estimate growth parameters and total mortality rate (Mildenberger et al. 2017). For this purpose, length frequency data were binned into 1 cm size classes. The growth performance index (Φ′) was also estimated according to Pauly & Munro (1984).

Total instantaneous mortality (*Z*) was estimated using the linearized length converted catch curve described by Pauly & Munro (1984) and implemented in the TropfishR package (Mildenberger et al. 2017). For natural mortality, the most recent formula was applied, which requires parameters (L_{inf} and *k*) of the von Bertalanffy growth equation (Then et al. 2015). The fishing mortality rate (*F*) was calculated as $F = Z - M$. Exploitation rate ($E = F/Z$) values were compared with an index proposed by Gulland (1971) to characterize the stock as either underexploited, optimal, or overexploited.

The gonads were dissected and then weighed (GW). Each specimen was macroscopically assigned to a gonadal stage on the basis of a scale consisting of five maturity phases: immature (phase I), developing or regenerating (phase II), spawning capable (phase III), actively spawning (phase IV), and regressing (phase V; Brown-Peterson et al. 2011). To corroborate the macroscopic classification of females, all ovaries were used for histological analysis; specifically, a subsample of an approximately 1.0 cm wide section from the central part of the ovary was preserved in 10% buffered formalin. Tissue sections were washed in a buffer solution, dehydrated in ethanol and *n*-butanol series, and embedded in paraffin, and then 5 µ sections were cut with a microtome and mounted on slides. The sections were stained with haematoxylin-eosin and then examined under a light microscope.

Immature (phase I) ovaries contained oocytes in the primary growth phase and a thin ovarian wall (PG). Oocytes of developing ovaries (phase II) showed the initiation of the secondary growth phase with the formation of cortical alveoli (CA). Entry into the spawning capable phase was characterized by the appearance of Vtg3 oocytes and the actively spawning phase can be used to identify fish that are progressing through germinal vesicle breakdown (GVBD) or hydration. The regressing phase was identified by the presence of oocyte atresia, a reduced number of vitellogenic oocytes, and, in some specimens, postovulatory follicles (POF). The regenerating phase was distinguished from the immature phase by: (i) a thicker ovarian wall (OW), (ii) the presence of more space, interstitial tissue, and capillaries around PG oocytes, and (iii) the presence of muscle bundles (Brown-Peterson et al. 2011).

To determine the spawning season, the gonadosomatic index (*GSI*) and the condition factor were calculated as $GSI = [GW/TW] * 100$ and $CF = [TW - GW / TL^3] * 100$, respectively. The overall sex ratio (♂/♀) was calculated and tested using the Chi-square test (Sümbüloğlu & Sümbüloğlu 2005). Length at first maturity (L_m) was defined as the length at which 50% of specimens had already spawned at least once, and was calculated by including individuals with gonadal phases higher than phase II. L_m was estimated for both sexes using a logistic function that was fitted to the proportion of sexually mature individuals by each size class using a nonlinear regression following King's (1995) formula:

$$P = \frac{1}{1 + exp[-r(L - L_m)]}$$

where *P* is the proportion of mature individuals in each size class, and *r* (–*b* slope) is a parameter controlling the slope of the curve (Saila et al. 1988). For this calculation, the sizeMat package (Torrejon-Magallanes 2020) was employed in R programming. Markov Chain Monte Carlo was used for logistic regression (Bayes GLM), which generates a sample from the posterior distribution of a logistic regression model using a random walk Metropolis algorithm.

3. Results

A total of 580 individuals of common sole were measured monthly throughout the year. Total length of all specimens varied from 11.1 to 29.5 cm (mean length 20.91 ± 3.62 cm). No statistically significant differences ($p > 0.05$) in mean length were found between males and females (Fig. 1). Length–weight relationship values for all samples are shown in Table 1. The ANCOVA test indicated that there were no significant differences between the slopes (*b*) estimated for females and males. All relationships were highly significant ($p < 0.001$).

Length-at-age values and the number of individuals in each age class are presented in Table 2. The estimated age ranged from 1 to 3 years, with age class 2 being the most abundant one (52.3%). Females reached a maximum size of 35.8 cm, which is 4 cm larger than males (31.3 cm). This indicates that females grew slightly faster than males (Table 3). In addition, growth parameters for all individuals were calculated for pooled data according to the ELEFAN method and found to be $L_\infty = 36.08$, $k = 0.26$, $C = 0.42$ (Fig. 2). The obtained *C* value indicates that the growth characteristics of the sole in the Sea of Marmara fluctuate considerably during the year. The length-converted catch curve showed that the total mortality rate (*Z*) was 1.42 year^{-1}. The natural (*M*) and fishing (*F*) mortality rates were calculated as 0.47 and 1.01, respectively. In addition, the exploration ratio (*E*) was calculated as 0.68.

