Indian J. Fish., 72 (3): 45-57, 2025 doi:10.21077/ijf.2025.72.3.154488-05

Available online at: epubs.icar.org.in/index.php/IJF

Biology of the widenose guitarfish *Glaucostegus obtusus* (Muller and Henle, 1841) (Rhinopristiformes: Glaucostegidae) from the eastern Arabian Sea

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Abstract

The study delves into the reproductive biology of *Glaucostegus obtusus*, a benthic, inshore batoid species currently listed as Critically Endangered, for which life history information remains scarce. A total of 331 specimens, collected as bycatch from shrimp trawl and gillnet fisheries operating at depths of 2-65 m between 2016 and 2022 off Karnataka, the south-west coast of India, were examined and analysed. Specimens ranging from 22 to 109.2 cm total length (TL) and 0.023 to 5.7 kg total weight (TW) were observed in the fishery. The length–weight relationship (LWR) derived was $W = 0.000392\ TL^{3.506478}$ (r^2=0.991), with no significant difference observed between sexes. Length-at-maturity ($Lm_{50\%}$) estimates for females and males are 60.4 and 50.4 cm TL, respectively. *G. obtusus* has two functional ovaries, with the ovarian cycle and gestation occurring simultaneously. Pregnant females were observed year-round, suggesting a non-seasonal reproductive cycle. Uterine fecundity ranged from 2 to 14 and estimated birth sizes, between 22 and 25 cm TL. Breeding peaks were identified in October–December and May-July, with the highest abundance recorded in the post-monsoon. Stomach content analysis revealed *G. obtusus* feeds on diverse prey, comprising mainly crustaceans (82% IRI) and teleosts (18% IRI). The present study provides preliminary insights into *G. obtusus* distribution and critical habitats based on fishery interaction and can contribute to marine conservation spatial planning. This study provides baseline data for fisheries management, conservation, and population assessment of the widenose guitarfish in the eastern Arabian Sea.

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Keywords:
Elasmobranchs, Length-weight relationship, Marine spatial planning, Maturity, Trophic ecology

Received : 08.01.2024
Accepted : 19.09.2025

Introduction

Elasmobranch fisheries demand improved management strategies to ensure sustainable harvests, prevent overexploitation and mitigate adverse impacts on the ecosystem and extinction risks (Moore *et al*., 2012; Jabado *et al*., 2017; Jabado, 2018; Jabado *et al*., 2018; Choy *et al*., 2022). Within the elasmobranch families, guitarfishes emerge as notably susceptible, ranking second in vulnerability only to sawfishes (Dulvy *et al*., 2014; Moore, 2017, Purushottama, *et al*., 2022). The international shark fin trade, particularly prevalent in Asia, significantly propels the demand for products derived from wedgefish and giant guitarfish (Choy *et al*., 2022).

The widenose guitarfish *Glaucostegus obtusus* (Muller and Henle, 1841), inhabits the Northern Indian Ocean from Pakistan to Thailand. It is commonly found in benthic inshore areas and extends over inner continental and insular shelves at depths of 60 m (Last *et al*., 2016). This species is frequently encountered as bycatch in coastal fisheries, including trawl and gillnet operations in the eastern Arabian Sea (Raje, 2006; Purushottama *et al*., 2022). In India, four *Glaucostegus* species have been reported: *G. granulatus* (Cuvier, 1829), *G. obtusus* (Muller and Henle, 1841), *G. thouin* (Anonymous, 1798) and *G. typus* (Bennett, 1830) (Akhilesh *et al*., 2014; Kizhakudan *et al*., 2018), which continues to remain one of the most data-limited groups and is assessed as Critically Endangered (CR) on the IUCN red list of threatened species (Kyne and Jabado, 2021). There is growing concern for the extinction risk of Rhinopristiformes and other batoids,

prompting considerations for their inclusion in the CITES Appendix II in 2019 (Moore, 2017; Jabado, 2018; Purushottama *et al*., 2020a) and protection in several countries. While this CITES categorisation does not outrightly prohibit global trade, countries under the Convention are obligated to ensure its legality, sustainability and traceability (Choy *et al*., 2022).

The assessment of guitarfish vulnerability is further compounded by a lack of comprehensive scientific information regarding their reproductive biology, dietary habits, and stock status in the northern Indian Ocean (Kizhakudan *et al*., 2015; Jabado, 2018; Purushottama *et al*., 2022). Poor understanding of the life history and spatial distribution patterns of *G. obtusus*, particularly in the Arabian Sea and adjacent waters and the Bay of Bengal, is highlighted by previous studies (Jabado, 2018; Nasir and Afsar, 2020; Mozzam and Osmany, 2020; Haque *et al*., 2021; Kottillil *et al*., 2023), which hampers effective conservation actions. Addressing this knowledge gap is crucial for unravelling the life history of the species, contributing valuable insights into its ecological and biological aspects, and fostering informed and sustainable management practices within the context of fisheries in the eastern Arabian Sea (Jabado *et al.,* 2018; Akhilesh *et al.,* 2021; Purushottama *et al*., 2022).

This underscores the necessity for a comprehensive understanding of the fishery and various biological traits exhibited by exploited shark-like batoids. To formulate effective management and conservation strategies in Indian waters, an in-depth exploration of their ecological characteristics, including reproductive biology and dietary preferences, is essential.

The present study aims to bridge this knowledge gap through a comprehensive investigation of biology and fishery interaction patterns.

Materials and methods

Between January, 2016 and December, 2022, a total of 331 specimens of *G. obtusus* were collected from trawl net and gillnet landings at the fisheries harbours of Mangaluru (12°51'10.8"N; 74°49'58.8"E) and Malpe (13°20'49.2"N; 74°42'3.6"E) along the Karnataka coast (Fig. 1). This study included 167 females and 164 males, caught as bycatch in fisheries at depths 2 to 65 m in the eastern Arabian Sea off the coast of Karnataka. All specimens were measured for total length (TL, cm) and total body weight (W, g) and sex of each specimen was recorded. The umbilical scar was categorised from the healing status *i.e.,* open, healing, or closed. Based on the state of the umbilical scar, as well as the TL, the individuals with open and healing umbilical scars were classified as neonates, while the ones with closed scars were identified as juveniles.

The size distribution (with 3 cm class intervals) for each sex was subjected to Shapiro-Wilk test (Shapiro and Wilk, 1965) to ascertain deviation from normal distribution. Sex-wise differences in the size distribution were ascertained using $\chi 2$ test (Cochran, 1952). Sex ratios were also tested across seasons: Pre-monsoon (February-May), Monsoon (June-September), and Post-monsoon (October-January).

