

Age, growth, and reproductive biology of Atlantic bonito (*Sarda sarda* Bloch, 1793) from the Turkish coasts of the Black Sea and the Sea of Marmara

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Abstract: This study aims to investigate some biological characteristics of Atlantic bonito, *Sarda sarda* Bloch, 1793, from the Turkish coasts of the Black Sea and the Sea of Marmara. A total of 212 *S. sarda* (100 females, 89 males, and 23 undetermined) were sampled monthly between May 2011 and September 2012. The sex ratio (β/φ) was 0.89; females prevailed but not statistically significantly so. Fork lengths of all sampled individuals ranged from 17.7 to 63.0 cm. The length–weight relationship for all individuals was calculated as $W = 0.01 L^{3.085}$. The ages of the fish ranged from 0+ to 2+. Growth parameters calculated according to the von Bertalanffy growth equation were $L_{\infty} = 69.565$ cm, $k = 0.439$, $t_0 = -1.327$ for females; $L_{\infty} = 74.603$ cm, $k = 0.364$, $t_0 = -1.518$ for males; and $L_{\infty} = 67.883$ cm, $k = 0.463$, $t_0 = -1.220$ for both sexes. One hundred ovaries were obtained from the females, and these ovaries were histologically examined to determine the reproductive conditions and developmental stages of oocytes. The gonadosomatic index values calculated for females indicated that spawning generally occurred between May and August. The most intensive spawning period was observed in June and July. The length at first maturity was estimated to be 42.5 cm for females and 36.8 cm for males.

Key words: Atlantic bonito, *Sarda sarda*, age and growth, reproduction, Black Sea, Sea of Marmara

1. Introduction

Atlantic bonito (*Sarda sarda* Bloch, 1793), which is a member of Scombridae, is an epipelagic and neritic fish species exhibiting wide distribution in temperate and tropical coastal areas, including the Mediterranean Sea (Collette and Nauen, 1983; Sabatés and Recasens, 2001). Since 1950, it has been clear that this species has been caught mostly on the Turkish coasts of the Black Sea (Prodanov et al., 1997; FAO, 2014). Several authors (Klawe, 1961; Macias et al., 2005; Zaboukas et al., 2006; Valeiras et al., 2008) have investigated its age determination and growth, fecundity, and reproductive biology. Furthermore, studies concerning the fisheries, spawning areas, migration, and behavior patterns of schools have been performed by Rey and Cort (1981) and Sabatés and Recasens (2001). In addition, Ateş and Kahraman (2002) and Zengin et al. (2005) carried out preliminary investigations about the fisheries and population parameters of *S. sarda* in Turkish waters. There have also been some research studies by Oray et al. (1997), Ateş et al. (2008), and Cengiz (2013) regarding the age and growth of this species.

S. sarda is a multiple spawner with asynchronous oocyte development that releases eggs multiple times throughout the spawning season (Majorova and Tkacheva,

1959; Rey et al., 1984). Atlantic bonito is a species that feeds on small fish, especially clupeoids such as anchovy, sardine, and sprat, and also on crustaceans (Campo et al., 2006). In different places in the world, it is generally caught with trolling lines, hand lines, long lines, set gillnets, drift nets, and purse seines (Kahraman and Karakulak, 2012). In Turkish waters, this species is mainly caught by purse-seiners. In addition, dalians (traps), encircling gillnets, and set gillnets (without leadlines) are also used.

Modern conservation and management strategies for the stocks of Atlantic bonito require updating, and area-specific information on its reproductive biology is needed to ascertain that the Black Sea and some parts of the Sea of Marmara are its spawning areas. In fact, little information is available for *S. sarda* in the study area; thus, this study aimed to determine the growth parameters, developmental stages of oocytes together with the seasonal cycle of sexual maturity based on determination of the gonadosomatic index (GSI), and length at first maturity.

