VOL.65 NO.02 JULY-DECEMBER 2023 • PRINT ISSN 0025-3146 • ONLINE ISSN 2321-7898

JMBAI

JOURNAL OF THE MARINE BIOLOGICAL ASSOCIATION OF INDIA

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Available online at: www.mbai.org.in doi:10.6024/jmbai.2023.65.2.2415-11

Length-weight relationship and reproductive biology of *Otolithes ruber* (Bloch & Schneider, 1801) from the Southwest coast of India

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Received: 08 Feb 2023 Revised: 01 Sep 2023
Accepted: 12 Sep 2023 Published: 14 Nov 2023

Original Article

Abstract

The length-weight relationships (LWRs) of *Otolithes ruber* (Bloch & Schneider, 1801) from Cochin Harbour, Kerala, were estimated. The study is based on 723 samples (209 male and 416 female) collected at monthly intervals for a period of 24 months (February 2020 to January 2022). No significant difference ($P<0.05$) was observed in the growth rate for both sexes. The 'b' values were estimated at 3.19, 3.05, and 3.09 with 'r^2' values of 0.992, 0.986 and 0.986 for male, female, and pooled samples, respectively. The length at first maturity was calculated as 215 mm for females and 255 mm for males. The GSI values of females varied from 0.36-4.84 (2020-2021) and 0.25- 9.89 (2021-2022), and those of males ranged from 0.21-5.45 (2020-2021) and 0.28- 5.45 (221-2022). The peak values in the months of October and November for females correspond to their spawning seasons. To evaluate fish stocks, it is essential to have up-to-date knowledge of the functional length-weight relationships in fish for males, females, and mixed fish. The findings will aid Kerala's fishery managers in enacting the necessary legislation for sustainable fishery management.

Keywords: *Length-weight relationship, GSI, length at first maturity, fecundity, Otolithes ruber, Kerala coast*

Introduction

Representatives of the family Sciaenidae (croakers or drums) are widely distributed in the shelf waters of the tropical and subtropical Indian, Pacific, and Atlantic oceans (Lowe-McConnell, 1962; Druzhinin, 1974; Trewavas, 1977; Sasaki, 1996) and are important components of fisheries in several countries (Fischer and Bianchi, 1984). Nelson *et al.* (2016) reported 283 species, mostly marine species, in about 67 genera, with a few entering freshwaters. Parenti (2020) reported that the family Sciaenidae is widely distributed throughout the world, with 69 genera and 289 valid species.

The total marine sciaenid landings in India was 10,1281 t, and the sciaenid landings in Kerala during 2021 were 9600 t (CMFRI, 2022). Of the various sciaenids landed, *Otolithes ruber* forms an important fishery resource in Cochin (Nair *et al.*, 2015). The biological and population parameters of this resource have not been studied from these waters. Sciaenids are commercially important medium-sized species, widely distributed in the tropical, subtropical and temperate seas, including the Persian Gulf and Oman Sea, the Indian and Pacific Oceans, China, and the Malayan Archipelago (Brash and Fennessy, 2005). Sciaenids are found at depths between 10 and 40 m along the Indian coast (Sasaki, 2001); the largest size recorded was 90 cm (Sousa and Dias, 1981). The sciaenids are widely used for their air bladder, and world trade is also influential on the landing of large sciaenids (Ben-Hasan *et al.*, 2021).

Fishery biology and population dynamics of the species are greatly impacted by length-weight relationships (LWRs). The length-weight relationship plays a significant role in fishery research, especially in analyzing fish population dynamics and growth (Bhakta *et al.*, 2022; Chirwatkar *et al.*, 2022), taxonomic differences, events in life history like metamorphosis, maturity

(Le Cren, 1951), and to the fisheries officials in evolving effective policies for management and conservation of the resource (Nair *et al.*, 2021). To determine the health of fish, the length-to-weight ratio is useful (Bhakta *et al.*, 2022). Fish length and weight are mathematically related, which helps us understand their survival, growth, maturity, reproduction, and general well-being (Le Cren, 1951). Fishery biologists can also use LWRs to monitor a population (Cone, 1989). According to Carlander (1969), the value of 'b' fluctuates between 2.2 and 4.5, while Pauly and Gayanilo (1997) suggest that values may vary between 2.5 and 3.5. The fish that follow the cube law in growth *i.e.*, unchanged body form and specific gravity, have isometric growth. Fishes which do not follow the cube law in growth rate have allometric growth (positive or negative). According to Pauly (1984), b values less than 3 indicate that fish become slender as they grow, while b values greater than 3 indicate that fish become heavier as they grow. Length-weight relationship is an important tool in fish biology, physiology, ecology, and fisheries assessment. In the present study, the length-weight relationship of *O. ruber* was estimated to determine the status of the fishery in Cochin, which could be helpful for the management of the fishery.

