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Reproduction and growth of the Red Sea goatfish *Parupeneus forsskali* in its new environment (Cyprus, eastern Mediterranean Sea)

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Summary: In the Mediterranean Sea, six species of Mullidae have been recorded, four of them being alien to the area. The most recent arrival in the Mediterranean is the Red Sea goatfish (*Parupeneus forsskali*), which was first spotted there in the year 2000. Although *P. forsskali* is endemic to the Red Sea and the Gulf of Aden, it has recently expanded its distribution; it was confirmed in Cyprus in 2014. Since then, it has established a thriving population around the island, and is now commercially important. In the present study, the spawning season and gonad development of *P. forsskali* off the coast of Cyprus were studied, along with important biological parameters. Macroscopic and histological analyses of the gonads indicated five maturity phases for both ovaries and testes. The gonadal maturity phases and the gonadosomatic index indicated that *P. forsskali* spawns in the summer months, with the peak of the spawning season in July. Males were bigger, heavier, and more abundant than females, and the length-weight relationship was found to be $TW=0.0065\ TL^{3.17}$ for males and $TW=0.0086\ TL^{3.07}$ for females, both indicating positive allometric growth. The size at first sexual maturity (LM) was 14.2 cm for males and 11.8 cm for females. Five age groups were identified from the length-frequency distribution (0-4 years old). Age group 1 was the most dominant one, containing almost 60% of the sampled individuals. Natural mortality (M) declined with age, and the mean natural mortality coefficient across ages was 0.563 $year^{-1}$. Overall, this is the first study that provides important information on the spawning season of the Red Sea goatfish and other estimations on various biological traits in its non-native habitat that can be of great importance for fisheries management.

Keywords: alien; gonads; histology; maturity phases; reproductive cycle; growth.

Resumen: En el mar Mediterráneo se han registrado seis especies de Mullidae, cuatro de las cuales son exóticas. La llegada más reciente al Mediterráneo es un salmonete del mar Rojo (*Parupeneus forsskali*), que fue visto allí por primera vez en el año 2000. Aunque *P. forsskali* es endémico del mar Rojo y el golfo de Adén, recientemente ha ampliado su distribución; en Chipre se confirmó su presencia en 2014. Desde entonces ha establecido una exitosa población alrededor de la isla, que ya ha adquirido importancia comercial. En el presente trabajo, se estudió el período de puesta y el desarrollo gonadal de *P. forsskali* frente a las costas de Chipre, además de importantes parámetros biológicos. Los análisis macroscópicos e histológicos de las gónadas indicaron cinco fases de madurez tanto para las hembras como para los machos. Las fases de madurez gonadal y el índice gonadosomático indicaron que *P. forsskali* desova en los meses de verano, con el pico de puesta en julio. Los machos fueron más grandes, pesaban más, y eran más abundantes que las hembras, la relación talla-peso fue $TW = 0{,}0065\ TL^{3{,}17}$ para los machos y $TW = 0{,}0086\ TL^{3{,}07}$ para las hembras, indicando ambos un crecimiento alométrico positivo. La talla de primera madurez sexual (LM) fue de 14,2 cm para los machos y de 11,8 cm para las hembras. Se identificaron cinco grupos de edad a partir de la distribución de frecuencia de tallas (0-4 años). El grupo de edad 1 fue el más dominante, con casi el 60% de los individuos muestreados. La mortalidad natural (M) disminuyó con la edad y el coeficiente medio de mortalidad natural, en todas las edades, fue de 0,563 $año^{-1}$. En general, éste es el primer estudio que proporciona información relevante sobre la época de puesta del salmonete del mar Rojo y otras estimaciones sobre varios rasgos biológicos en su hábitat no nativo que pueden ser de gran interés para la gestión pesquera.

Palabras clave: exóticas; gónadas; histología; fases de madurez; ciclo reproductivo; crecimiento.

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INTRODUCTION

Goatfish are members of the family Mullidae and can be found worldwide in tropical, subtropical and temperate waters (Uiblein 2007). Goatfish are of great commercial and economic importance on a global scale, including the Mediterranean Sea (Whitehead et al. 1984, Nelson et al. 2016). There are six confirmed mullid species present in the Mediterranean, two of which are native (Froese and Pauly 2022): the red mullet (*Mullus barbatus*, Linnaeus, 1758) and the surmullet (*Mullus surmuletus* Linnaeus, 1758). The most recent alien goatfish species to arrive in the Mediterranean is the Red Sea goatfish (*Parupeneus forsskali* [Fourmanoir and Guézé, 1976]), which migrated through the Suez Canal, and was first spotted off the coast of Turkey in 2000 (Çinar et al. 2006).

The Red Sea goatfish is endemic to the Red Sea and the Gulf of Aden and is the most common goatfish in the area (Randall 1983, 2004), as well as one of the most exploited goatfishes in the Red Sea (Farrag et al. 2018). In its native range, it can live for up to five years (Mehanna et al. 2018), reaching a total length of up to 28.5 cm (Sabrah 2015) and a size at maturity of 16 cm (Farrag et al. 2018). The geographical range of the Red Sea goatfish has increased considerably in recent years. Since it was first spotted around Turkey in 2000, it has spread throughout the eastern Mediterranean (Evagelopoulos et al. 2020) and has been found as far west as Tunisia (Capapé et al. 2018). Its presence was first confirmed around Cyprus in 2014, when a single specimen was caught in the area of Cape Pyla (Chartosia and Michailidis 2016). Since then, the species has been established around the island, possibly becoming the most abundant goatfish in shallow waters around Cyprus, and has already become commercially important (Evagelopoulos et al. 2020).

Only a few studies have been done on the biology of the Red Sea goatfish in the Mediterranean, but none of them have focused on its reproduction and spawning period, both of which are important elements for population dynamics and fisheries management (Hunter et al. 1992). In the present study, the maturity, spawning, growth and mortality of the Red Sea goatfish were examined for the first time in the Mediterranean Sea (Cyprus). The results of this study will facilitate monitoring of the population around Cyprus and help to assess the impact of its establishment on Mediterranean fisheries and on biodiversity.

