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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Fecundity, condition, and ovarian histology of the Lessepsian migrant fish *Siganus luridus* (Rüppell, 1829) inhabiting the Southern Aegean Sea

Güney Ege Denizi'nde yaşayan Lessepsiyen göçmen balık *Siganus luridus* (Rüppell, 1829)'un fekonditesi, kondisyonu ve ovaryum histolojisi

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Abstract: In recent years, one of the lessepsian migrant, *Siganus luridus* (Rüppell, 1829) extended its dispersal towards the Aegean Sea. Because of lacking data on the reproduction of the species along the Turkish coast, the aim of the present study was to determine some reproductive characters of dusky spinefoot *Siganus luridus* such as the reproductive cycle, fecundity and condition factor. A total of 181 female fish were sampled from Gökova Bay in the southern Aegean Sea using small-scale fisheries (trammel nets) and recreational fishing methods (angling and trap fisheries) between July 2019 and June 2020. Variations in the gonadosomatic index (GSI) and gonadal histological changes indicated that reproduction of *S. luridus* started in May, peaked in August and gradually decreased in September. Individuals ready to spawn were mostly observed between May and September, with the highest occurrence in August. The highest K value was found in April (1.67 ± 0.11) and the lowest in September (1.39 ± 0.11). Spawning females ranged from 14.8 to 25.6 cm total length. Absolute fecundity varied between 98,607 and 801,460 oocytes per female within a total length range of 12.2–25.6 cm. Relative fecundity ranged from 1,107 to 2,952 oocytes g^{-1}, with an average value of 1,734 ± 747 oocytes g^{-1}. Length at maturity value was calculated to be 16.19 cm. Findings of the present work are useful for fisheries management and may serve as the fundamental source for aquaculture of the species.

Keywords: Rabbitfish, gonadosomatic index (GSI), spawning season, reproductive biology, lessepsian migration

Öz: Son yıllarda, Lessepsiyen göçmen türlerden biri olan *Siganus luridus* Ege Denizi'ne doğru dağılımını genişletmiştir. Türün Türkiye kıyılarındaki üremesine ilişkin verilerin yetersizliği nedeniyle, bu çalışmanın amacı, esmer sokar balığı (*Siganus luridus*)'nun üreme döngüsü, fekonditesi ve kondisyon faktörü gibi bazı üreme özelliklerini belirlemektir. Temmuz 2019 ile Haziran 2020 tarihleri arasında, Gökova Körfezi (Güney Ege Denizi)'nden küçük ölçekli (gırgır ağları) ve amatör (olta ve tuzak balıkçılığı) avcılıkla aylık olarak toplam 181 dişi birey örneği toplanmıştır. Gonadosomatik indeks (GSI) değişimleri ve gonad histolojik incelemeleri, üremenin Mayıs ayında başladığını, Ağustos ayında zirveye ulaştığını ve Eylül ayında kademeli olarak azaldığını göstermiştir. Yüksek GSI değerleri Temmuz ve Ağustos aylarında saptanmıştır, ancak yumurtlamaya hazır bireyler esas olarak Mayıs–Eylül arasında gözlenmiş, en yoğun dönem Ağustos olmuştur. En yüksek K değeri Nisan ayında (1,67 ± 0,11), en düşük değer ise Eylül ayında (1,39 ± 0,11) bulunmuştur. Yumurtlayan dişilerin toplam boyları 14,8–25,6 cm arasında değişmiştir. Mutlak fekondite dişi başına 98.607 ile 801.460 oosit arasında (12,2–25,6 cm LT), relatif fekondite ise 1.107 ile 2.952 oosit g^{-1} arasında olup ortalama 1.734 ± 747 oosit g^{-1} olarak hesaplanmıştır. İlk eşeysel olgunluk boyu 16,19 cm olarak belirlenmiştir. Elde edilen bulgular, balıkçılık yönetimi için yararlı olmanın yanı sıra türün yetiştiriciliği için temel kaynak niteliği taşımaktadır.

Anahtar kelimeler: Sokar balıkları, gonadosomatik indeks (GSI), üreme dönemi, üreme biyolojisi, lesepsiyen göç

INTRODUCTION

Family Siganidae comprises 29 species distributed worldwide, ranging from East Africa to French Polynesia. In addition to their Indo-Pacific distribution, several species are also present in the Mediterranean Sea. While the larvae are pelagic, juveniles and adults inhabit littoral and sublittoral zones. Members of this family are commercially important as food fish, and several brightly colored species are popular in the aquarium trade (Froese and Pauly, 2022). Many Siganidae species are cultured in Malaysia, the Philippines, Indonesia, the east coast of Africa, the Middle East, and the Mediterranean region (FAO, 2022). In contrast, wild stocks are primarily harvested using a variety of fishing methods, including spearfishing, gillnets, beach seines, small-mesh nets, cast nets, and baited hooks and lines, employed in both commercial and recreational fisheries (Pacific Community, 2019). Global capture production of Siganidae—including the dusky spinefoot—from the eastern and western Indian Ocean, the Mediterranean Sea, and the Western Central Pacific was reported to be 121,992 tons in 2023 (Fisheries and Aquaculture software, 2025).