2. Materials and methods

A total of 212 specimens were caught on the Turkish coasts of the Black Sea and the Sea of Marmara, mostly by commercial purse-seiners, between May 2011 and

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September 2012. Especially in summer months, samples were also obtained from the dalians and fishermen using various types of gillnets. For each specimen, fork length (FL, cm) and total wet weight (TW, g) were measured. Thereafter, gonads (ovaries and testes) were removed and weighed (± 0.01 g), and the sex was macroscopically recorded as male or female. Two aging structures (the first dorsal fin spine and sagittal otoliths) were removed from each sample. The spines were then cut into thin cross sections (~ 50 μ m) at an approximately 90° angle near the base of the spine using a Buehler low-speed Isomet saw with a diamond wafering blade. The entire otolith was cleaned in ethanol and then immersed in glycerin for examination using an image analysis system (Leica DFC295 camera attached to a Leica S8APO stereomicroscope with LAS software).

The length–weight relationship was calculated using the equation $W = aL^b$, where W is the total weight, L is the fork length (FL), and a and b are the parameters of the equation (Ricker, 1973). Growth parameters were calculated according to the von Bertalanffy growth equation, $L_t = L_\infty [1 - e^{-k(t - t_0)}]$ (Sparre and Venema, 1992). The growth performance index (Φ') was also estimated according to Pauly and Munro (1984).

A section of 0.5 cm in width from the central part of 1 ovary was taken and preserved in 10% buffered formalin and stored. A portion of each preserved section was washed in buffer solution, dehydrated in an ethanol and *n*-butanol series, and embedded in paraffin. The samples were sectioned at approximately 5 μ m with a microtome and were mounted on slides. The preparations were then stained with hematoxylin & eosin and examined with a light microscope. Furthermore, the diameters of the oocytes were measured. Maturity stages were classified according to Tyler and Sumpter (1996), Coward and Bromage (1998), and Susca et al. (2001). Finally, to identify the spawning period, the GSI, $[\text{Gonad weight (GW)} / (\text{Total weight (TW)} - \text{Gonad weight (GW)})] \times 100$ (Gibson and

Ezzi, 1980), and the condition factor, $K = [(\text{Total weight (TW)} - \text{Gonad weight (GW)}) / \text{Fork length (FL)}^3] \times 100$ (Htun-Han, 1978), were calculated. Furthermore, the empirical equation of Froese and Binohlan (2000) was used to determine the length at first maturity (L_m) for both sexes:

$$\text{Female: } \log L_m = 0.9469 \times \log L_\infty - 0.1162,$$

$$\text{Male: } \log L_m = 0.8915 \times \log L_\infty - 0.1032.$$

An independent-samples t-test was used to test for possible significant differences in mean length between males and females, and the overall sex ratio was assessed using the chi-square test (Zar, 1996). Statistical analyses were performed with SPSS 14.0, and a significance level of 0.05 was adopted.

3. Results

A total of 212 Atlantic bonitos were collected during the study period. The fork length of all individuals ranged from 17.7 to 63.0 cm (mean length: 35.97 ± 0.71 cm); the total weight was from 68.97 to 3860.05 g (mean weight: 819.66 ± 0.050 g). Furthermore, 100 females ranged from 25.5 to 63.0 cm (mean: 39.81 ± 0.91 cm), 89 males from 23.0 to 56.5 cm (mean: 35.86 ± 0.95 cm), and 23 unidentified specimens from 17.7 to 25.7 cm (mean: 19.71 ± 0.41 cm) (Figure 1). The results of the independent-samples t-test indicated that there were no significant differences ($P > 0.05$) in mean length between males and females.

The relationships between fork length (cm) and total weight (g) values of all samples are shown in Table 1 and Figure 2. The a - and b -values obtained from the estimated length–weight relationship equation ($W = aL^b$) were calculated as 0.01 and 3.085, respectively. The relationship between the 2 variables was observed to be highly significant ($P < 0.001$). In addition, the t-test indicated that there were no significant differences between the slopes (b) estimated for females and males ($P > 0.05$), and positive allometric growth was also observed.