Gonadosomatic Index (GSI) is used as a flag to establish the reproductive status of the fish. The gonadosomatic index (GSI) is one of the important parameters of fish biology that provides a detailed assessment of fish reproduction and reproductive status in addition to helping to determine fish breeding periods (Sindhe and Kulkarni, 2004). The production of eggs and milt is greatly influenced by environmental changes. Breeding season determination is an essential part of fish biological research (Saksena, 1987). Several researchers have used the gonadosomatic index and the volume of the gonad to identify different fish species' breeding seasons (Mishra and Saksena, 2012). Breeding success affects fishery resources, and endangered species of fish are declining because of this. The importance of studying gonadal development indexes such as GSI and fecundity can be seen in the fact that they provide first-hand information about the breeding season. Keeping this in view, the present study was devised to determine the spawning season of *O. ruber*.

Studies on the understanding of fish reproductive biology and strategies are essential for fishery management and assessment (Dinh, 2017; Hossain *et al.*, 2017). Fish length at first sexual maturity is important to understand the causes of changes in maturity stages and is an indicator of minimum allowable capture sizes (Templeman, 1987; Hossain *et al.*, 2017). Further, it is important to determine the spawning potential or probable stock of a species through an understanding of fish fecundity, *i.e.*, how many eggs a fish produces in a year (Lagler, 1956; Kovacic, 2005). Fecundity is one of the main guiding factors in theoretical and applied population biology and represents the maximum possible reproductive output of an individual over their lifetime (Bradshaw and McMahon, 2008). Maternal age, fitness of progeny, and other characteristics of life history can all affect reproductive success. A genetic and developmental trait, fecundity evolves within a particular selective framework in India's most valuable commercial fishery resources. Individual and population fecundity fluctuates both temporally and spatially during their lifetime. Studies on fecundity change are therefore important because they are primarily determined by environmental stochasticity and demography.

Many studies have been conducted on the reproductive biology of sciaenids from the Indian coast (Bal and Pradhan, 1945; Gopinath, 1946; Jacob, 1948; John, 1951; Prabhu, 1956; Vaidya, 1960; Annigeri, 1963; Rao, 1963; Pantulu, 1966; Dutt and Thankam, 1968; Devadoss, 1969; Bhusari, 1975; Nair, 1977; Murty, 1979; Baragi and James, 1980; Muthiah, 1982; Murty and Ramalingam, 1986; Jayasankar, 1989, 1994; Chakraborty *et al.*, 2000; Ghosh *et al.*, 2009; Manojkumar, 2011; Sandhya, 2012; Bhakta *et al.*, 2022). However, though two reports are available on *O. ruber* (Pillai, 1983; Devadoss, 1969) from India, important parameters such as length at first maturity, GSI, and fecundity of the fish are lacking. Such aspects are essential for promoting sustainable fisheries for the concerned species in the region. Since the biological and population parameters of this fish from the southern coast of the country have not been studied in detail, the present study attempted to investigate such vital aspects of the reproductive biology of the fish in the Cochin region of India.

Material and methods

Material collection: Fish samples of *O. ruber* (Fig. 1a) were collected from two landing centres of Kalamukku centre (9°59' 05.4" N 76°14' 31.8" E) and Cochin Fisheries Harbour (9°56' 20.6" N 76°15' 46.3" E) (Fig. 2) from the Southwest coast of India during February 2020 to January 2022. The freshly collected fish samples were transported to the laboratory in a plastic-insulated box after being preserved in ice. On average, 30 specimens were collected every month between February 2020 and January 2022. In the laboratory, each fish was measured for total length (TL in mm), standard length (SL in mm), whole body weight (BW in g), and gonad weight (GW in g). The LWR for both male and female specimens was calculated separately following the formula (Ricker, 1975):

$$W = a\,L^{b}$$

This equation can also be expressed logarithmically as suggested by Le Cren (1951)