The rabbitfish *Siganus luridus* was first recorded in the Mediterranean in 1931 along the Syrian coastline (Gruvel, 1931). A member of the family Siganidae, it is considered an invasive species in the Mediterranean, having entered the region through the Suez Canal (Froese and Pauly, 2022). Beyond the Mediterranean, the species is widely distributed, occurring throughout the Red Sea and the western Indian Ocean, from East African coasts to offshore island systems. The depth range of the dusky spinefoot varies generally between 2 and 40 m and it is known to be a marine and reef-associated species. Although it possesses venomous dorsal,

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anal and pelvic spines used for defense against predators and posing a risk to humans, it is still of minor commercial importance (Froese and Pauly, 2022).

The first report of dusky spinefoot from Turkish seas was provided by Bilecenoğlu (2010). *S. luridus*, together with other Siganid species, *Siganus rivulatus*, is commercially valuable species along the Mediterranean and Southern Aegean coast of Türkiye. The most prevalent fishing methods for these species in Türkiye are gillnets and traps (Soykan et al. ,2020). Although it has economic importance, official annual landing data for Türkiye are lacking, despite its regional economic significance for the southern Aegean Sea and the Mediterranean coast.

Fecundity, condition, and reproductive traits are of crucial importance, particularly for invasive fish populations, and their assessment is essential for properly evaluating reproductive output and dispersal potential (Bariche et al., 2009). Although numerous studies have examined the occurrence of the species in the Mediterranean Sea (Ounifi–Ben Amor et al., 2016; Durovic et al., 2014; Poloniato et al., 2010; Castriota and Andaloro, 2008; İşmen et al., 2015; Schembri et al., 2012), its feeding habits were described by Shakman et al. (2009) along the Libyan coast, and its invasion potential in the Mediterranean ecosystem was evaluated by Hassan et al. (2003). However, studies addressing the reproduction biology of the species remain limited. The reproductive features of *S. luridus* were investigated by Azzurro et al. (2007) in the Strait of Sicily, while fecundity and condition were reported from the northern coast of Lebanon by Bariche et al. (2009).

Reproductive characteristics of females are among the primary determinants of population sustainability in fish species. In many fish species, reproductive success is associated with the number of eggs spawned per year. Accordingly, the objective of this study was to provide baseline information on the annual reproductive pattern of *S. luridus* by analyzing monthly changes in the gonadosomatic index and gonadal histology, as well as estimating fecundity in the north-eastern Mediterranean (Aegean Sea). The findings of this study are expected to contribute to fisheries management and may provide a scientific basis for aquaculture development in the Mediterranean region.

MATERIALS AND METHODS

Study area and sampling

Fieldwork for this study was conducted in Gökova Bay and Datça, southern Aegean Sea, between July 2019 and June 2020 (Figure 1).

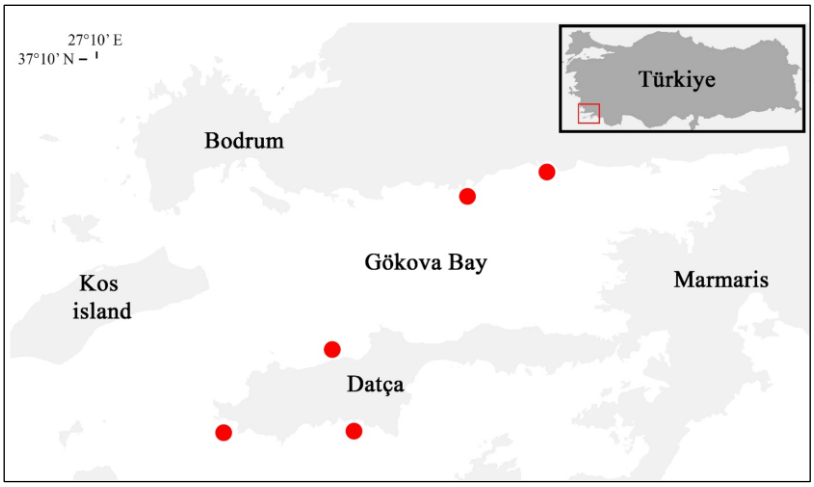

Figure 1. Map of the study area showing the sampling locations of *S. luridus* in Gökova Bay and Datça (southern Aegean Sea). Red points indicate fishing grounds.

Monthly sampling was conducted using both small-scale fishing gears, including trammel nets, and recreational fishing methods such as angling and trap fisheries. Fish samples were collected by commercial fishers.

Biological measurements and sex determination

In total, 181 female specimens of *S. luridus* were examined in this study. Total length (TL) was used as the size metric and measured to the closest millimeter while the fish was maintained in its natural body posture. The weight of the whole body (W) and the gonads (Wg) was recorded with an accuracy of 0.01 g. Sex determination was performed macroscopically. In individuals where sex could not be reliably identified based on external or macroscopic gonadal characteristics, particularly outside the reproductive season, histological examination was conducted to confirm sex. Gonadal development was classified into five maturity phases following Brown-Peterson et al. (2011): immature (I), developing (II), spawning capable (III), actively spawning (IV), and regressing (V). Ovarian samples representing the actively spawning phase (stage IV) were chosen based on visual criteria described by Bariche et al. (2003).