Maturity stages were classified following the maturity scale proposed by Stehmann (2002). In females, the state with undeveloped ovaries or ovaries with maturing oocytes and thin, ribbon-like uteri were considered immature, while those with fully developed ovaries and uteri were considered mature. In males, the extent of calcification of the claspers was assessed. Those with partially calcified claspers were considered immature, while those with well calcified claspers were categorised as mature. For

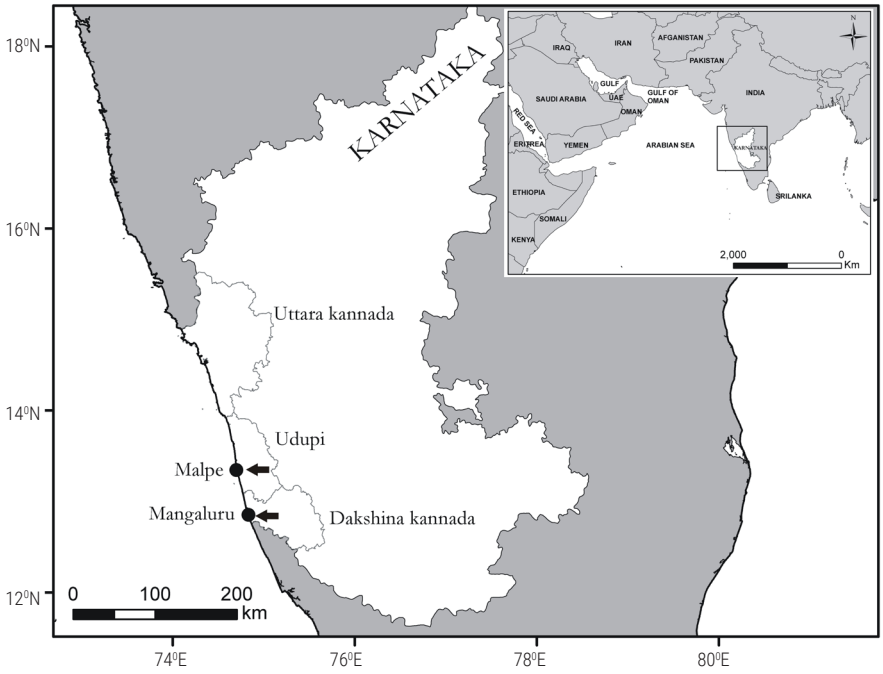

Fig. 1. Map of study area indicating the locations of *G. obtusus* sample collection

embryos, the mean embryonic TL (measured to the nearest mm) was compared for each month. Fecundity was assessed from the number of uterine embryos in each pregnant female. Differences in litter size between left and right uteri were tested for statistical significance using the t-test. In males, the relationship between clasper length and body size was studied by comparing the outer clasper length (L_{CO}) and TL of each individual.

The $L_{m50\%}$ for both sexes was derived by logistic regression, using the equation $p_L = \{1 + e^{[-\ln(19)\,(TL-TL_{50})\,(TL_{95}-TL_{50})]-1}\}^{-1}$, where p_L is the proportion of mature fishes at a given length (TL), while TL_{50} and TL_{95} are constants. The SOLVER routine in Microsoft™ Excel was used to derive maximum likelihood estimates of the parameters, where the likelihood of immature and mature individuals was calculated as 1 - p_L and p_L, respectively. The 95% C.I. was estimated as 2·5 and 97·5 percentiles of 200 estimates derived from re-sampled data, with the same sample size, drawn from the data on the observed maturity status at TL for males (Wood, 2004; White, 2007; Purushottama *et al.,* 2017). The distribution of juveniles, sub-adults and adults of both sexes based on $L_{m50\%}$ was also analysed.

Length-weight relationship (LWR) was estimated using the exponential equation $W = a\ TL^b$ (Le Cren, 1951) after logarithmic transformation, W being the weight of the fish in g and TL the total length in cm; *a* the intercept and *b*, the regression coefficient (Froese, 2006). The confidence and prediction intervals were calculated as per Montgomery *et al*. (2012). Sex-wise difference in LWR was tested for statistical significance by analysis of covariance and the F-test (Montgomery *et al*., 2012).

Analysis of diet was done to estimate the percent Index of Relative Importance (%IRI) as IRI=(%*N* +%*M*)* %*O*, where *O* is the frequency of occurrence, *N* is the composition by number and *M* is the percent composition by mass (Pinkas *et al*., 1971). Expression of IRI as %IRI allowed comparison between the prey groups (Cortes, 1997).

Results

In all, 382 individuals of *G. obtusus* were examined in the field and laboratory, comprising 167 females, 164 males and 51 unsexed specimens recorded between January 2016 and December 2022. Specimens of *G. obtusus* length ranged from 22.7 to 109.2 cm total length (TL) (mean+S.E. = 71.6 + 1.3) and weight from 30 to 5770 g (mean+S.E. = 1572 + 91) for females, length ranged from 22.0 to 101 cm TL (mean+S.E. = 64.8 + 1.2) and weight from 23 to 4500 g (mean+S.E. =1117 + 63) for males. The landings from trawl and gillnet comprised a wide size range of individuals. Thirty-one size classes (3 cm TL intervals) were used for the classification, from 21 to 111 cm TL (Figs. 2a and b). The χ^2 test revealed significant differences ($p<0.05$) in length frequency distributions between females and males, with more females between 55 - 90 cm TL and 60-75 cm TL for males captured. The size-sex frequency distribution indicates that gillnets predominantly captured mature individuals of *G. obtusus*, while trawlers had more sub-adults, juveniles and neonates.

The overall female to male ratio observed was 1.02:1 slightly in favour of females and did not differ significantly from 1:1 ($p>0.05$) (Fig. 3). Seasonal sex ratio was estimated; in pre-monsoon (February-May) sex ratio was 1.4:1, in monsoon (June-September) (0.9:1) and also in post-monsoon (October-January) (0.9:1). The distribution of females and males of *G. obtusus* did not differ significantly in sampling months (χ^2, d.f. =10, $p>0.05$) The size-frequency distribution of *G. obtusus* is presented in Fig. 4, the sex ratio showed significant differences favouring females in the size class of 41-45 cm TL, 81-85 cm TL, 91-95 cm TL, 96 -100 cm TL and 101-105 cm TL and favouring males in the size class of 21-25 cm TL, 36-40 cm TL, 56-60 cm TL, 66-70 cm TL. The distribution of females and males differed significantly in the different

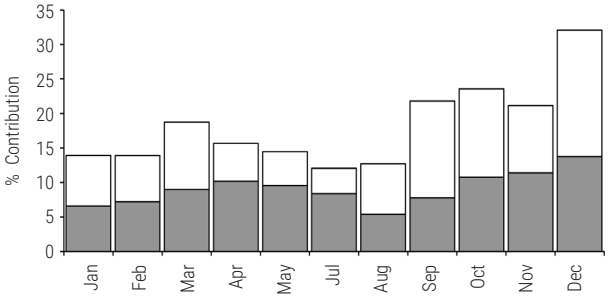

Fig. 3. Monthly % contribution of females (■, *n*=167, to males (□, *n*=164) of *G. obtusus* landings at Karnataka from January 2016 to December 2022

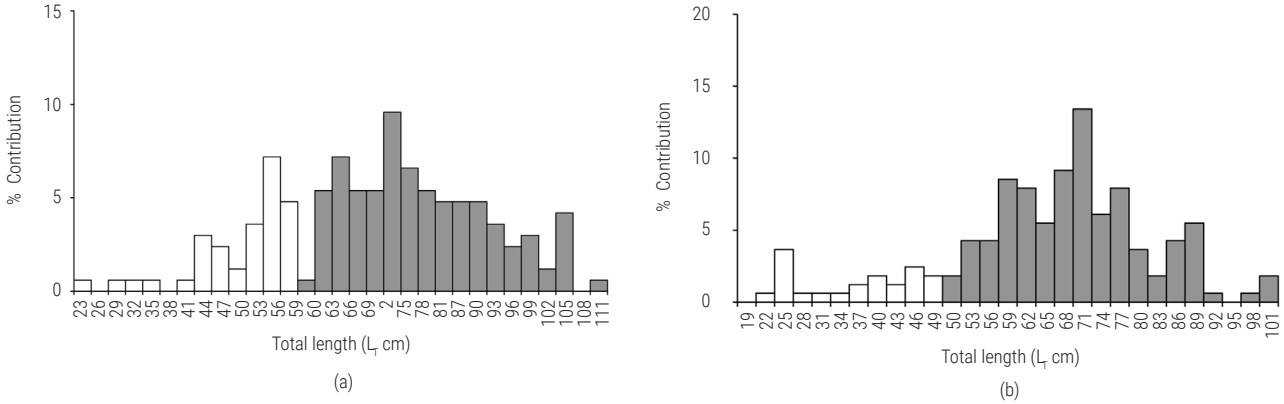

Fig. 2. Total length (L_T)-frequency histograms for immature (□) and mature (■) *G. obtusus* captured in trawl and gillnet fisheries (*n*=382) in the eastern Arabian Sea from January 2016 to December 2022. All individuals in L_T classes <60.4 cm and <50.4 cm were considered immature for (a) female and (b) male, respectively, based on estimates of size at maturity in this study