Table 1

Parameters of the length–weight relationship ($W = a\,TL^b$) for all samples, females (F), males (M) and unidentified specimens of *S. solea*

	a	*b*	R^2	Growth type
Pooled	0.022	2.6838	0.9456	Negative Allometric
F	0.0349	2.5536	0.9032	
M	0.0253	2.6235	0.934	
Unidentified	0.0201	2.7179	0.941	

Table 2

Length-at-age key for all samples of *S. solea* based on otolith age readings

Length class (cm)	Age (years)			Total
	1	2	3	
11	6			6
12	9			9
13	18			18
14	16			16
15	13			13
16	10			10
17	3			3
18	5	3		8
19		16		16
20		38		38
21		77		77
22		111		111
23		52	29	81
24			67	67
25			47	47
26			19	19
27			15	15
28			9	9
29			4	4
Total	80	297	190	567

Table 3

Von Bertalanffy growth parameters calculated for *S. solea*

Sex	N	K	t_o	L_∞
Pooled	580	0.48	−0.18	33.7
F	248	0.37	−0.49	35.8
M	294	0.57	0.03	31.3

Of all collected specimens, 248 specimens (64%) were females with an average length of 23.5 ± 2.08 cm, ranging from 12.6 to 29.5 cm, and 294 specimens (36%) were males with an average length of 22.7 ± 2.92 cm, ranging from 11.8 cm to 27.8 cm. The sex ratio (♂/♀) was 1.18, and was statistically significantly different from the ratio of 1:1 ($p < 0.05$), indicating that males dominated. The gonadosomatic index (*GSI*) values calculated monthly for both sexes are shown in Figure 3. In general, the *GSI* values increased markedly both in late spring and autumn, when the cycle of gonadal development was initiated in the ovaries by increasing their weight. We found that *GSI* values peaked in May, September and October, and reached the maximum level in May. In addition, the condition factor (*CF*)