MATERIALS AND METHODS

Collection of samples

Red Sea goatfish samples were collected in the first or second week of each month along the southern coast of Cyprus from November 2020 to October 2021 (12 months, n=466). They were fished by local fishers at 15 to 20 m depth using a gillnet with an 18 to 20 mm net opening and examined shortly after. An additional sampling was carried out in July 2021 using hand nets with a smaller mesh size to ensure that fish of all sizes could be examined. The samples were mostly kept and examined fresh, but some samples had to be stored in a freezer or in a 10% buffered formalin solution for later examination. Total length (TL, cm) was measured to the nearest 0.1 cm, and total weight (TW, g) and gutted weight (GW, g) were measured to the nearest 0.01 g.

Histological analysis

Determining the maturity phases of fish is done either by examining the gonads macroscopically (or visually) or by histological analysis of the gonads. When gonads are examined histologically, the maturity of oocytes in ovaries and spermatocytes in testes are used to determine the maturity phase of the gonads. The gonads were extracted and weighed to the nearest 0.001 g. The sex of the fish and the gonad maturity phases (based on size, shape, colour, stiffness and presence of blood vessels) were determined macroscopically (Brown-Peterson et al. 2011). After weighing, the gonads were fixed and stored in 10% formalin until further examination. Ten gonad samples from each month were selected for histological analysis randomly and others were chosen because the identification of the maturity phase macroscopically was not a straightforward procedure owing to the bad condition of the gonads. For the histological analyses, about 0.5-cm-thick tissue samples were taken from the middle part of either lobe of the ovaries and testes. The samples were then dehydrated in a graded series of ethanol, embedded in paraffin wax, sectioned at 7 μm and then mounted on microscope slides and stained with haematoxylin and eosin (e.g. Longenecker et al. 2017). The sections were examined under a Zeiss Primo Star microscope, and pictures of the sections were taken with a Zeiss Axiocam ERc 5s microscope camera. The histological maturity phases were determined on the basis of oocyte and spermatocyte development (Brown-Peterson et al. 2011).

Morphology of gonads

Ovaries and testes were divided into five clear maturity phases both macroscopically and histologically following Brown-Peterson et al. (2011). The following five phases were determined: i) immature, where individuals never spawned (Fig. 1); ii) developing, where gonads begin to develop but they are not ready to spawn (Fig. 2); iii) spawning capable, where individuals are able to spawn in this cycle (Fig. 3); regressing, where there is cessation of spawning (Fig. 4); and regenerating, sexually mature but reproductively inactive (Fig. 5).

Time of spawning

The development of fish gonads in time can be described at a macroscopic level using the gonadosomatic index (GSI), which can be used to detect the onset and duration of spawning (Tsikliras et al. 2010). Monthly changes in the GSI and maturity phases were used to determine the spawning season of Red Sea goatfish.

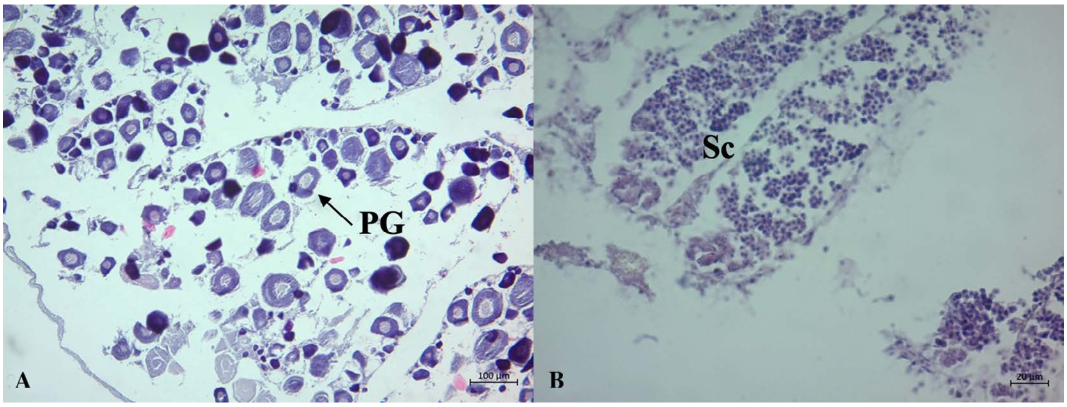

Fig. 1. – Immature individual of *P. forsskali*. A, female; B, male. PG, primary growth oocytes; Sc, spermatocytes.

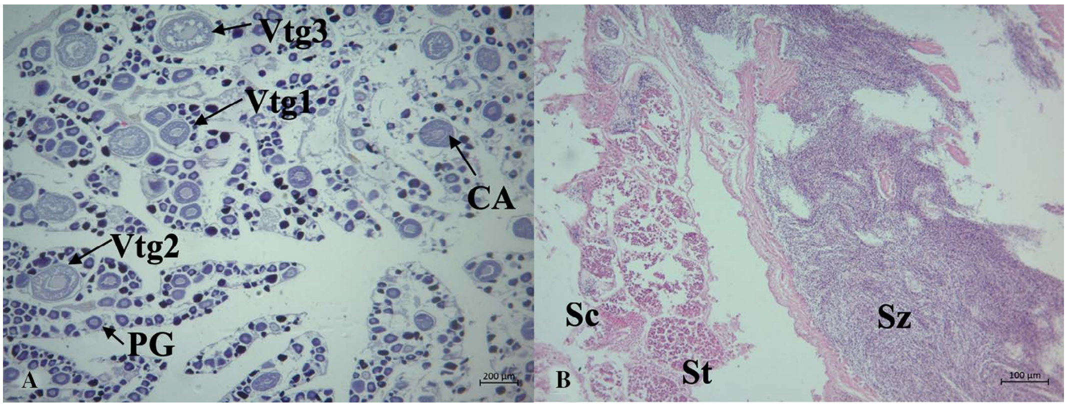

Fig. 2. – Developing individual of *P. forsskali*. A, female; B, male. Vtg1, primary vitellogenic oocyte; Vtg2, secondary vitellogenic oocyte; Vtg3, tertiary vitellogenic oocyte; Sc, spermatocytes; St, spermatids; Sz, spermatozoa.

