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Population parameters of sawtooth barracuda *Sphyraena putnamae* (Jordan and Seale, 1905) exploited along western Bay of Bengal

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ABSTRACT

Population parameters have been studied in nine of the 21 species of barracudas reported globally. Along the Bay of Bengal, *Sphyraena putnamae* (Jordan and Seale, 1905) forms a significant fishery; however, no information exists globally with respect to its growth, mortality and exploitation. This maiden study details the population dynamics analysed from samples collected from trawlnetters, gillnetters and hooks and lines along the western Bay of Bengal during January 2017 to December 2019. The mean fork length in the catch was 50.8 cm with the largest individual measuring 108.0 cm, the highest ever length recorded for the species. von Bertalanffy growth equation derived is $L_t = 113.87\ [1 - e^{-0.23\ (t + 0.0636)}]$. The fishery was dominated by 1-4 year old age classes and lifespan estimated was 12.98 years. Year-round recruitment with the major peak producing 60.87% of the annual recruits was observed from February to June. Natural, fishing and total mortalities were 0.46, 0.25 and 0.71 per year, respectively. Exploitation rate (E) estimated was 0.35 with the exploitation ratio (U) being 0.18. Though the current status indicates that the stock is underexploited, it is however prudent to adopt a precautionary approach, considering the small size as well as age of exploitation, through adoption of measures such as increase in mesh size of trawlnetters and spatio-temporal fishing restrictions in nearshore nursery waters.

Keywords: Bay of Bengal, Exploitation, Growth, Mortality, Sawtooth barracuda, *Sphyraena barracuda*

Introduction

The Bay of Bengal Large Marine Ecosystem (BoBLME), located in the tropical monsoon belt of the northern Indian Ocean exhibits considerable spatial and temporal variability. The monsoon rain produces a warm, low saline, nutrient and oxygen rich layer to a depth of 100-150 m and this layer floats above a deeper, more saline, cooler layer that does not change significantly with the monsoons (Dwivedi and Choubey, 1998). With high primary production in the coastal waters caused due to rich influx of nutrients (Dwivedi, 1993), fishery in nearshore waters is supported by lower trophic level groups. With the absence of large scale mixing or upwelling, the central parts of the Bay are less productive and are dominated by higher trophic level groups. Excessive fishing capacity is a problem in the Bay contributing substantially to overfishing, resulting in biomass changes and threatening long-term sustainability. A multitude of gears exploits the fishery in the Bay, which is multi-species in nature. The number of overexploited stocks is low, but on the rise with most landings recorded from fully exploited stocks (Preston, 2004). Consequently, most marine stocks are not as abundant as they were before. The region also faces other sustainability issues, such as pollution and habitat degradation (Ghosh *et al*., 2015).

The family Sphyraenidae, popularly called barracudas, has only one genus globally, *Sphyraena* with 27 species (Nelson *et al*., 2016), of which ten are known to exist in the Bay (Rajesh *et al*., 2020). Of these, five species; *Sphyraena jello* (Cuvier 1829), *Sphyraena obtusata* (Cuvier 1829), *Sphyraena barracuda* (Edwards 1771), *Sphyraena putnamae* (Jordan and Seale 1905) and *Sphyraena qenie* (Klunzinger 1870) formed a fishery of considerable importance. In recent years, the landings of sawtooth barracuda, *S. putnamae*, particularly in the trawl fishery have increased in the western part of the Bay, where it formed one of the dominant barracuda resources. *S. putnamae* is distributed widely in the tropical waters of the Indian and the Pacific Oceans and prefers to be near shore in lagoons, bays and reefs and are known to move in shoals (Senou, 2001). Semi-pelagic fish trawls (Overall length from 11 to 15 m and powered by engines with horsepower from 90 to 250) with cod-end meshes varying from 20 to 30 mm, are operated at depths of more than 30 m and extensively exploit *S. putnamae* in the coastal waters. Also, large individuals are caught offshore using gillnets (mesh size of 175-200 mm) and hooks and lines (hook number 3). The species is commercially important and is favoured in the region owing to the excellent flesh quality.

Fundamentally, fish stock assessment aims to provide fishery managers advisories on the optimum level of exploitation and on effectively managing the resources using the information on population characteristics gained from estimating age and growth (Sparre and Venema, 1998). Though information on population dynamics exists for other barracuda species *viz*., *S. jello*, *S. obtusata*, *Sphyraena picuda*, *Sphyraena afra*, *Sphyraena sphyraena*, *Sphyraena viridensis*, *Sphyraena novaehollandiae, Sphyraena chrysotaenia* and *Sphyraena flavicauda* (Edwards *et al*., 1985; Kasim and Balasubramaniam, 1990; Bertoni, 1994; Kasim, 2000; Allam *et al*., 2004; Rim *et al*., 2009; Najmudeen *et al*., 2015; El-Ganainy *et al*., 2017; Ayo-Olalusi and Ayoade, 2018) globally, no information is available for *S. putnamae*. Therefore, the present study was undertaken to investigate the population dynamics and to estimate the population parameters for *S. putnamae* exploited from the western Bay of Bengal. The present study would ensure evolving sustainable management policy for commercially exploiting the resource in the region.