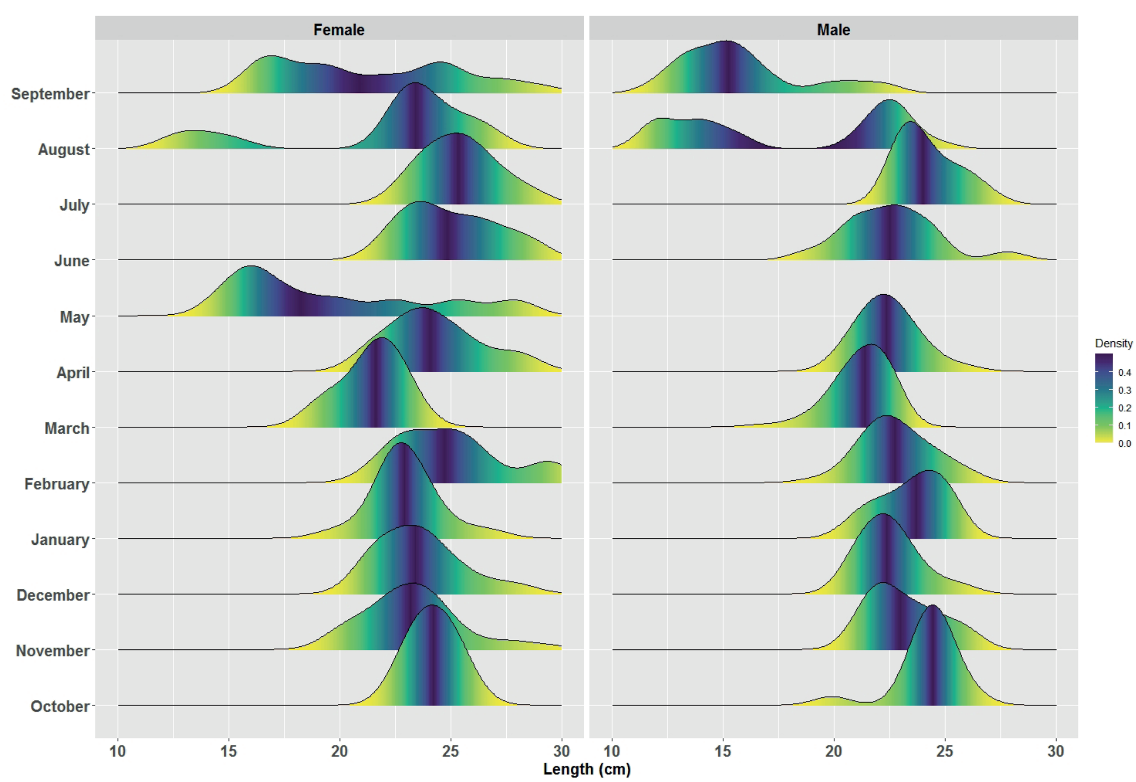

Figure 1

Monthly length–frequency distribution for females and males of *S. solea*

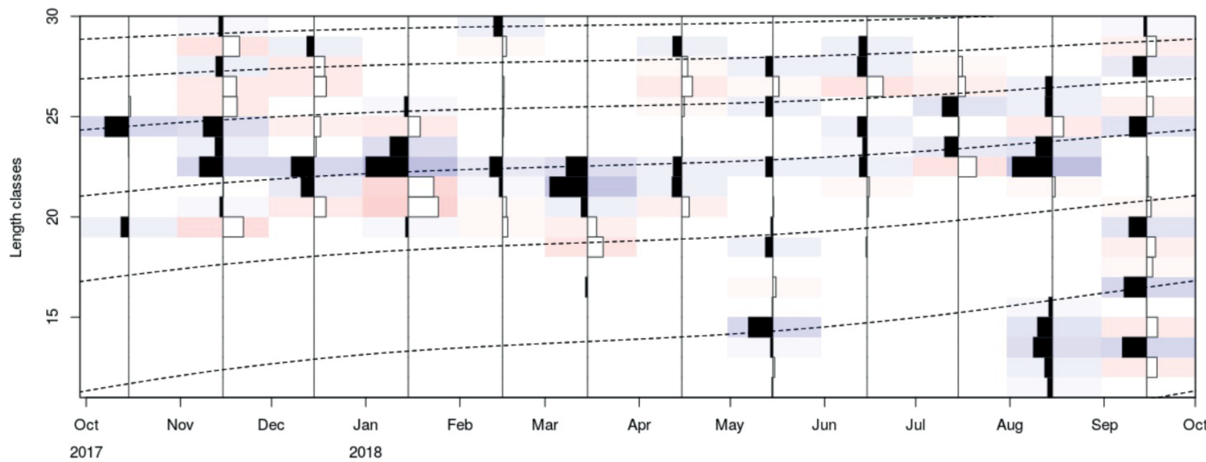

Figure 2

Seasonally oscillating growth curve generated from length–frequency distribution for *S. solea*

values calculated for both sexes are presented in Figure 3. As the *GSI* increased, so did the *CF,* especially in May, September and October, indicating a positive correlation between *CF* and *GSI* values.

Four different developmental phases of common sole oocytes were identified in this study (Fig. 4), with 71 females collected in May–June and October–November being sexually mature (phases III, IV, and V) and almost all of them being larger than 21 cm. On the other hand, virgin specimens were common during nearly all months. Post-spawning oocytes were first noticed in June–July and December. These findings showed that the spawning activity of the common sole occurs at the end of autumn and spring. In addition, estimates of L_m for females and males were calculated and were 21.5 cm and 18.6 cm, respectively (Fig. 5). The upper and lower 95% CIs were 21.1–22 cm for females and 17.7–19.1 cm for males. Micrographs of gonadal cross-sections showed that ovaries of spawning females contained oocytes in different developmental phases, and thus this species in the study area demonstrated 'asynchronous' ovarian development with multiple spawning events.

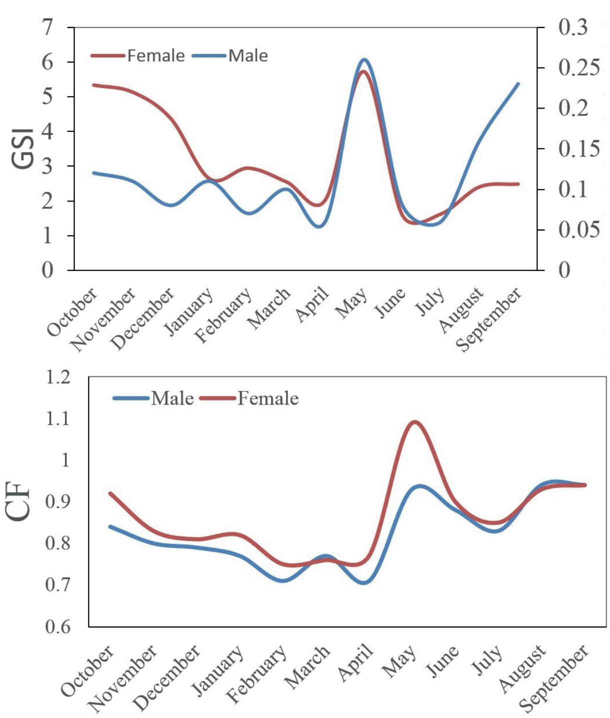

Figure 3

Monthly changes in the mean gonadosomatic index (GSI) and condition factor (CF) by sex of *S. solea* from the Sea of Marmara

4. Discussion

The present study shows the age composition, growth, and mortality of common sole from the Sea of Marmara. The first attempt at histological analysis of oocyte development and other reproductive aspects of the common sole from the Sea of Marmara are also presented here.