$$\text{Log } W = \text{Log } a + b \text{ Log } L$$

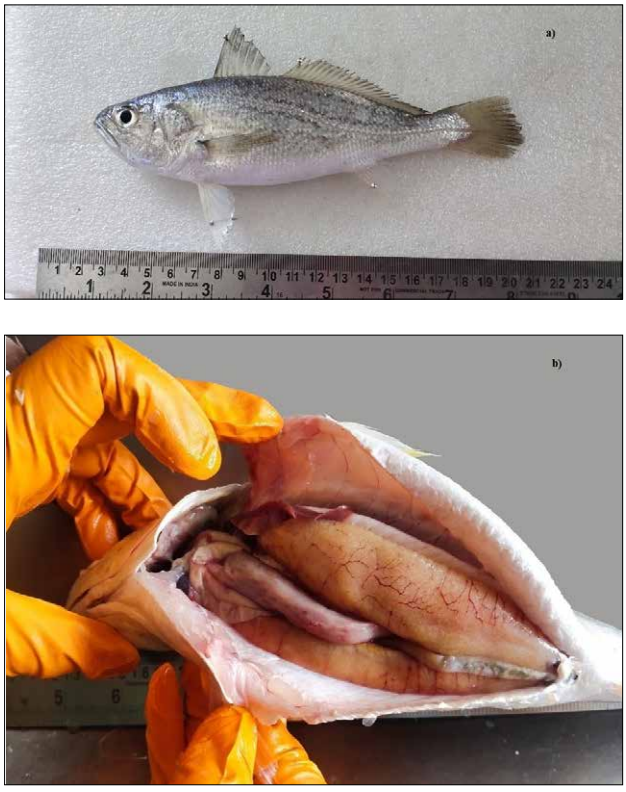

Fig. 1. a) Image of *O. ruber* and b) a fully matured gonad of female.

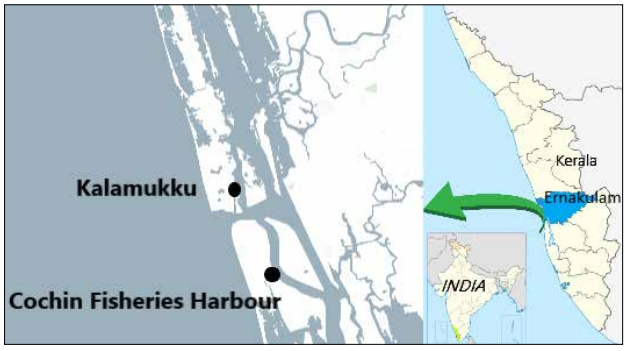

Fig. 2. Study area in Cochin of Kerala

Where, W = weight of fish in gm, L = length of fish in mm, a and b are the intercept and regression coefficient, respectively.

Nomenclatures for the description of stages of the gonads were based on a six-point scale with some modifications from Lanzuela (2020). Sex determination of each specimen of *O. ruber* was determined macroscopically after examining the specimen in the laboratory (Fig. 1b). For studying maturity, female specimens of *O. ruber* ranging from 140-342 mm and 23-405.00 g in total weight were examined. Maturity stages were recognised based on the colour, shape, size and space occupied by the gonad in the body cavity. The developmental stages and annual reproductive cycle for females were determined as immature, early maturing, late maturing, early mature, late mature, ripe, and spent.

The macroscopic gonad stages 1 and 2 were marked as immature and stages 3 and above as mature, with some modifications from Lanzuela (2020). The length at which 50% of individuals were mature (L_{50}) was calculated as the proportion of fish assigned as mature in each 1 mm length class and fitted a logistic curve to the data using a non-linear least squares procedure in Microsoft Excel (Solver). The L_{50} for males and females was calculated separately and compared to the values and logistic curves. Based on the examination of the maturity stages, the length at first maturity (Lm) was determined. In this study, female specimens in stages III and higher were considered mature (Farmer *et al.*, 2005). The length at which half of the population reaches adulthood is considered length at first maturity. It was found graphically from the percentage of cumulative frequency curve of mature fishes against size (Udupa, 1986).

The gonadosomatic index of each fish was calculated using the formula:

GSI (%) = Gonad weight (g) / Body weight (g) *100

Based on monthly variations in GSI indicators and the percentages of each maturity stage, the spawning season was identified (Zhang *et al.*, 2009). Fecundity was determined by gravimetric means, which involved determining the relationship between the weight of the ovary and the number of oocytes (Hunter and Goldberg, 1980; Murua *et al.*, 2003). Fecundity was determined by using the formula below:

Absolute fecundity = total ovary weight/weight of subsample × No. of ova in the subsample

Relative fecundity was obtained by dividing absolute fecundity by the total weight of fish.