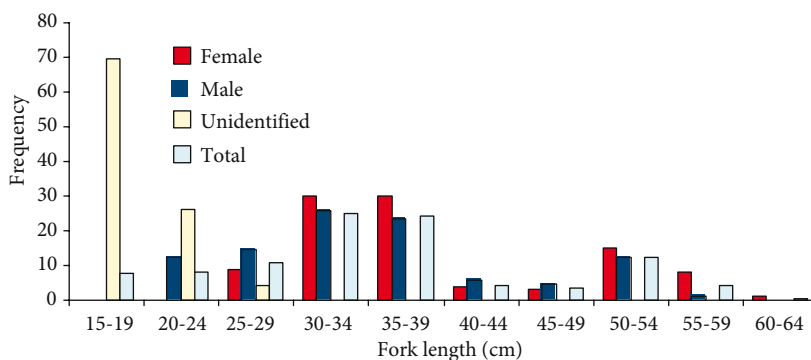
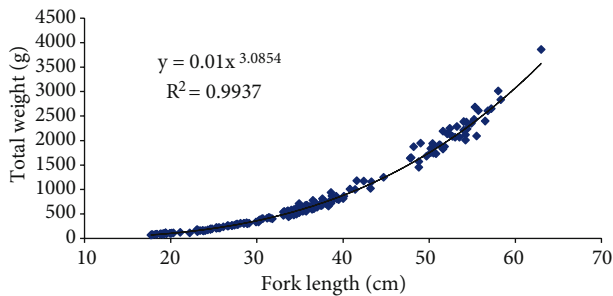


Figure 1. Length–frequency distribution for females, males, unidentified specimens, and all samples of *S. sarda* (n = 212).

Table 1. Parameters of length–weight relationship ($W=aFL^b$) for all samples of *S. sarda*.

Sex	N	FL (cm)		TW (kg)		Parameters of length–weight relationship ($W = aFL^b$)			
		Min.	Max.	Min.	Max.	<i>a</i>	<i>b</i>	SE (<i>b</i>)	R ²
All samples	212	17.7	63	68.97	3860.05	0.01	3.085	0.026	0.994
Females	100	25.5	63	216.66	3860.05	0.007	3.168	0.032	0.990
Males	89	23	56.5	138.24	2398.11	0.009	3.099	0.031	0.992
Unidentified	23	17.7	25.7	68.97	211.51	0.050	2.553	0.189	0.897

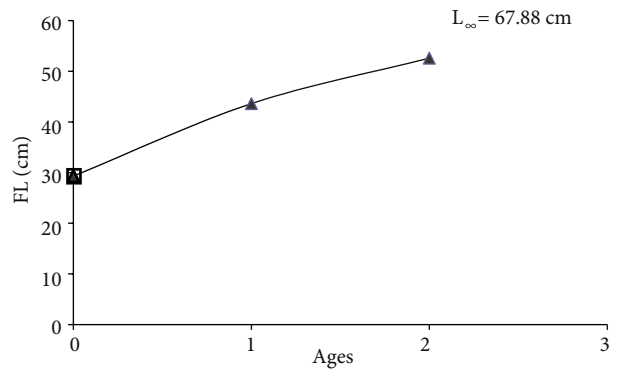
**Figure 2.** Length–weight relationship for all samples of *S. sarda* (n = 212).

We found that almost all annuli on dorsal fin spine cross-sections were not clearly visible, and they did not provide an accurate age estimate for each examined fish. Hence, age determination was based on otolith reading, as otoliths were also removed from all collected individuals of *S. sarda*. Length-at-age values and the number of individuals in each age class are presented in Table 2. It was found that the estimated ages ranged from 0+ to 2+ years,

Table 2. Length-at-age key for all samples of *S. sarda*.

Length class FL (cm)	0+	1+	2+	Total
15–19	16			16
20–24	17			17
25–29	22	1		23
30–34	44	9		53
35–39	16	35		51
40–44	2	5	2	9
45–49		3	4	7
50–54		3	23	26
55–59		2	7	9
60–64			1	1
Total	117	58	37	212

with the 0+ year class (55.2 %) being the most abundant; no specimens older than 2+ year class were observed. The von Bertalanffy growth curve for all samples is presented in Figure 3. It is clear from this curve that individuals grow quickly during the first year of life.