Fecundity estimation

Ovaries were excised and weighed to the nearest 0.01 g. Subsamples were taken from the anterior, middle, and posterior regions of each ovary to account for intra-ovarian variability. Each subsample was weighed and the number of advanced vitellogenic and hydrated oocytes was counted under a stereomicroscope. Batch fecundity was estimated using the gravimetric method as: F = (n × GW) / g, where n is the mean number of oocytes in the subsample, GW is the total gonad weight, and g is the subsample weight. Histological analysis was conducted to validate oocyte developmental stages and ensure accurate selection of spawning batches.

Histological procedure

Determination of the gonadal development phases was based on histological examination. Gonad samples were fixed in buffered 10% formalin solution for 24 h. Tissue processing included dehydration in a series of increasing ethanol concentrations, clearing with xylene, and embedding in paraffin wax. Paraffin-embedded tissues were sectioned at a thickness of 5 µm using a Leica 2125 rotary microtome. The sections were stained with haematoxylin and eosin following established protocols (Luna, 1982; Bancroft & Stevens, 1996) and examined under an Olympus JX31 light microscope. Although all gonads were included in the histological analysis, only the highest-quality images were captured using an Olympus E330 digital camera.

Gonadosomatic index and condition factor

The spawning season was determined based on monthly changes in the gonadosomatic index (GSI, %), calculated using the following equation:

$$GSI = [W_g / (W - W_g)] \times 100$$

In this formula, Wg represents gonad weight (g), while W denotes the total body weight of the fish in grams (Ricker, 1975).

Fulton's Condition Factor (K) was calculated to evaluate monthly variation in body condition using the following formulae:

$$K = 100\ (W_T - W_g).\ L^{-3}$$

Monthly variations in gonadosomatic index (GSI) and condition factor (K) were evaluated using non-parametric statistical approaches. Prior to analysis, data distribution was assessed, and due to deviations from normality and the presence of heterogeneity, non-parametric tests were preferred. Differences among months were tested using the Kruskal–Wallis test. When significant differences were detected, pairwise multiple comparisons were performed using Dunn's post-hoc test with Bonferroni correction. Mean values were presented with 95% confidence intervals (CI), calculated as mean ± 1.96 × standard error (SE). Here, 1.96 is the conventional z value corresponding to the 95% confidence level. All statistical analyses were conducted at a significance level of $p < 0.05$.

Length at first maturity (Lm) was defined as the size at which 50% of the sampled individuals reached spawning maturity (King, 1996). The size corresponding to 50% sexual maturity was estimated using the following logistic equation:

$$L_m = 1/(1 + \exp(-(r \times (TL - TL50))))$$

In this model, *r* represents the slope of the logistic curve, TL denotes the mean total length for each length class, TL50 is a model constant, and Lm corresponds to the mean length at sexual maturity, defined as the size at which 50% of individuals are reproductively active. Monthly sea surface temperature data for the period 2019-2020 were obtained from Turkish State Meteorological Service, division of marine meteorology. The relationships between absolute fecundity (F*abs*) and total length (L), total weight (W), and gonad weight (GW) were examined using regression analysis. Power regression models were applied for the relationships between fecundity and total length and total weight, while a linear regression model was used for the relationship between fecundity and gonad weight. The significance of each regression model was tested using analysis of variance (ANOVA), and the overall model fit was evaluated based on the coefficient of determination (r^2) and F-statistics. STATISTICA 8.0 software and Microsoft Excel 2016 were used for the visualizations and calculations mentioned.

RESULTS

The number of female individuals captured each month is shown in Figure 2. Total length of the female individuals ranged from 12.2 to 25.6 cm, and total body weight varied between 25.8 and 288.5 g. The mean length and the mean weight of the sample (n=181) were 18.2 ± 0.3 cm and 121.7 ± 7.2 g, respectively. The length–weight relationship was $W= 0.0045L^{3.455}$ ($R^2= 0.97$) indicating positive allometric growth (Figure 3).

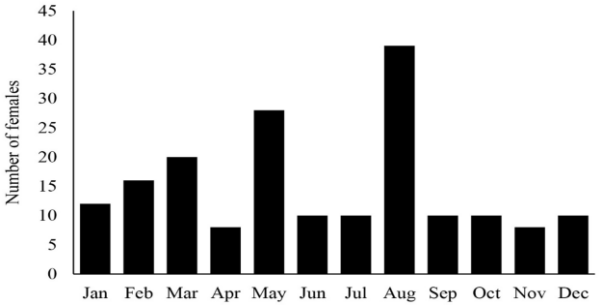

Figure 2. Monthly variation in number of female individuals

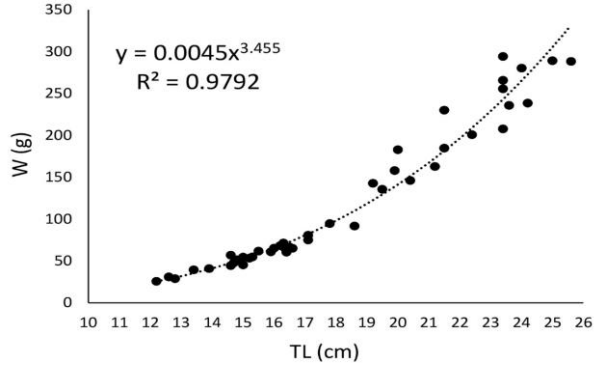

Figure 3. Length–weight relationship of *S. luridus* from the Southern Aegean Sea, Türkiye