Batch fecundity is the number of eggs released per fish during a single spawning event and was estimated for each fish as described in Lasker (1985) to estimate batch fecundity. The hydrated oocyte (HO) was counted by cutting three pieces of 0.10 g each from one lobe of the ovary, weighing, and measuring. According to this procedure, there are no significant differences between the left and right ovaries when calculating the number of HO per unit weight, as described by Sanz and Uriarte (1989). Three sub-samples of the ovary were taken from the anterior, middle, and posterior sections and weighed to the nearest 0.1 g.

Batch fecundity (FB) = Gonad mass (mg) x (subsample egg count/gonad subsample mass)

Results and discussion

Length-weight relationship

A twenty-four-month collection period was undertaken to observe the length-weight relationship and the GSI of *O. ruber* in Cochin. A total of 723 specimens (209 male and 416 female) of *O. ruber* collected during 2020-2022 were analyzed for LWR relationships within the range of 120-342 mm total length and 16.2-405 g total weight. A total of 209 males with sizes ranging from 150-310 mm and 36-313.00 g were used for the study. In females, 416 specimens ranging in size from 140-342 mm to 23-405.00 g were used for the study. The LWR for both sexes is presented through the scatter diagram (Fig. 3), and the logarithmic equation is as follows:

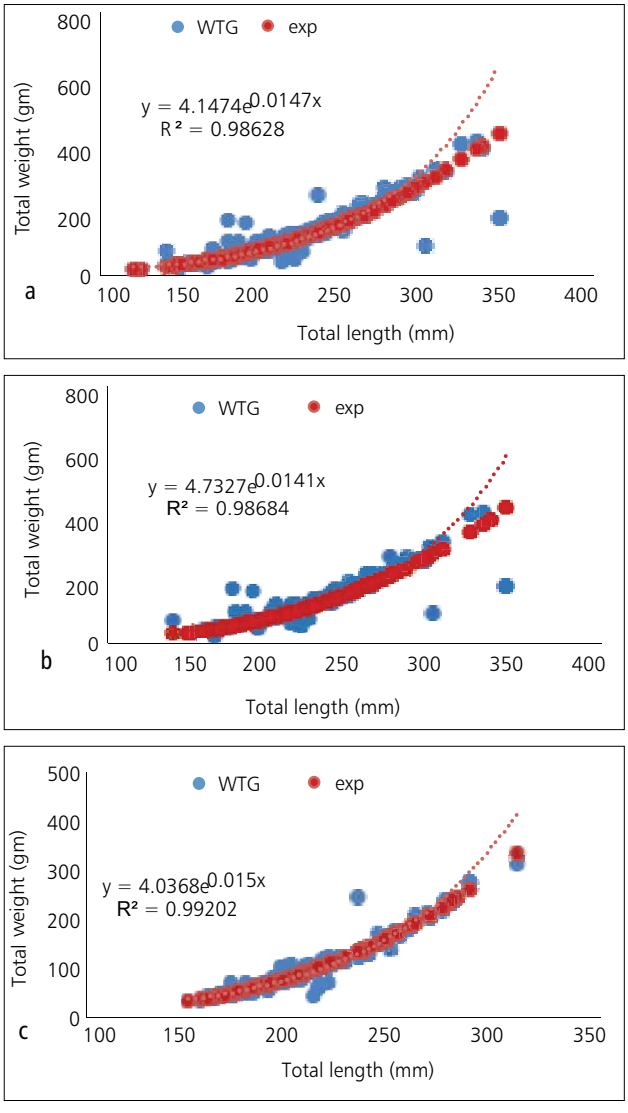

Fig. 3. Length-weight relationship a) pooled b) female and c) male

Male : Log W = -5.42 + 3.19 Log L (r^2 = 0.992)
Female : Log W = -5.09 + 3.05 Log L (r^2 = 0.986)
Pooled : Log W = -5.19+ 3.09 Log L (r^2 = 0.986)

The result of the LWRs, along with the descriptive statistics, is presented in Table 1. In the present study, the coefficient of correlation (r^2) is 0.986 for males, 0.992 for females, and 0.986 for both sexes, and the regression coefficient b is 3.19 for males, 3.05 for females, and 3.09 for both sexes (pooled). Generally, the regression coefficient (b) value of 3 for LWR indicates that the fish grows symmetrically or isometrically. Values other than 3 indicate allometric growth (positive or negative allometric). Fish having 'b' value of 3 maintain their specific body shape throughout their lives (Day, 1888; Bal and Rao, 1984).