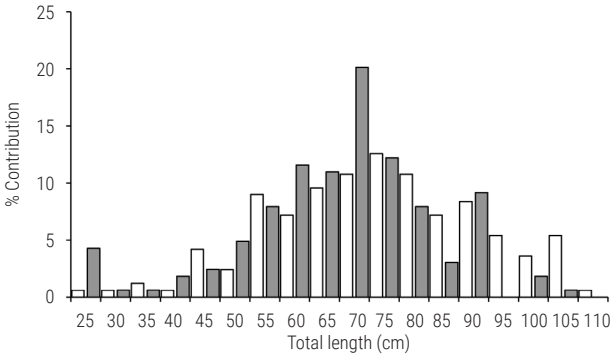

Fig. 4. Total length (TL) frequency histogram of *G. obtusus*. [Females (□), *n*=167; males (■), *n* =164) studied

sub-groups *viz.*, juveniles, sub-adults and adults (χ^2, d.f. =2, p<0.05). The sex ratios of female to male in juveniles (<40 cm TL), sub-adults (41-59 cm TL) and adults (>60 cm TL) were 1:0.42, 1:3.1 and 1:0.9, respectively. The monthly TL frequency distribution (pooled years) shows no clear trends of females and males, possibly due to fishing methods (Fig. 5). Landings were represented by a restricted size range of individuals in all of the months for which data were obtained, except for October and November.

The distribution pattern of *G. obtusus* (females and males) juveniles, sub-adults and adults in different months (pooled data) shows that juveniles (<40 cm TL) reported maximum in July and October (6%), sub-adults (41-59 cm TL) in July (22%) and March (19%) and adults (>60 cm TL) in December (18%) and November (12%) for female (Fig. 6a), juveniles (<40 cm TL) accounted maximum in July (50%), sub-adults (41-49 cm TL) in February, April, September (25%), and adults (>60 cm TL) between September and December, with the highest in December (21%) for male (Fig. 6b).

The weight of *G. obtusus* ranged from 30 to 5770 g in females and from 23 to 4500 g in males. The equations relating to total length (TL) and weight (W) (TL *v. W*) of *G. obtusus,* consisting of 167 females (22.7-109.2 cm TL) and 164 males (22.0-101 cm TL), are presented below, thus enabling approximate masses of guitarfishes to be estimated from a given total length. The slopes were not found to be significantly different between the sexes (p>0.05).

Females: $\text{Log}_{10}W = -7.64946 + 3.464692\ \text{Log}_{10}TL$ (r^2= 0.981, 95% of C.I. of *b* = 3.291458 - 3.637927, *n*=167)

Males: $\text{Log}_{10}W = -7.38447 + 3.393558\ \text{Log}_{10}TL$ (r^2= 0.980, 95% of C.I. of *b* = 3.223880 - 3.563236, *n*=164)

Pooled: $\text{Log}_{10}W = -7.84435 + 3.506478\ \text{Log}_{10}TL$ (r^2= 0.992, 95% of C.I. of *b* = 3.331154 - 3.681801, *n*=331)

A total of 331 (Females = 167; males =164) guitarfishes were used for the reproductive biology studies. Mature females, with ovaries containing maturing oocytes (Maximal ovarian fecundity) ranged between 4 and 100 (mean+S.D. 22.0+17.5) and oocyte diameter measuring from 1.0 to 38 mm (mean+S.D. 9.2 + 8.6). Functional uteri, were observed in specimens ranging from 66.8 to 109.2 cm TL. The oviducal gland width (OGW) from mature females was measured and OGW ranged from 14 to 31 mm (mean+S.D. 22.7+4.6). There is a significant positive correlation found between the matured female total length and OGW (p<0.005). The largest immature female was 102.7 cm TL. Female *G. obtusus* matured between 58 and 62 cm TL, with 50% maturing at 60.4 cm TL (95% C.I) (Fig. 7a). The smallest mature male *G. obtusus* recorded was 45.3 cm TL, whereas the largest immature male was 90 cm TL. Males matured in a different size range (48-52 cm TL) and 50% matured at 50.4 cm TL (95% C.I.) (Fig. 7b).

The claspers of males of *G. obtusus* become elongate and rigid at approximately 45 cm TL and most of the examined were fully calcified at >55 cm TL. Sizes of maturity classes for *G. obtusus* were up to <40 cm TL (3.0%, *n*=5) for juveniles, 41-59 cm TL (22%, *n*=37) for sub-adults and >60 cm TL for mature (adults) (75%, *n*=125) for female and <40 cm TL (7.0%, *n*=12) for juveniles, 41-49 cm TL (7.0%, *n*=12) for sub-adults and >50 cm TL for mature (adults) (85%, *n*=140) for male. The classification was done based on 50% maturity ($L_{m50\%}$) in this study (Fig. 8).

Sixty-four pregnant female *G. obtusus* (66.8-109.2 cm TL; mean+S.D. 89+11 cm) were dissected and each contained two to fourteen (mean+S.D. 7 + 3.5) fully formed embryos of 13.5-23.6 cm TL; (mean+S.D. 18.4 + 2.2 cm) and weight ranging from 4 to 27 g (mean+S.D. 12.4 + 5.1 g) (Fig. 9). The reproductive mode is aplacental viviparity. The size-frequency distribution of pregnant *G. obtusus* is presented in Fig. 10.

Pregnant females of *G. obtusus* were observed in all months, which exhibits a non-seasonal reproductive cycle, the maximum pregnant females were observed in the length classes of 76-80 cm TL, 86-90 cm TL, 91-95 cm TL and 101-105 cm TL (Fig. 11). Embryos, ranging in size from 1.3-20 cm TL had the yolk-sac stalk still attached and the late term (near to parturition) embryos of 21 cm TL -23.6 cm TL were with umbilical scar. The smallest specimen observed in the fishery was 22 cm TL, however, the number of newborn/juveniles observed in the gillnet catch was very low (in the trawler landings at Mangalore, Karnataka newborns of 22-25 cm TL were observed more in number). Based on the current dataset, the size at birth of *G. obtusus* in the south-west coast of India was estimated to be between 22 to 25 cm TL. The study reports the greatest number of embryos, containing 14 embryos (Left-6 and Right-8) with mean size 20.0 cm TL and sex ratio 1.5:1 (female: male) recorded from any *G. obtusus* (93.5 cm TL, 3282 g, so far. The total number of embryos recorded in this study was 112, but the sex was determined in 46 litters from 8 females. The overall sex ratio within these individual litters was significantly different from parity (χ^2, d.f. =1, p<0.05), sex ratio of embryos was observed to be 1.8:1 (female to male), the largest embryo was observed in a female of 22.5 cm TL and a male of 23.6 cm TL. No significant positive correlation was observed between maternal total length (TL) and the number of embryos per pregnant individual (Pearson's *r* = 0.509, *n* = 64, p>0.05) and also no relationship was established for maternal TL with the largest females producing the greatest number of pups (Pearson *r* =0.450, *n*=26, p>0.05). A significant functional relationship between maternal TL and liver weight was also found (Pearson *r* = 0.817, *n*=26, p<0.001).