Absolute fecundity (*F*abs) was estimated as *F*abs = 278,446 oocytes per ovary (SD = 181,345, range = 98,607-801,460) and relative fecundity (*F*rel) was *F*rel = 1734 ± 747 oocytes g^{-1}. The relation between the *F*abs and *W* and *L* for *S. luridus* was expressed using a power function ($y = ax^b$) while the relationship between *F*abs and *GW* was described using a linear function ($y = a + bx$) (Table 1). The relation between fecundity and size is presented in Figure 4. Fecundity gradually increased and peaked at 21 cm TL, followed by a gradual decline. Furthermore, the relation between fecundity and GW is shown in Figure 5 and was statistically significant (p<0.01)

Table 1. Associations of absolute fecundity (Fabs) with total length (L), total weight (W), and gonad mass (GW) in *S. luridus* (n = 46)

Relation	r^2	F	P
Fabs = $5.1177L^{3.6758}$	0.60	41.34	<0.01
Fabs = $1323.5W^{1.1}$	0.69	64.08	<0.01
Fabs = 157375 + 7606GW	0.82	204.29	<0.01

In the present study conducted in the Southern Aegean Sea, total length (TL) ranged between 12.2 and 25.6 cm, with a sample size of 46 individuals. Absolute fecundity (Fabs) was 278446, with a standard deviation of 181345 and a range of 98607–801460. The condition factor (K) was calculated as 1.67 ± 0.11. The length at first maturity (Lm) was determined to be 16.19 cm.

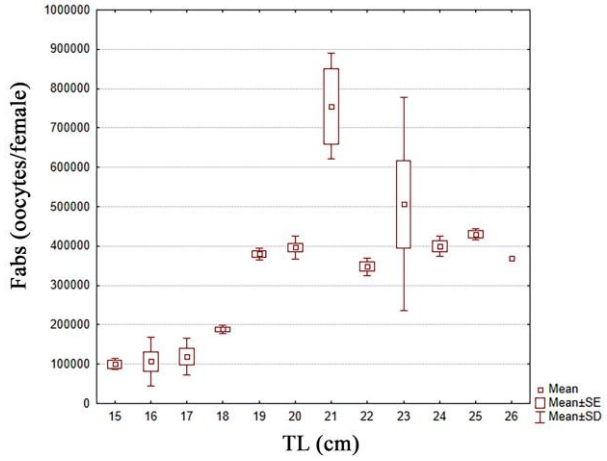

Figure 4. Changes in absolute fecundity across size classes of *S. luridus*

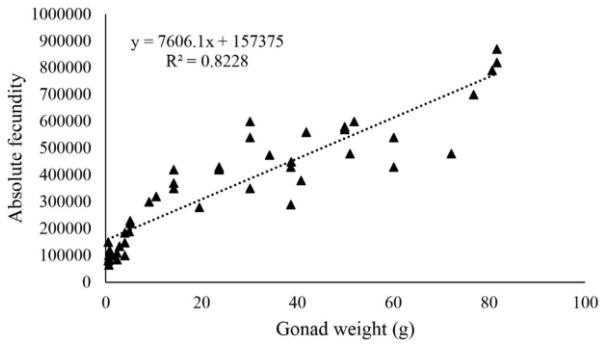

Figure 5. Absolute fecundity versus gonad weight (GW) (g) for 46 *S. luridus* sampled from the Southern Aegean Sea

In *S. luridus*, the gonads are located in the posterior region of the body cavity, beneath the digestive tract. They consist of two asymmetrical lobes that are joined at the medial apical region. The ovaries exhibit a central lumen and a stratified internal organization extending toward the ovarian core.

Spawning females ranged from 14.8 to 25.6 cm total length. During ovarian development, the ovaries increased rapidly in size and became yellow-orange, thickened and opaque. At this stage, some oocytes were at the chromatin nucleolus stage (CNS), whereas most of the small sized oocysts were at the perinucleolus stage (PNS), characterized by one or more nucleoli surrounding the nucleus. Larger oocytes were observed at the cortical alveolar stage (CAS). Well-developed ovaries were clearly distinguishable macroscopically, and vitellogenic oocytes reached a size allowing visual identification without magnification. During the resting phase, the gonads were shorter, and the gonadal wall was thick and opaque. The presence of fully developed vitellogenic oocytes marked the transition between the developmental and maturation phases. In developing ovaries, oocyte size increased progressively, with vitellogenic (Vit) oocytes predominating, while only a small proportion of mature (Mat) oocytes, and early perinucleolar (PNS) oocytes were observed. In mature females, the gonads were enlarged, swollen, and filled with hydrated oocytes. Microscopic examination revealed that the most advanced oocytes (MAOS) remained hydrated within the follicular structure and lamellae, accompanied by stretching of the gonadal wall. This stage was characterized by the abundance of cortical alveolar and late vitellogenic oocytes, although some pre-vitellogenic oocytes were still present. The post-ovulation follicle (POF) was not prominent. During the phase of spent, multiple post-ovulation follicles (POF) were observed throughout the histological sections, and most of which had collapsed. The MAOS may also have been composed of hydrated oocytes and represented residual eggs that were usually atretic. Numerous oocytes at various perinucleolar and cortical alveolar stages were also observed. In addition, some mature oocytes that had not been released exhibited varying degrees of atresia, and the ovaries contained many several empty spaces. Accordingly, maturity of *S. luridus* females were evaluated in 5 stages;

