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Reproductive features of *Gerres longirostris* Lacepède, 1801 (Perciformes: Gerreidae) off the Red Sea coast of Jeddah, Saudi Arabia

by

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Abstract

Sustainable management and conservation strategies are crucial for any species of *Gerreidae*. Without comprehensive research on population biology, maintaining a balance between having healthy natural stocks and the socio-economic benefit of fisheries is difficult. Therefore, we studied some aspects of the biology of *Gerres longirostris* based on 474 specimens collected from the Red Sea (Jeddah coast, Saudi Arabia). The overall sex ratio of males to females was found to be 1:1.52, which was significantly different from the expected ratio of 1:1 ($p < 0.05$). Histological analysis of ovaries and testes and monthly variations in GSI values for *G. longirostris* indicated that spawning occurs between March and June, with a peak in GSI in May, and the trend was similar for both sexes. Size at 50% sexual maturity was estimated at 19.8 cm for females and 20.2 cm for males. The maximum batch and relative fecundity were estimated at 315,210 ova, 10,832 ova/cm, and 1068 ova/g, respectively. Batch fecundity and relative batch fecundity were significant correlated with total length (TL, cm) and body weight (BW, g) at $p < 0.05$. Histological examination of gonads revealed that their maturation in this species is asynchronous, with different developmental stages of oocytes at the same time, which indicates that the species is a multiple-batch spawner with indeterminate fecundity.

Key words: *Gerres longirostris*, Gonadosomatic Index, size at first sexual maturity, fecundity, histology, Red Sea

1. Introduction

The world's population and consumption of fish have increased simultaneously due to their high nutritional value and health benefits for the growing human population. The Red Sea and Arabian Gulf capture fisheries and aquaculture sectors contribute to the food security of the Saudi population. As indicated in the latest catch statistics report published by the Ministry of Environment, Water and Agriculture (MEWA 2019), Saudi Arabia's total annual fish production has increased over the last two decades from 61,335 tons in 2001 to 141,536 tons in 2019. Sustainable management and conservation strategies are critical to any species of capture fisheries.

Accurate assessment of population parameters pertaining to fish reproduction is crucial for effective fisheries management (Brown-Peterson et al. 2011). Estimates of population structure, fecundity, sexual maturity, and spawning strategies, which have a large impact on how populations change over time, are important components of fisheries science (Hunter et al. 1992). Information on length at maturity and spawning season identifies when and at what length fish should be protected, and is therefore important for proper management and conservation of fish stocks (Ilkyaz et al. 2018). Moreover, histological studies of reproductive biology have consistently yielded increasingly accurate and precise results (Balci & Aktop 2019).

The strongspine silver-biddy, *G. longirostris*, is one of the economically valuable food fish with high protein content (Al-Ghais & Varadharajulu 2019). It is available in the fish market throughout the Gulf countries, including Saudi Arabia, and is one of the preferred fish. *G. longirostris* is a member of the Gerreidae family, which includes about 53 species commonly known as mojarras (Fricke et al. 2023). It is the dominant gerreid species inhabiting the Red Sea and contributes to fishery production (Iwatsuki et al. 2001). The Red Sea, which is part of the Indo-Pacific region, has a unique biologically diverse reef community (DeVantier et al. 2000), and *G. longirostris* is found throughout this region (Grandcourt et al. 2006; Iwatsuki et al. 2001; Sumon et al. 2020). This species prefers shallow coastal water, mainly seagrass beds (Hosny & Al-Jaber 2017), coral reefs (Gell & Whittington 2002) and feeds on small mollusks, crustaceans and polychaete worms (Sumon et al. 2020). Randall and Hoover (1995) documented the largest total length for *G. longirostris* in the coastal waters of Oman at 37 cm length (TL), Allen & Erdmann (2012) at 44.5 cm TL in the East Indies, and Hosny and Al-Jaber (2017) at 30 cm and 40 cm TL for males and females, respectively, in the western Arabian Gulf.

The reproductive biology of gerreids has been extensively studied throughout most of their geographical distribution (Iqbal et al. 2007; Kanak & Tachihara 2008; Lamtane et al. 2009; Sivashanthini 2008; Subardja Sjafei & Dian Syaputra 2009; Valdez-Zenil et al. 2014). Hosny and Al-Jaber (2017) and Grandcourt et al. (2006) previously studied the reproductive biology of *G. longirostris* in the Arabian Gulf. However, fecundity assessment and histological observations of gonadal cell development, as well as reproductive biology of this species off the Red Sea coast of Jeddah have not yet been carried out. Therefore, the purpose of this study was to evaluate the reproductive biology in terms of sex ratio, size at first sexual maturity, GSI, spawning season, fecundity, in addition to histological observations of the developmental stages of gonads.

2. Materials and methods

2.1. Sample collection and preparation

A total of 474 fresh samples (188 males and 286 females) of the strongspine silver-biddy were collected between August 2019 and July 2020. Monthly samples were obtained from artisanal fishermen using gillnets in Jeddah fisheries (Fig. 1). The collected samples were transported to the marine biology research laboratory at King Abdulaziz University where total length (TL) and wet weight (TW) were measured to the nearest 0.1 cm and 0.1 g, respectively. Specimens were dissected and their gonads were removed and kept in 10% formalin for further analysis. Sex was determined by macroscopic examination of the gonads. Different stages of maturity were macroscopically defined as: I – immature, II – maturing virgin and recovering spent,

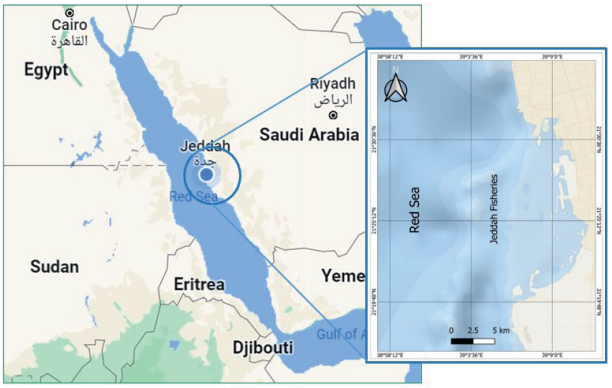


Figure 1

Sampling location for *G. longirostris* in the Red Sea, Jeddah fisheries, Saudi Arabia.

