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Reproductive biology of largehead cutlassfish *Trichiurus lepturus* Linnaeus 1758 along eastern Arabian Sea and western Bay of Bengal

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Abstract

The reproductive biology of *Trichiurus lepturus* Linnaeus 1758, was studied based on 6167 and 3346 specimens collected weekly along Eastern Arabian Sea (EAS) and Western Bay of Bengal (WBB) respectively during 2014 to 2018. The sex ratio varied significantly ($p<0.05$) throughout the year with a predominance of females during all months except September and October in EAS while, it did not differ significantly ($p<0.05$) except during June and July in WBB. The estimated length at first maturity (L_m50) for females was 58.0 cm TL in EAS and 55.5 cm in WBB. Higher Gonadosomatic index (GSI) values were recorded in February and May along EAS and in February and October along WBB. The proportion of ripe and partially spawned fishes were high to moderate during January to May in EAS and during October to March in WBB indicating peak spawning periods for *T. lepturus*. The presence of ripe, partially spawned, spent and spent-recovering fishes throughout the year in varied proportions implied prolonged spawning throughout the year. Microscopic and histological examination of the ovaries further confirmed *T. lepturus* to be an asynchronous batch spawner. The estimated absolute fecundity ranged from 21,930 to 1,85,941 [average 28,245±3306 (SE)] and 17,294 to 1,86,667 [average 75,000±10,436 (SE)] per female fish along EAS and WBB respectively. The relative fecundity (per g body weight) varied from 12 to 841 [average 105±12.2 (SE)] and 64 to 241 [average 64±15.1 (SE)] in EAS and WBB respectively.

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Introduction

The cutlassfish *Trichiurus lepturus* Linnaeus 1758, also known as largehead hairtail is distributed world-wide in tropical and subtropical marine and coastal waters (Elliot *et al*., 2007). It is a benthopelagic species, moving in dense schools and is found in shallow inshore waters and up to a depth of 350 m in the open sea (Randall, 1995; Al-Nahdi *et al*., 2009). Among eight species of cutlassfishes reported from the Indian waters (James *et al*., 1986), *T. lepturus* supports commercial fishery all along the Indian coast due to its high abundance and enormous demand for domestic use and also for export to China and other south-east Asian countries (Khan, 2006; Rohit *et al*., 2015). The largehead hairtail is exploited mainly by multiday trawlers both in eastern Arabian Sea (EAS), west coast of India and Western Bay of Bengal (WBB), east coast of India. Initially, the exploitation of this species was confined to the coastal waters using traditional as well as motorised gears. Later, with the introduction of mechanised multiday trawlers during 1990's, exploitation expanded to deeper waters (100-200 m depth). The introduction of mechanised vessels also resulted in horizontal expansion of operational area across maritime states along the coast and increased fishing duration (single day to multiday mode of operation) up to 13-15 days. This led to enhanced production and the annual catch of *T. lepturus* in the country increased from 79,220 t (4.5% of total marine catch) during 1990's (Thiagarajan *et al*., 1992) to 2,18,736 t (5.93% of total marine fish catch) in 2019 (CMFRI, 2020).

The largehead hairtail has a flexible reproductive strategy, with females exhibiting group synchrony and often spawning more than once in a reproductive season (Thiagarajan *et al*., 1992; Kwok and Ni, 1999; Martins and Haimovici, 2000). A female dominated sex ratio is common among large sized *T. lepturus* (Kwok and Ni, 1999; Martins and Haimovici, 2000; Al-Nahdi *et al*., 2009; Clain *et al*., 2021). There is some region-specific information available on reproductive biology of cutlassfishes from both the coasts of India, which includes Gujarat (Ghosh *et al*., 2014), Maharashtra, Karnataka (Rajesh *et al*., 2015), Andhra Pradesh (Reuben *et al*., 1997; Abdussamad *et al*., 2006; Ghosh *et al*., 2014) and West Bengal and Odisha (Ghosh *et al*., 2014). There is a targeted fishing for *T. lepturus* by multiday trawl fleets by expanding their area of operation both vertically and horizontally all along west and east coasts of India, to meet the domestic and export demand. Consolidated information on the biology of *T. lepturus* on a regional (EAS and WBB) basis would help fishery managers and policy makers to propose effective management strategies to harvest the resources at sustainable levels. Therefore, the present study to investigate in detail, the reproductive biology of largehead cutlassfish *T. lepturus* along EAS and WBB was taken up.