I–Immature (Im)

This stage is characterized by the presence of oogonia and small oocytes in the chromatin nucleolus and early perinucleolar stages (December-January). Individuals at this stage were not sexually mature and had very small and thin gonads. (Figure 6A).

II– Developing (De)

Some oocytes, particularly smaller ones, were at the chromatin nucleolus stage (CNS) and early perinucleolar stage (PNS), characterized by one or more nucleoli surrounding the nucleus. Larger oocytes were observed at the cortical alveolar stage (CAS) (February–March) (Figure 6A-B).

III–Spawning capable

Oocytes at the CAS continued to increase in size. A small number of mature oocytes with vitellogenic and migrative nucleui were also observed and, small PNS oocytes were still present. Although development began in mid-spring, developing germ cells were observed in May. Macroscopicall sex determination was performed macroscopically, and ovaries were pinkish-yellow and granular in appearance (Figure 6B-C).

IV- Active spawners

Hydrated oocytes were observed within the follicular structure and lamellae. Many oocytes were at the cortical alveolar stage and post-vitellogenic phase, whereas pre-vitellogenic oocytes were still present. Post-ovulation follicles were not detected. The gonadal wall was stretched and clearly distinguishable. The ovaries exhibited an orange-to-pink coloration and were highly vascularized. Females at this stage contained large, transparent, and fully developed oocytes. This period extended from early summer to the beginning of autumn (June-September) (Figure 6D-E).

V–Regressing

Many post-spawning follicles were observed at this stage, along with several empty spaces within the ovaries. Oocytes that were not released exhibited different degrees of atresia and were observed during October and November. The eggs were clustered and appeared darkly stained. The structure of the gonadal wall began to degenerate (Figure 6F).