The length range of specimens examined in our study (Table 4) was generally similar to that found in other studies carried out in the Eastern Mediterranean Sea. In addition, we found that the *a* and *b* values estimated in this study are similar to the results obtained by Oral (1996) from the Sea of Marmara, and we did not find any outliers when parameter *b* was plotted against *log a* values.

Table 5 shows the age and growth parameters of common sole obtained by several researches. The growth parameters (L_∞, k, t_0, and Φ') from the present

Table 4

Length–weight relationships for *S. solea* in different areas

a	*b*	Sex	Length (cm)	Length	R^2	N	Locality	References
Eastern Atlantic								
0.005	3.20	M + F	10.0–42.0	–	0.975	334	North Sea	Froese & Sampang 2013
0.0071	3.095	M + F	21.0–43.0	TL	0.954	325	North Sea coast of Germany	Duncker 1923
0.0048	3.175	M + F	2.0–59.0	TL	0.998	5804	Bay of Biscay	Dorel 1986
0.0039	3.264	M + F	3.0–49.0	TL	1.000	3,799	East and West Channel	Dorel 1986
0.0036	3.313	M + F	11.0–29.0	TL	–	13	German Bight & Clyde	Coull et al. 1989
0.0046	3.21	M + F	–	–	–	518	Douarnenez Bay, Brittany	Deniel 1984
0.004	3.251	M + F	9.0–49.0	TL	–	945	North–eastern Atlantic	Mahé et al. 2018
0.0078	3.08	M + F	10.5–38.9	TL	0.969	–	Arade Estuary, Central Algarve	Veiga et al. 2009
0.0071	3.092	M + F	20.5–46.0	TL	0.908	58	Nazaré to St André	Mendes et al. 2004
Central and Western Mediterranean Sea								
0.0086	2.99	F	–	TL	–	–	Gulf of Lion	Campillo 1992
0.0109	2.94	M	–	TL	–	–		
0.0062	3.04	M + F	5.0–45.0	TL	0.980	561	Gulf of Lion	Vianet et al. 1989
0.0106	3.062	M + F	6.5–25.0	SL	0.981	82	Acquitina, Italy	Maci et al. 2009
0.0019	3.453	M + F	19.8–32.5	TL	0.946	2,130	Northern Adriatic	Dulčić & Glamuzina 2006
0.01	2.96	M + F	15.0–45.0	TL	0.932	406	French Catalan Coast	Crec'hriou et al. 2013
Eastern Mediterranean Sea								
0.049	2.35	Juvenile	11.2–24.4	TL	0.980	13	Iskenderun Bay	Gökçe et al. 2010
0.0117	2.988	M	8.8–25.0	TL	0.922	550	Iskenderun Bay	Türkmen 2003
0.0091	3.077	F	10.5–28.2	TL	0.947	533		
Aegean Sea								
0.0098	3.002	Juvenile	11.0–22.1	TL	0.988	21	Porto-Lagos	Koutrakis & Tsikliras 2003
0.0023	3.369	M + F	18.6–33.7	TL	0.920	171	Aegean Sea	Bilge et al. 2014
0.0088	3.024	M	3.1–29.0	TL	0.9925	529	Güllük Bay	Cerim 2017
0.007	3.1013	F	7.1–37.0	TL	0.9866	607		
Sea of Marmara								
0.0043	3.171	Juvenile	6.9–16.0	TL	0.928	55	Sea of Marmara	Bök et al. 2011
0.0183	2.727	M	13.0–27.0	TL	–	206	Sea of Marmara	Oral 1996
0.0011	3.674	F	13.0–34.0	TL	–	218		
0.0253	2.6235	M	11.8–27.8	TL	0.9	294	Sea of Marmara	This study
0.0349	2.5536	F	12.6–29.5	TL	0.934	248		

study were compared with the results obtained by other authors from Greece, Italy, the Netherlands, Denmark, and Turkey. Asymptotic length (L_∞) obtained in our study (Table 6) is quite similar to that reported in studies from Dutch ports (De Veen 1976), the Tyrrhenian Sea (Wurtz & Matricardi 2020), the North Sea (Nielsen 1972), and Adriatic Sea (Froglia & Giannetti 1985). Furthermore, similar to the above-mentioned studies, our L_∞ value for females (37.2 cm) was relatively higher than the value for males (35.4 cm), indicating that males grow relatively faster than females. The growth performance index (Φ') obtained in this study was similar to that obtained in other studies carried out in the North Sea (Beverton & Holt 1959; Nielsen 1972), in the Tyrrhenian Sea (Wurtz & Matricardi 2020), Dutch ports (De Veen 1976), and the Amvrakikos Gulf (Stergiou et al. 1997). A statistically significant difference in Φ' values (*t*-test; $p < 0.05$) was found when compared to the above-mentioned studies. However, no spatial trend was observed across this large number of studies from different parts of the Northern Hemisphere.