The L_{CO} was found to increase with body size; the smallest male of 22.0 cm TL had L_{CO} of 1.0 cm while the largest male of 101.0 cm TL had L_{CO} of 16.0 cm (Fig. 12).

In this study, sexual and size segregation of *G. obtusus* were observed. The juveniles of *G. obtusus* (22.5-34 cm TL) were found mostly in the depth range of 2-5 m, sub-adults were in 10-45 m

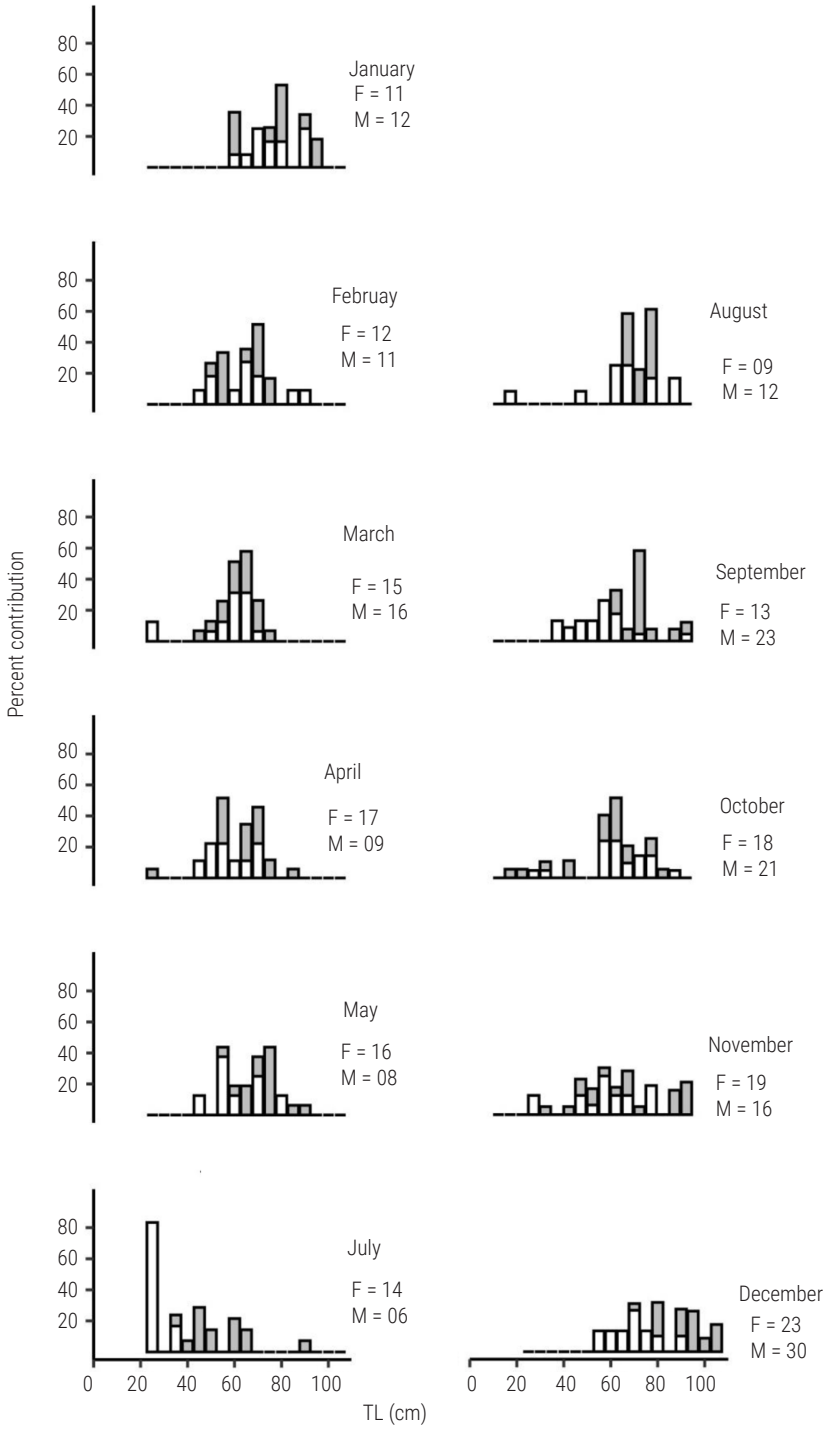

Fig. 5. Monthly total length (TL) frequency histograms for females (■) and males (□) of *G. obtusus* in the eastern Arabian Sea from January 2016 to December 2022. Pooled over the seven years of survey

depth, and adults were found in the depth range of 2-65 m along the west coast of India. Mature females were dominantly caught during post-monsoon season (October-January) between 25 to 42 m depth ranges. The females and males were active at different times or migrate separately during different seasons; juveniles of both the sex measuring from 35 to 40 cm TL were found in 35-60 m depth and their migration was observed during post-monsoon season. Female and male sub-adults were found in 10-58 m and 10-45 m depths, respectively, in all the seasons. In the study, sexually active females and males of 60-80 cm TL were found in all the depths, migrating for feeding and mating purposes in the pre-monsoon season. In all the seasons, mostly pregnant females

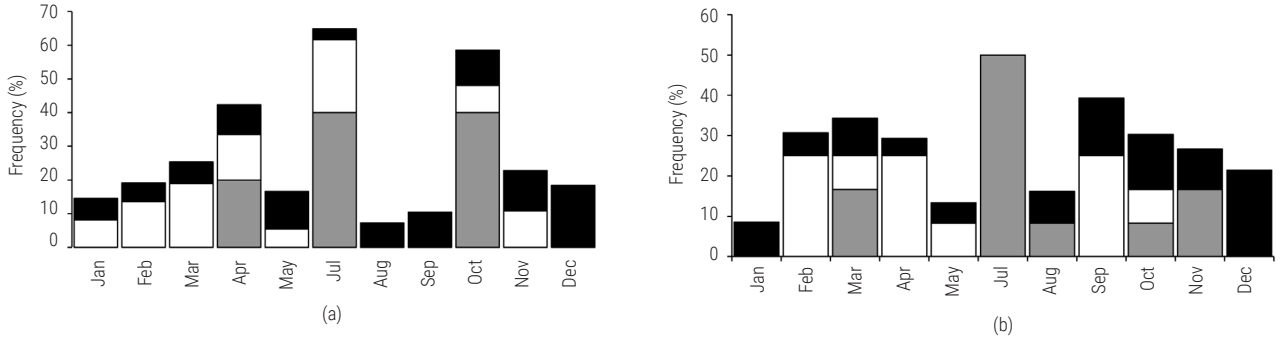

Fig. 6. Monthly frequency of occurrence of *G. obtusus* sampled in the eastern Arabian Sea between January 2016 to December 2022 (Pooled data) for juveniles (■), sub-adults (□), adults (■) for (a) female and (b) male