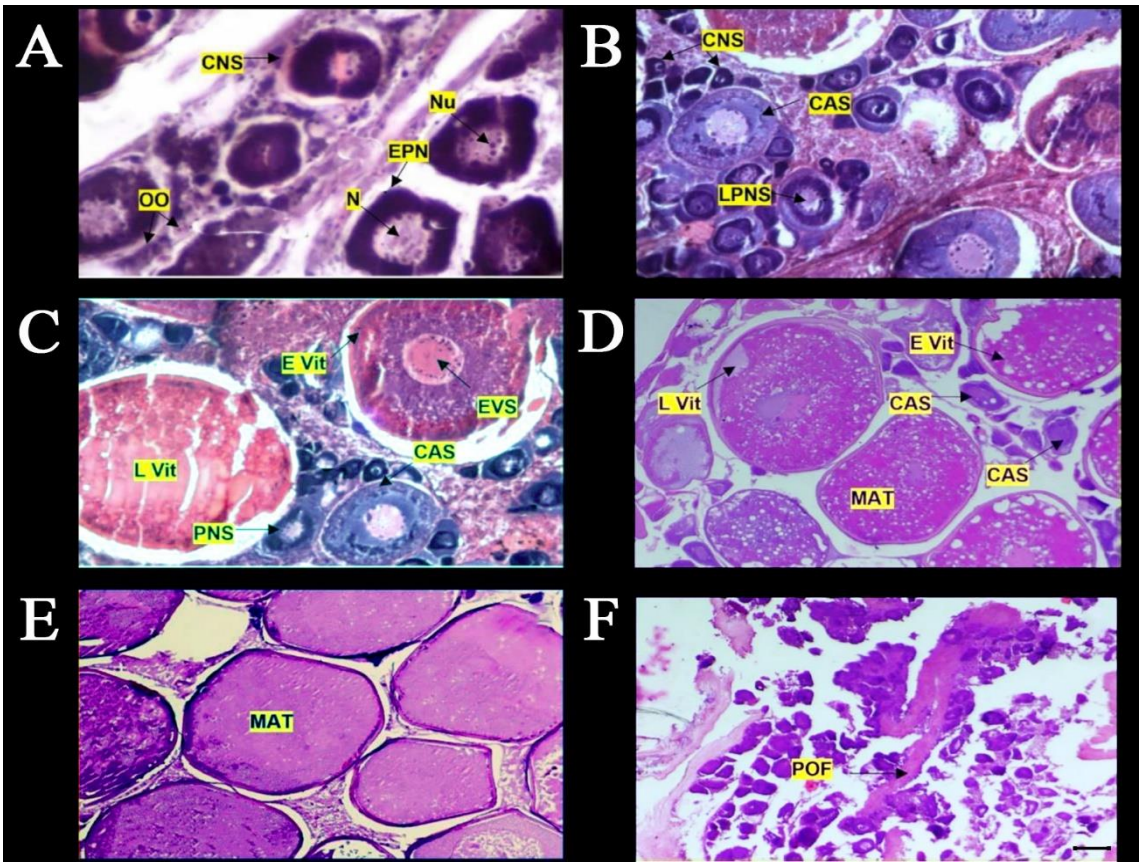

Figure 6. Different developmental stages of *S. luridus* ovaries. Histological sections showing ovarian development stages: (A) immature; (B–C) developing; (D–E) spawning capable; (F) regressing. Abbreviations: OO, oogonia; CNS, chromatin nucleolar stage; EPNS, early perinucleolar stage; LPNS, late perinucleolar stage; CAS, cortical alveoli stage; PNS, perinucleolar stage; EVit, early vitellogenic; LVit, late vitellogenic; Mat, mature; POF, post-ovulatory follicle; N, nucleus; Nu, nucleolus. Scale bar: 100 µm, Magnification: 100×.

Gonadosomatic index (GSI) and condition factor (K) values showed significant differences among months (Kruskal–Wallis test, GSI: $H = 79.07$, $p < 0.001$; K: $p < 0.05$). Pairwise multiple comparisons using Dunn's test indicated that both GSI and K values differed significantly between several months (Figure 7). Mean GSI and K values with corresponding 95% confidence intervals are presented in Figure 7.

The highest K value was observed in April (1.67 ± 0.11), whereas the lowest value was recorded in September (1.39 ± 0.11). High GSI values were detected in July and August, while spawning-ready individuals were mainly observed between May and September, peaking in August. It was found that while GSI values increased by the temperature, whereas K values showed an opposite trend (Figure 7).

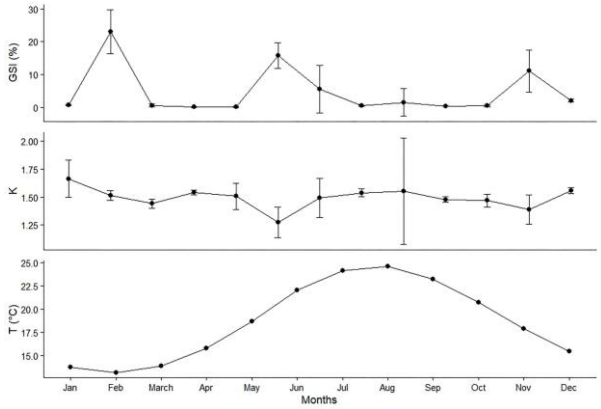

Figure 7. Monthly variation of gonadosomatic index (GSI) and condition factor (K) shown as mean values with confidence intervals. The line represents water temperature measured on the sampling day for each month.

The smallest recorded female measured 12.2 cm in total length, while the length at first maturity was estimated to be 16.19 cm TL (Figure 8).

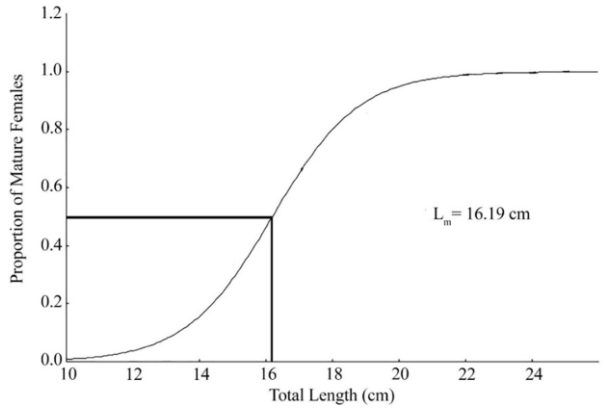

Figure 8. Length at maturity of female *S. luridus* from the Southern Aegean Sea, Türkiye

DISCUSSION

This study provides baseline information on several biological parameters of *S. luridus* in the Aegean Sea, including condition factor, fecundity, spawning season and gonad histology. Updated knowledge on the reproduction characteristics of invasive species such as the dusky spinefoot is essential due to their ecological impacts and biological interactions. Although the occurrence of dusky spinefoot from Turkish seas was first reported in 2010 by Bilecenoğlu (2010), scientific information on the reproductive patterns of the species has been limited until the present study.