Materials and methods

Samples of largehead hairtail were collected on a weekly basis from multiday trawl landings in three maritime states along EAS and from single and multiday trawl and motorised hook & line landings in two maritime states along WBB (Fig. 1) during 2014 to 2018. A total of 6,167 and 3,346 specimens were collected from the landing centres located along EAS and WBB respectively (Table 1). The samples were collected all through the year, except during June-July along EAS and April-May along WBB, when the seasonal ban on operation of mechanised fishing vessels is in place. The collected specimens were transported in iced condition to the laboratory for further analysis.

The total length (TL) and weight of all the specimens was measured using a graduated measuring scale (to the nearest cm) and digital weighing balance (to the nearest mg) respectively. The fish were cut open carefully from the ventral side of the belly portion and the sex was assessed based on the presence of testes or ovary. Maturity stage was assigned based on the size, physical appearance and the space occupied by the testes or ovary. Further, the ovarian stages were evaluated and confirmed histologically. The slides

Table 1. Details of major crafts and gears, depth of operation and sample size of *T. lepturus* collected during January 2014 to December 2018 from various landing centres located in different states along Eastern Arabian Sea and Western Bay of Bengal

State	Fish landing centres	Major crafts landing *T. lepturus*	Depth (m) of operation	No. samples collected	
				Female	Male
Gujarat	Veraval and Mangrol Fishing harbours	Multiday trawl boats	20-450	622	533
Maharashtra	New ferry Wharf, Mumbai	Multiday trawl boats	10-80	944	626
Karnataka	Mangalore and Malpe Fishing harbours	Multiday trawl boats	20-120	1946	1496
Eastern Arabian Sea				3512	2655
Tamil Nadu	Kasimedu, Chennai and Pamban Therkuvadi Fishing harbours	Single day and multiday trawls	30-100	1018	982
Andhra Pradesh	Visakhapatnam and Kakinada Fishing harbours	Multiday trawls and Motorised crafts (Hook and lines)	30-200	693	653
Western Bay of Bengal				1711	1635

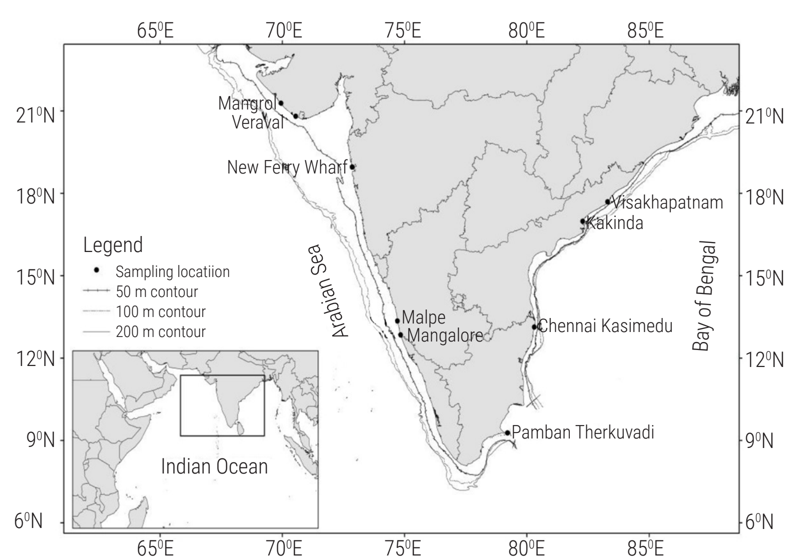

Fig. 1. Sampling locations along Eastern Arabian Sea and Western Bay of Bengal, India with depth contours of multiday trawl boat operations for the exploitation of *T. lepturus*

were observed through Ziess Primostar with Zen software and photographs were taken to identify the maturity stages of ova (Kiernan, 2008; Kerr, 2009). Cytological changes in the cytoplasm and nucleus of the oogonia were identified following McMillan (2007).

As the maturity stage was more distinct in males, it was classified based on macroscopic observations. The gonadosomatic index (GSI) of male and female gonads was determined separately using the equation, GSI = Weight of gonad/Weight of fish × 100. The annual spawning period was estimated on the basis of peaks of GSI and frequency of maturity stages recorded during different months.