III – ripening, IV – ripe/running and V – spent. Gonads were preserved for later fecundity assessment and histological observations.

2.2. Sex ratios

The sex ratio was computed based on the proportion of males and females in each month and in different length groups (3 cm length interval), using the following equation: proportion of males (or females) = [males (or females)/total samples] × 100. The chi-square (χ2) test was used to determine whether the sex ratios differ from the expected ratio of 1:1.

2.3. Gonadosomatic Index

The Gonadosomatic Index (GSI) was computed as: GSI = (WG/TW – WG) x 100, where WG is gonad weight in grams and TW is total weight in grams (Şahin et al. 2009). The monthly mean GSI for males and females was estimated to determine the spawning season.

2.4. Size at first sexual maturity (L_m)

The proportion of maturity (maturity stages I and II are considered immature) at length (P_m) was determined by fitting the following logistic model (Gunderson et al. 1980):

$$P_m = \frac{1}{1+e^{(dTL+c)}}$$

where d and c are the slope and intercept, respectively. The mean size at first sexual maturity (L_m), where 50% of fish are sexually mature, was calculated from the estimated values of c and d according the following form:

$$L_m = -\frac{c}{d}$$

An analysis of variance (ANOVA) test was used to check for significant differences in percent maturity at different lengths (maturity ogive) between males and females.

2.5. Fecundity

Seventy-one ripe female ovaries (pre-spawned) were used to estimate the fecundity of *G. longirostris*. Three subsamples were collected from each ovary and the total number of ripe ova in each subsample was counted, then the average number of ripe ova in the three subsamples was calculated. The total number of ripe ova in the ovaries of each female (individual batch fecundity) was estimated according to the following equation: $BF = W_G \times N / W_S$, where BF is the individual batch fecundity, W_G is the total weight of the female's ovaries, N is the average number of ova in all subsamples, and W_S is the average weight of all subsamples. The relative BF (BF_{rel}) was estimated by dividing the batch fecundity by total length (cm) or total body weight (g). The standard regression analysis was used to describe the nature and strength of the relationship between fish fecundity (batch and relative) and fish size (TL or BW) of females.

2.6. Gonad histology

Small sections of fixed ovaries and testes (washed, dehydrated, cleared, and embedded in paraffin wax) were used for routine histological assessment. The 4 µm thick sections were cut out using a microtome (LEICA RM2255) and then stained with hematoxylin and eosin. The mounted slides were viewed under a microscope (AmScope) using a digital camera connected to a personal computer, where AmScope software was used to take and save images. The developmental stages of ovaries and testes were categorized (Table 1) based on standardized terminology of Knuckey and Sivakumaran (2001) and Brown-Peterson et al. (2011).

2.7. Statistical analyses

The chi-square (χ2) test was used to determine whether monthly or within-length-groups sex ratios differ from the expected ratio of 1:1. The analysis of variance (ANOVA) test was used to check for significant differences in percent maturity at different lengths (maturity ogive) between males and females using Excel software.

3. Results

3.1. Population structure

The total length of the examined *G. longirostris* specimens ranged from 11.5 cm to 33.1 cm with a mean of 22.4 ± 3.74 cm for females and from 11.4 cm to 27.8 cm with a mean of 20.3 ± 3.1 cm for males. The total weight ranged from 21.7 g to 405 g with a mean of 151 ± 71.8 g for females and from 24.6 g to 284.6 g with a mean of 111 ± 52.42 g for males.

Table 1

Maturity categories based on histological descriptions of the developmental stages of the gonads of *G. longirostris* from the Red Sea.

Maturity categories	Most advanced oocyte stages	Most advanced sperm stages
Immature	Peri-nucleus stage	Spermatogonia
Early developing	Yolk vesicle stage	–
Developing	Primary or secondary yolk globule stage	Primary or secondary spermatocytes
Late developing	Tertiary yolk globule stage	Spermatids
Ripe/running	Migratory nucleus or hydrated oocytes stages or yolk globule stages and postovulatory follicle	Spermatozoa
Spent	Peri-nucleus stage with atretic oocytes or postovulatory follicle	Residual spermatozoa (rs) + spermatogonia

Monthly variations in the sex ratio of *G. longirostris* are shown in Figure 2. Females predominated in all months, with significant differences in sex proportions in favor of females found in October and November (Table 2). The estimated overall sex ratio was found to be significantly different from the expected ratio of 1:1 (χ^2 = 20.262, p < 0.05), with a skew toward females (1.52:1). Variations in the sex ratio in the size classes of *G. longirostris* are presented in Figure 3. Variations in the proportions of sexes related to sizes showed female dominance in all sizes, with significant dominance of females in the size classes from 16 to 27 cm (Table 3).

3.2. Gonadosomatic Index and spawning season

Monthly changes in GSI for both females and males showed a significant increase in values in March with a peak in May (females: 8.0; males: 3.5; Fig. 4). A sharp

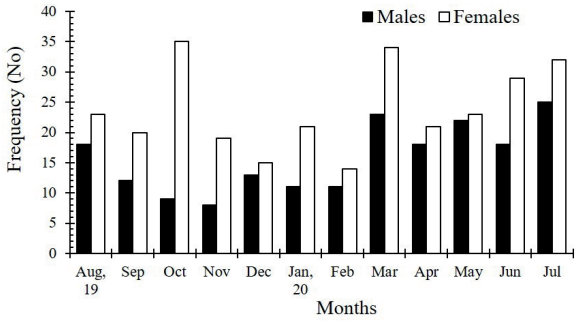


Figure 2

Monthly variations in the sex ratio of *G. longirostris* in Jeddah fisheries.

