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RESEARCH PAPER

Reproductive biology of female sawcheek scorpionfish, *Brachypterois serrulata* (Richardson, 1846) (Teleostei; Scorpaenidae) from Visakhapatnam Coast, India

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Abstract
We examined the reproductive biology of sawcheek scorpionfish, *Brachypterois serrulata*, collected from Visakhapatnam fish landing center (fishing area covered 16.98°–20.20°N, 82.19°–86.53°E). We studied the annual reproductive cycle, fecundity, size at first maturity, mode of spawning with periodical changes and histological preparations. Size distribution and size at sexual maturity were calculated as 108 mm TL for females. The mean gonado somatic index values of female increased rapidly from January to December, and reached its peak during January and February. The fecundity of the fish species is determined by the size and weight of the individuals. The fecundity varied from 1896 to 20,488, with an average of 5721.90 ova.

Keywords *Brachypterois serrulata* · Central-Eastern Coast of India · Fecundity · GSI · Length at first maturity

Introduction

The scorpaenoid fishes are one of the largest and most morphologically diverse teleost groups with more than 1400 species, distributed both in shallow waters and middle and great depths (Boehlert and Yamada 1991; Love et al. 2002; Nelson et al. 2016; Washington et al. 1984). They are mainly demersal, and live in the tropical zones on coral reefs, and at high latitudes on rocky shore grounds (Pavlov and Emel'yanova 2007). Numerous species of scorpaenids fish have complex venomous glands at the bases of the dorsal or caudal fins.

Reproductive strategies and development influence the success and competitive capability of any fish species. Moreover, both are significant parameters in population biology, and an understanding of them is crucial for managing conservation risks (Grandcourt et al. 2004). Scorpaenids are particularly interesting because of the large array of reproductive specialization, ranging from oviparous to viviparous strategies (Wourms 1991). Also, their eggs are encompassed by gelatinous-type material in oviparous, zygoparous and embryoparous fish species (Fishelson 1978; Kusakari 1995). Some species produce floating, gelatinous egg masses in which the eggs are implanted in a single layer (Orton 1955). Reproductive strategies in the scorpaenoids have evolved from basic oviparity to matrotrophic viviparity. However, oviparity is most common in the genus *Scorpaena* (Koya and Munoz 2007; Muñoz et al. 2002, 2005). The evolution of viviparity occurred in the family Scorpaenidae, but fertilization occurs externally in some groups (Boehlert and Yamada 1991; Wourms 1991). Fish of the scorpaenoid genus *Sebastes* are considered comparatively primitive among viviparous teleosts with respect to the maternal–fetal relationship (Nagahama et al. 1991) and their reproductive mechanisms, including the maturation of gonads, fertilization, maintenance of gestation and parturition (Boehlert et al. 1991).

So far, there have not been any studies concerning the biology of scorpion fishes, particularly the sawcheek scorpionfish, *B. serrulata,* in Indian waters. The most important contributions are that of Gardner et al. (2015), Morris Jr

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et al. (2011), Muñoz and Casadevall (2002), Muñoz et al. (2002, 2005) and Stewart and Hughes (2010).

This present study aimed to investigate some aspects of reproductive biology (gonad maturity, size at first maturity, sex ratio, gonado-somatic index, fecundity, and spawning season) of the sawcheek scorpionfish. Understanding the reproductive biology and recruitment of juveniles are primarily of importance in developing an optimal strategy for management of the fish stock to promote conservation of this fishery resource.

Results

The gonads of *B. serrulata* are bilobed structures, lying in the upper, posterior part of the abdominal cavity. The lobes are unequal in length, with the right ovarian lobe being relatively larger than the left. Both concentrate posteriorly towards the oviduct, which opens at the terminal portion of the opisthonephric duct.

Morphological and microscopic classification of ovaries and ova diameter frequency studies of *B. serrulata*

Microscopic and macroscopic examination of the ovaries allowed the recognition of four developmental stages used for *B. serrulata*: stage I (immature), stage II (maturing), stage III (mature), stage IV (ripe) (Fig. 1a–h). In stages I and II, there was no confirmation of preceding spawning in the form of intralamellar muscle bundles, yellow–brown bodies, post-ovulatory follicles or atretic oocytes in the ovaries of immature females.

Stage I: Immature: Ovary small, thin and thread-like; sex cannot be determined by cross examination. Microscopic examinations reveal that the immature ova are not separable. The thread-like ovaries are pale white in colour.