Female to male ratio was estimated and tested using Chi-square test to check whether it is significantly different from the expected sex ratio of 1:1. The length at which 50% of the fishes reached maturity (Lm_{50}) was estimated following the logistic equation of King (2007). Histological sections of ovaries of different maturity stages of *T. lepturus* were observed through Zeiss Primostar with Zen software and images were taken to identify the maturity stages of ova (Kiernan, 2008; Kerr, 2009).

Fecundity was estimated from 54 and 18 mature gonads of fishes collected from the EAS and the WBB respectively by using the gravimetric method (Murua *et al*., 2003). The relationships between fecundity, fish length and body weight were estimated by the least square method. Oocyte diameter was measured using a compound microscope fixed with an ocular micrometer.

Results and discussion

Size composition and female to male sex ratio

The TL of female and male *T. lepturus* specimens collected from EAS ranged from 16.0 to 142 cm and 15.8 to 155.2 cm respectively. The TL of fishes collected from WBB ranged from 10.0 to 111.0 cm and 9.5 to 101 cm for females and males respectively. Most of the fishes collected were between 50 and 90 cm TL (81.7% of females and 80.4% males) in EAS (Fig. 2a) and 45 and 75 cm TL (89.1% of females and 92.1% of males) in WBB (Fig. 2b). The mean estimated TL of females (70.5 cm) and males (65.8 cm) in the EAS was higher compared to the WBB (57.4 cm for females and 53.0 cm for males). The present study recorded a maximum TL of 155.2 cm from EAS which is higher compared to all other previous maximum lengths recorded from Indian waters. The reported maximum TL from Indian waters were 101.0, 109.9, 110.0, 114.0, 125.9 and 124 cm from Visakhapatnam (Reuben *et al*., 1997), northern Bay of Bengal (Ghosh *et al*., 2014), Karnataka and Gujarat (Rohit *et al*., 2015; Koya *et al*., 2018), Kakinada (Abdussamad *et al*., 2006), northern Arabian Sea (Ghosh *et al*., 2014) and Mumbai (Khan, 2006) respectively. However, the maximum TL recorded globally is 193 cm (= 78 cm pre-anal length) from south-eastern Australia (Clain *et al*., 2021) and is almost similar to that of Taiwan waters (79 cm pre-anal length) where the authors (Shih *et al*., 2011) recorded only the pre-anal length. The variations in the maximum size of fish recorded in EAS and WBB in the present study and recorded elsewhere could be the result of variations in fishing pressure, and variations in growth between stocks/ or sub-populations of the species (Shih *et al*., 2011; Tu *et al*., 2018; Clain *et al*., 2021).

The sex ratio of *T. lepturus* examined for samples from EAS revealed that it varied significantly ($p<0.05$) from the expected ratio of 1:1 throughout the year. Females predominated during all months except in September and October, when males outnumbered females. In contrast, the sex ratio of fishes from WBB did not differ significantly ($p<0.05$) from the expected ratio of 1:1 except during June and July. In general, females outnumbered males in almost all the months except in March, June and July (Table 2). Similar predominance of females over males from Indian waters was reported earlier by Ghosh *et al*. (2014) and Rajesh *et al*. (2015) and also from the Caribbean Sea (Del Toro, 2001), Arabian Sea, Oman (Al-Nahdi *et al*., 2009), Gulf of Mexico (De la Cruz-Torres *et al*., 2014) and south-eastern Australian waters (Clain *et al*., 2021). However, as in the present study, the dominance of males over females during some months of the year has been reported in Indian waters (Reuben *et al*., 1997; Khan, 2006) and also from Brazil (Martins and Haimovici, 2000). The higher uneven sex ratio observed in EAS and to a lower extent in WBB could be due to the segregation of females for spawning, or in response to ecological variations or due to the movement of fishes to and from commercial fishing grounds (Reuben *et al*., 1997; Ghosh *et al*., 2014; Ojelade *et al*., 2019).