According to Hussain and Abdullah (1980), the 'b' value for pooled samples of *O. ruber* was found to be 2.916, with the value of the correlation coefficient (r) being 0.980 from Kuwaiti waters, which showed a highly significant relationship between length and weight. Jayasankar (1990) reported the LWR of *O. ruber* from the Gulf of Mannar and Palk Bay with 'b' values of 3.28 (n = 150) for females, 3.2426 (n=177) for males and 3.2744 (n = 266) for combined specimens. The LWRs were highly significant, and the coefficient of determination (r^2) values were 0.984, 0.978 and 0.982, respectively. Fennessy (2000) reported a pooled 'b' value of 3.13 with 'r' value of 0.996 from the east coast of South Africa. Chu *et al.* (2011) reported 'b' and 'r' values of 2.630 and 0.831 for combined sexes of *O. ruber* collected from Taiwan waters. Eskandari *et al.* (2012) reported 'b' value of 3.19 (r^2 = 0.993) and Raeisi *et al.* (2012) reported 'b' value of 2.89 (r^2 = 0.946) for *O. ruber* from the Persian Gulf, Iran. The 'b' value obtained from the present study is similar to the study of Jayasankar (1990) but differs from Mersing *et al.* (2021) and Chu *et al.* (2011). The observed differences in 'b' values may be due to the combination of one or more factors like habitat, area, seasonal effects, the degree of stomach fullness, gonad maturity, sex ratio, health condition, preservation techniques, and length groups of studied specimens (Tesch, 1971). Variation in the relative growth (b) of the species reported from different places suggests an inter-regional difference in the LWR of the fish. A comparative LWR of *O. ruber* is presented in Table 2.

Length at first maturity (Lm)

All five stages of the ovarian development of *O. ruber* were observed throughout the year. In the present study, by plotting the percentage of females against total length, the length at first maturity was found to be 215 mm in females and 255 mm in males (Fig. 4). It was observed that the female population attained sexual maturity at smaller sizes than males. The

Table 1. Descriptive statistics and estimated length-weight distribution of *O. ruber* collected from Cochin

		Regression parameters				
Group	N	a	b	95% CL of a	95% CL of b	R^2
Male	341	-5.3489	3.16	-5.52662- (-5.1714)	3.0832-3.2367	0.990
Female	430	-5.0839	3.05	-5.3002- (-4.8675)	2.9545-3.0399	0.984
Pooled	839	-5.2183	3.10	-5.3458- (-5.0909)	3.0489-3.1590	0.984

Table 2. Comparative length-weight relationship of *O.ruber* by other researchers

Author	Sex	Intercept (a)	Slope (b)	Correlation coefficient (r)	Sample size	Area of study
Hussain and Abdullah, (1980)	—	0.020	2.916	0.980	-	Kuwait
Jayasankar (1990)	Female	-5.662	3.2899	0.984	150	Gulf of Mannar and Palk bay
	Male	-5.5598	3.2426	0.978	117	
	Pooled	-5.6285	3.2744	0.982	266	
Fennessy (2000)	Pooled	.00049	3.13	0.996	2511	South Africa
Chu *et al.* (2011)	Pooled	0.0300	2.630	.830	311	Taiwan
Eskandari (2012)	Pooled	0.005	3.19	0.993	968	Persian Gulf, Iran
Raeisi *et al.* (2012)	Pooled	0.0153	2.89	0.946	90	Persian Gulf, Iran
Farkhondeh *et al.* (2018)	Male	0.0132	2.92	0.96	1512	Makran Sea
	Female	.0101	3.01	0.95	2088	
	Pooled	.0125	2.94	0.91	3600	
Ni (2018)	Pooled	0.0055	3.21	0.98	328	Southwestern Taiwan
Al-Zaidy (2020)	Male	0.0000108	2.975	0.986	72	Iraqi marine waters
	Female	0.00000714	3.05	0.982	89	
	Pooled	0.00000797	3.03	0.984	174	
Baloch *et al.* (2020)	Pooled	0.016	2.829	0.969	278	Pakistan (Balochistan coast)
Lanzuela (2020)	Male	0.00837	3.01	0.865	-	San Miguel Bay, Philippines
	Female	0.00521	3.18	0.918		
Das *et al.* (2021)	Pooled	0.066	2.352	0.954	-	Malaysia
Santhoshkumar *et al.* (2014)	Pooled	0.018	2.834	0.885	250	Thoothukudi coast, Tamil Nadu, India
Present study	Female	-5.08	3.05	0.984	430	Kochi

length at first maturity was reported by Devadoss (1969) and Chakraborty *et al.* (2000) for *O. ruber* with a length of 200 and 175 mm from Mumbai, respectively. The size at first maturity may vary in aspects such as the environment, population size, food availability, and estimated length frequency (Hossain *et al.*, 2017). The present report is the first from the southwest coast.