Figure 6 shows a spatial pattern generated by log-transformed values of L_{inf} and k parameters of VBGP (von Bertalanffy growth parameters). It appears that common sole in the Sea of Marmara grows faster than in other bodies of water, but does not reach large sizes. The Sea of Marmara is an inland sea and is surrounded by several big cities such as İstanbul. In addition, a huge amount of organic pollutants from agricultural activities is found around this small sea, which makes it a nutrient-rich area. For this reason, the common sole benefits from this type of ecosystem and naturally grows faster.

Table 5

Von Bertalanffy growth parameters (L_∞ – asymptotic mean length; *k* – growth rate; t_0 – hypothetic age at zero length) and growth performance index values (Φ') obtained in different areas for *S. solea*

L_∞ (cm)	*K* (1/y)	t_0 (years)	Ø'	Sex	Locality	Reference
Eastern Atlantic						
34.2	0.35	−1.3	2.62	M	Dutch ports	De Veen 1976
35.6	0.38	−0.5	2.68	F	Dutch ports	De Veen 1976
36.9	0.28	−2.3	2.58	F	Dutch ports	De Veen 1976
37.4	0.31	–	2.64	M + F	North Sea	Nielsen 1972
39.0	0.4	–	2.78	M + F	North Sea	Beverton & Holt 1959
39.6	0.35	−0.8	2.74	F	Dutch ports	De Veen 1976
42.4	0.39	0.09	2.85	M	Bay of Biscay	Deniel 1990
48.2	0.32	0.08	2.88	F	Bay of Biscay	Deniel 1990
49.8	0.13	–	2.51	M + F	Celtic Sea	Jennings et al. 1998
Central and Western Mediterranean Sea						
37.9	0.504	−5.36	2.86	F	Adriatic Sea	Froglia & Giannetti 1986
38.3	0.492	−3.57	2.86	M + F	Adriatic Sea	Froglia & Giannetti 1985
40.1	0.68	–	3.04	M + F	Adriatic Sea	Piccinetti & Giovanardi 1984
39.6	0.44	−0.46	2.84	M + F	Northern Adriatic	Colloca et al. 2013
35.8	0.41	–	2.72	M + F	Tyrrhenian Sea	Wurtz & Matricardi 2020
48.8	0.24	−0.77	2.76	M + F	Gulf of Lion	Vianet et al. 1989
47.2	0.274	–	2.79	F	Gulf of Lion	Girardin et al. 1986
38.8	0.24	−1.09	2.56	M	Castellon coast	Ramos 1982
46.4	0.22	−0.75	2.68	F	Castellon coast	Ramos 1982
Eastern Mediterranean Sea						
26.0	0.221	−1.31	2.17	M	Iskenderun Bay	Türkmen 2003
29.9	0.181	−1.55	2.21	F		
30.0	0.33	−1.51	2.47	M + F	Bardawil Lagoon	El-Gammal et al. 1994
Aegean Sea						
31.1	0.33	−1.04	2.5	M	Aegean Sea	Hoşsucu et al. 1999
42.5	0.17	−1.96	2.49	F		
30.21	0.19	−0,26	2.24	M	Aegean Sea	Cerim & Ateş 2020
36.95	0.23	−0,03	2.50	F		
34.9	0.38	−0.41	2.67	M + F	Amvrakikos Gulf	Stergiou et al. 1997
Sea of Marmara						
28.63	0.62	−0.91	2.71	M	Sea of Marmara	Oral 1996
35.79	0.72	−1.06	2.96	F		
31.3	0.57	0.03	2.74	M	Sea of Marmara	This study
35.8	0.37	−0.49	2.67	F		

The mortality rates (*Z*, *M*, and *F*) in this study were compared with the results of other studies (Table 6). The exploitation rates indicate that there is a high fishing pressure on the common sole stock off the Mediterranean coast. A recent study shows that 21.9% of all landings of common sole from the Sea of Marmara were landed during the spawning season (Yildiz et al. 2020a). Unfortunately, fisheries monitoring is largely non-existent in this area, and fishing operations and landing sites are far from proper management objectives. The exploitation rates (Table 6) are generally just above 0.5 regardless of the fishing gear. Measures such as improved gear selectivity in terms of mesh size should be mandatory for each technique to reduce the exploitation rate below 0.5.