Length at first maturity

The estimated length at first maturity (Lm_{50}) for *T. lepturus* females was 58.0 cm TL in EAS (Fig. 3A) and 55.5 cm in WBB (Fig. 3B). The study indicated that the Lm_{50} of largehead hairtail in the WBB is smaller than that observed in samples from the EAS. The estimated Lm_{50} in this study is almost concurrent with the Lm_{50} of 60 cm TL reported by Thiagarajan *et al*. (1992) from Rajakkamangalam

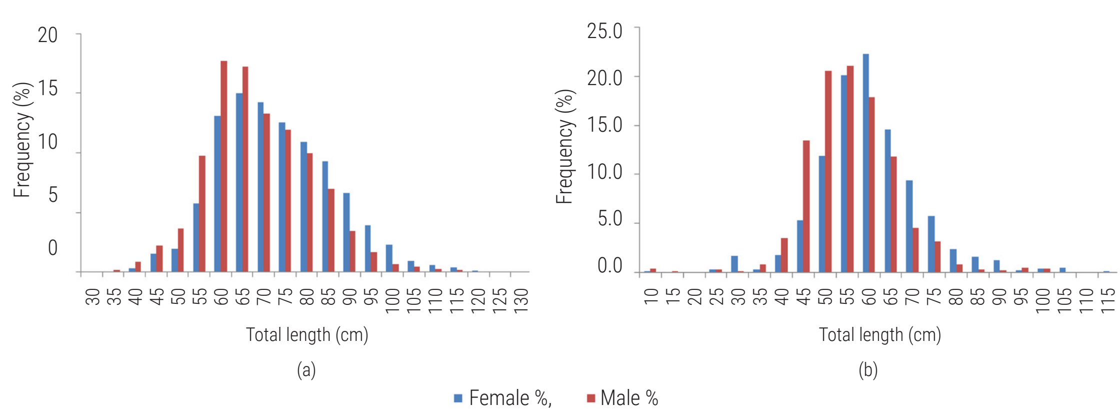

Fig. 2. Size composition of *T. lepturus* samples collected from (a) Eastern Arabian Sea and (b) Western Bay of Bengal during January 2014 – December 2018

Table 2. Female to male ratio of *T. lepturus* samples collected in different months during 2014-18 from Eastern Arabian Sea and Western Bay of Bengal

Months	Eastern Arabian Sea				Western Bay of Bengal			
	Female	Male	Sex ratio (F/M)	Chi square values	Female	Male	Sex ratio (F/M)	Chi square values
Jan	448	313	1.43	23.95*	199	168	1.18	2.62
Feb	354	185	1.91	52.99*	110	109	1.01	0.001
Mar	371	209	1.78	45.25*	82	96	0.85	1.10
Apr	304	204	1.49	19.69*	-	-	-	-
May	332	253	1.31	10.67*	-	-	-	-
Jun	-	-	-	-	81	200	0.41	50.40*
Jul	-	-	-	-	168	108	1.56	13.04*
Aug	322	274	1.18	3.87*	191	159	1.20	2.93
Sep	254	351	0.72	15.55*	246	209	1.18	3.01
Oct	315	380	0.83	6.08*	305	291	1.05	0.33
Nov	386	282	1.37	16.19*	201	179	1.12	1.27
Dec	426	204	2.09	78.23*	128	116	1.10	0.59
Total	3512	2655	1.32	119.1*	1711	1635	1.05	1.73

- Denotes no samples due to monsoon fishing ban for mechanised vessels
* Significantly different at $p<0.05$

Estuary, Tamil Nadu, 61.2 and 59.2 cm TL by Ghosh *et al*. (2014) from northern Arabian Sea and northern Bay of Bengal respectively, 55.4 cm TL by Rajesh *et al*. (2015) from Karnataka and 59 cm TL by Munekiyo and Kuwahara (1984) in Japan. However, the estimated Lm_{50} of 42.5 cm TL reported by Reuben *et al*. (1997) from Vishakhapatnam waters, 47.3 cm TL by Abdussamad *et al*. (2006) from Kakinada, 35 cm TL by Sheridan *et al*. (1984) in Gulf of Mexico and 39.0 cm TL by Bellini (1980) in south-east Brazil were lower compared to the present study. On the other hand, higher Lm_{50} in comparison to the estimated values in the present study have been reported *viz*., 69 cm TL by Martins and Haimovici (2000) from southern Brazil, 71 cm TL by Kwok and Ni (1999) in the South China Sea, 79 cm TL by Al-Nahdi *et al*. (2009) from the Arabian Sea coast of Oman and 108 cm TL by Clain *et al*. (2021) from south-eastern Australia. The variations observed in length at first maturity from different geographical areas are related to the marked variations in temperature, fishing pressure and also due to the genetic variations among different stocks (Sampson and Al-Jufairly, 1999; Martins and Haimovici, 2000; Al-Nahdi *et al*., 2009; Amador and Aggrey-Fynn, 2020).