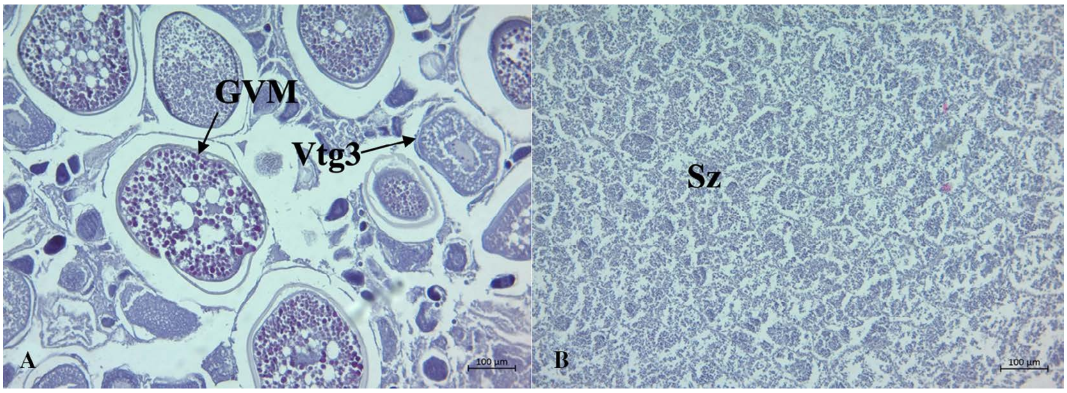

Fig. 3. – Spawning capable individual of *P. forsskali*. A, female; B, male. GVM, germinal vesicle migration; Vtg3, tertiary vitellogenic oocyte; Sz=spermatozoa.

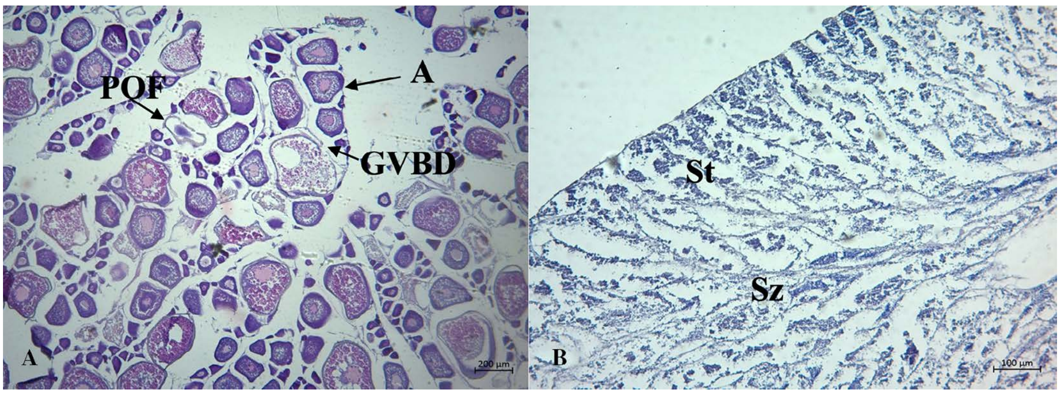

Fig. 4. – Regressing individual of *P. forsskali*. A, female; B, male. POF, postovulatory follicle complex; GVBD, germinal vesicle breakdown; A, atretic oocyte; Sz, residual spermatozoa; St, spermatids.

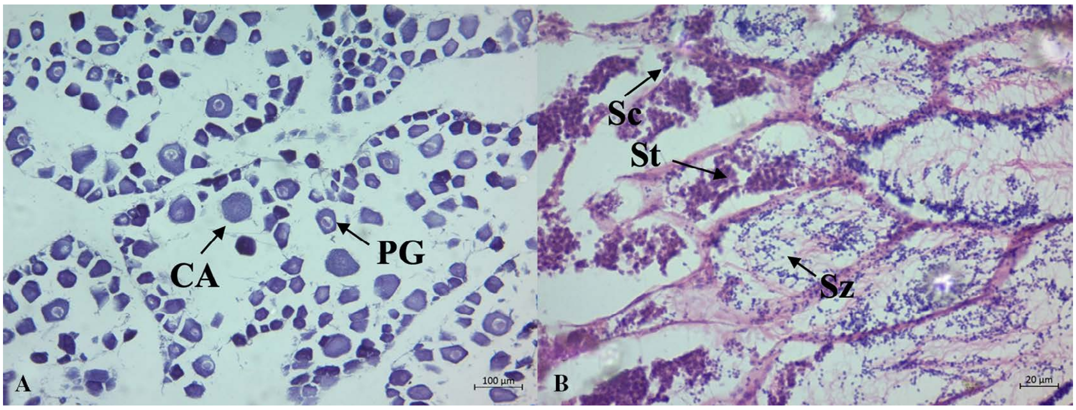

Fig. 5. – Regenerating individual of *P. forsskali*. A, female; B, male. PG, primary growth oocytes; CA, cortical alveolar oocytes; Sc, spermatocytes; St, spermatids; Sz, spermatozoa.

GSI was calculated using the following formula:

GSI=100 (gonad weight/gutted weight).

Size at first maturity

TL was used to estimate size at first sexual maturity (L_M), defined as the size at which 50% of individuals were sexually mature (Tsikliras et al. 2013) The estimation included individuals which had previously reproduced and the virgin ones that were going to reproduce in the current reproductive season for the first time. The fish were split into length classes of 0.5 cm and the proportion of the maturing individuals (P) was calculated in each length class (L). Size at first maturity (L_M) was estimated taking into account only the individuals from the spawning season (May-September), by fitting a logistic curve to the percentage of mature fish (P) per length class (L) for both sexes (Echeverria 1987):

$$P = \frac{e^{(v_1+v_2L)}}{1+e^{(v_1+v_2L)}}$$

and

$$L_M = -\frac{v_1}{v_2}$$

Length-weight relationship

The length-weight relationship (LWR) was estimated and expressed by the following equation (Le Cren 1951, Froese 2006):

$$TW=aTL^b$$

where TW is total weight, TL is total length, a (intercept) is a coefficient related to body form and b (exponent) is a coefficient indicating isometric or allometric growth (Froese 2006). When b=3, the growth is isometric, so the shape of the fish does not change as it grows and the condition of small and large individuals is the same. If b>3, the growth is positive allometric, so the fish increases in weight faster than in length, and if b<3 the growth is negative allometric, so the body shape becomes more elongated as the fish grows in size (Froese 2006).