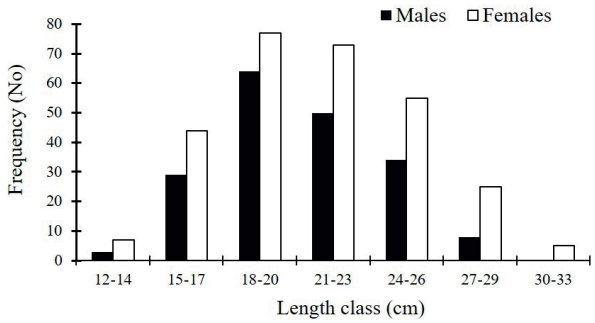


Figure 3

Sex ratio variations in size classes of *G. longirostris* from Jeddah fisheries.

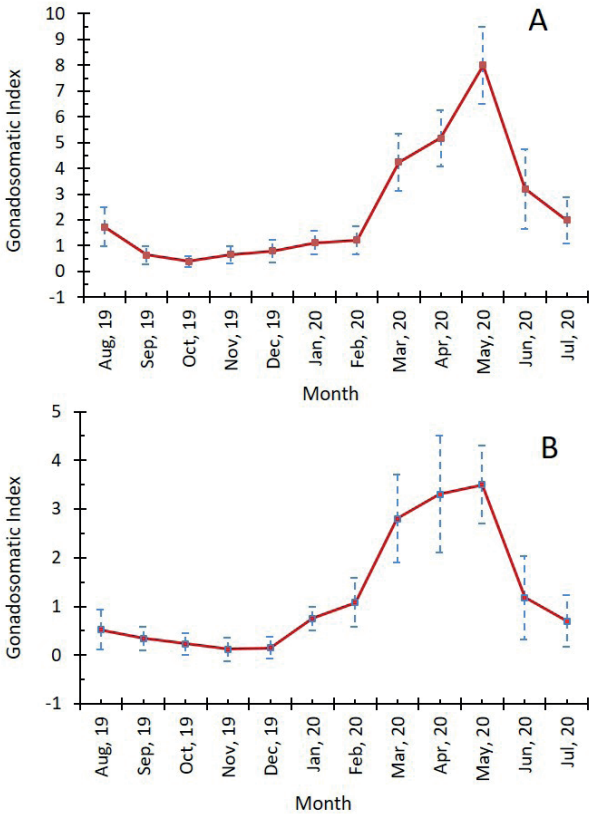


Figure 4

Monthly variation in GSI of females (A) and males (B) of *G. longirostris* collected from Jeddah fisheries.

Table 2

Monthly variation in Gonadosomatic Index (GSI), sex ratio and chi-square (χ2) test for *G. longirostris* collected from Jeddah fisheries.

Month	Total specimens	Males		Females		Sex ratio (M:F)	χ^2	P-value
		No.	GSI (mean ± SD)	No.	GSI (mean ± SD)			
Aug	41	18	0.52 ± 0.41	23	1.73 ± 0.76	1:1.28	0.610	0.4350
Sep	32	12	0.34 ± 0.24	20	0.64 ± 0.36	1:1.67	2.000	0.1570
Oct	44	9	0.23 ± 0.22	35	0.39 ± 0.22	1:3.89	15.36	0.0001*
Nov	27	8	0.12 ± 0.24	19	0.65 ± 0.33	1:2.38	4.481	0.0343*
Dec	28	13	0.15 ± 0.22	15	0.80 ± 0.43	1:1.15	0.143	0.7050
Jan	32	11	0.75 ± 0.25	21	1.12 ± 0.44	1:1.91	3.125	0.0771
Feb	25	11	1.08 ± 0.50	14	1.22 ± 0.54	1:1.27	0.360	0.5480
Mar	57	23	2.80 ± 0.90	34	4.24 ± 1.11	1:1.48	2.123	0.1450
Apr	39	18	3.30 ± 1.20	21	5.17 ± 1.10	1:1.17	0.231	0.6310
May	45	22	3.50 ± 0.80	23	8.00 ± 1.50	1:1.05	0.022	0.8820
Jun	47	18	1.18 ± 0.85	29	3.20 ± 1.54	1:1.61	2.574	0.1090
Jul	57	25	0.70 ± 0.53	32	1.99 ± 0.90	1:1.28	0.860	0.3540
Total	474	188		286		1:1.52	20.262	0.00001*

M = Male, F = Female; *significant difference at $p \leq 0.5$

Table 3

Sex ratio and chi-square (χ2) test comparisons by length groups of *G. longirostris* collected from Jeddah fisheries.

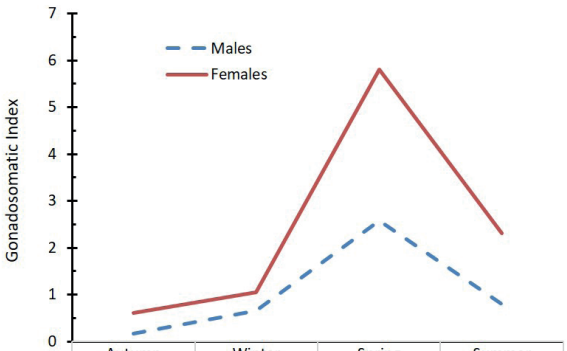
Total length (cm)	Total specimens	Males	Females	Sex ratio (M:F)	χ^2	P-value
12–15	17	7	10	1:1.43	0.529	0.4670
16–19	175	74	101	1:1.36	4.166	0.0412*
20–23	152	63	89	1:1.41	4.447	0.0350*
24–27	91	28	63	1:2.25	13.462	0.0002*
28–31	21	9	12	1:1.33	0.429	0.5125
32–35	18	7	11	1:1.57	0.889	0.3460

M = Male, F = Female; *significant difference at $p \leq 0.5$

decline in mean GSI values for females was recorded in June before reaching a minimum value in October. For males, GSI values showed similar monthly variations compared to females, albeit with lower values (Fig. 4). Average seasonal values of GSI for males and females indicate that the spawning season of *G. longirostris* occurs in spring (Fig. 5). The mean values and range of GSI corresponding to each month and maturity stage for males and females are given in Table 2 and Table 4, respectively. Mean GSI values of each ovarian maturity stage determined by macroscopic analysis showed that females with stage III to V ovaries tended to occur from March to June. This indicated that the likely spawning season of *G. longirostris* lasted from March to June with a single period of spawning.