Stage II: Maturing: The ovary is enlarged, transparent white and pinkish in colour, and occupies approximately one quarter the length of the body cavity. The gonad wall is thin, and lamellae are filled with tightly packed ova. Ova are not visible to the naked eye. Ovaries are cream to light yellow in colour with thin ovarian wall, oocytes visible small yellow translucent or opaque.

Stage III: Mature: Ovaries are enlarged and occupy approximately two thirds the length of the body cavity; oocytes are large and opaque; eggs are golden yellowish in colour and translucent, ovary is large in relation to body cavity; ovary wall is thin.

Stage IV: Ripe: Large, yellowish in the ovary, which occupies 2/3 of the body cavity; eggs are visible, and it takes place to prepare for spawning in the mature active ripe females.

Ova diameter frequency

Ova diameter frequency polygons of various maturity stages of *B. serrulata* are shown in Fig. 2. Observations based on ova diameter frequency polygons are as follows

In stage I, the immature eggs formed a mode at 0.07 mm with maximum oocyte diameter of 0.09 mm

In stage II, the immature formed eggs are in a major mode at 0.16 mm and a minor mode at 0.17 mm with maximum oocyte diameter of 0.19 mm.

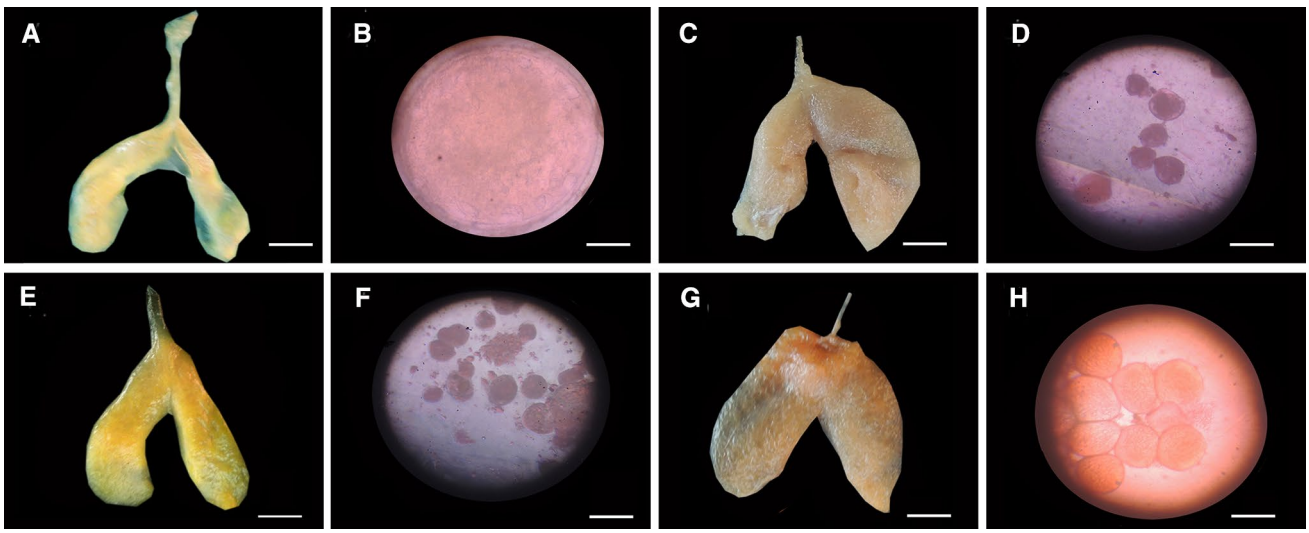

Fig. 1 Female gonads (ovary) of *Brachypterois serrulata* showing different maturity stages and microscopic view of eggs. **a**, **b** Stage I immature; **c**, **d** stage II maturing; **e**, **f** stage III mature; **g**, **h** stage IV ripe stage (scale bar: 1 cm)