Age and growth

Growth rate is determined by the relationship between size and age. The von Bertalanffy growth equation is likely the most commonly used growth model in fisheries biology and is used to determine growth parameters (von Bertalanffy 1938):

$$L_t=L_\infty(1-e^{-K(t-t_0)}),$$

where L_t (cm) is the fish somatic TL at time t, L_∞ (cm) is the asymptotic length, i.e. the mean length the fish would have if they were to grow indefinitely, K (y^{-1}) is the rate at which asymptotic length is approached, and t_0 is the time when length is theoretically zero. Relative age was determined on the basis of the length-frequency distribution of the samples using Bhattacharya's method (Bhattacharya 1967), which splits a composite distribution into separate normal distributions, each representing an age group of fish. The program FISAT II (2005) was used for this analysis. The non-linear least-squares method was used to estimate the parameters of the von Bertalanffy growth function, which was fitted to the mean lengths of the age groups.

Mortality

Natural mortality (M) was estimated using Pauly's (1980) equation (1) and the Chen and Watanabe method (2) (Chen and Watanabe 1989) because the latter allows the estimation of M per age class.

Then, an average M across ages was calculated as the average value of these methods (Quinn and Deriso 1999).

$$\log(M)= -0.0066-0.279 \log(L_\infty) + 0.6543 \log(K) + 0.4634 \log(T) \quad (1)$$

$$M(t)=\frac{K}{1-e^{-K(t-t_0)}} \quad \text{when } t \le t_M \quad (t_M=-\frac{1}{K} log(|1-e^{Kt_0}| + t_0)$$

$$M(t)=\frac{K}{a_0+ a_1(t-t_M) + a_2(t-t_M)^2} \quad \text{when } t>t_M \quad (2)$$

Data analysis

Data analysis was done using R version 4.1.3 (R Core Team 2016). The Shapiro-Wilk test was used to test normality of the data, and equal variance was tested with an F-test where needed. The sex ratio between males and females was tested using a chi-squared test at a significance level of 0.05 to see if it differed from unity. Mean TL (± SD) and mean TW (± SD) were calculated and the two-sample t-test was used to test the difference in mean length between sexes. TW of males and females did not have the same variance, so Welch's t-test was used to test the difference there.

RESULTS

Morphometric characteristics of the species

A total of 466 individuals of the Red Sea goatfish were sampled, of which 140 were females, 274 were males and 52 were unsexed (37 juveniles with non-visible gonads and 15 with either non-distinguishable or destroyed gonads). The male to female ratio of Red Sea goatfish was 1.96:1 and differed significantly from the expected ratio (1:1), since a disproportionately large proportion of males were caught (0.66, SE=0.02; chi-squared test, n=414, $P<0.05$).

Overall, TL ranged between 8.2 and 24.1 cm (Table 1). TL ranged from 12.1 to 26.1 cm for males (mean=19.1 cm, SD=2.48) and from 10.3 to 24.1 cm for females (mean=17.4 cm, SD=2.13). The smallest recorded individual was 8.2 cm and was unsexed, but the smallest spawning capable fish was a 10.4 cm long female. TW ranged from 16.69 to 204.22 g for males (mean=79.36 g, SD=33.52) and from 11.07 to 148.19 g for females (mean=58.90 g, SD=22.49). On average, males were heavier and bigger than females, with a significant difference in TW (t=7.26, df=383, $P<0.05$) and TL (t=6.52, df=412, $P<0.05$).

Spawning season

The monthly mean values of the GSI peaked in July for both males (0.747±0.109 SE) and females (4.791±0.353 SE). The GSI decreased in the autumn and reached its minimum monthly mean value in November for females (0.339±0.043 SE) and in March for males (0.072±0.012 SE). It remained low in the winter months but started to rise slowly in the spring for both sexes, and then increased rapidly from May to June (Fig. 6).

The number of spawning capable males and females was highest in July and June for females and in August for males (Fig. 7). Males at all maturity phases were observed in August and July, whereas in November, December and January only regenerating males were present in the sample. In March all females were regenerating, and in September they were all in the regressing phase (Fig. 7).

Size at first sexual maturity

The smallest spawning capable female was 10.4 cm (sampled in June) and the largest immature female was 15.6 cm (sampled in July). The smallest sexually mature male was 14.3 cm (sampled in July) and the largest sexually immature male was 13.5 cm (sampled in August). The estimated size at which 50% were sexually mature was 14.2 cm for males and 11.8 cm for females (Fig. 8).

Table 1. – Total length (cm) and total weight (g) of the male, female and unsexed individuals of the Red Sea goatfish collected in Cyprus waters. SD=standard deviation.

Data	Number of individuals	Total length (cm)	Mean±SD	Total weight (g)	Mean±SD
Male	272	12.1–26.1	19.0±2.48	16.69–204.22	79.06±33.52
Female	140	10.3–24.1	17.4±2.13	11.07–148.19	58.90±22.49
Unsexed	52	8.2–19.0	14.8±3.19	4.49–74.25	38.48±21.44
All	466	8.2–26.1	18.1±2.83	4.49–204.22	68.48±32.49

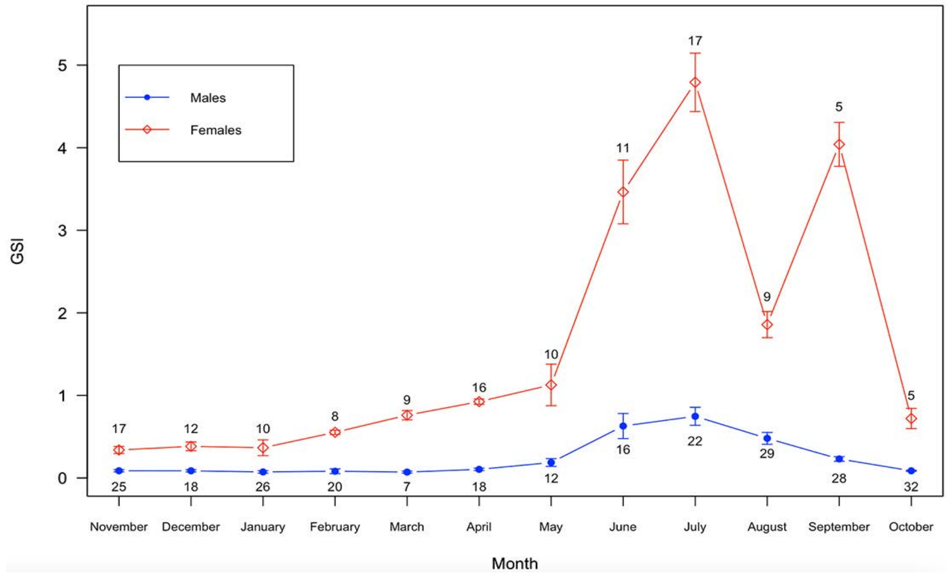

Fig. 6. – Monthly mean values of the gonadosomatic index (GSI) for both males (blue line and dots) and females (red line and dots) of the Red Sea goatfish collected in Cyprus waters. Error bars indicate standard error. Numbers show the number of individuals examined.