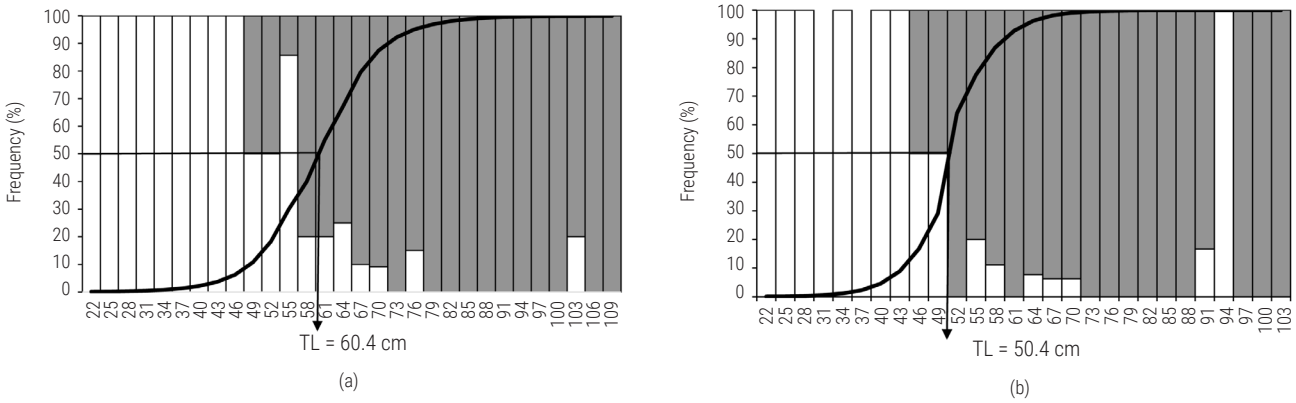

Fig. 7. Percentage frequency of occurrence of immature (⌐) and mature (■) *G. obtusus* in sequential total length (TL) classes for (a) females and (b) males. Logistic curves were derived from the following equation: $P_L = [1+e^{-\ln 19\,(TL - TL_{50})/(TL_{95} - TL_{50})}]^{-1}$. Arrows indicate the TL at which 50% of females and males attain maturity ($L_{m50\%}$)

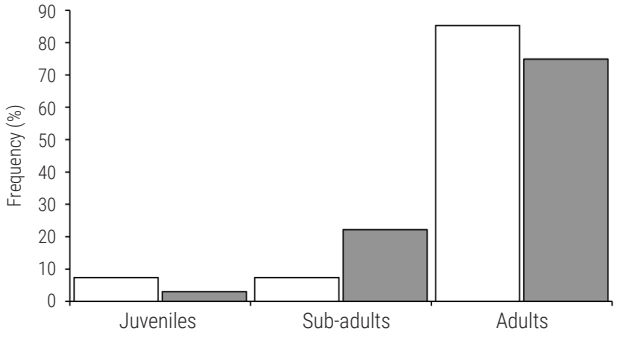

Fig. 8. Percentage frequency of occurrence of juveniles, sub-adults and adults of *G. obtusus* for female (■) and male (⌐)

(nearing parturition) were observed in estuarine and coastal waters in the depth range of 2-20 m (Fig. 13).

The size segregation of female and male sub-adults and adults was observed. Sub-adult females measuring in length from 41 to 59 cm TL were found in pre-monsoon season at 2-58 m depth range and specific size ranges of adult females measuring from 63.1-70.1; 73.1-75; 82.1-86.4 and 95-98 cm TL were frequently landed during the study from different depth ranges in pre-monsoon season. Pregnant females (nearing parturition) measuring >75 cm TL, preferring estuarine and coastal habitats were recorded during the monsoon season (June-September) and post-monsoon (October-January). Similar behaviour of size segregation was observed in sub-adult and adult males too. Notably, the size segregation of sexually active females and males in the length range of 60-80 and 55-70 cm TL, respectively, was observed together in all the seasons at 10-50 m depth ranges.

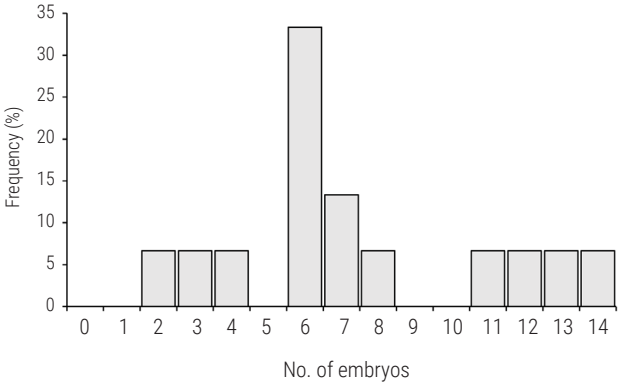

Fig. 9. Frequency of females with their corresponding number of embryos for *G. obtusus*

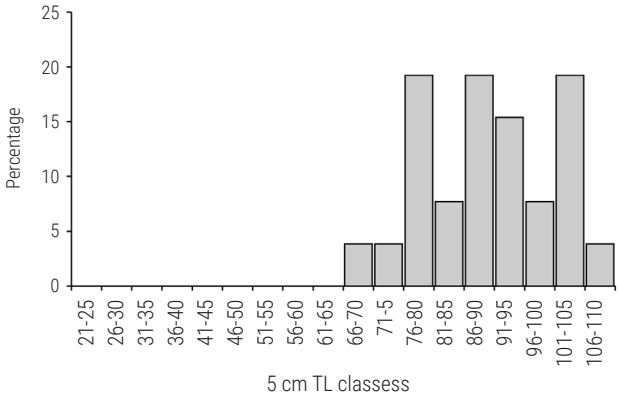

Fig. 10. Total length (TL) frequency histogram of pregnant *G. obtusus*

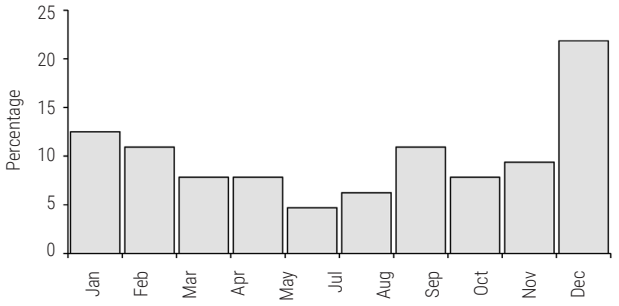

Fig. 11. Percent frequency of occurrence of pregnant females of G. *obtusus* in the eastern Arabian Sea

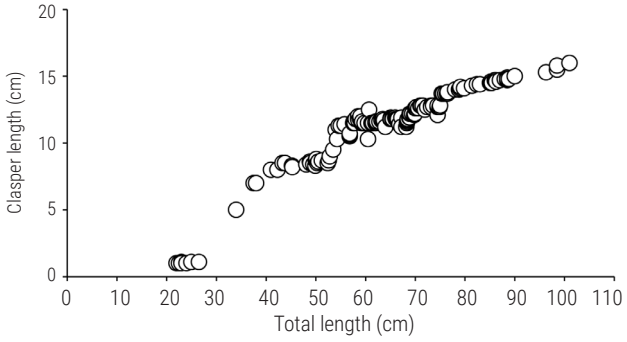

Fig. 12. Relationship between outer clasper length (L_{CO}) and total length of males of *G. obtusus*

A total of 293 specimens (50-109.2 cm TL) were examined to understand the prey selection habit of *G. obtusus*. Of these, only 27.3% (*n*=80) contained prey items, 22.5% (*n*=66) contained either semi-digested or highly digested food that could not be identified, and 50.2% (*n*=147) were empty. The fullness of the stomach revealed that 50.2% (*n*=147) were empty, 25.3% (*n*=74) were quarter full, 18.1% (*n*=53) were half full, 2.4% (*n*=7) contained trace contents only, 3.8% (*n*=11) were three-quarter full, 0.3% (*n*=1) were full and none were gorged (Fig. 14). The analysis of stomach contents (%IRI) revealed that *G. obtusus* feeds primarily on crustaceans (82%) and teleosts (18%). The major prey items included *Cynoglossus* spp. (4.0 %IRI), *Sillago sihama*. (0.2%IRI), *Oratosquilla* spp. (23 %IRI) and *Acetes* spp. (15%IRI) (Table 1).