**Figure 3.** The von Bertalanffy growth curve for all samples.

The von Bertalanffy growth parameters were estimated for both sexes and overall (Table 3). It was observed that the L_{∞} (asymptotic length) value of males (74.603 cm) was considerably greater than that obtained for females (69.565 cm); males grew slightly faster than females.

In this study, it was determined that 100 specimens (47.17%) were female and 89 specimens (41.98%) were males. Thus, the sex ratio (σ/ϕ) was 0.89. Although females were more represented in samples, no statistically significant difference was noticed in general ($\chi^2 = 0.6402$,

Table 3. The von Bertalanffy growth parameters calculated for *S. sarda*.

Sex	N	<i>k</i>	<i>t</i> ₀	<i>L</i> _∞	<i>W</i> _∞	Φ'
All samples	212	0.463	−1.220	67.883	4476.95	3.329
Females	100	0.439	−1.327	69.565	4806.09	3.327
Males	89	0.364	−1.518	74.603	5726.83	3.307

$df = 1$, $P = 0.4236$). GSI values were calculated monthly for both sexes (Figure 4). In general, GSI values increased remarkably in the summer months, when reproductive activities were intense. It was observed that these values peaked in June and July.

The K values calculated monthly for both sexes are given in Figure 5. As can be seen in Figures 4 and 5, it was found that the GSI values increased, while the K values showed a tendency to decrease notably, in June, July, and August. Thus, there was an inverse correlation between K values and ovarian development. It was also observed that an increase occurred in the condition factor in September, when reproductive activity ended.

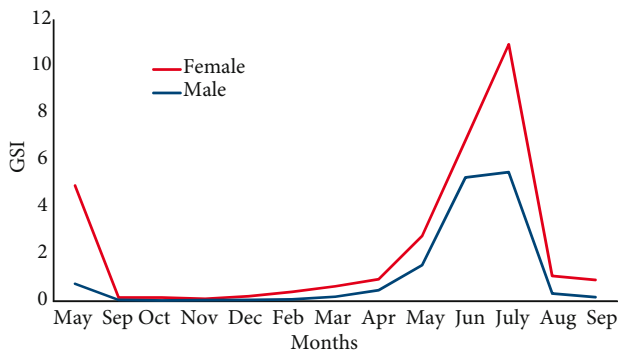


Figure 4. Monthly changes in the mean GSI estimated for both sexes.

It was determined that the ovaries presented 4 different developmental stages of oocytes (Figure 6). Of all 100 females, it was found that 72 specimens were in stage *a*, 8 in stage *b*, 18 in stage *c*, and 2 in stage *d*. A total of 27 sexually mature females collected between April and August (stages *b*, *c*, and *d*) were all well over 36.0 cm FL (Table 4). In addition, it was determined that the length at first maturity was 42.5 cm (FL) for females and 36.8 cm (FL) for males.

Ovaries from immature fish showing only perinuclear stage oocytes (stage *a*) were found more frequently in the winter period between September and May. In contrast, the existence of vitellogenic oocytes (stages *b* and *c*),

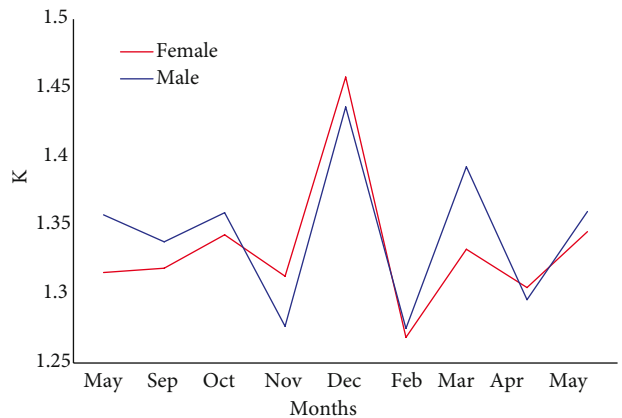


Figure 5. Monthly changes in the mean condition factor (K) estimated for both sexes.