3.3. Size at first sexual maturity (L_m)

The size at first sexual maturity estimated for males and females using the logistic model is shown in Figure 6. The estimated L_m for females and males was 19.8 cm and 20.2 cm TL, respectively. This indicates that both sexes of *G. longirostris* in the Jeddah fisheries mature at almost the same size. There was no statistically



	Autumn	Winter	Spring	Summer
Males	0.17	0.66	2.57	0.80
Females	0.61	1.05	5.80	2.31

Figure 5

Seasonal variation in GSI of males and females of *G. longirostris* collected from Jeddah fisheries.

Table 4

Mean values and range of Gonadosomatic Index (GSI), corresponding to the maturity stages of males and females of *G. longirostris* collected from Jeddah fisheries.

Maturity stage	Males				Females			
	Fish No.	Min.	Max	Mean ± SD	Fish No.	Min.	Max	Mean ± SD
I	41	0.090	0.784	0.326 ± 0.19	81	0.115	1.064	0.290 ± 0.18
II	21	0.119	1.872	0.989 ± 0.52	26	0.254	2.031	0.946 ± 0.57
III	24	0.559	4.120	1.732 ± 0.98	31	1.551	8.727	3.543 ± 1.02
IV	27	1.194	6.788	4.021 ± 1.38	52	6.588	10.144	8.566 ± 1.45
V	18	0.786	3.542	1.994 ± 0.98	29	2.485	9.152	5.084 ± 1.16

significant difference between males and females in terms of size at first maturity (F = 0.0198; p = 0.889; Fcrit = 4.07).

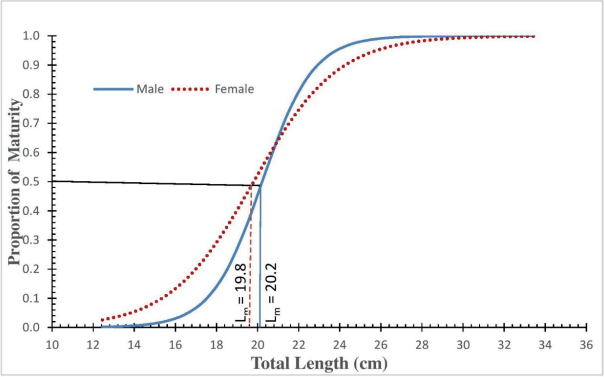


Figure 6

Size at first sexual maturity of males and females of *G. longirostris* collected from Jeddah fisheries.

3.4. Fecundity

The fecundity of *G. longirostris* was analyzed based on a sample of 71 mature females with a total body length ranging from 18.5 cm to 29.5 cm (24.54 ± 2.51 cm) and body weight ranging from 85 g to 300 g (187.12 ± 55.08 g). Significant ($p < 0.05$) relationships of batch fecundity (BF) and relative BF with total body length (TL) and body weight (BW) are described by the following equations and shown in Figure 7:

$$BF = 0.00002\ TL^{6.9} \quad (R^2 = 0.847)$$
$$BF_{rel} = 0.00002\ TL^{5.9} \quad (R^2 = 0.802)$$
$$BF = 0.592\ BW^{2.3} \quad (R^2 = 0.857)$$
$$BF_{rel} = 0.592\ BW^{1.3} \quad (R^2 = 0.660)$$

As the fish length increased from 18.5 to 29.5 cm, the batch fecundity increased from 9077 to 315,210 ova, and the relative BF increased from 480 to 10,832 ova/cm and from 102 to 1068 ova/g.

3.5. Classification of oocyte developmental stages

Based on histological observations, the oocytes of *G. longirostris* were classified into the following nine developmental stages:

1. Peri-nucleolus stage (Fig. 8a): Oocytes were very small with cytoplasm heavily stained with hematoxylin. Some large, spherical, intensely basophilic nucleoli were observed in the nucleus, as well as a thin follicle layer visible around the oocyte. The size of oocytes was 50–80 µm.
2. Yolk vesicle stage (Fig. 8b): The size of oocytes became larger, as well as the follicle layer was visible. White yolk vesicles began to appear in the cytoplasm underneath the cell membrane and near the nucleus. Oocytes ranged in size from 95 µm to 205 µm.
3. Primary yolk globule stage (Fig. 8c): The minute yolk globule appeared for the first time in the peripheral region of the cytoplasm. Smaller oil droplets were present around the nucleus. Yolk vesicles began to fuse at this stage. The follicle layer became thicker than in the previous stage. The size of oocytes was in the range of 145–235 µm.
4. Secondary yolk globule stage (Fig. 8d): Yolk globules increased in size and number and occupied most of the cytoplasm. Larger oil droplets were distributed in the cytoplasm. Oocytes were 210–300 µm in size.
5. Tertiary yolk globule stage (Fig. 8e): Yolk globules became larger and increased in number. Yolk globules filled the entire cytoplasm with many oil droplets. The size of oocytes was in the range of 270–400 µm.
6. Migratory nucleus stage (Fig. 8f): The nucleus moved toward the animal pole, where the micropyle is located. Oil droplets also began to fuse. Oocytes at this stage measured 290–460 µm.
7. Hydrated oocyte stage (Fig. 8g): At this stage, yolk