Gonadosomatic Index (GSI)

The reproductive cycle of a species for two years can be determined using the gonadosomatic index (GSI). It is a very helpful approach to identifying the species' spawning season at the field level. The GSI calculates the ratio of the gonad's mass (GW) to the animal's overall mass under the assumption that gonads grow as they develop (BW). The GSI value of males ranged from 0.21-5.45 (2020-2021) and 0.28- 5.45 (2021-2022). As we compare the data from two years high peaks are seen in October and November. In females, GSI ranged from 0.36- 4.84 (2020-2021) and 0.25-9.89 (2021-2022). In the year 2020-21, the number of mature specimens in the sample during November was very low, and hence the decrease in the value of GSI was noted compared to the value in the next year. The range is seen as explaining the gonadal changes over the seasons. Peaks are seen in January-February and October-November–December, which indicates the prolonged spawning activity of the species (Fig. 5). Even though both male and female spawning take place simultaneously, since the annual peak of the monthly mean female GSI in January, February, October, November, and December. Therefore, two periods, January-February

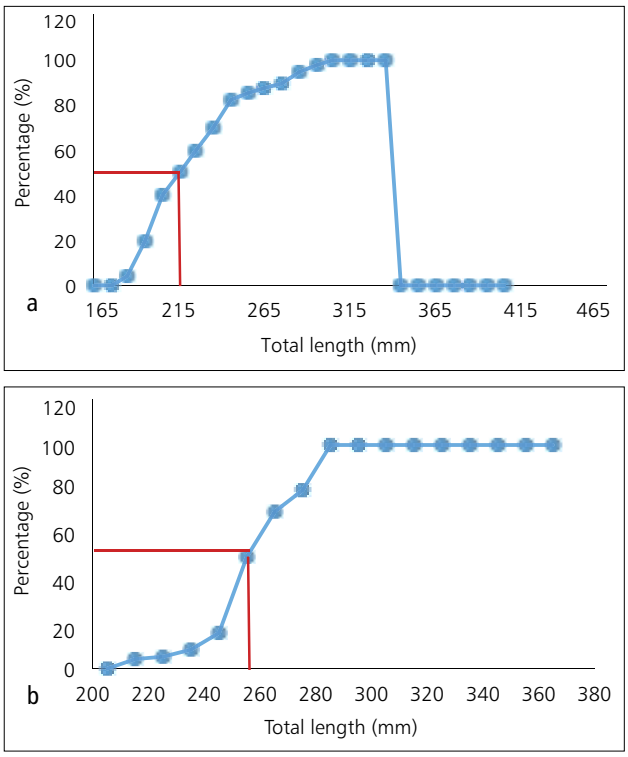

Fig. 4. Length at first maturity a) female and b) male

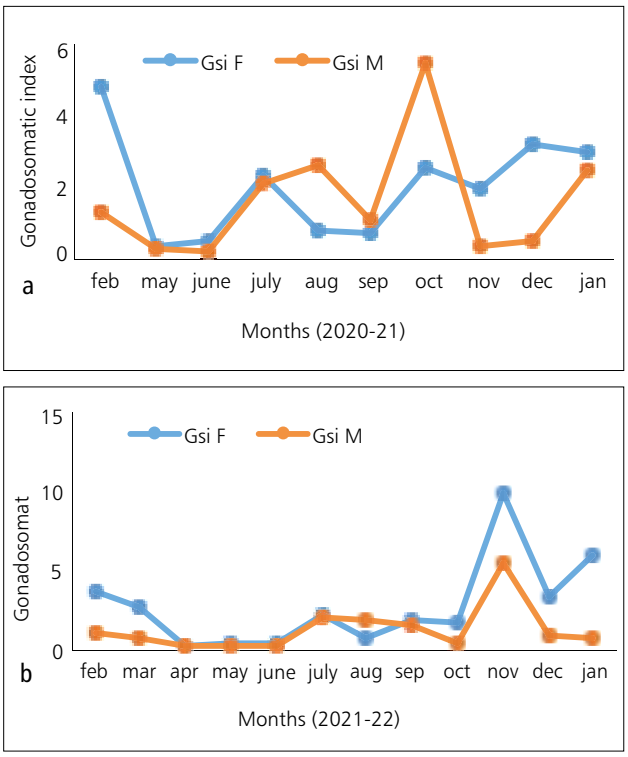

Fig. 5. GSI a) during the months of 2020-2021 and b) during the months of 2021-2022

and October-November-December, were primarily assigned to the spawning seasons of *O. ruber.*

Farkhondeh *et al.* (2018) showed an upswing trend from January to June and pointed out that in the waters of the Makaran Sea, the GSI was 7.1 in April. This result showed that the tiger-tooth croaker can spawn year-round, with a spawning surge occurring from April to June (spring season). Azhir (2008), in his study of the Oman Sea, pointed out that gonadosomatic Index (GSI) showed two peaks a minor one in October and a major one in March-April. Lanzuela (2020) mean monthly GSIs indicate July to November as the main spawning season of the species of *O. ruber* from San Miguel Bay, Philippines.