Microscopic and histological observations of gonads

Histological examination of gonads plays a vital role in reproductive studies, as it aids in confirmation of sex, sexual pattern and the maturity stage (Alon so-Fernandez *et al*., 2011). Seven ovarian developmental stages were categorised for *T. lepturus* based on the appearance of oogonia, formation of nucleoli, cortical alveoli, the zona pellucida, lipid, peripheral migration and dissolution of the germinal vesicle (Fig. 4 a-p). The maturity stages examined by the physical appearance of gonad with the aid of macro and microscopic views were confirmed with histological observations. The microscopic and histological examinations of the ovaries confirmed the presence of different stages of oocytes within the same individual suggesting *T. lepturus* to be an asynchronous batch spawner. This observation is supported by the previous reports from the Caribbean Sea (Del Toro, 2001), Mumbai, west coast of India (Khan, 2006), northern Arabian Sea and northern Bay of Bengal (Ghosh *et al*., 2014) and south-eastern Australia (Clain *et al*., 2020).

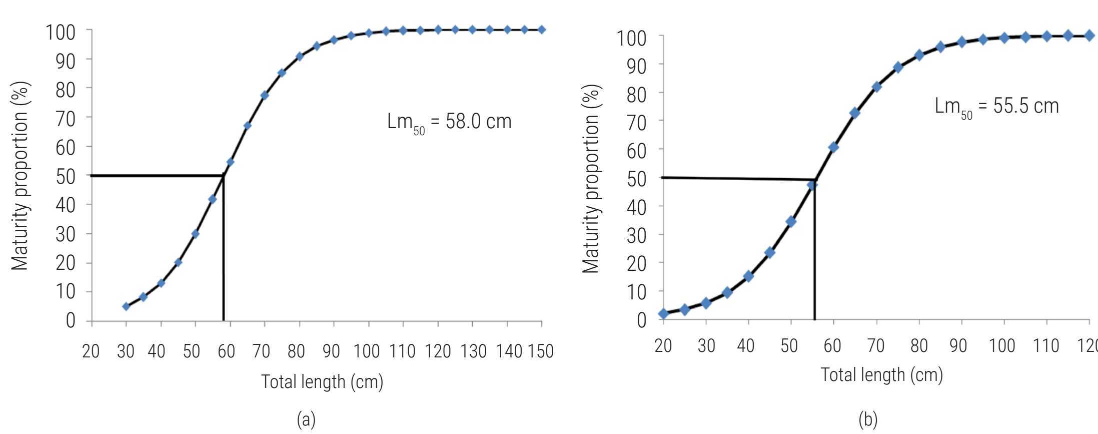

Fig. 3. Estimated lengths at first maturity of *T. lepturus* (females) collected from (a) eastern Arabian Sea and (b) western Bay of Bengal