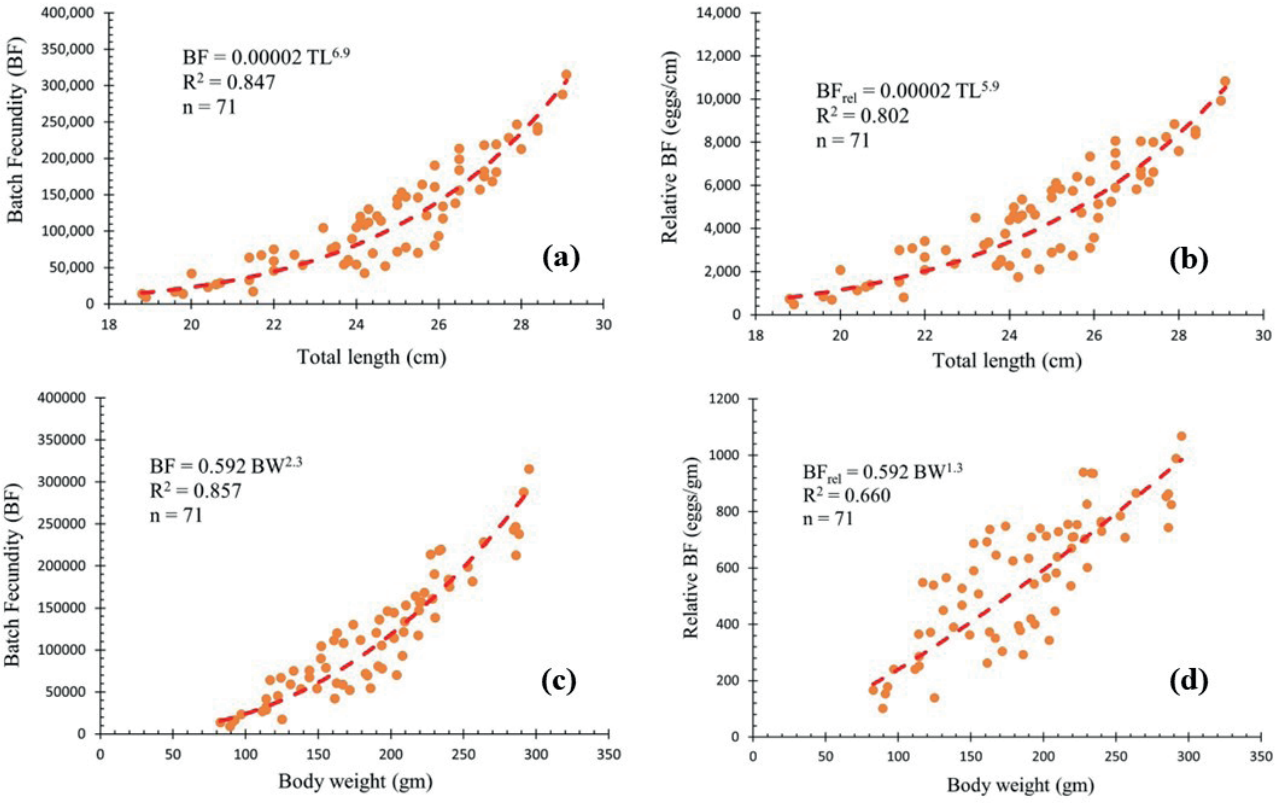


Figure 7

Relationship between (a) batch fecundity (BF) and total length, (b) relative BF and total length, (c) batch fecundity (BF) and body weight, and (d) relative BF and body weight in *G. longirostris* collected from Jeddah fisheries.

globules completely fused together and became large yolk plates. Oocytes ranged from 340 µm to 480 µm in size.

8. Postovulatory follicles stage (Fig. 8h): Many empty follicles were observed at this stage. Most of the postovulatory follicles were observed in July.
9. Atretic stage (Fig. 8i): At this stage, the nucleus and yolk globules liquefied together, and droplets, after passing through the granulosa and zona radiata, also disintegrated and disappeared.

Histological observations indicated that the ovary of *G. longirostris* is asynchronous, with oocytes at different stages of development. Monthly changes in female *G. longirostris* reproductive activity are shown in Figure 9. The highest proportion of ripe/running ripe ovaries with migratory nucleus, hydrated oocytes, and postovulatory follicles were observed in April (66.6%), May (70%), and June (65.4%), while the lowest percentage was recorded in August (34.7%). The first indication of spent/regressed ovaries was observed in June (6.9%), and this stage persisted until October (2.9%). Immature ovaries at the peri-nucleolus stage were detected between September (85%) and February (35.7%), with a predominance from October to November. An increasing number of oocytes with yolk vesicles was observed between November and March. Nevertheless, developing and late developing ovaries were found in January through July.

3.6. Testicular development

Histological sections through the male gonads in the present study identified five stages of testicular development, which include spermatogonia, primary spermatocytes, secondary spermatocytes, spermatids, and spermatozoa (Fig. 10). Spermatogonia were round-shaped cells that form nests or cysts, surrounded by Sertoli cells. Primary spermatocytes are arranged in bands of cysts and appear granular. Secondary spermatocytes were formed by mitotic division of primary spermatocytes and can be found, partially or completely, multiplying in most cysts