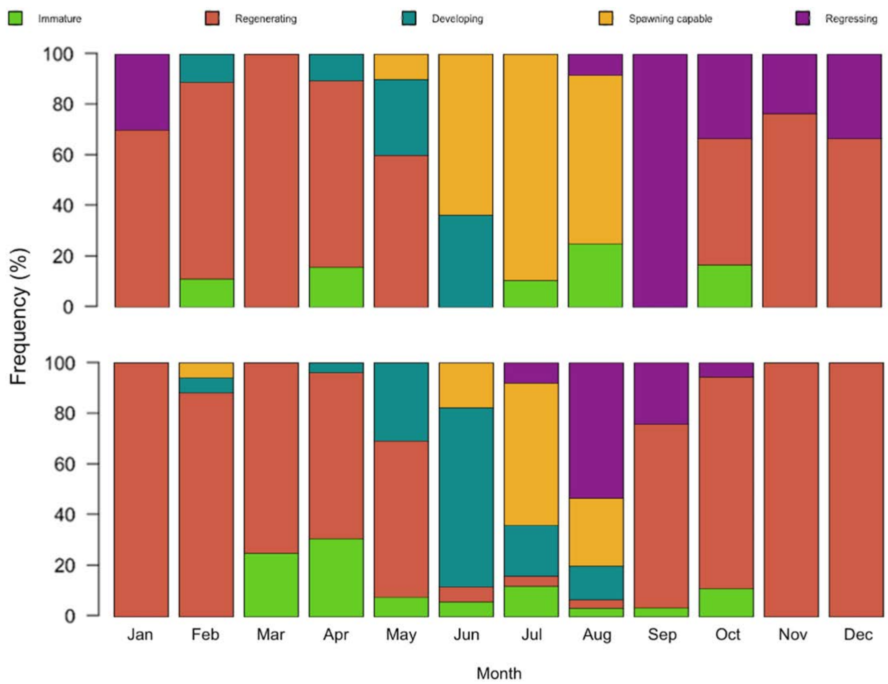

Fig. 7. – Frequency of maturity phases of the Red Sea goatfish collected in Cyprus waters in each month. Upper panel, females; lower panel, males.

Table 2. – The length-weight relationship parameters of the Red Sea goatfish collected from Cyprus waters. CI=confidence interval.

Data	Number of individuals	*a*	*b*	95% CI of *b*	Type of growth
Male	274	0.0065	3.17	3.12–3.23	Positive allometric
Female	140	0.0086	3.07	2.98–3.16	Positive allometric

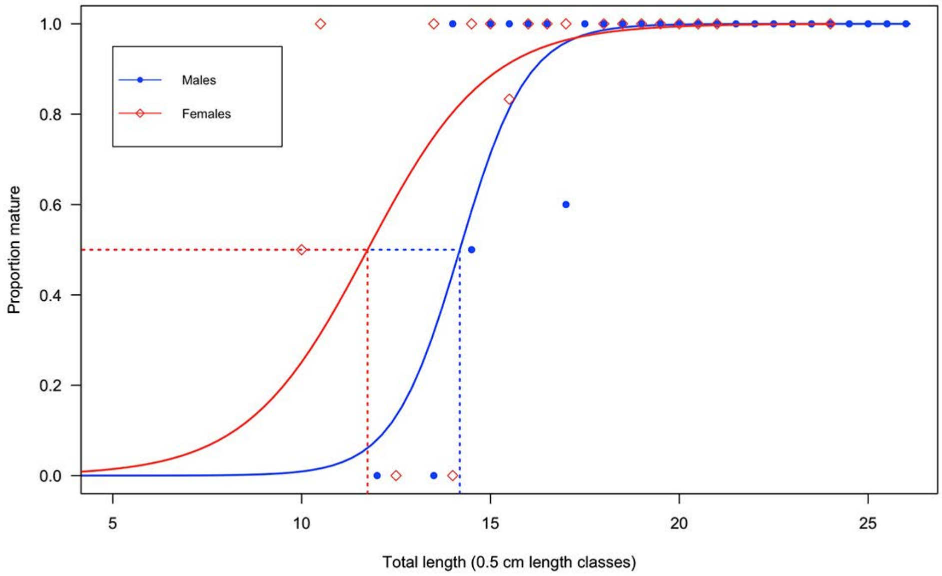

Fig. 8. – Observed (dots) and estimated (line) proportion of maturing individuals at length (L, cm) of the Red Sea goatfish collected in Cyprus waters (males, solid circles; females, open rhombus). The dotted lines indicate L_M.

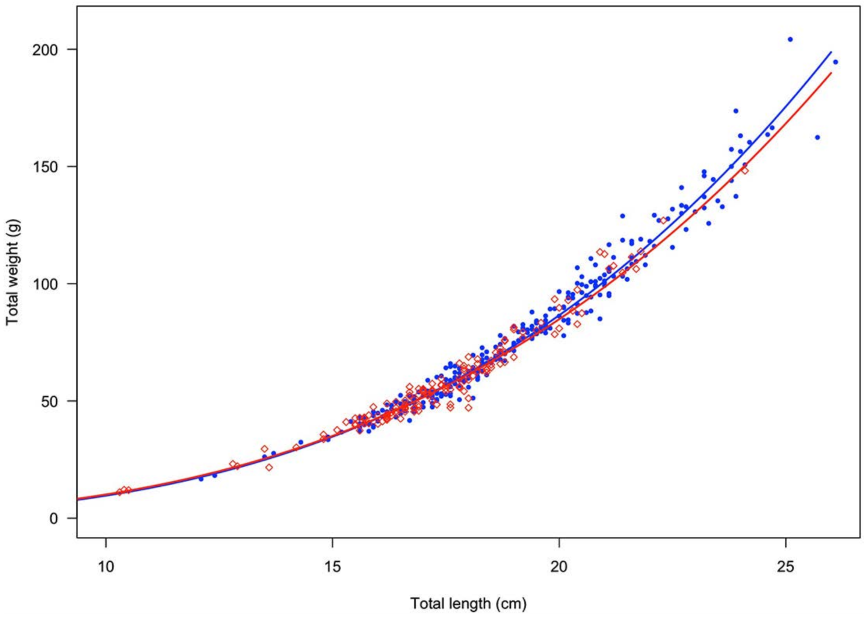

Fig. 9. – The total length-total weight relationship for males (blue solid dots and line) and females (red open rhombus and line) of the Red Sea goatfish collected from Cyprus waters.