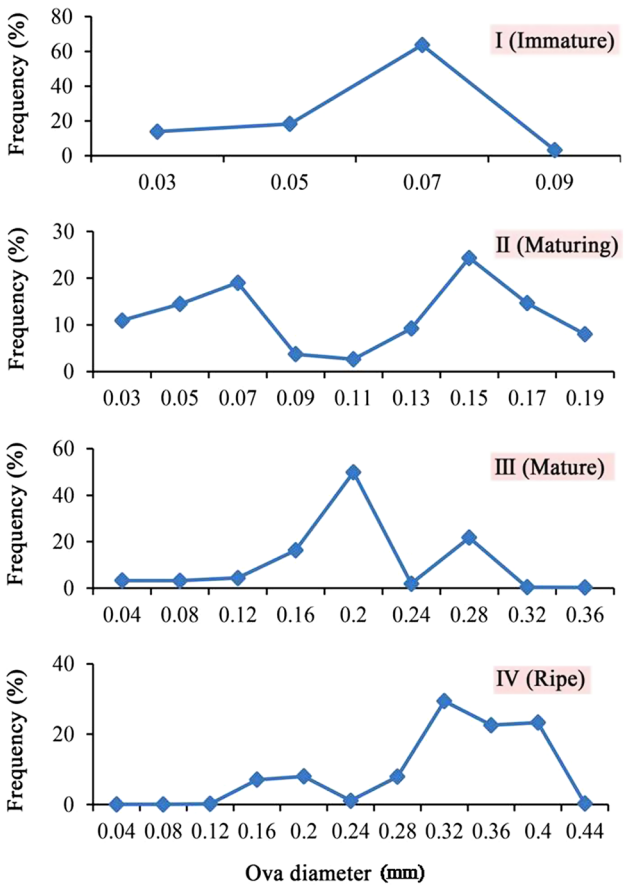

Fig. 2 Ova diameter frequency polygon of different maturity stages of *Brachypterois serrulata* off Visakhapatnam

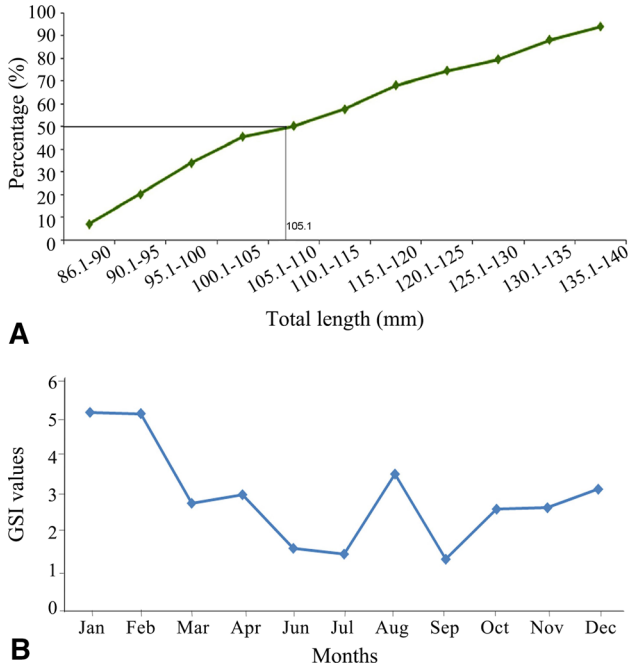

Fig. 3 **a** Monthly trends in gonado somatic index of female *Brachypterois serrulata* off Visakhapatnam. **b** Size at first maturity of female *Brachypterois serrulata* off Visakhapatnam

In stage III, the ripe eggs form a major mode at 0.2 mm and minor mode at 0.32 mm, with maximum oocyte diameter of 0.36 mm.

In stage IV, the ripe eggs form a major mode at 0.32 mm and minor mode at 0.04 mm, with maximum oocyte diameter of 0.44 mm.

Gonado somatic index (GSI)

Monthly trends of GSI were obtained from pooled data of female of *B. serrulate*, which were obtained from catches off Visakhapatnam, are represented in (Fig. 3a). Peak values of female GSI were observed in January and February. There was an abrupt decrease in March, followed by a less intense decrease from April to July and a second, smaller peak in August. This was followed by a quick decrease on September, slowly increasing from then to the January peak (Table 1).

Size at first maturity

The percentage of developed ovaries in relation to size were plotted to calculate their size at first maturity (Fig. 3b). The size at first maturity for females was calculated as 108 mm.

Relationship between fecundity (*F*) and total length of *B. serrulata*

The logarithmic relationship between fecundity (F) and total length (L) of fish showed a linear relationship (Fig. 4a). The regression equation of fecundity (F) on the total length (L) of the fish was expressed by the formula $F = 1E{-}13x^{8.403}$ and statistically significant ($R^2 = 0.831$).

Relationship between fecundity (*F*) and body weight (WB) of *B. serrulata*

The fecundity (F) and body weight (BW) showed a linear relationship (Fig. 4b). The regression equation of fecundity (F) on body weight (BW) was expressed by the formula $F = 28.18x^{2.029}$ and statistically significant ($R^2 = 0.750$).