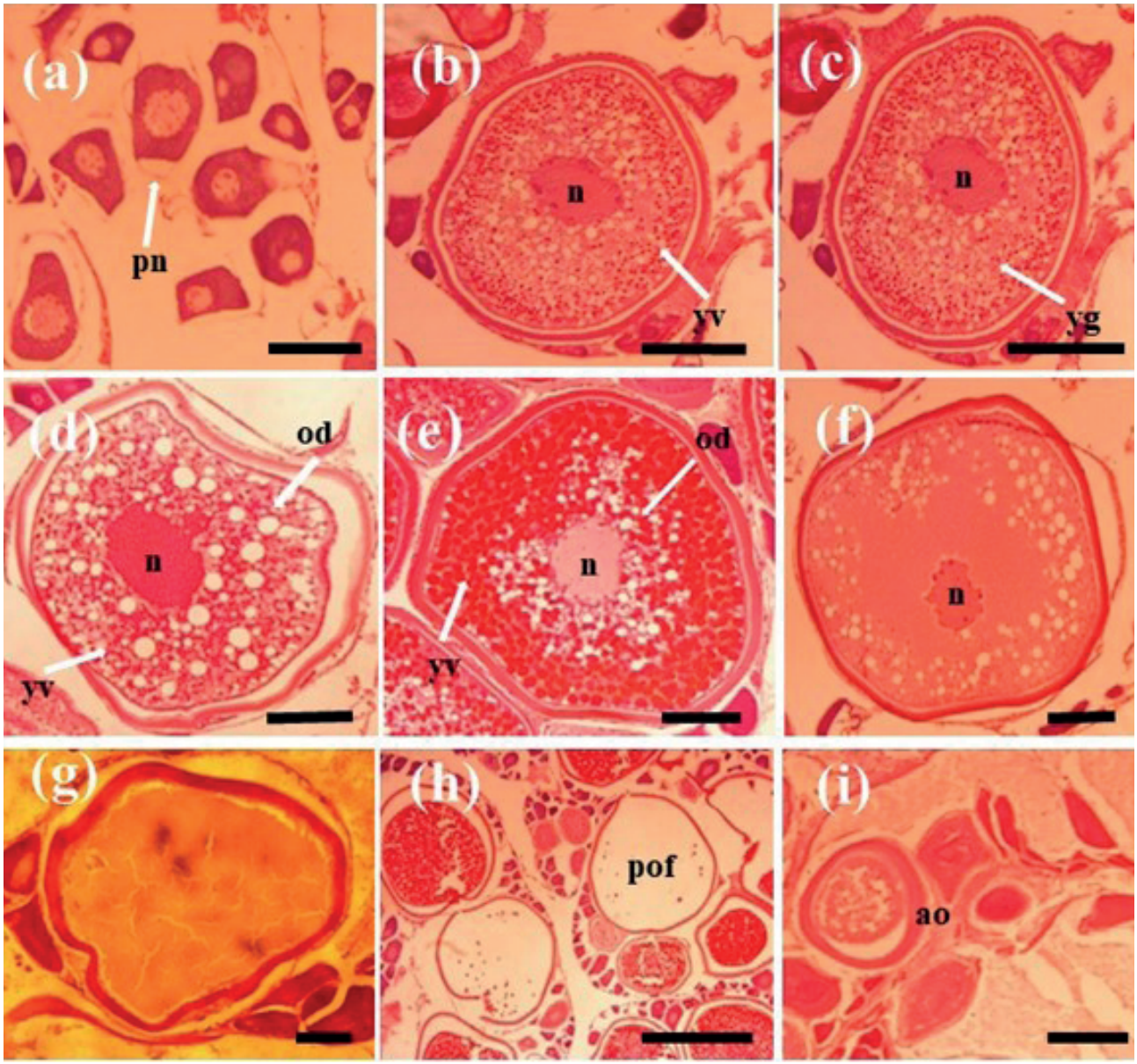


Figure 8

Ovarian histological sections showing different developmental stages in *G. longirostris* from the Red Sea coast of Jeddah: (a) peri-nucleolus stage, (b) yolk vesicle stage, (c) primary yolk globule stage, (d) secondary yolk globule stage, (e) tertiary yolk globule stage, (f) migratory nucleus stage, (g) hydrated oocyte stage, (h) postovulatory follicles, and (i) atretic oocyte. pn – peri-nucleolus oocyte; yv – yolk vesicle; yg – yolk globule; od – oil droplet; n – nucleus; pof – postovulatory follicle; ao – atretic oocyte. Scale bars: 100 µm.

in each lobule. Spermatids were formed by mitotic division of secondary spermatocytes. A round head is present in the case of spermatozoa, while the tail may not be visible or transparent. The head and tail may be formed together with a colloidal substance, and each retains individuality until they are discharged. With the disappearance of cysts arranged within the lobule, the lobules progressively advance toward maturity.

4. Discussion

There is a paucity of information on the reproductive biology of Gerrieds, especially *G. longirostris*, therefore the present study investigated some reproductive features, including sex ratios, spawning season, fecundity, size at sexual maturity

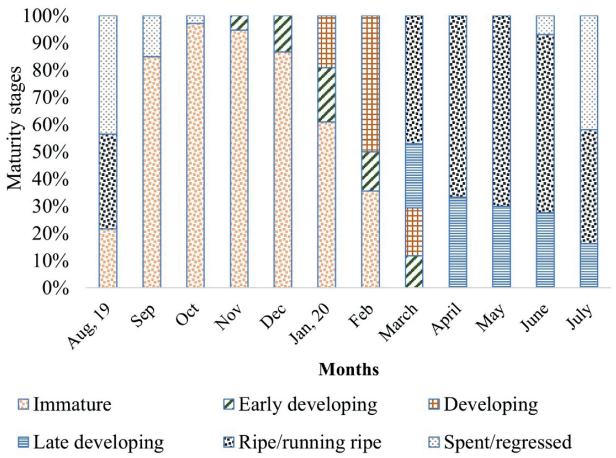


Figure 9

Monthly variations in the percentage of female *G. longirostris* maturity stages in Jeddah fisheries.

and gonad histology of *G. longirostris* in the coastal waters of Jeddah.