Length-weight relationship

The LWR was TW=0.0065 $TL^{3.17}$ (r^2=0.99, n=274) for males and TW=0.0086 $TL^{3.07}$ (r^2=0.97, n=140) for females, indicating positive allometric growth for both sexes (Table 2, Fig. 9).

Age and growth

Five age groups were identified from the length class-frequency distribution (Fig. 10, Table 3), from age group 0 to age group 4 (0-4 years old). The most dominant age group was age group 1, which accounted for more than 59% of fish (Table 3).

Table 3. – Length classes within relative age groups and mean length and frequency of age groups of the Red Sea goatfish collected from Cyprus waters. SD=standard deviation.

Age group	Mean length-at-age (cm) ± SD	Number of fish	Age group frequency (%)
0	11.3±1.7	30	6.44
1	17.2±1.0	278	59.66
2	20.2±1.1	129	27.68
3	23.3±0.8	26	5.58
4	25.8±0.6	3	0.64

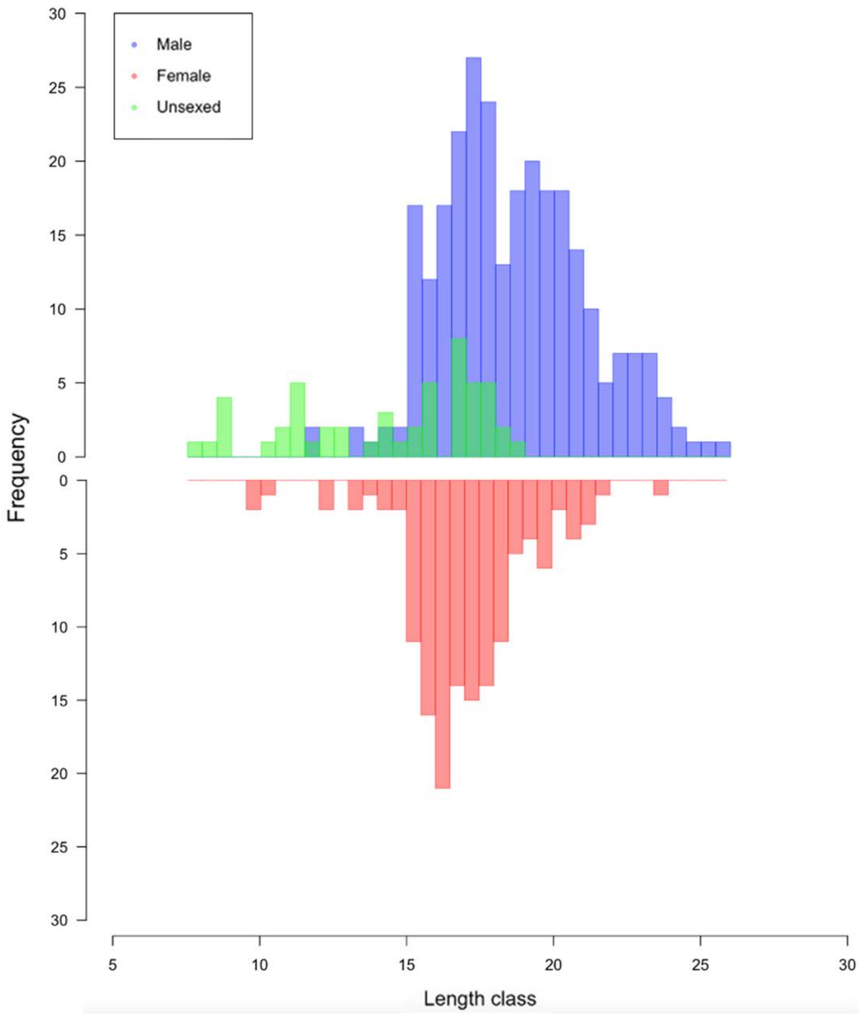

Fig. 10. – The length-frequency distribution of the Red Sea goatfish collected from Cyprus waters. Unsexed individuals are shown in green, males in blue and females in red.

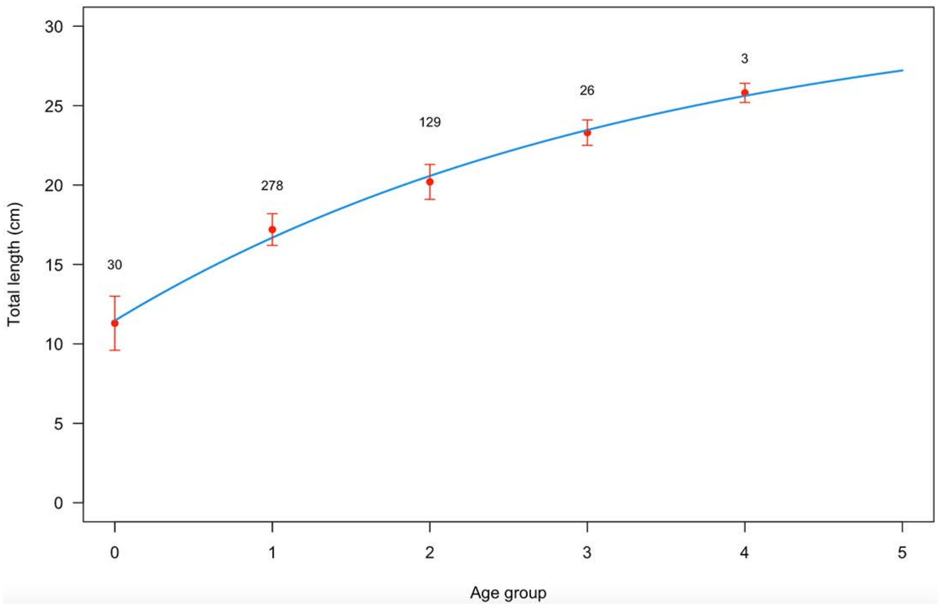

Fig. 11. – The von Bertalanffy growth curve of the Red Sea goatfish collected from Cyprus waters. The red dots indicate the mean total length in each age class, and the whiskers represent standard deviation. Numbers indicate the number of individuals examined.