Our study determined that the reproductive periods of the common sole were between October and December, and between April and June. Figure 7 shows that common sole does not have any spawning activity in the summer months, when the water temperature reaches a maximum (around 23°C) and the spawning season varies by region. The two spawning seasons previously reported for the common sole in the Sea of Marmara (Slastenenko 1956; Oral 1996) and the seasons found in our study partially overlap. The spawning season reported by Slastenenko (1956) coincides with the spring peak (around 12.8°C) determined in our study and the

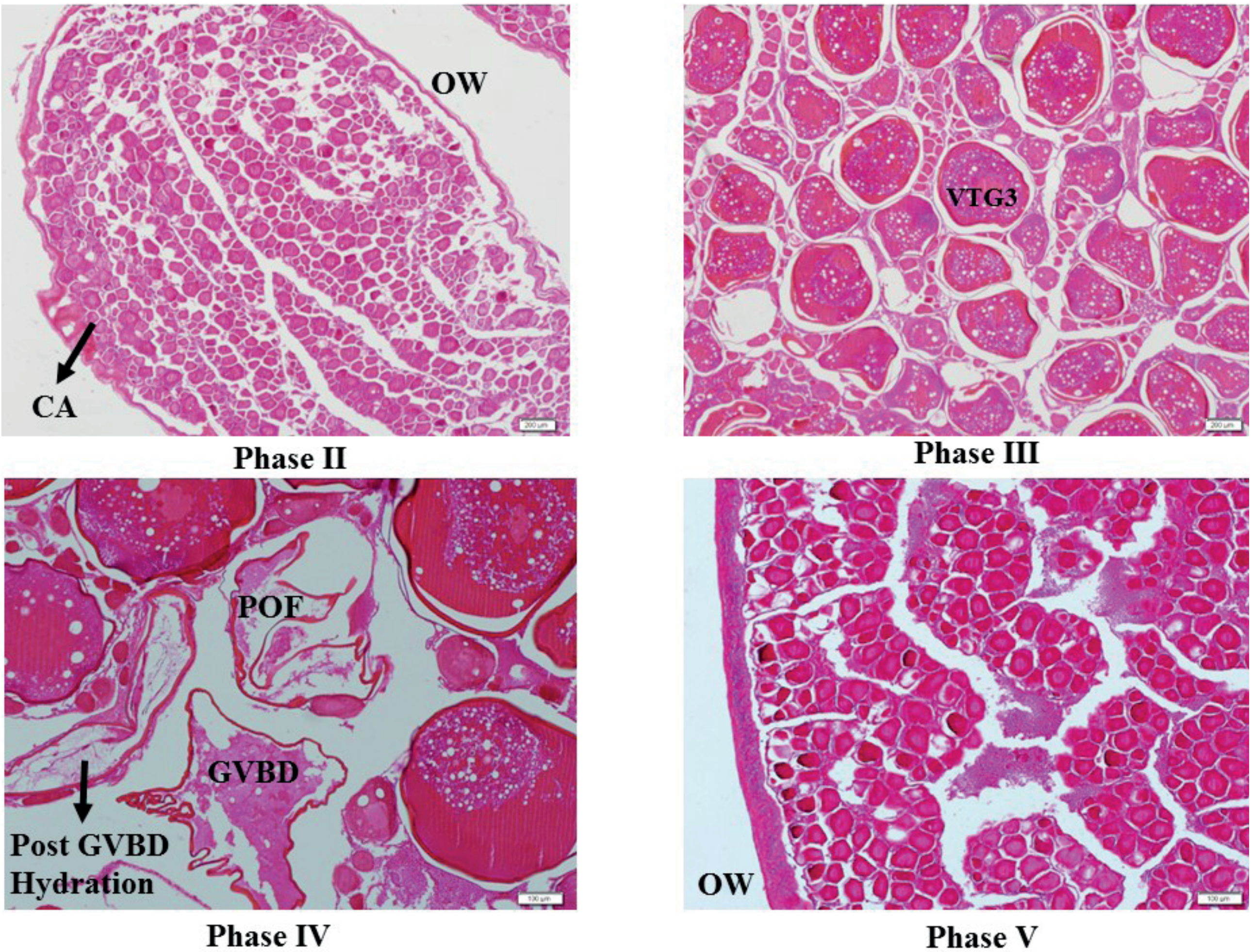

Figure 4

Micrographs from cross-sections of immature or virgin gonads, Phase II – Developing (ovaries begin to develop, but are not ready to spawn); Phase III – Spawning capable (fish are developmentally and physiologically capable of spawning); Phase IV – Regressing (cessation of spawning) with hydrated oocytes (HYD); Phase V – Regenerating (characterized by thick ovarian wall)*;* CA = cortical alveolar; GVBD = germinal vesicle breakdown; OW: ovarian wall; POF = postovulatory follicle complex; VTG3 = tertiary vitellogenic