During the current study, the overall sex ratio of males to females was found to be significantly different (1:1.52) from the normal 1:1 ratio. Similarly, the dominance of females over males was recorded by many authors at different locations. For example, Valdez-Zenil et al. (2014) reported a male-to-female sex ratio of 1:1.2 for *Eugerres mexicanus* from the Usumacinta River, Mexico. Grandcourt et al. (2006) reported a higher male-to-female sex ratio of 1:2.2 for *G. longirostris* from the southern Arabian Gulf, UAE. Hosny & Al-Jaber (2017) observed that the overall male-to-female sex ratio was 1:3.1 for *G. longirostris* in the western Arabian Gulf, Saudi Arabia. Kurup & Samuel (1991) reported even a higher dominance of females over males (1:11.4) in the Cochin Estuary, India. These large differences in the ratio between sexes may be controlled by some factors, such as sampling

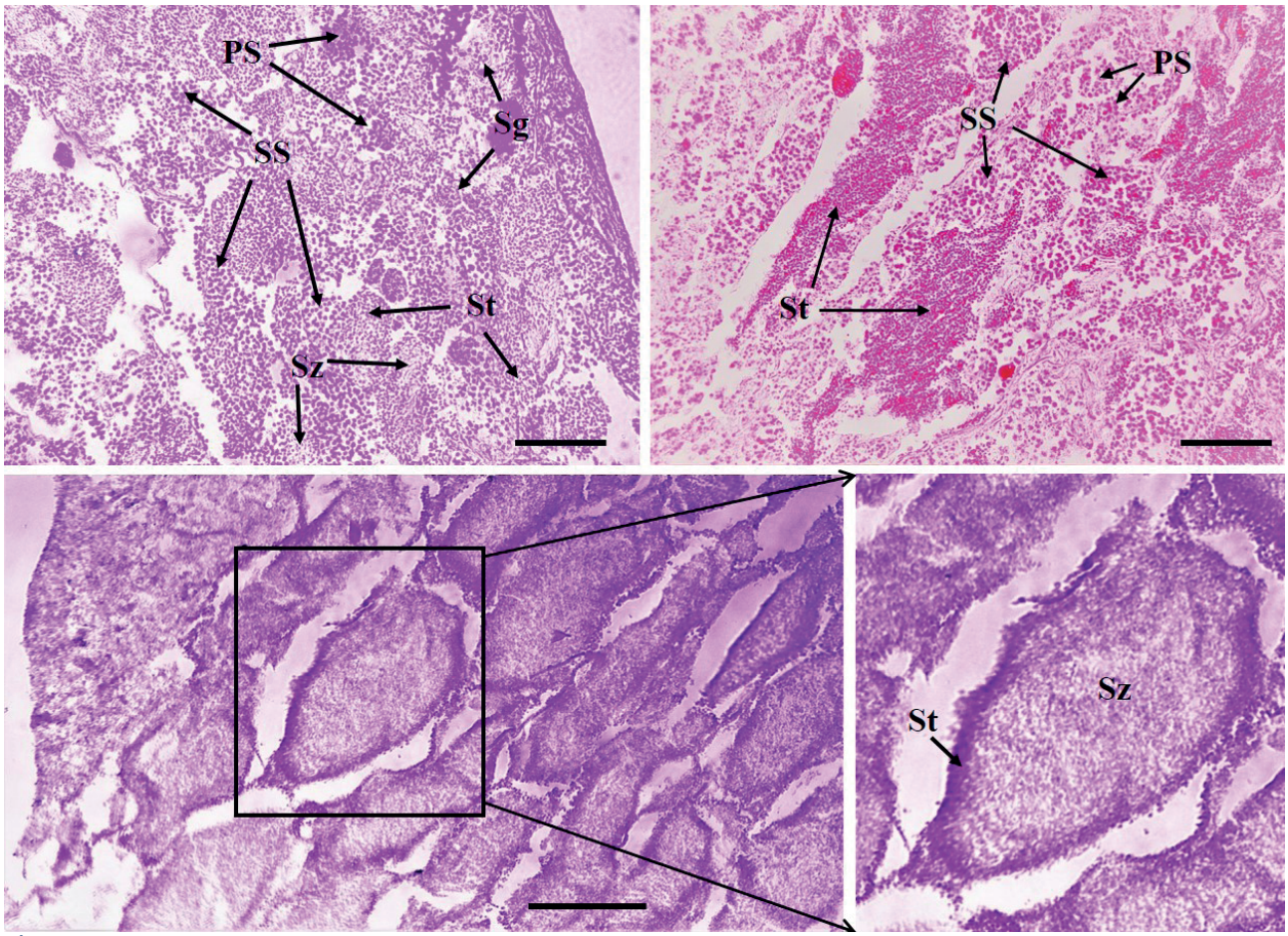


Figure 10

Photographs of histologically examined testes sections and different maturity stages of *G. lomgirostris* from Jeddah fisheries. Sg – spermatogonia; PS – primary spermatocytes; SS – secondary spermatocytes; St – spermatids; and SZ – spermatozoa. Scale bars: 100 µm.

Table 5

Size at first sexual maturity (L_m) of *G. longirostris* from different studies.

L_m of *G. longirostris*		Methods	Sampling period	Study areas	References
Males	Females				
-	11 cm (SL)	-	-	Southern African estuaries, South Africa	Whitfield et al. 1998
16.3 cm (FL)	20.6 cm (FL)	Logistic function	October 2003 to September 2004	Southern Arabian Gulf, United Arab Emirates	Grandcourt et al. 2006
23.8 cm (TL)	-	-	-	Pointe Monier, Rodrigues, Mauritius	Hardman et al. 2008
19.8 cm (TL)	19.1 cm (TL)	Logistic function	May 2012 to January 2014	Western Arabian Gulf, off Saudi Arabia	Hosny & Al-Jaber 2017
20.2 cm (TL)	19.8 cm (TL)	Logistic function	August 2019 to July 2020	Jeddah coast, Red Sea, Saudi Arabia	this study

bias due to fishing gear selectivity (Hosny & Al-Jaber 2017), sexual differences in the growth rate (Qasim 1966), and behavioral differences during spawning (Lowerre-Barbieri et al. 1996).