Table 1 Mean gonado somatic index (GSI) values of female *Brachypterois serrulata* represented in the catches of Visakhapatnam during January 2011 to December 2012

	Jan	Feb	Mar	Apr	May[a]	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GSI	5.11	5.079	2.768	2.99	–	1.607	1.458	3.521	1.326	2.617	2.653	3.131

[a]Fishing ban period

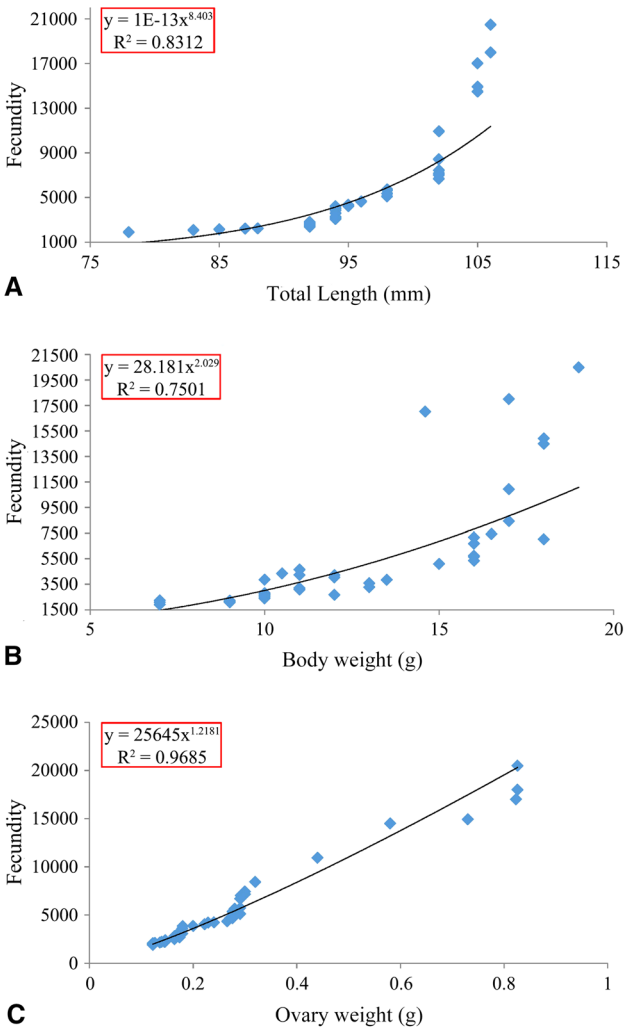

Fig. 4 **a** Relationship between fecundity and total length, **b** relationship between fecundity and body weight, **c** relationship between fecundity and ovary weight

Relationship between fecundity (*F*) and ovary weight (OW) of *B. serrulata*

The relationship between fecundity and ovary weight (OW) (Fig. 4c) is expressed by $F = 25645x^{1.218}$ and statistically significant ($R^2 = 0.968$).

Percentage of occurrence of females of *B. serrulata*

The percentage occurrence of female of *B. Serrulata* in different stages of maturity in different months during the present study period is given in Table 2. The occurrence of mature fish observed from January to February confirms that this species spawns during January to December.

Fecundity

The relative fecundity was estimated at 1896–20,488, with an average of 5721.90 ova (Table 3). The distribution of eggs in terms of frequencies of diameter is relatively open and often marked by two peaks. The diameter was not reached with the relative information to the literature. The relationship of the absolute and relative fecundity with the size and total weight of the fish specimens was significant in all cases.

Discussion

The present research of histological observation of the ovarian structure, combined with previous studies on the reproductive mode, and properties of mature and ripe eggs in scorpaenids, are summarized. In marine fishes, ovoviviparity is well-known to occur in ~55% (515 species) of chondrichthyan fishes, but only ~2–3% (510 species) of bony

Table 2 Percentage of occurrence of females of *Brachypterois serrulata* maturity in various months off Visakhapatnam during January 2011 to December 2012

Maturity Stages	Jan $n=63$	Feb $n=78$	Mar $n=65$	Apr $n=29$	May[a] –	Jun $n=45$	Jul $n=39$	Aug $n=20$	Sep $n=30$	Oct $n=25$	Nov $n=21$	Dec $n=52$
Stage I	14.2	33.3	29.2	17.2	–	8.8	17.9	20	56.6	16	52.3	48.0
Stage II	12.6	18.9	15.3	13.7	–	27.5	30.7	30	20	48	19.0	26.9
Stage III	22.2	21.6	24.6	20.6	–	8.8	15.3	40	6.6	12	19.0	5.7
Stage IV	50.7	47.4	30.7	48.2	–	64.4	35.8	10	16.6	24	9.5	19.2