Discussion

The study explores the often-overlooked aspects of batoid bycatch in the coastal waters of Karnataka, focusing on giant guitarfishes

Table 1. Dietary composition of *G. obtusus* in the eastern Arabian Sea

Prey item	% N	%M	% O	% IRI
Teleostei				
Sillaginidae	1	3	1	0.2
Sillago sihama				
Cynoglossidae	7	6	10	4
Cynoglossus spp.				
Other	11	23	13	14
Unidentified fishes				
Crustacea				
Sergestidae	16	2	26	15
Acetes spp.				
Squillidae	33	19	14	23
Oratosquilla spp.				
Other	21	38	17	32
Unidentified shrimp				
Other	11	9	19	12
Unidentified crab				

(family Glaucostegidae). The family comprises a single genus and ten valid species. The IUCN Red List of Threatened Species assessed seven out of the ten Glaucostegidae species as Critically Endangered due to population declines caused by overfishing, habitat loss and degradation (IUCN, 2023). This study contributes to our understanding of the distributional and biological parameters of *G. obtusus* in the south- eastern Arabian Sea.

G. obtusus is a species of giant guitarfish found in the Indo-Pacific region, including the Indian Ocean (Last *et al*., 2016). The size of *G. obtusus* can vary, but they typically reach a length of around 1 to 1.5 m, with females generally being larger than males (Raje *et al*., 2006). Usually, the batoid species were incidentally caught in the trawl and gillnet fishery specifically targeting high-value table fishes in the region. Limited information exists regarding the biology of *G. obtusus* in Indian waters, given its infrequent observation and underreporting in fisheries. In the north-eastern Arabian Sea, the *G. obtusus* fishery exhibited an average annual landing of 9.52 t yr^{-1} during 1989-1993, followed by a decrease to 2.68 t yr^{-1} in 1994-1998 and a further decline to 1.7 t yr^{-1} in 1999-2003 (Raje *et al*., 2006). In the northern Arabian Sea, Moazzam and Osmany (2020) reported maximum landings of 5.6 t between January 2019 and February 2020. In other regions, there were no reported instances of *G. obtusus* fisheries (Moore *et al*., 2012; Roy *et al*., 2013; Jabado, 2018). The size distribution data of *G. obtusus* observed in the trawl/gillnet/artisanal fishery in the south-eastern Arabian Sea (22.7-109.2 cm TL) varies slightly from data reported in other regions and included all life history sizes. Sujatha (2002) observed batoid fishes in trawl bycatch in the Bay

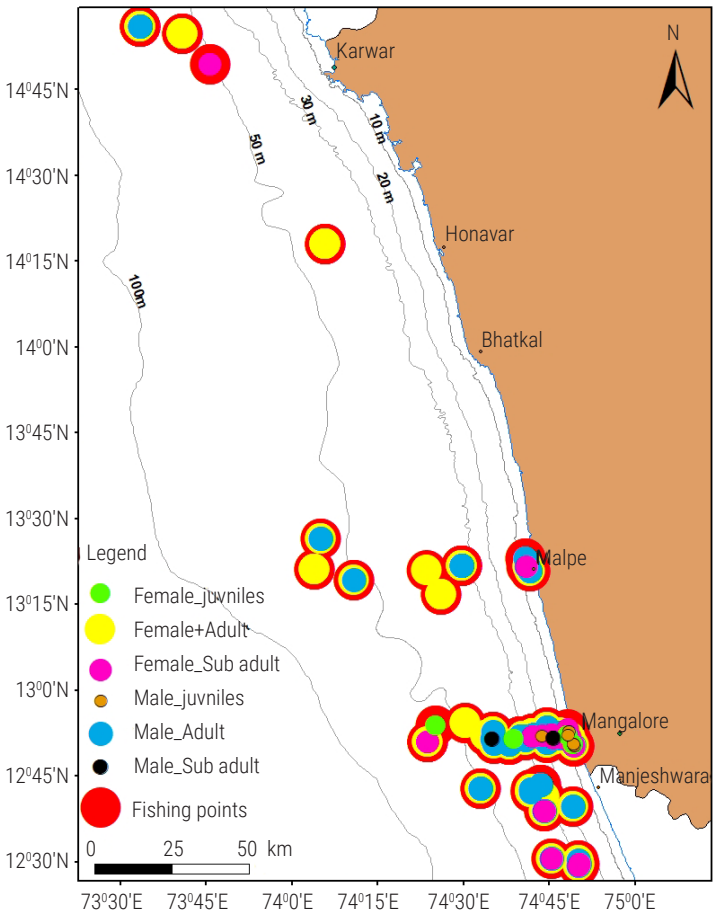

Fig. 13. The fishing pattern at different depth zones in the south-eastern Arabian Sea, where *G. obtusus* were caught along the Karnataka coast

of Bengal, examining two specimens of *G. obtusus* measuring 23 and 31 cm TL. Haque *et al*. (2021) investigated Rhinopristiformes in the Bay of Bengal, reporting a total of 282 specimens of *G. obtusus* and measuring twenty-two specimens, ranging from 60.96 to 137.17 cm TL. Raje (2006) from north-west coast of India examined 301 specimens, with sizes ranging from 36.9 to 80 cm TL for females (*n*=174) and 26 to 76 cm TL for males (*n*=123). Moazzam and Osmany (2020) recorded specimens ranging in size from 31 to 75 cm TL from Pakistan. Meanwhile, Nasir and Afsar (2020) reported two specimens, one female and one male, measuring between 59.0

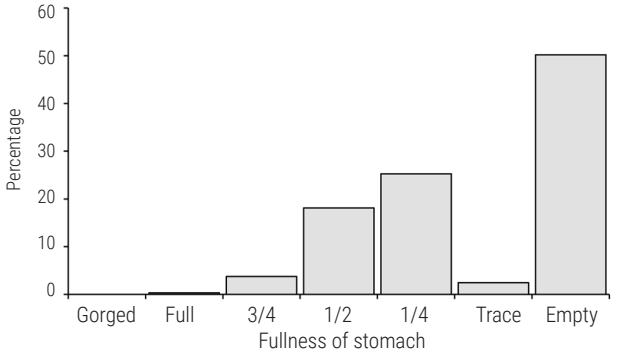

Fig. 14. Fullness of stomach analysed for *G. obtusus* (*n*=293)

and 63 cm TL, in the Northern Arabian Sea, Pakistan. Kottillil *et al*. (2023) measured 114 out of 234 specimens, revealing a mean size of 66.3+19.7 cm TL for females and 74.1+20.9 cm TL for males in Malvan, Central west coast of India. The differences may arise from various factors such as fishing gear selectivity, sample size, and regional differential growth based on habitat (Motta *et al.* 2005, Purushottama *et al*., 2017). Last *et al*., 2016 reported a maximum length of 93 cm TL for this guitarfish, however maximum length observed in this study was 109.2 cm TL for females and 101 cm TL for males. The observed difference in size frequency distributions between females and males likely stems from sexual segregation or gear selectivity, a common attribute of shark and ray populations typically linked to reproduction, migration, or competition (Springer, 1967; Klimley, 1987; Stevens and Mcloughlin, 1991; Motta *et al*., 2005; Purushottama *et al*., 2017). *G. obtusus* landings revealed a prevalence of large individuals, with females primarily falling within the 65-80 cm TL range and males within the 60-75 cm TL range. The average size of females significantly exceeded that of males and 38% of recorded landings consisted of pregnant females. In general, studies on sharks and rays by Moore *et al.* (2012) in Kuwaiti waters and Purushottama *et al.* (2017) in Indian waters reported a female-biased sex ratio in landings, with pregnant females comprising a substantial proportion of the catch.