The histological analysis of the ovaries and the monthly variations in GSI values for *G. longirostris* indicated that spawning occurs between March and June, with a single period of spawning. This single spawning period is confirmed by Hosny & Al-Jaber (2017) and Grandcourt et al. (2006) for *G. longirostris* (May and June, and April to August, respectively), Valdez-Zenil et al. (2014) for *E. mexicanus* (March and April) and Iqbal et al. (2007) for *G. equulus* (June to September). Other authors, however, reported that several other gerreid species, including *Diapterus rhombeus* and *G. aprion* in Sepetiba Bay, Brazil (Gerson Araújo & Clistenes de Alcantara Santos 1999), and *G. acinaces*, *G. filamentosus*, and *G. rappi* in the KwaZulu-Natal estuaries, South Africa (Cyrus & Blaber 1984), spawned throughout year. There are several possible explanations for this variability in spawning, including interspecific differences, geographical location, food availability, rainfall, and water temperature (Millán 1999; Sumon et al. 2022a; Sumon et al. 2022b; Suyama et al. 2019; Val et al. 2006).

The results indicate that there is no significant difference in size at maturity between females and males of *G. longirostris* ($p > 0.05$), where the size at sexual maturity was estimated at 19.8 and 20.2 cm TL for females and males, respectively, which is similar to the findings of Hosny & Al-Jaber (2017) in the Western Arabian Gulf, Saudi Arabia (Table 5). Grandcourt et al. (2006), on the other hand, found that females mature at larger sizes than males in the Arabian Gulf, UAE (Table 5). Hardman et al. (2008) and Whitfield et al. (1998) also studied the size at first sexual maturity of *G. longirostris* with missing sex information (Table 5). For other gerreid species, females reaching sexual maturity at smaller sizes than males were recorded by Sivashanthini (2008) for *G. filamentosus* (females: 13.66 cm and males: 14.38 cm TL) and Sjafei & Syaputra (2009) for *G. kapas* (females: 10.5 cm and males: 11.5 cm). In contrast, males reaching sexual maturity at smaller sizes than females were observed by Kanak & Tachihara (2008) for *G. Oyena* (males: 9.2 cm and females: 10.4 cm SL) and Valdez-Zenil et al. (2014) for *E. mexicanus* (males: 17.3 cm and females: 20.5 cm TL). However, this variability in size at maturity in different regions may be related to environmental variability experienced by fish in their habitats, affecting fish conditions and thus the process and timing of maturation (Ferreri et al. 2021), or may be due to fishing pressure, where overexploitation of stocks can lead to a decrease in the size and age at maturity (Olsen et al. 2004; Lappalainen et al. 2016).

The relationships of batch fecundity and relative BF versus TL and BW of females were estimated and found to be nonlinear (power form) and strongly correlated and significant. The maximum BF and relative BF were estimated at 315,210 ova and 10,832 ova/cm, respectively. Lamtane et al. (2009) studied the fecundity of *G. oyena* with a total length ranging from 13.2 cm to 20.1 cm, with ripe gonads from October to December, and the number of ripe ova per fish (stage IV) varied from 22,600 to 367,200. The fecundity of *G. setifer* ranged from 17,293 to 161,505 ova with a size range of 8.8–19.3 cm TL (Patnaik 1971) and *G. filamentosus* from 64,278 to 387,576 ova with a size range of 10–14.8 cm SL (Kurup & Samuel 1991). Sivashanthini (2008) estimated the annual fecundity of whipfin silver-biddy *G. filamentosus* and recorded that it ranged from 121,700 to 2,062,278 ova.

For females, the ovaries of multiple spawners have both postovulatory follicles and vitellogenic oocytes at the same time, and then the postovulatory follicles slowly disappear as the vitellogenic oocytes develop (Hunter & Macewicz 1985). According to Iqbal et al. (2007), the Japanese silver-biddy, *G. equulus*,

collected off the coasts of southern Japan during the spawning season (June–September), had ovaries with yolk globule oocytes, hydrated oocytes of different sizes, and some yolk globules were found together with postovulatory follicles, which indicated multiple spawning. In this research, the tertiary yolk globule stage first emerged in March, and by April and May all ovaries had migratory nuclei and hydrated oocytes. In some ovaries, yolk globules, migratory nucleus stages, and unyolked oocytes also emerged at the same time. These results suggest that the ovarian development of this species is asynchronous (Wallace & Selman 1981). Ripe ovaries also exhibited empty follicles, indicating that ovulation had taken place earlier. Furthermore, the presence of hydrated and yolk globule stages indicates that the species is a multiple spawner with indeterminate fecundity. For males of *G. longirostris* from the Jeddah fisheries, the present study revealed five distinct stages of testicular development, namely spermatogonia, primary spermatocytes, secondary spermatocytes, spermatids, and spermatozoa, which were similar to those reported by Kanak & Tachihara (2008) for *G. oyena* collected from Okinawa Island, southern Japan. In December, cysts or nest-like primary spermatocytes were observed in the testes. Subsequently, after continuous meiotic division, spermatozoa were observed from March to May, when GSI values were high. In addition, immature germ cell spermatogonia were also observed in May, and their number gradually increased in the subsequent months as the GSI decreased. No testes were found at advanced stages of development after July, with only immature stages observed.

5. Conclusions

In conclusion, females of *G. longirostris* in the Jeddah fisheries predominate over males in all months and size groups, with the overall sex ratio of males to females was found to be significantly different (1:1.52) from the normal 1:1 ratio. Based on the monthly and seasonal variations in the GSI of *G. longirostris*, the present study found that the spawning occurs between March and June, with a single spawning season in the spring months. Both sexes of *G. longirostris* are almost of the same size at first sexual maturity, with no statistically significant difference found between L_m for males and females. There is a strong nonlinear relationship between batch fecundity and relative BF versus TL and BW of females. Based on gonadal histology, this species is a multiple-batch spawner with a single spawning season. For sustainable management and conservation strategies, this work provides important information on the reproductive biology of *G. longirostris*, detailing its fecundity and gonad histology for the first time.

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Ethical statement

An ethics committee was not required because experimental animals were not used in the study, and sampling was made in the form of dead fish obtained from fishermen.

Conflicts of Interest

The authors declare no conflicts of interest.

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