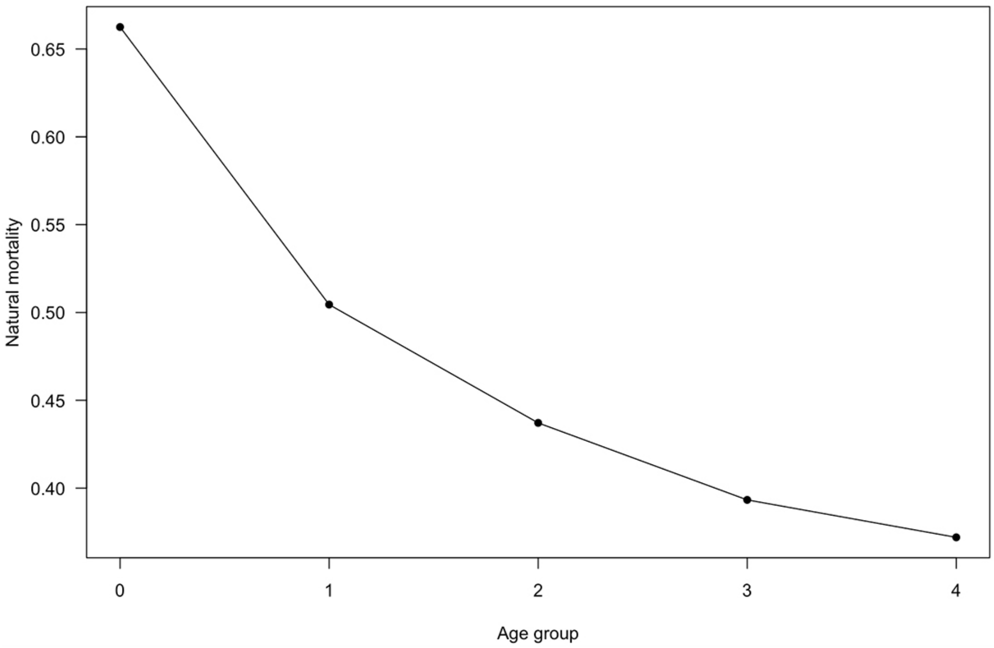

Fig. 12. – The natural mortality coefficient of each age group of the Red Sea goatfish collected from Cyprus waters.

The parameters of the von Bertalanffy growth function were L_∞=31.86 cm (SE=4.70), K=0.30 year^{-1} (SE=0.12), and t_0=–1.51 (SE=0.40), giving the equation (Fig. 11):

$$L_t=31.86(1-e^{-0.30(t+1.51)})$$

Mortality

The average natural mortality coefficient (M) was 0.474 year^{-1} across age groups using the Chen and Watanabe method and 0.651 year^{-1} using Pauly's equation. Therefore, a mean M of 0.563 year^{-1} was calculated using both methods. According to the Chen and Watanabe equation, natural mortality declined with age (Fig. 12).

DISCUSSION

According to Daskalaki et al. (2022), research regarding the biology of Mediterranean marine fishes should now focus mainly on vulnerable species and species that could potentially pose a threat to the Mediterranean marine habitat, such as non-indigenous species. The results of this study partly fill the gap regarding the maturation phases, spawning season, size at first maturity, length-weight relationship and mortality of the Red Sea goatfish *Parupeneus forsskali* in its new environment, the Mediterranean Sea.

Sabrah (2015) studied the species in the Red Sea in a yearlong study and found that TL ranged from 11.1 cm to 28.5 cm (n=456). Another yearlong study in the Red Sea reported a TL of 11.5 to 27.9 cm and a TW of 16.6 to 275.3 g (n=375) (Mehanna et al. 2018). Neither of these studies fished specifically for smaller individuals as was done in the month of July in the present study, and they had nets with a larger mesh size (2-3 cm), which could explain why their smallest individuals are larger than the smallest individuals sampled here. A possible reason for smaller sizes in Cyprus is the deficiency of food in the oligotrophic system of Cyprus and the temperature range, which is wider than that of the species' native Red Sea (Ben-Tuvia 1966).

Males were on average heavier and bigger than females, but the LWRs of males and females were similar, and both indicated positive allometric growth, meaning that the fish becomes rounder as it grows. Besides technical issues related to sampling and preservation method, the parameters of the LWR can be affected by numerous biological factors, such as the availability of prey, environmental conditions, and gonadal maturity stages (Froese 2006). In most fish species, the females grow bigger than the males, even though they have to spend more energy on reproduction. Males usually spend more energy on courtship or fighting with competitors, limiting their growth (Pauly 2019). Studies on red mullet *Mullus barbatus* (Sieli et al. 2011) and Por's goatfish *Upeneus pori* (Geraci et al. 2018), both off the coast of Italy, reported significantly larger females. On the other hand, Sabrah (2015) reported slightly larger Red Sea goatfish males than females in the northern Red Sea, as in the present study. This could mean that the Red Sea goatfish females are more active than males. Further, the same study also reported more Red Sea goatfish males than females in the Red Sea, a result that agrees well with our results. On the contrary, a study on other mullids (*Upeneus guttatus* and *U. pori*) in the Gulf of Suez showed that females were more abundant, with almost a 1:2 ratio (Sabrah et al. 2017). Amin et al.

(2016) reported a female dominance of the surmullet *Mullus surmuletus* in the Egyptian Mediterranean. The reason for this high proportion of males in the present study is difficult to pinpoint, but the difference in the sex ratio was by far greatest in the months of August, September and October, so it could have something to do with post-spawning activities. Since females spend a lot of energy on reproduction, they might be more susceptible to injury, disease or predation after spawning (Wootton and Smith 2015). Further, in this study 52 individuals were labelled as unsexed for various reasons. Thirty-seven of them were small-sized juveniles, so with non-distinguishable gonads, while the remaining 15 were individuals of larger sizes that could not be assigned to a sex, mostly because the gonads were destroyed. The relatively high number of unsexed individuals could, in theory, increase the uncertainty in estimating the sex ratio of the population, especially in small sizes.