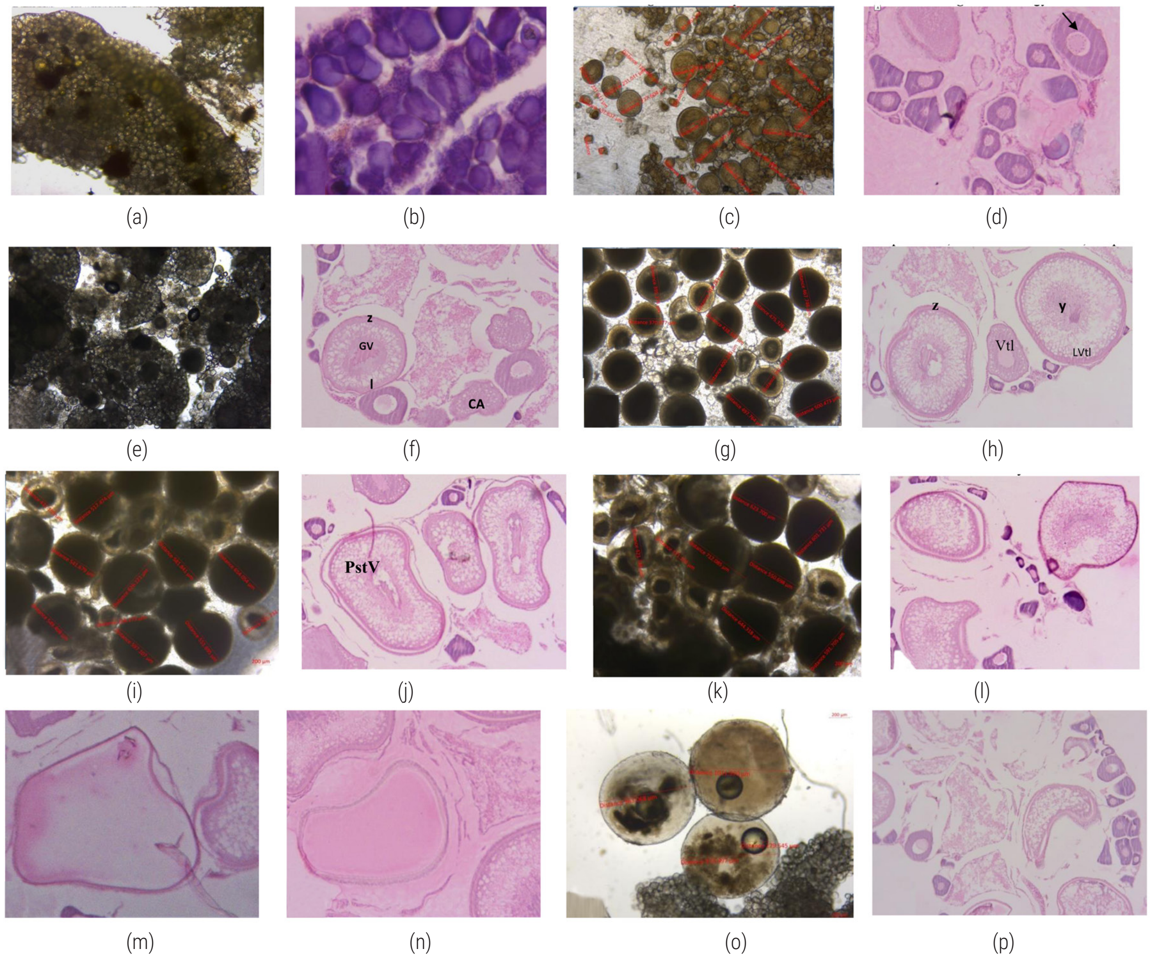

Fig. 4. Ovarian developmental stages of *T. lepturus:* Macroscopic and histological views. (a) Stage 1- Microscopic view; (b) Stage 1- Histology; (c) Stage 1I- Microscopic view; (d) Stage 1I - Histology: Indicates nucleoli moving to the periphery of the nucleus; (e) Stage III - Microscopic view; (f) Stage III Histology: GV - Germinal vesicle; Z - Zona pellucida, CA - Cortical Alveoli; l - lipid; (g) Stage IV - Macroscopic view; (h) Stage IV - Histology; Z - Zona pellucida; y-yolk; Vtl - Vitellogenic oocyte; LVtl - Late Vitellogenic oocyte; (i) Stage V - Macroscopic view; (j) Stage V - Histology: Oocytes are irregular in shape on account of the pressure from the adjacent oocytes; PstV - Post vitellogenic oocyte; (k) Stage VI - Macroscopic view; (l) Stage VI - Histology: L-lipid droplets; (m) Stage VI - Histology: Eight hours before spawning, Coalescence of lipid droplets is complete and the germinal vesicle has arrived at the periphery of the oocyte; (n) Stage VI - Histology: the oocyte is completely clear and the germinal vesicle has disappeared; (o) Stage VII - Macroscopic view: Spent oocytes; (p) Stage VII - Histology: Spent phase