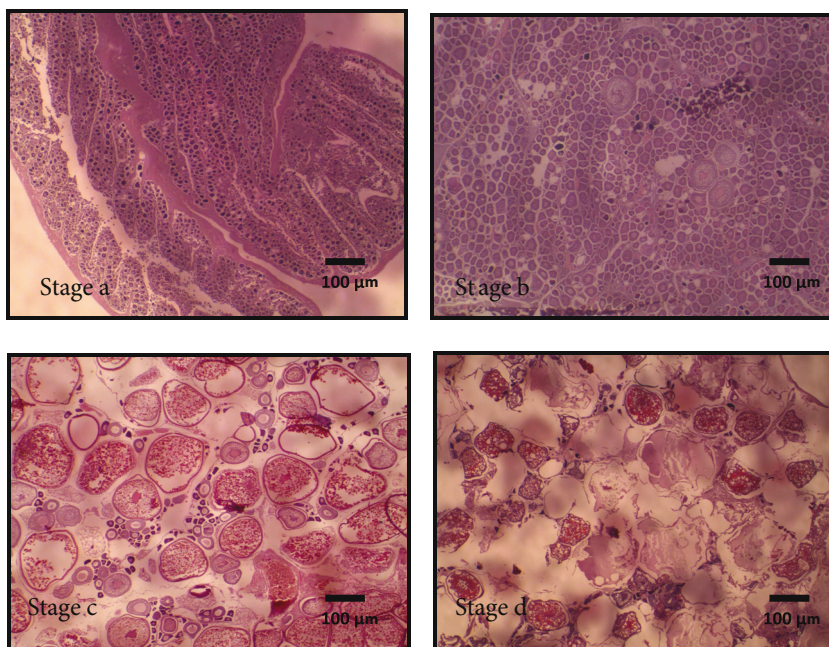


Figure 6. Micrographs from gonad cross-sections of immature stage (a), nonspawning mature stage (b), spawning stage (c), and postovulatory stage (d).

Table 4. Oocyte developmental stages related to fork length (FL, cm) in immature and maturing female *S. sarda* as identified by histological sections.

Months	N	FL (cm)	Oocyte developmental stages and numbers exhibiting these stages			
			Stage (a)	Stage (b)	Stage (c)	Stage (d)
May	2	55.5–63.0		1	1	
September	7	26.1–31.8	7			
October	4	29.9–31.6	4			
November	5	25.5–35.8	5			
December	6	33.5–36.5	6			
February	9	33.1–34.9	9			
March	11	33.3–39.5	10	1		
April	14	35.9–40.0	8	6		
May	21	34.5–58.3	14		7	
June	10	43.2–58.0			9	1
July	1	41.6				1
August	7	48.8–54.4	6		1	
September	3	52.7–55.7	3			

mostly observed between May and September, showed that the reproductive activity of *S. sarda* occurred primarily during the summer months. The spawning specimens with postovulatory follicles (stage *d*) were first observed in June and July. The average GSI values increased starting in May and peaked in June and July, thus leading to the conclusion that these specimens reached complete sexual maturity in June and July.

4. Discussion

This study represents the first attempt at a histological identification of the oocyte developmental stages of *S. sarda* from the Turkish coasts of the Black Sea and the Sea of Marmara, and also deals with some other reproductive aspects, as well as age and growth parameters of this species.

As seen in Table 5, the length range of specimens in this study was similar to those found in other studies [Gibraltar Strait: 40.0–55.0 cm (Rodriguez-Roda, 1966) and 33.0–70.5 cm FL (Rey et al., 1984); the Spanish Mediterranean coasts: 41.0–48.0 cm (Macias et al., 2005) and 40.0–61.0 cm (Valeiras et al., 2008); Tiran and Sicily coasts of Italy, respectively: 35.0–82.0 cm and 35.0–67.0 cm (Di Natale et al., 2006); Adriatic Sea coasts: 33.0–67.0 cm (Franičević et al., 2005); the Turkish coasts of the Black Sea, the Sea of Marmara, and the Mediterranean Sea: 14.0–90.0 cm (Kara,

1979), 23.0–66.0 cm (Oray et al., 2004), 23.5–71.0 cm (Ateş et al., 2008), 23.8–72.0 cm (Cengiz, 2013), and finally the present study: 17.7–63.0 cm]. Therefore, we concluded that our sampling captured a representative size distribution that is similarly reflected in most of the previous studies. Furthermore, the *a*- and *b*-values estimated in the present study are consistent with those of other studies based on fork length.