Suboptimal environmental and physiological conditions, including reduced water temperature, changes in nutritional status, stress, and inappropriate photoperiods, can influence oocyte atresia rates in teleost fishes (Nagahama, 1983; Hunter and Macewicz, 1985). Although information on oocyte atresia in *S. luridus* gonads is limited, the present findings are consistent with those Azzurro et al. (2007). All germ cell stages (chromatin nucleolus, early perinucleolus, late perinucleolus stage) were observed in the ovaries during the immature or resting phases, indicating a primary developmental stage. Perinucleolar and cortical alveolar (CAS) oocytes were detected during stage II. As ovarian maturation progressed, yolk accumulation and vitellogenesis began, accompanied by thickening of the oocyte membrane and clearer differentiation of the follicular layer and zona radiata. During advanced maturation stages, yolk granules accumulated in the cytoplasm, and oocytes reached ovulation-ready maturity. Gonads were classified as maturity stages III and IV, occurring mainly between the end of May and September. Notably, post-spawning individuals were not observed in Linosa waters (western Mediterranean) during July (Azzurro et al., 2007). The distribution of maturity stages observed in the present study was also comparable to that reported for siganid populations inhabiting Lebanese waters, where mature eggs were recorded during similar periods (Bariche et al., 2003). *S. rivulatus* (Forsskål, 1775) is one of the two Siganidae species living in Turkish waters together with *S. luridus*. Due to the limited information on gonadal development and reproductive cycle of S. *luridus*, comparisons were made with *S. rivulatus*. Previous studies have demonstrated regional variability in the reproductive timing. Ben-Tuvia et al. (1966) reported mature females between July and November in the southeastern Mediterranean. In contrast, Amin (1985) observed earlier gonadal development in the Red Sea (Jeddah region) compared to the eastern Mediterranean, with maturity occurring between January and March and spawning extending from March to September. Along the Mediterranean coast, Hussein (1986) identified the spawning period as July–September. Subsequent studies also highlighted spatial variation, with Golani (1990) reporting a spawning between May and August along the Israeli Mediterranean coast, Yeldan and Avşar (2000) reporting July–August for the northeastern Mediterranean coast of Türkiye, and Engin et al. (2020) identifying peak spawning activity in June in the southern Aegean Sea. The present study showed that gonadal maturation of *S. luridus* began at the end of May, peaked in August, and continued until the end of September. Accordingly, the spawning period of *S. luridus* in the Aegean Sea waters appears to be longer than that of *S. rivulatus*.

Fecundity is an important descriptor of reproduction (Kartas and Quignard, 1984) and is highly sensitive to suboptimal environmental conditions (Lamber and Dutil, 1997). The wide range of fecundity values observed both in the present study and in previous reports indicates a high degree of inter-individual variability, commonly associated with differences in body size, age, nutritional status, and reproductive stage. The fecundity values obtained in the present study represent the first evidence for the Southern Aegean Sea, and limited data are available for direct comparison. Both absolute and relative fecundity values of *S. luridus* in the Southern Aegean Sea fall within the range reported for siganids from Linosa and Lebanese waters, and the size distribution of sampled individuals was also comparable among studies (Azzurro et al., 2007; Bariche et al., 2009) (Table 2).

Table 2. Comparison of studies including some reproduction aspects of *S. luridus* in the Mediterranean Sea

	Bariche et al. (2009) Eastern Mediterranean Sea	Azzurro et al. (2007) Mediterranean Sea	Present Study Southern Aegean Sea
TL (cm) (min-max)	16 - 24	16.5 – 21.8	12.2 - 25.6
n	32	8	46
Fecundity (F_{abs})	245273 (SD = 164211, range = 87476–863 487)	315433 (SD= 187138, range= 115739–740433)	278446 (SD = 181345, range = 98607-801460)
Condition factor (K)	1.80 ± 0.12	1.50-2.06	1.67 ± 0.11
Lm	-	16.5	16.19

The larger sample size used in the present study (n = 46) compared to earlier studies likely provides a more representative estimate of population-level fecundity. The total length (TL) range in this study (12.2–25.6 cm) is broader than those reported previously, particularly due to the inclusion of smaller individuals. The presence of immature or early-maturing individuals may have contributed to slightly lower average fecundity values, whereas the inclusion of larger individuals likely accounts for the upper range of fecundity observed, reflecting the well-established positive relationship between body size and reproductive output in teleost fishes. Reported fecundity (Fabs) values for *S. rivulatus* from the Red Sea and other regions ranged between 18,000 and 735,000 oocytes (Popper and Gundermann, 1975; Popper et al., 1979; Hashem, 1983; Hussein, 1986; Bariche et al., 2003, 2004, 2009; Abu-El-Regal et al., 2019; Abdelhak et al., 2020).

The present findings indicate that the fecundity characteristics of *S. luridus* are generally consistent with previously reported values across the Mediterranean basin. The mean absolute fecundity (Fabs) estimated in this study (278,446 oocytes per ovary) falls between the values reported by Bariche et al. (2009) (245,273 oocytes) and Azzurro et al. (2007) (315,433 oocytes), indicating comparable reproductive output across different geographic regions.

Bariche et al. (2009) reported that absolute fecundity increases with both body length and gonad weight, typically following a power function (y = a × b), and that the constants "a" and "b" may vary depending on population and environmental conditions. Kartas and Quignard (1984) described the proportional relationship between fecundity and body mass, and the exponential value close to one indicates proportional growth between these variables, as observed in the present study. A linear relationship between absolute fecundity and gonad weight was established (Table 1). Higher fecundity values were recorded in relatively smaller females compared to those of Bariche et al. (2009), which may be associated with differences in food availability and regional environmental conditions.