Gonadosomatic index and maturity stages

The mean GSI of female *T. lepturus* fluctuated from 0.6 to 3.2 in the EAS (Fig. 5a) and 1.8 to 4.6 in the WBB (Fig. 5b). The highest values of GSI were recorded in February followed by May in the EAS while it was during February and October in the WBB. Both the regions depicted bimodal peak for GSI with primary peak during February. However, the secondary peak in the EAS immediately followed the primary peak in May, whereas in the WBB the secondary peak was in October. The peak GSI months in EAS was supported by 48.9% ripe and partially spawned (Fig. 5a) while these stages in the WBB comprised 47.3% (Fig. 5 b). Similarly, the secondary peaks in both the EAS and the WBB were supported by 36.7 and 31.1% of ripe and partially spawned stages respectively. The combination of higher GSI and higher proportions of ripe and partially spawned female fishes confirmed February to be the peak spawning period in both regions, while May and October months were secondary spawning periods for EAS and WBB respectively. In general, the GSI and proportion of ripe and partially spawned fishes were high to moderate during January to May in EAS (Fig. 5a) and October to March in WBB (Fig. 5b), indicating these periods as spawning season of *T. lepturus*. However, the presence of ripe, partially spawned, spent and spent recovered fishes throughout the year in varied proportions implied that spawning takes place throughout the year in different magnitudes. Similar peak spawning in winter and pre-monsoon seasons with prolonged spawning throughout the year in various magnitude was reported from northern Arabian Sea and northern Bay of Bengal (Ghosh *et al*., 2014), north-west coast of India (Bapat *et al*., 1982) and in the Arabian Sea coast of Oman (Al-Nahdi *et al*., 2009).

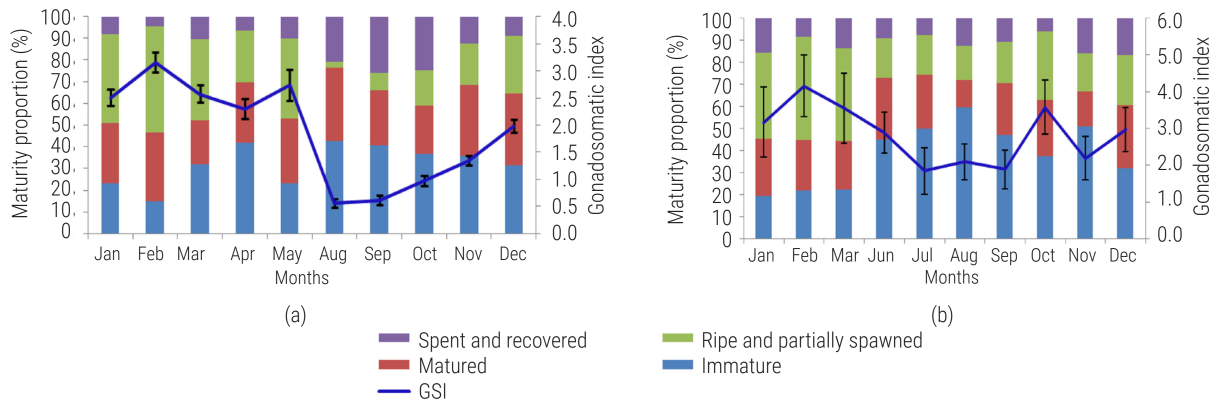

Fig. 5. Mean Gonadosomatic index and maturity stages of *T. lepturus* collected from (a) Eastern Arabian Sea and (b) Western Bay of Bengal

Absolute and relative fecundity

The estimated absolute fecundity ranged from 21,930 in a fish of 63.7 cm TL to 1,85,941 eggs in a fish of 70.6 cm TL with an average of 28,245±3306 (SE). In WBB, the estimated fecundity varied from 17,294 for a fish measuring 61.0 cm TL to 1,86,667 for a fish measuring 108 cm TL with an average of 75,000±10,436 (SE). The relative fecundity (per g body weight) varied from 12-841 with an average of 105±12.2 (SE) and 64-241 with mean of 64±15.1 (SE) in EAS and WBB respectively. Fecundity of *T. lepturus* correlated positively with the total length and body weight both in EAA (Fig. 6 a, b) and WBB (Fig. 7 a, b) indicating bigger females produced more eggs compared to smaller individuals.