Table 6

Mortality rates and exploitation ratio for *S. solea* from different geographical areas in the Mediterranean Basin

Z	*F*	*M*	*E*	Fishing technique	Region	Reference
2.49	1.83	0.66	0.73	–	Egypt	Mehanna & Salem 2012
1.7	1.18	0.52	0.69	gillnet	Egypt	Mehanna et al. 2015
1.32	8.2	0.5	0.6	bottom trawl	Iskenderun Bay	Türkmen 2003
0.97	0.66	0.31	0.68	gillnet	Güllük Bay	Cerim & Ateş 2019a
1.42	1.01	0.47	0.68	beam trawl & gillnet	Sea of Marmara	this study

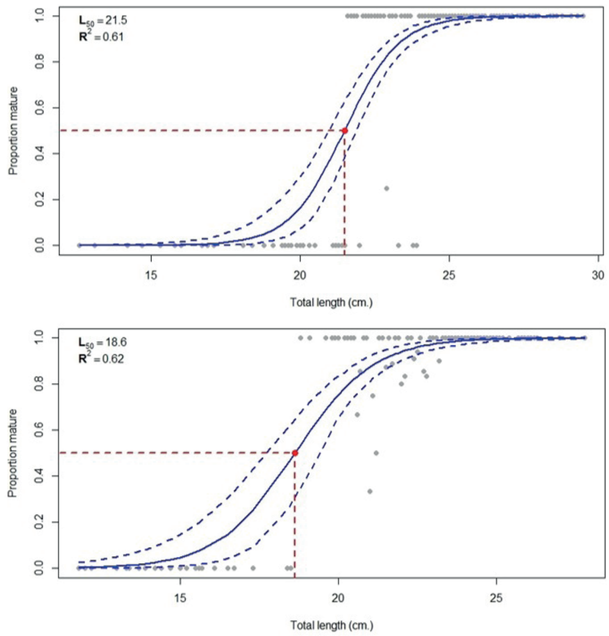

Figure 5

Maturity ogives for males (upper) and females (lower) by total length (TL) for *S. solea*

month of December reported by Oral (1996) agrees with our autumn peak (around 19.2°C). Based on these data, it can be concluded that the common sole in the Sea of Marmara shows the maximum reproductive activity in water temperatures above 10°C and below 20°C. In the eastern Atlantic, on the other hand, the reproductive activity generally occurs between March and May, suggesting that the Mediterranean stock has a longer spawning season than the Atlantic stock.

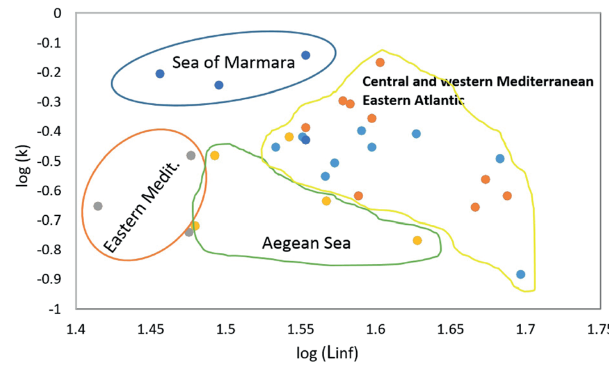

Figure 6

Scatter plot and regional groupings in terms of $\log_{(Linf)}$ and log (*k*) distributions for *S. solea*

These arguments are consistent with the hypothesis that extended spawning may be observed in fish stock closer to the tropics (Tsikliras et al. 2010).

In this study, histological analysis of the gonads demonstrated that common sole has an asynchronous spawning pattern, and this is consistent with previous studies on the gonads by Cerim & Ateş (2019) and Follesa & Carbonara (2019). In this study, length at the onset of sexual maturity (L_m) was 18.6 cm for males and 21.5 cm for females.

As shown in Table 7, the L_m size for females and males was relatively close to the results obtained in other studies carried out in the North Sea (Froese & Sampang 2013), the Bay of Biscay (Dorel 1986) and the Aegean Sea (Kinacigil et al. 2008). The reasons for regional differences in the sex ratio, spawning season, oocyte diameters, *GSI*, *CF*, and L_m values

Table 7

Length at the onset of sexual maturity (cm) for *S. solea* from different studies