The condition factor (K) is closely associated with environmental variability, as many fish species utilize substantial energy reserves during gonadal development (Htun-Han, 1978). The condition factor (K) obtained in this study (1.67 ± 0.11) is slightly lower than that reported by Bariche et al. (2009) (1.80 ± 0.12), yet remains within the range provided by Azzurro et al. (2007) (1.50–2.06). These differences may reflect spatial and temporal variability in environmental conditions, food availability, and energy allocation strategies, all of which are known to influence somatic condition and reproductive investment. Although previous studies are limited, Bariche et al. (2009) reported that K values peaked in April–May and decreased in June–July, corresponding to the spawning period (Bariche et al., 2003). Similar patterns were also reported by Hashem (1983). In the present study, the highest K value was observed in April, whereas the lowest value occurred in August, coinciding with peak spawning activity.

The length at first maturity (Lm) of *S. luridus* was estimated as 16.19 cm. Although maturity length data for this species are scarce, the present result is consistent with that reported by Azzurro et al. (2007). Previous studies reported maturity lengths for *S. rivulatus* as 12.6 cm (Bariche et al., 2003), 15 cm (Hussein, 1986; Fahmy, 2019), 12 cm (Abdelhak et al., 2020), and 11.5 cm (Makbal et al., 2014). The maturity length of *S. rivulatus* in Turkish seas was also reported as 16.6 cm (Soykan et al., 2020), indicating similar maturation sizes for both species in Türkiye.

Overall, the results from the Southern Aegean Sea corroborate previous findings from the Mediterranean and demonstrate that the reproductive biology of *S. luridus* is largely consistent across its distribution range. Nevertheless, minor differences in fecundity and condition indices emphasize the influence of local environmental conditions and sampling design. Lower fishing pressure and higher food availability in the Southern Aegean Sea may facilitate the establishment of Lessepsian migrant rabbitfishes in this basin and promote efficient gonadal development and successful reproduction. The rapid population expansion of rabbitfish and other thermophilic species has been observed in the Mediterranean in recent decades, and increasing sea surface temperature associated with global warming is considered one of the main driving factors (Francour et al., 1994; Azzurro, 2008).

Global protein demand continues to rise, while marine natural resources are under increasing pressure. It is predicted that marine capture production will gradually decline, whereas aquaculture production may become approximately twice that of fisheries by 2050 (FAO, 2021). Currently, Mediterranean countries and Türkiye primarily focused on the aquaculture of European sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*). The development of alternative aquaculture is necessary to address challenges related to

market demands, disease resistance, genetic diversity, environmental sustainability, export and competitiveness, and feed conversion efficiency. Recent studies have investigated the culture potential of Siganidae species worldwide. Several rabbitfish species are considered promising aquaculture candidates, including *S. rivulatus* for the Mediterranean, *Siganus randalli, Siganus lineatus,* and *Siganus fuscescens* for the Pacific region, *Siganus canaliculatus* in Africa, *Siganus canaliculatus, Siganus fuscescens,* and *Siganus guttatus* for China, *Siganus canaliculatus, Siganus guttatus, Siganus virgatus, Siganus spinus, Siganus punctatus, Siganus fuscescens,* and *Siganus javus* in Malaysia, the Philippines, and Indonesia (FAO, 2022). The scarcity of studies on *S. luridus* is notable. The reproductive potential and cycle of the dusky spinefoot revealed in the present study may provide preliminary guidance for future culture feasibility assessments.

The present study aimed to investigate the length-weight relationship, fecundity, spawning period, condition factor, and gonadal development of invasive *S. luridus* along the Turkish coast of the eastern Mediterranean. The results indicate that the species reaches final gonadal maturation stages, suggesting the potential for successful spawning along the Turkish coast. This ability may be attributable to the high adaptive capacity of dusky spinefoot to establish sustainable populations in new habitats. Future studies should focus on monitoring population dynamics and reproductive parameters of the species, particularly the transition from egg to larval stages, in relation to aquaculture potential. The findings of the present work are also valuable for fisheries management and may serve as a baseline for dusky spinefoot culture studies.

Despite providing valuable insights into the reproductive biology of *S. luridus* in the Southern Aegean Sea, this study has several limitations that should be acknowledged. First, the sample size, although adequate for histological and reproductive analyses, may not fully represent the entire population structure of the species across different spatial scales. Second, sampling was restricted to a single geographical region and a one-year period; therefore, interannual environmental variability and broader regional differences could not be evaluated. Third, fecundity estimation was based on batch fecundity analysis, which may introduce uncertainty compared to multiple spawning assessments in species exhibiting complex reproductive strategies. Finally, environmental factors other than temperature, such as food availability and habitat characteristics, were not directly quantified. Future studies incorporating multi-year monitoring and broader ecological variables would help to improve understanding of the reproductive dynamics of this invasive species.

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AUTHORSHIP CONTRIBUTIONS

Serhat Engin: Conceptualization, Methodology, Laboratory processes, Writing - original draft preparation, Hasan Cerim: Sampling, Preparation of samples, Writing - original draft preparation, Ozan Soykan: Sampling, Writing - original draft preparation.

CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

ETHICS APPROVAL

This study did not require approval from a research ethics committee, as the specimens were not directly collected by the researchers but were instead obtained from professional fishers after capture. Therefore, responsibilities on the welfare of the fish samples didn't belong to authors of the study.

DECLARATION OF AI USE

The authors declare the use of AI solely for grammar correction and language editing during manuscript preparation.

DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

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