Fecundity

Eight mature females with a total length and weight varying from 216 to 320 mm and 105 to 357 g, respectively, were studied for fecundity. The absolute fecundity ranged from 62977 to 431526 eggs. Relative fecundity varied from 600 to 1430 eggs g-1 body weight and from 11694 to 17558 eggs g-1 ovary weight. Fecundity of fish exhibited a significant correlation with total length ($R^2 = 0.831$), body weight ($R^2 = 0.788$), and ovary weight ($R^2 = 0.927$) of *Otolithes ruber* indicating that larger females produce more eggs compared to that of smaller fishes (Fig. 6). A linear relationship between fecundity (F) and other parameters such as total length (TL), total weight (TW), and

Table 3. Fecundity of *Otolithes* spp. reported from Indian waters

Species	Absolute fecundity	Relative fecundity	Location	Author
O. ruber	43,810-1,70,130	-	Porto Novo	Pillai (1983)
O. ruber	44,621-1,79,659	237-620	Bombay	Devadoss (1969)
O. cuvieri	1,21,445-1,85,786	-	Bombay	Chakraborty (1988)
O. cuvieri	1,05,454-3,55,913	-	Veraval	Rao *et al* . (1992)
O. cuvieri	3,06,769-3,57,871	71,574–79,680	Bombay	Telvekar *et al.* (2005)
O. cuvieri	1,12,350-6,30,500	814-2278	Ratnagiri	Sandhya (2012)
O. ruber	62977–431526	600–1430	Kochi	Present study

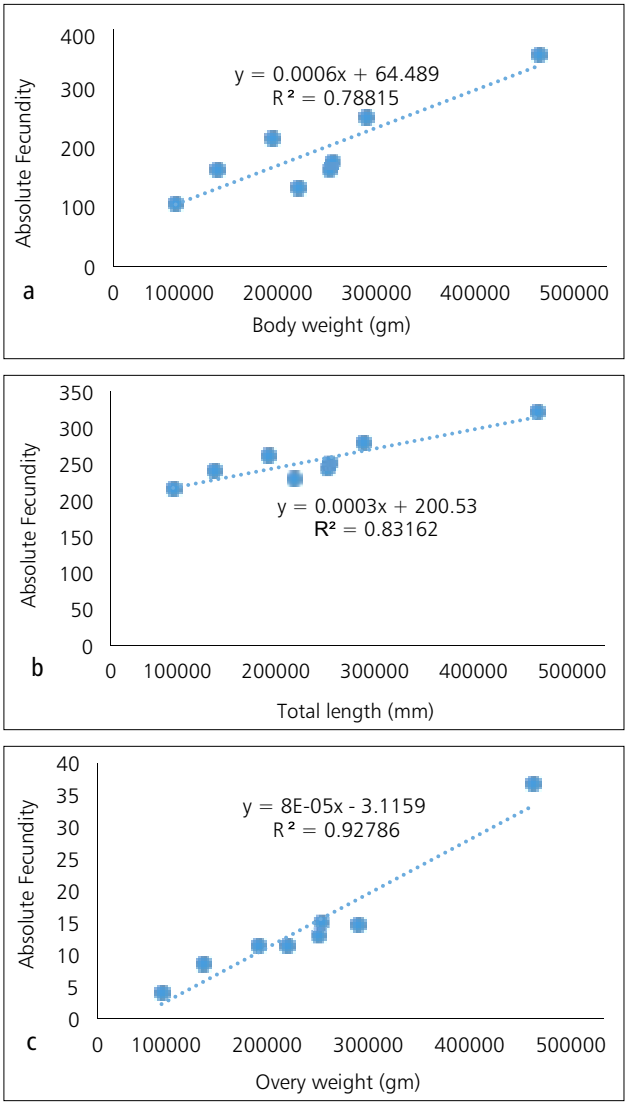

Fig. 6. Relationship between fecundity (F) and (a) total body weight (BW), (b) total length (TL), and (c) ovary weight for female *Otolithes ruber*

ovary weight (OW) of the fish (Fig. 6) was established after log transformation for convenience and presented as follows:

a) $y = 0.0003 x + 200.53$ ($R^2 = 0.831$) where y = fecundity and x = TL
b) $y = 0.0006 x + 64.489$ ($R^2 = 0.788$) where y = fecundity and x = TW
c) $y = 8E\text{-}05 x - 3.1159$ ($R^2 = 0.927$) where y = fecundity and x = OW