Knowing the timing of maturity in fish species is important for effective fisheries management (Tsikliras and Stergiou 2014). According to our results, the monthly mean GSI of the Red Sea goatfish peaked in July for both males and females. It was quite high in June and August as well, indicating a summer spawning season. The mean GSI of females showed a sharp drop in August and in September rose again. This can be explained by a lack of female samples during this period, since only five females were obtained in September, all having a relatively high GSI (all in the regressing phase). Further, in August only nine females were obtained, with most of them being spawning capable (eight individuals) and one in the regressing phase. If the number of individuals from August to September were higher, the fall in the GSI of females in August would not be so pronounced and would probably follow the GSI of males, which seems to be more indicative owing to the higher number of examined individuals. The maturity phases indicate that spawning activities take place in the summer, since the most advanced phases were mainly observed in those months. The GSI and maturity phases therefore show that the Red Sea goatfish around Cyprus typically spawns from May to August, and possibly also in September. Farrag et al. (2018) reported a spawning season of the Red Sea goatfish from April to August in the Red Sea, and this slight difference from our results can probably be attributed to the more stable and higher temperatures prevailing in the tropical Red Sea. Other mullids in the Mediterranean and the Gulf of Suez have been observed spawning in the spring and summer months: for example, the native red mullet (*Mullus barbatus*, April-June in the northern Aegean Sea) (Kokokiris et al. 2014) and the aliens *Upeneus guttatus* (May-September in the Gulf of Suez) (Sabrah et al. 2017), *Upeneus pori* (April–June in the Egyptian Mediterranean) (Ramadan and El-Halfawy 2014) and the golden-banded goatfish (*Upeneus moluccensis*, August–September off the southern coast of Turkey) (Kaya et al. 1999). It is obvious that the alien mullids have a later spawning season that appears mainly in summer months, and this can be attributed to their tropical origin, which means that they are well adapted to higher sea temperatures (Uiblein 2007).

The size at maturity was estimated at 14.2 cm for males and 11.8 cm for females. A study on the Red Sea goatfish conducted in the Red Sea reported an LM of 15.38 cm for both sexes (Sabrah 2015), although a net with a larger mesh size was used, so smaller fish were more likely to escape and this could explain the difference between these two LM values. The LM of the Red Sea goatfish in the Mediterranean can be used in fisheries management to determine the optimum mesh size of the fishing nets, either to ensure that the spawning population is maintained to keep the fishery sustainable, or to eliminate the species or reduce its abundance in certain marine areas because it is not a native species and can have a negative impact on native mullids, although this management strategy may not be as effective as predicted (Michailidis et al. 2022). According to the same authors, the biomass of alien mullids in Cyprus was estimated at 0.068 t km^{-2}, whereas for the native mullids it was estimated at 0.072 t km^{-2} (Michailidis et al. 2022, Appendix A. Supplementary material). Furthermore, Michailidis et al. (2019) estimated that in Cyprus alien fish accounted for 29% of fish production. Thus, it is urgent to understand that in Cyprus, were oligotrophic conditions prevail and empty niches are still available, alien mullids (and other alien species) thrive and can probably reach abundances similar to those of native ones. In order to clarify the impacts of alien mullids (including the Red Sea goatfish) on the native ones, more studies comparing various biological and ecological characteristics of the species need to be performed. From fishers' testimonies, it seems that the abundances of native mullids in Cyprus are declining (personal communication with fishers).

Five age groups were identified for Red Sea goatfish in the current study. Mehanna et al. (2018) and Sabrah (2015) identified six age groups in the Red Sea using otoliths, scales and length-frequency data for ageing. However, the largest individuals sampled in these studies were 27.9 cm and 28.5 cm long, respectively, whereas the largest individual in the present study was only 26.1 cm long. Furthermore, in the study by Sabrah (2015), the mean length of age group 5 was 26.9 cm, which is considerably larger than the largest fish sampled in the present study. It is possible that the Red Sea goatfish does not reach these sizes around Cyprus and only lives for four years because of less favourable conditions, as opposed to five years in its native region, or that larger individuals are indeed present in the sea but were not sampled. This can also explain the mortality (M), which is known to be increasing in the older ages because of senescence, but this is not clear in our results because we did not catch all ages and especially the older and larger ones. Natural mortality was on average 0.563 $year^{-1}$. Sabrah (2015) reported an M of 0.9 $year^{-1}$ and Farrag et al. (2018) reported a mean M of 0.55 $year^{-1}$, both in the Red Sea. The difference in these values could be due to technical issues related to the sample size and the length-frequency distribution of the samples, but more importantly to differences in growth and environmental temperature; natural mortality is related positively to sea temperature and negatively to asymptotic length (Pauly 1980). The mean length of age group 4 was 25.8 cm, which is similar to the same age group reported by Sabrah (2015), 25.5 cm. Age group 1 was the most dominant, which could indicate extensive targeting of larger individuals by fisheries. Mehanna et al. (2018) reported the same results, with 46.1% of individuals belonging to age group 1, whereas Sabrah (2015) reported age group 2 to be the most dominant with 40.6% of individuals and age group 1 to be the second most dominant with 25.2% of individuals.

Maturing individuals from all age groups were sampled, meaning that the Red Sea goatfish are able to mature in their first year of life. The equation of the von Bertalanffy growth function was

$$L_t=31.86(1-e^{-0.30(t+1.51)})$$

similar results were presented by Mehanna et al. (2018), with L_∞=31.62 cm, K=0.32 year^{-1} and t_0=–1.27, and by Sabrah (2015), with L_∞=30.0 cm, K=0.38 year^{-1} and t_0=–0.43. The differences in the von Bertalanffy parameters can possibly be explained by different maximum observed lengths in each study. Further, the negative value of t_0 in our results can also be explained by the low number of small individuals of the 0 age group (<10 cm), and the fact that only a very small number of the larger-sized age 0 individuals were taken; therefore the growth curve was shifted to the left and caused a deviation of t_0 from 0. Changes in the growth rate between years can indicate changes in the environment, such as in the temperature of the ocean, so this information on age composition and growth rate can be used to predict the status of the population in the future.

In conclusion, this study has identified the spawning season of Red Sea goatfish in the eastern Mediterranean Sea and described the cycle of maturity stages that the species goes through each year. It has also identified the size at maturity, the LWR, growth rate parameters, and natural mortality. The Red Sea goatfish has only recently entered the eastern part of the Mediterranean Sea but is migrating further and further west at a rapid rate. Therefore, research on this species must be carried out across the Mediterranean in the coming years in order to compare and have a more holistic view of the aforementioned biological features to facilitate the management of this alien species more quickly in time.

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