The overall sex ratio of females to males recorded from the landings (1.02:1) showed unequal trends in monthly sex ratios. Seasonal and size class sex ratio analyses indicated that the sub-adults and adults of *G. obtusus* show a sex and size segregation. Females appear to be more vulnerable to fishing than males. In the north-eastern Arabian Sea, Raje (2006) conducted observations on the sex ratios of guitarfishes, revealing a male-to-female ratio of 1:1.41 in *G. obtusus R. granulatus* (1:1.2), *R. annandalei* (1:2.1). The monthly analysis indicated a noteworthy disparity, particularly in August and September, where females were predominant. Notably, females exhibited bimodal distribution at 50.0 and 75.0 cm TL, whereas males had a unimodal distribution centred at 50.0 cm TL. In the mutli-gear regime operating in the Arabian Sea and adjacent waters, Jabado (2018) recorded a nearly equal distribution of females and males (1.16:1) among the Rhinopristoids in the landings, a finding consistent with our study results. In contrast, Purushottama *et al*. (2020a) reported a female-biased sex ratio of 1.6:1 in the north-eastern Arabian Sea for *R. annandalei*. Moore and Peirce (2013) reported a sex ratio of 1:5 (males: females) for *Rhinobatos* cf. *punctifer* (Rhinopristiformes) in Bahrain waters. White and Dharmadi (2007) observed a female-biased sex ratio in various batoid species in eastern Indonesia, including *Rhinobatos jimbaranensis* exhibited a skewed sex ratio (1.4:1) with female dominance in the landings, while that of *Rhinobatos penggali* was 0.97:1. To establish genuine trends in sexual segregation, comprehensive information on sex ratios in provincial fishery/ populations of *G. obtusus* across its known range is necessary. The Interpreting differences in landed sizes and unequal sex ratios in sharks and rays can be challenging, as these variations may stem from factors such as sexual or spatial segregation by depth or area, gear selectivity, or even natural phenomena (Motta *et al*., 2005; Sims, 2005; Henderson *et al*., 2007; Purushottama *et al*., 2017; Jabado, 2018; Purushottama, *et al*., 2020a, b; Purushottama, *et al*., 2022).

Data from 331 individuals, comprising 167 females (ranging from 22.7 to 109.2 cm TL and 30 to 5770 g) and 164 males (ranging from 22 to 101 cm TL and 23 to 4500 g), were utilised to establish length-weight relationships (TL *v.* W) for *G. obtusus*. The smallest measured individual in this study was a female with a length of 22.7 cm TL weighing 30 g, while among males, the smallest individual had a length of 22 cm TL and a weight of 23 g. Notably, the length-weight relationships exhibited no significant differences between the sexes (b>3), aligning with allometric growth patterns where the fish tends to grow faster in weight than in length. The length-weight relationship for *G. obtusus* was estimated, resulting in distinct regression equations: Log W= -11.3859+2.8179 Log L (r=0.95) for females and Log W= -6.6566+2.0559 Log L (r=0.87) for males (b<3), aligning with allometric growth patterns where the fish tends to grow faster in length than in weight (Raje, 2006). It is worth noting that this investigation focused on a limited size range, encompassing only juvenile or sub-adult fishes in the north-eastern Arabian Sea. Furthermore, the derived *a* and *b* values were underestimated. Comprehending the length-weight relationship is crucial for estimating population size, age structure, growth rates and reproductive patterns, as well as overall biomass (Ricker, 1968; Park *et al*., 2016; Zhang *et al*., 2016; Purushottama *et al*., 2018). These insights are essential in managing and conserving shark and ray species, gaining a better understanding of their ecological roles and assessing the broader health of marine ecosystems.

The present study determined the $L_{m50\%}$ of females *G. obtusus* to be 60.4 (58.0-62.0) cm TL. Raje (2006) observed maturity in females with a length of 58 cm TL. The smallest adult male observed in the current study was 45.3 cm TL. Raje (2006) reported the maturity of males at 51 cm TL based on 123 specimens in the north eastern Arabian Sea, while Haque *et al*. (2021) determined the length at maturity in the Bay of Bengal to be approximately 48 cm TL. In the present investigation, the L_{m50} of males was estimated as 50.4 (48-52) cm TL; however, Last *et al*. (2016) reported that males mature at around 48 cm TL. Consequently, the present study provides the first detailed account of size at maturity for male *G. obtusus* in Indian waters. The study indicates that females and males generally mature between 50.0 and 60.0 cm TL, with males likely maturing at a smaller size.

The species exhibited a mean litter size of 7, ranging from 2 to 14 embryos, with estimated birth sizes between 22 and 25 cm total length (TL). Devadoss (1977) reported embryo numbers in *G. obtusus* between 4 and 8 from Portonovo, Bay of Bengal. Raje (2006) reported uterine fecundity one to six in the north-eastern Arabian Sea. Mozzam and Osmany (2020) observed a single pregnant female, measuring 100 cm TL, carrying 18 mid-term embryos without a yolk sac (ranging from 11.5 to 19.0 cm TL) in the northern Arabian Sea, Pakistan. Haque *et al*. (2021) documented the observation of a single gravid female with three litters in Bangladesh. In the present study, neonates with fresh, unhealed umbilical scars were recorded, measuring 22.0 cm TL, while those with healed umbilical scars measured 25.0 cm TL in the fishery. Pregnant females of *G. obtusus* were consistently observed throughout the year, with peak occurrences in September-November and December-February, reaching a maximum in December (22%).

The presence of term embryos and vitellogenic follicles concurrently in females of *G. obtusus* suggests an annual reproductive cycle with simultaneous ovarian and gestation phases. This reproductive pattern aligns with observations in wedgefish and guitarfish species, such as *R. laevis, R. annandalei,* and *R. ancylostomus*. Reproductive activity among Rhinopristoids in Indian waters appears to be most prevalent during the monsoon and post-monsoon months, with maximum occurrences of gravid or parturient females noted from October to December (Raje, 2006; Raje *et al*., 2007; Purushottama *et al*., 2020a; Purushottama *et al*., 2020b; Purushottama *et al*., 2022).

Recognising the significance of aggregation sites, especially in proximity to range limits, such as the estuarine and coastal waters of Mangaluru and Malpe along the Karnataka coast, appears to be a critical habitat of *G. obtusus* at various life cycle stages. The aggregation definition was adopted from Otway *et al*. (2003), locations where five or more Widenose guitarfish were consistently found throughout the year. Juvenile *G. obtusus* landings were consistently observed in the depth range of 2-5 m throughout the study period. Strong *et al*. (1996) proposed that smaller sharks employ spatial restriction as a strategy to minimise interactions with larger conspecifics, a notion supported by Ryklief *et al*. (2014), who, during observations in Mossel Bay, found a substantial proportion of juvenile *Carcharodon carcharias* favouring sheltered conditions. This preference suggests that juveniles may enhance their rates of growth and development while minimising predation risk (Branstetter, 1990; Heupel *et al*., 2007; Milankovic *et al*., 2021). Sreekanth *et al*. (2023) reported that coastal batoids use inshore and estuarine habitats as an important habitat for life history.