[a]Fishing ban period

Table 3 Fecundity estimates of *Brachypterois serrulata* represented in the catches of Visakhapatnam during January 2011 to December 2012

S. no.	Total length (mm)	Body weight (g)	Gonad weight (g)	Fecundity
1	78	7	0.12	1896
2	83	7	0.12	2080
3	83	9	0.12	2085
4	85	9	0.13	2147
5	87	9	0.13	2204
6	87	9	0.14	2214
7	88	7	0.14	2231
8	92	10	0.14	2382
9	92	10	0.16	2505
10	92	10	0.16	2727
11	92	10	0.16	2740
12	92	10	0.16	2800
13	92	10	0.16	2621
14	92	12	0.17	2667
15	94	11	0.17	3194
16	94	13	0.17	3264
17	94	11	0.17	3074
18	94	13	0.17	3583
19	94	13.5	0.18	3845
20	94	10	0.20	3863
21	94	12	0.22	4031
22	94	12	0.22	4208
23	95	11	0.24	4221
24	95	10.5	0.26	4344
25	96	11	0.27	4630
26	96	11	0.27	4651
27	98	16	0.27	5344
28	98	16	0.28	5648
29	98	16	0.29	5726
30	98	15	0.29	5098
31	102	16	0.29	6681
32	102	18	0.29	7013
33	102	16	0.30	7170
34	102	16.5	0.30	7430
35	102	17	0.32	8425
36	102	17	0.34	10,935
37	105	18	0.34	14,494
38	105	18	0.38	14,921
39	105	14.6	0.82	17,017
40	106	17	0.82	18,001
41	106	19	0.82	20,488

S. no., Serial number

fishes (Osteichthyes), such as Embiotocidae, Scorpaenidae, and Sarcopterygii (Wourms and Demski 1993; Yamada and Kusakari 1991). Naranji et al. (2018) reported length–weight relationship of 19 scorpaenid fish species from the Indian coast. Sawcheek scorpionfish, *B. serrulata*, has been considered a well- conserved fish species (Grandcourt et al. 2004) with a broad distribution on both sides of the Indo-Pacific and in some areas of Atlantic Ocean. The scorpaenid fish species spawning typically occurs at a time when ecological circumstances are most favourable for successful larval and maturity (Blaber 2000; Fishelson 1978; Fujita and Kohda 1996, 1998; Grandcourt et al. 2004; Koya and Munoz 2007; Mito and Uchida 1958; Nagahama et al. 1991; Wourms 1991). The spawning period of the scorpionfish is apparently delimited between July and October, a period which coincides closely with that given for the Gulf of Leon (Duclerc and Adebert 1968) and the Algiers region (Siblot-Bouteflika 1976). Fischer et al. (1987) stated that the reproduction of this scorpaenid species in the coast of the Mediterranean occurs probably in May; a hypothesis which we consider to be erroneous. Sexual dimorphism is lacking in some species of scorpaenids, and it is expressed inadequately in other species (Love et al. 2002; Muñoz et al. 2005). The shape of the urogenital papilla may help differ males from females. In the former, the papilla is smaller than in females in several species, such as *Sebastes* (Lenarz and Echeverria 1991; Love et al. 2002). In *B. serrulata,* external sexual dimorphism is not evident (Matsunuma et al. 2013). However, substantial differences in the size of the urinary bladder were observed between sexes; in males, this organ is more than three times larger than in females. The data on the organization of the urogenital system in fishes from the scorpaenids are not extensive [for example, *Sebastapistes cyanostigma* (Pavlov and Emel'yanova 2007)]. Similar observations were reported for black scorpionfish, *Scorpaena porcus* (Soin and Chepurnov 1986). Erickson and Pikitch (1993) noted the gelatinous egg clutches of the fishes from the Scorpaenidae group were bilobed as observed also in *Sebastolobus* spp. and *Scorpaena guttata* (Orton 1955). In *Scorpaena miostoma* (Kimura et al. 1989), eggs were released in two batches.

The first records of GSI values for sawcheek scorpionfish, *B. serrulata*, and microscopic staining of ovaries indicated the peak period of occurrence of mature fish was from January to February. This suggests that in this species the peak months of spawning are from December to January. GSI values of females increase rapidly from September to December and peak during January and February. The GSI values decreased from March to July and August to September.