For successful fisheries management, an accurate assessment of fecundity is crucial to recognise the revival ability of fish populations (Lagler, 1956; Hossain *et al.*, 2017). There were no reports on the estimated fecundity of *O. ruber* from Kochi waters; hence, the present findings were compared with the literature available on other *O. ruber* and a few reports of *O. ruber* (Table 3). Batch fecundity (BF) based on the most advanced mode of stage 3 vitellogenic oocytes ranged from 62977 oocytes for 216 cm TL fish to 431526 oocytes for 320 cm TL fish. Devadoss (1969) reported that the absolute fecundity of *O. ruber* ranged from 44,621 to 1, 79,659 in Bombay waters. Pillai (1983) reported a range of 43,810–1,70,130 eggs in *O. ruber* from Porto Novo, Tamil Nadu. A few reports are available regarding the fecundity estimation of *O. cuvieri* from Indian waters. Chakraborty (1988) reported a range of 1, 21,445 to 1, 85,786 eggs from Bombay waters, while Rao *et al.* (1992) reported that the number varied from 1, 05,454 to 3, 55,913 eggs from Veraval waters. Telvekar (2002) estimated the absolute fecundity of *O. cuvieri* from Bombay waters contains eggs in the range of 3,06,679 to 3,62,030 in fish of lengths ranging from 305 to 343 mm. Sandhya (2012) reported that the absolute fecundity ranged from 1, 12, 350 to 6, 30, 500 eggs in *O. cuvieri* with

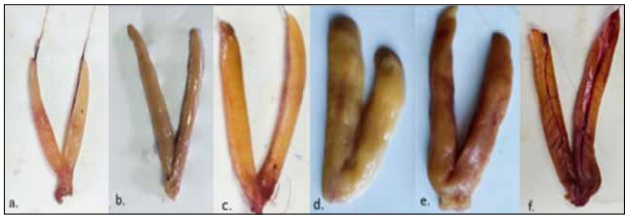

Fig. 7. Key features to the maturity stages in the female of *Otolithes ruber* a. Immature; b. Immature; c. Maturing; d. Mature; e. Ripe; f. Spent

Table. 4. Maturity stages in *O. ruber* (female)

Maturity stages	Classification	Nature of Ovary
Stage I	Immature	Ovary creamy in colour, ova not visible through the naked eye, gonad occupies ¼ of body cavity
Stage II	Immature	Ovary dark creamy colour, ova visible to naked eye, occupying half of the body cavity, but thin in nature
Stage III	Maturing	Colour of ovary pink, creamy, occupying a little more than half of the body cavity, thicker in nature
Stage IV	Mature	Ovary creamy to light yellowish, blood vessels visible, occupy 2/3 of the body cavity, thicker in nature
Stage V	Ripe	Ovary reddish, blood vessels very prominent and ova can be seen from the ovarian wall, occupy about 3/4 of the body cavity, thick, fleshy
Stage VI	Spent	Ovary shrunken in nature, pale blood or pale creamy in colour, occupying more Then 3/4 of body cavity, thin, flabby

an ovary weight between 5.51 and 26.0 g collected from Ratnagiri waters in Maharashtra.

Gonadal stages

The gonads of *O. ruber* are bilobed and open out through a common duct. Their attachment is closest to the kidneys in the dorsal portion of the body cavity. The female ovaries are easily differentiated into six successive maturity stages. The maturity stages of the gonad were classified into five stages, namely immature (stage I), immature (stage II), maturing (stage III), mature (stage IV), ripe (stage V), and spent (stage VI), following the procedure described by Lanzuela (2020), as shown in Table 4.

Conclusion

The study revealed that *O. ruber* has a distinctive spawning season, which is January-February and October-November-December. The presence of native species throughout the year indicates that the fish is a continuous spawner. The environmental conditions off Kochi are also favourable for its breeding season. There is a need for management measures such as gear modifications and Minimum Legal Size (MLS) regulations directed towards the sustainability of the *O. ruber* stock and its productivity on the Kochi coast.

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