The age and growth parameters obtained by various researchers as well as those of the present study are shown in Table 6. In the western Mediterranean Sea, Valeiras et al. (2008) observed 3 different ages (age classes 1–3) from dorsal fin spines of bonitos. In the Strait of Gibraltar (Spain), Rey et al. (1986) determined 5 different ages (age classes 0–4) from dorsal fin spines, otoliths, and vertebrae. In the Ionian Sea, Santamaria et al. (1998) found 5 different ages (age classes 0–4) from dorsal fin spines and vertebrae. In Turkish waters, Ateş et al. (2008) and Cengiz (2013) conducted age and growth studies on *S. sarda* from otoliths, and 4 different ages (age classes 0–3) were observed. In this study, 3 different ages (age classes 0–2) were determined from otoliths. It is clear that our growth parameters (L_{∞} , k , t_0 , and Φ') show similarities with the findings of other authors (Table 6).

As seen in Table 6, the growth performance index values obtained from the individuals sampled in the

Table 5. The length–weight relationships (LWR) for *S. sarda* in different areas.

Author(s)	Area	N	$L_{\min}$ – $L_{\max}$ (cm)	LWR
Rodríguez-Roda, 1966	Strait of Gibraltar, Spain	165	40.0–55.0	$W = 0.0148 FL^{2.97}$
Rey et al., 1984	Strait of Gibraltar, Spain	878	19.0–72.0	$W = 0.0072 FL^{3.16}$
Macias et al., 2005	Spanish coast of the Mediterranean Sea	183	41.0–48.0	$W = 0.0046 FL^{2.67}$
Valeiras et al., 2008	Spanish coast of the Mediterranean Sea	136	40.0–61.0	$Lt = 62.5(1 - e^{-0.719(t + 1.21)})$
Di Natale et al., 2006	Tyrrhenian coast, Italy	240	35.0–82.0	$W = 0.0003 FL^{2.83}$
	Sicilian coast, Italy	109	35.0–67.0	$W = 0.0004 FL^{2.18}$
Franičević et al., 2005	Coast of the Adriatic Sea	665	33.0–67.0	$W = 0.0085 FL^{3.12}$
Kara, 1979	Turkish coasts of the Black Sea and the Sea of Marmara	1608	14.0–90.0	$W = 0.0236 FL^{2.87}$
Oray et al., 2004	Turkish coasts of the Black Sea and the Sea of Marmara	1168	23.0–66.0	$W = 0.0039 FL^{3.32}$
Ateş et al., 2008	Turkish coasts of the Black Sea and the Sea of Marmara	694	23.5–71.0	$W = 0.0054 TL^{3.21}$
Cengiz, 2013	Northern Aegean Sea (Gallipoli Peninsula and Dardanelles)	238	23.8–72.0	$W = 0.0028 TL^{3.32}$
Yankova et al., 2013	Black Sea, Bulgaria	411	29.0–37.6	$W = 0.001 TL^{3.89}$
Present study	Turkish coasts of the Black Sea and the Sea of Marmara	212	17.7–63.0	$W = 0.01 FL^{3.085}$

Table 6. The von Bertalanffy growth parameters (L_{∞} : asymptotic mean length; K : growth rate; t_0 : hypothetical age at zero length) and growth performance index values (Φ') obtained from different areas for *S. sarda*.