Based on oocyte counts, mature females preparing to spawn were capable of releasing 1896–20,488 with an average of 5721.90 ova per female during each event, with greater number of eggs released by larger females. The reproductive biology of *B. serrulata* has never been investigated before. Therefore, the results of this study could be only closely related species of scorpaenoids. Recent surveys in different coastal waters allowed capture of scorpaenoid

specimens to enhance knowledge of the size at first sexual maturity of females, to delineate the reproductive period and assess fecundity (Chilton 2007; Mito and Uchida 1958; Morris et al. 2009, 2011; Washington et al. 1984). Compared with a few species in the Scorpaenidae, the fecundity of *B. serrulata* is higher. In *Scorpaena notata*, the fecundity was 6000–33,000 (Muñoz et al. 2005). In rockfishes, *Sebastes* spp fecundity was estimated (1700–417,000 eggs or embryos) (Haldorson and Love 1991). Fecundity increases with the size of the female, in so far as larger fish produce significantly more eggs than smaller animals (Bagenal 1978). It should be noted that the fecundity of *B. serrulata* is rather low compared with other species from the Scorpaenidae whether they are typically oviparous species, such as *Trigla lyra* (Muñoz et al. 2002) or zygoparous, such as *Helicolenus dactylopterus*, with the highest egg count of 8,7000 per female (Barzotto et al. 2017; Kaim-Malka and Jacob 1985; Muñoz and Casadevall 2002). The fecundity of *B. serrulata* is determined by the size and weight of the individuals with a high degree of correlation.

Conclusion

The investigation on the reproductive biology of *B. serrulata* is essential for the fundamental input to conservation and management.

Materials and methods

Study area and sample collection

Specimens of sawcheek scorpionfish, *B. serrulata,* were collected fortnightly from commercial catches and fishing lines in the Bay of Bengal, Visakhapatnam fishing area (16.98°–20.20°N, 82.19°–86.53°E), Central Eastern Coast of India between January 2011 to December 2012. In this study, a total of 225 *B. serrulata* were examined. Specimens were obtained by means of diverse fishing gears, such as gill nets (115–143 m Hung length and 100–270 mm width) operated off Visakhapatnam coastal region at 20–30 m depth, shore seine of 10–20 mm mesh size, and trawl net (37–46 m head rope length; cod end mesh size 15–32 mm) operated at depth of 20–50 m from a fishing boat of LOA (length overall) of 9.6–11.1 m. Most of the specimens originated from multiday fisheries. Multiday fishing voyage lasted 6–12 days, whereas an individual fishing vessel undertook 2–3 such trips in one month. Gill nets soaking time ranged from 4 to 7 h, whereas each trawl haul lasted for 3–4 h. The fish samples were transported to the laboratory and washed thoroughly in tap water. Each fish was weighed to the nearest milligram, and the total length was measured to the nearest millimeter. After measuring the total length, the gonads were dissected out and weighed to the nearest 0.1 g, and preserved in 5% (v/v) formalin until further analysis. The spawning period was determined following the monthly changes of the gonado somatic index (GSI), and calculated after the formula: gonad weight (GW)/total fish weight (TW) (Miller 1961; Yuen 1955). For ova diameter measurements, various stages of ovaries were preserved in modified Gilson's fluid for two days (Bagenal 1978). The size of the egg was determined using a sensitive micrometer (at 0.01 mm sensitivity). The long and small axes of eggs were measured binocular microscope using counting chamber. To avoid selection of the longest or the shortest diameter in measuring the ova, the method adopted by earlier workers like (Clark 1934; Prabhu 1956). Length at first maturity was determined after Murua and Saborido-Rey (2003). Fecundity and egg size were evaluated using 42 females ranging from 78 to 112 mm TL with ovaries containing mature (stage III) and ripe (stage IV) eggs. Fecundity was computed by applying a previously published formula (Drevetnyak and Kluev 2005; Mertz and Myers 1996):

$$F = \frac{\text{gonad weight} \times \text{number of mature ova}}{\text{weight of sample}}.$$

The relationships between fecundity and length, weight of the fish and gonad weight were calculated using the least square method.

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Author contributions MKN performed the sample collection, data analysis work, preparation of manuscript, and arranged the figures and tables. VGR and KS provided contributed analysis tools, reagents.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest

Animal and human rights statement All applicable international, national, and institutional guidelines for the care and use of animals were followed by the authors.

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