The absolute fecundity estimated in the present study is comparable with the previous report of Ghosh *et al*. (2014) from northern Arabian Sea (23,756-2,08,300 eggs fish^{-1}) and northern Bay of Bengal (21,672-156,695 eggs fish^{-1}). In contrast, the absolute fecundity (eggs/fish) reported by Khan (2006) in New Ferry Wharf, Mumbai (4,900-81,000), Ojelade *et al*. (2019) in Bight of Benin waters, Nigeria (7051-12,456) and Amador and Aggrey-Fynn (2020) from the coast of Ghana (4,876-43,410) were less compared to the present study. However, the mean absolute fecundity documented by Abdussamad *et al*. (2006) from Kakinada (40,250) waters was higher than values observed for the EAS (28,245) but lower than the estimated fecundity of the fish in the WBB (75,000) of the present study. The wider variations recorded in the fecundity of *T. lepturus*

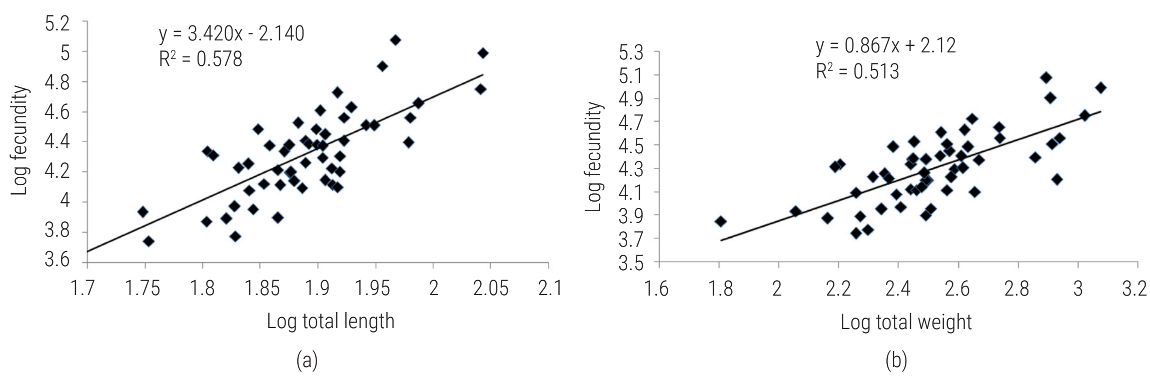

Fig. 6. Relationship between Fecundity and (a) total length and (b) body weight of *T. lepturus* from the Eastern Arabian Sea

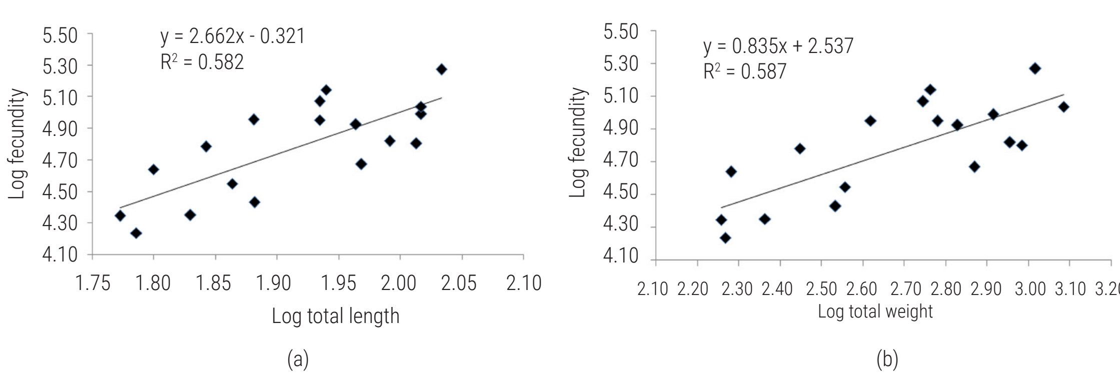

Fig.7. Relationship between Fecundity and (a) total length and (b) body weight of *T. lepturus* from the western Bay of Bengal

from different locations could be due to the variations in the size of the eggs as *T. lepturus* is a batch spawner, and is also influenced by variations in environmental factors (Suyani *et al*., 2021). Further, individuals of the same species are known to exhibit wide variations in fecundity depending on the size and distributional range (Bagenal, 1957).

The present investigation on reproductive biology of ribbonfish from both west and east coast of India would assist the policy makers in preparing uniform management strategies for both the coasts for sustainable harvest of ribbonfish from Indian Exclusive Economic Zone. Further, the length at first maturity estimated for both the coasts would assist to determine the minimum legal size for ribbonfish for the west and east coasts of India.

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