Author(s)	Study area	L_{∞}	K	t_0	Φ'
Numann, 1955	Black Sea, Turkey	67.8	0.79	-	3.56
Nikolov, 1960	Black Sea, Bulgaria	95.6	0.24	-1.24	3.34
Rey et al., 1986	Strait of Gibraltar, Spain (FL)	80.8	0.35	-1.70	3.36
Santamaria et al., 1998	Ionian Sea - Italy (FL)	80.6	0.36	-1.37	3.37
Ateş et al., 2008	Black Sea and Sea of Marmara (TL)	68.0	0.82	-0.39	3.58
Cengiz, 2013	Northern Aegean Sea (Gallipoli Peninsula and Dardanelles) (TL)	69.8	0.76	-0.44	3.57
Present study	Black Sea and Sea of Marmara (FL)	67.9	0.46	-1.22	3.33

western Mediterranean, the northern Aegean Sea, the Sea of Marmara, and the Black Sea show similarities with each other. On the other hand, the studies conducted by Ateş et al. (2008) and Cengiz (2013) were based on total length. Therefore, the Φ' values of these studies are greater than those of the other studies as well as the present study, which are based on fork length. Furthermore, it is obvious that when compared to other studies, the Φ' value of our study exhibits no significant difference (t-test; $P > 0.05$). The asymptotic length (L_{∞}) values calculated for the Ionian Sea (Italy) and the Strait of Gibraltar (Spain) are higher than those of other studies as well as that of our study. In addition,

Table 6 shows that the L_{∞} values of the studies by Ateş et al. (2008) and Cengiz (2013) are lower than those of other studies (excluding Valeiras et al., 2008) as well as those of the present study. The possible causes of observed differences in length distribution, length–weight relationships, length at age, growth parameters, and length at first maturity could be affected by several factors such as environmental conditions (e.g., temperature and salinity), season, habitat, fishing area, depth, sampling methodology, selectivity of fishing gear, sex, and gonad maturity (Ricker, 1969; Baganel and Tesch, 1978; Weatherley and Gill, 1987; Potts et al., 1998; Basilone et al., 2006; Froese, 2006; Soykan et al., 2010).

This study is the first to analyze the histological features of the ovarian maturation stages of *S. sarda* in Turkish waters. It has been reported that the spawning period in the western Mediterranean starts at the beginning of early summer (Rey et al., 1984; Pujolar et al., 2001), and that reproduction in the eastern Mediterranean, including the Black Sea and the Sea of Marmara, occurs during June and July (Yoshida, 1980). In this study, it was revealed that the spawning period extends from May to August, with most spawning occurring in June and July. The micrographs of gonad cross-sections (Figure 6) show that the oocyte development is an “asynchronous” type, as indicated by Majorova and Tkacheva (1959) and Rey et al. (1984).

Cengiz (2013) reported that the length at first maturity of this species (age group: 0) was estimated as 41.9 cm TL (total length). Rey et al. (1984) indicated that this value was 38.0 cm FL (age group: 1). In addition, the FAO (2013) reported that the length at first maturity was 40.5 cm FL. In our study, the length at first maturity was estimated as 42.5 cm FL for females and 36.8 cm FL for males. Furthermore, in view of the oocyte maturity findings, it was determined that all sexually mature females were well over 36 cm FL. It can be concluded that our findings show similar results for the length at first maturity as those reported in previous studies. On the other hand, the minimum landing size for

this species is indicated as 25.0 cm (TL) in the Turkish Commercial Fishery Regulations 3/1, numbered 2012/65 (BSGM, 2012); however, it has been considered that there is no scientific evidence to support this regulation. Thus, further studies should be done to determine the exact minimum landing size for *S. sarda*.

In conclusion, the Atlantic bonito populations are considered overexploited in all cases and strict management measures are recommended. In addition, continued excessive fishing pressure on bonito could ultimately reduce the spawning stock below levels sufficient to maintain the population. However, the International Commission for Conserving Atlantic Tuna, responsible for fisheries management of species belonging to Scombridae in the Mediterranean, has not yet announced any regulations for *S. sarda*. Therefore, it is expected that our results will contribute to further studies to be carried out in the future in terms of fishery management of this species.

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