The study investigated the influence of season, sex and size on *G. obtusus* presence at different depths and seasons, shedding light on the causes of aggregations and sexual segregation observed in estuarine and coastal waters. Pregnant females (near to parturition) were noted to use coastal and estuarine waters as pupping grounds, while other sex-specific and size-specific aggregations remain unknown. Female bull sharks were observed returning to rivers or estuaries, likely for pupping (Tillet *et al*., 2011; Werry *et al*., 2011; Werry and Clua, 2013). Habitat segregation by sex is a common phenomenon among sharks (Klimey, 1987; Wearmouth and Sims, 2008), where adult females and males within a species utilise different habitats for social, thermal, or foraging reasons (Sims, 2005). This behaviour can result in varying susceptibility to threats for females and males (Sims, 2005). Sexual segregation in white sharks has been observed at aggregation sites with distinct seasonal visitation patterns for males and females (Anderson and Pyle, 2003; Kock *et al*., 2013). However, evidence suggests that sexual segregation is not limited to adults (Kock *et al*., 2013). While various hypotheses attempt to explain sexual segregation in animals, the reasons behind its occurrence remain controversial and largely unresolved for many taxa (Wearmouth and Sims, 2008; Mucientes *et al*., 2009).

The present study reveals sexual segregation in different seasons, extending the observation that sexual segregation in *G. obtusus* is not restricted to adults but is evident among juveniles and sub-adults as well. Females, particularly those frequently using coastal and estuarine waters, are identified as being at risk due to potential impacts from fishing, pollution, and habitat damage associated with coastal development.

To enhance the effectiveness of conservation efforts for wedgefish and guitarfish populations, it is crucial to gain a comprehensive understanding of how these species utilise coastal and estuarine waters. Given the limited global data available for wedgefish and guitarfish, prioritising further research, particularly through satellite tagging programs, is essential. This initiative will contribute significantly to advancing conservation research on sharks and rays, allowing managers and conservation authorities to better educate and formulate targeted strategies for the protection of these species.

Limited research has been conducted on the dietary preferences of *G. obtusus*. The current study in the northern Indian Ocean reveals that *G. obtusus* primarily exhibits a carcinophagous feeding behaviour, with a diet comprising mainly crustaceans (82%) and teleosts (18%). Mozzam and Osmany (2020) observed crushed pieces of unidentified gastropods in the stomach of *G. obtusus* in northern Arabian Sea, Pakistan. Purushottama *et al*. (2020a) detailed the diet of *R. annandalei*, emphasising the presence of *Solenocera* spp., *Parapenaeopsis sculptilis*, *Parapenaeopsis stylifera* and various sciaenids. This investigation characterises *G. obtusus* as a benthopelagic species with benthic feeding behaviour, emphasising its vital role in the food chain, particularly with its invertebrate-dominant diet.

In conclusion, shark-like batoids face heightened vulnerability to overexploitation from fisheries due to their distinctive life history traits, which encompass late maturity, low fecundity, slow growth, extended life spans, and a strong correlation between the breeding biomass size and the number of offspring produced (Stevens *et al*., 2000; White and Dharmadi, 2007; Gianeti *et al*., 2009, Raje and Zacharia, 2009; Moore *et al*., 2012; Varghese *et al*., 2016, Arunrugstichai *et al*., 2018; Jabado, 2018, Purushottama *et al*., 2020a,b; Tyabji *et al*., 2020, Purushottama *et al*., 2022). Coastal rhynchobatids, in particular, are at a heightened risk due to their limited coastal habitat, specific life history characteristics, susceptibility to various fishing gears, and the continually increasing demand (Moore, 2017; Jabado, 2018; Purushottama *et al*., 2022; Choy *et al*., 2022; Kottillil *et al*., 2023). This places them among the most susceptible chondrichthyan fishes (Moore, 2017). To ensure sustainable fishery management, a comprehensive understanding of their life history and habitat characteristics is crucial (Choy *et al*., 2022; Purushottama *et al*., 2022). This article contributes novel and detailed biological insights into *G. obtusus* in Indian waters, covering aspects such as sex, size distribution, maturity, embryo size and feeding habits. This information is indispensable for formulating effective management strategies for this poorly understood and functionally important vulnerable elasmobranch species in our oceans (Pacoureau *et al*., 2021).

Leveraging the collective influence of stakeholders, policy makers and researchers, collaborative conservation can revolutionise the sustainable management of elasmobranchs (Karnad *et al*., 2020; Akhilesh *et al.,* 2021; Haque *et al*., 2021). Specifically targeting the critically endangered group of wedgefish and guitarfishes, the innovative approach of installing artificial reefs in coastal areas emerges as a crucial strategy (Purushottama *et al*., 2022), which restricts fishing operations in the areas. This method not only supports the conservation of these species but also enhances productivity by creating niches that contribute to the population growth in the northern Indian Ocean. The comprehensive effort brings together diverse perspectives and expertise to address the challenges facing these species, laying the groundwork for a more resilient and thriving marine ecosystem.

Addressing the pressing need for balancing the socio-economic well-being of fishermen, it is imperative to prioritise research and conservation efforts (Akhilesh *et al*., 2021; Kottillil *et al*., 2023). A key component of this approach involves the identification and protection of critical habitats and ecologically significant areas within the Arabian Sea. Recognising its conservation importance, the widenose guitarfish (*G. obtusus*) has been listed under the Wild Life (Protection) Amendment Act, 2022. Additionally, India's National Plan of Action for the Conservation and Management of Sharks (NPOA-Sharks) outlines several species-specific and area-based measures aimed at safeguarding vulnerable elasmobranch populations through science-based management interventions.

Mapping Important Shark and Ray Area (ISRA) represents a vital conservation strategy aimed at improving spatial understanding of critical habitats, ecological processes, and species-specific requirements (Jabado *et al*., 2023). This framework facilitates the identification and delineation of priority zones essential for the protection of threatened elasmobranch species. ISRAs adopt a holistic approach by integrating ecological significance with socio-economic considerations, particularly the reliance of artisanal and small-scale fisheries on marine resources. By promoting the preservation of key marine habitats while accounting for the livelihoods of fishing communities, the ISRA initiative supports ecosystem-based management and fosters sustainable

coexistence between human activities and marine biodiversity in the Arabian Sea.

Acknowledgements

Authors are thankful to the Director, ICAR-CMFRI, Kochi and Scientist In-Charge, ICAR-CMFRI, Mangaluru for the support and the facilities provided. Mr. G. D. Nataraja, Mr. U. Jeyaram, Mrs. Sathyavathi, Mr. Shrinath, B., Mr. Dharamaraju, L. B., Mr. Sujith Kumar, Mr. Nagaraj S. Gond and Naveen Raju K. G. Naik, ICAR-CMFRI, Mangaluru are acknowledged for the support in the field and laboratory. We thank the fishers and traders who supported data collection along the Karnataka coast. This work was supported by the Indian Council of Agricultural Research (ICAR), New Delhi, under the Project codes FISHCMFRISIL201200500005, DEM/ELS/11 and FFD/ELM/07.

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