L_m	Sex	Country	Region	Study
18.8	M + F	Germany	North Sea	Froese & Sampang 2013
22.0	M	France	Bay of Biscay	Dorel 1986
24.8	M + F	UK	North Sea	Jennings et al. 1998
26.0	M + F		North Sea	Rijnsdorp & Vethaak 1997
27.0	M + F	Holland	Dutch ports	De Veen 1976
28.0	F	France	East and West Channel	Dorel 1986
29.0	M + F	UK	Celtic Sea	Anonymous 2001
30.0	M + F	Holland	Dutch ports	De Veen 1976
31.0	F	France	Bay of Biscay	Dorel 1986
32.0	F	France	Douarnenez Bay, Brittany	Deniel 1990
20.8	F	Turkey	Aegean Sea	Kinacigil et al. 2008
22.7	M			
20.4	F	Turkey	Güllük Bay	Cerim & Ateş 2019b
21.5	F	Turkey	Sea of Marmara	this study
18.6	M			

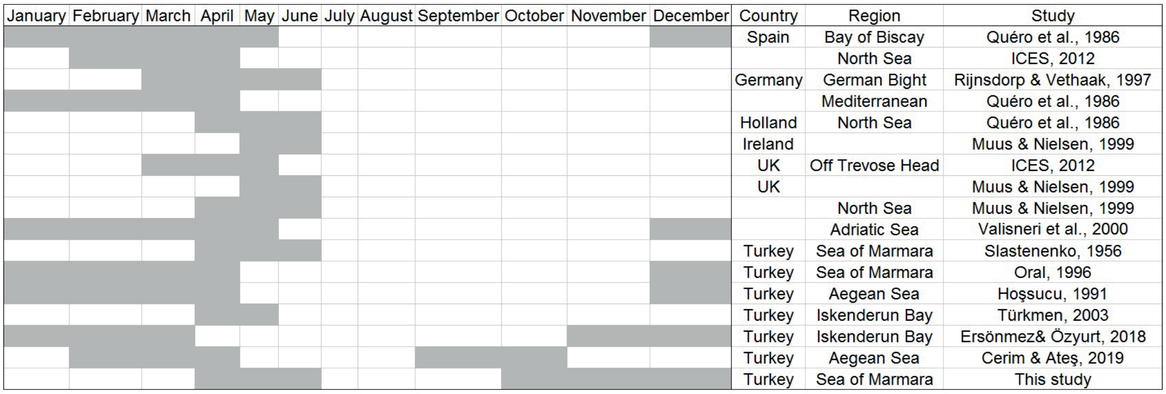

Figure 7

Spawning season of *S. solea* in different studies from the Mediterranean Sea

can be attributed to local factors such as seawater temperature and salinity, habitat and diet differences, maturity stages, fishing mortality, and genetic variation (Ricker 1969; Baganel & Tesch 1978; Basilone et al. 2006; Froese 2006). In this respect, Tsikliras et al. (2010) indicated that due to the oligotrophic nature of the Eastern Mediterranean basin, most species spawn over a short period of time that corresponds to the conditions favorable for the survival of their offspring. In addition, the spawning season of the Eastern Mediterranean stock is limited to late spring and early summer, coinciding with abundant phytoplankton and zooplankton blooms, which exhibit a seasonal cycle and are related to water temperature (Siokou-Frangou et al. 2009).

5. Conclusion

In the European Union, the minimum conservation reference size (MCRS) for common sole is 24 cm TL (EU 2019). In the current Turkish legislation, on the other hand, this size has been defined since 2006 as 20 cm TL (Yildiz & Ulman 2020b) and we consider that there is no scientific basis for this regulation. Furthermore, it can be concluded that different L_m sizes of common sole were calculated for different areas of Turkish waters. Regional fisheries management options should be considered to solve the regional differences based on scientific evidence. Therefore, we proposed that the MCRS for *S. solea* should be at least 22.0 cm to guarantee future generations of common sole in the Sea of Marmara. Fish catches below the MCRS must be discarded. Modifications to fishing gear and improvements in selectivity are likely to prove useful, e.g. the use of a larger mesh size for gillnets, the use of a square mesh panel or larger codend for beam trawlers.

A recent assessment study revealed that the common sole stock in the Aegean Sea is in poor condition and is overexploited regionally (Tsikliras et al. 2021). Moreover, a large-scale stock assessment study conducted in the Eastern Mediterranean Sea and the Black Sea showed a dramatic decline in commercial species (Demirel et al. 2020). The common sole has been listed in the IUCN Red List of Threatened Species under the "Data Deficient" category, and its subpopulations in the Mediterranean Sea have recently been assessed as "Least Concern" (Golani et al. 2011). However, common sole populations in the Sea of Marmara are overexploited and high fishing pressure on common sole, mainly from beam trawlers, can reduce the spawning stock biomass below levels sufficient for population productivity. The results of this study may contribute to better fisheries management for the common sole, as well as the entire region, and will then serve as a basis for further research.

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