Materials and methods

Random samples of *S. putnamae* were collected fortnightly for three years from January 2017 to December 2019 from Visakhapatnam (17.696°N; 83.301°E) and Kakinada (16.984°N; 82.279°E) fishing harbours; Pudimadaka (17.491°N; 83.004°E), Dummulapeta (16.958°N; 82.273°E) and Bhairavapalem (16.733°N; 82.319°E) beach landing centres, along the western Bay of Bengal and their fork length (L_F) (cm) and weight (g) were recorded. Fork length of individual fishes was measured to the nearest millimeter (mm) and total weight to 0.1 g precision. No samples were obtained in May, as a ban on mechanised trawling from mid of April to mid of June exists along this coast. The collected samples were placed in insulated ice boxes and transported to the laboratory of Visakhapatnam Regional Centre of ICAR-Central Marine Fisheries Research Institute for further analysis. A total of 2482 individuals ranging in L_F and weight from 14.7 to 108.0 cm and 20 to 5,382 g, respectively were analysed during the study period. Length frequency obtained in each sampling day were grouped into 10 mm class intervals and raised for the day based on the sample weight and the total catch observed for the species on the sampling day. Daily raised length frequencies were summed up for the two observed days in the month and multiplied by the monthly raising factor taking into consideration the total fishing days in that month to arrive at monthly raised numbers (Sekharan, 1962).

Monthly raised length frequencies were analysed using the ELEFAN I module of FiSAT software (Gayanilo *et al*., 1996) for estimating the von Bertalanffy growth parameters *viz.,* asymptotic length (L_∞) and growth co-efficient (K). The output of the growth curve was obtained and length based growth performance index (Ø) was calculated from the final estimates of L_∞ and K (Pauly and Munro, 1984). The length at first capture (L_c) was estimated as in Pauly (1984) and the age at zero length (t_0) from Pauly's (1979) empirical equation, $\text{Log}(-t_0) = -0.3922 - 0.2752 \text{ Log } L_\infty - 1.038 \text{ K}$. The growth and age were estimated using the von Bertalanffy growth equation, $L_t = L_\infty (1 - e^{-k(t - t_0)})$. The mid-point of the smallest length group in the catch was taken as length at recruitment (L_r). The recruitment pattern was studied from the recruitment curve using final estimated values of L_∞, K and t_0. Lifespan (t_{max}) was estimated at $3/K + t_0$ (Pauly, 1983a).

Natural mortality (M) was estimated as in Pauly (1980), by taking the mean sea surface temperature as 27°C and total mortality (Z) from length converted catch curve (Pauly, 1983b) using FiSAT software. Fishing mortality (F) was estimated as F = Z - M. Length structured Virtual Population Analysis (VPA) of FiSAT was used to obtain fishing mortalities per length class. Exploitation rate (E) was estimated from the equation, E = F/Z and exploitation ratio (U) from $U = F/Z (1 - e^{-z})$. Optimal fishing length (L_{opt}), the length at which the unfished cohort provides the maximum biomass was estimated from length frequency using the equation proposed by Froese and Binohlan (2000).

Results

From the length composition of *S. putnamae*, it is evident that the species is caught round the year. The mean length (L_{mean}) in the landings was 50.8 cm L_F, with a maximum of 71.36 cm observed in April and a minimum of 33.54 cm in August. Both, the smallest (14.7 to 16.9 cm L_F) and the largest (104.0 to 108.0 cm L_F) individuals in the catches were observed in April. Smaller individuals below 20.0 cm L_F were also observed in March. Again, large individuals, more than 95.0 cm L_F were recorded in January and February. Several modes in the length frequency distribution were observed (Fig. 1). Primary modal peaks were at 28.45 and 32.45 cm, followed by secondary peaks at 29.45, 30.45 and 40.45 cm L_F.

The population parameters for *S. putnamae* are presented in Table 1. von Bertalanffy's growth equation

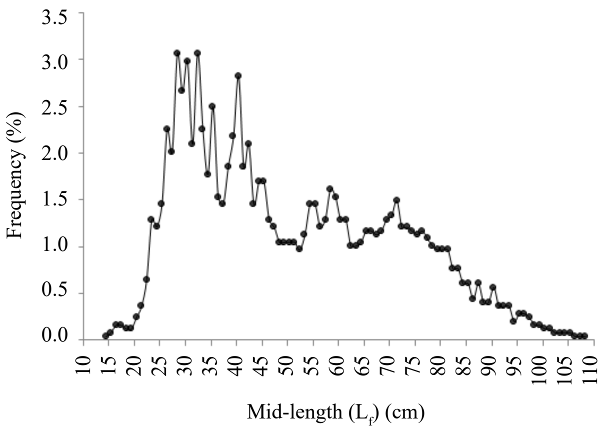

Fig. 1. Length frequency distribution of *S. putnamae* from western Bay of Bengal

Table 1. Population parameters of *S. putnamae* from western Bay of Bengal (n = 2482)

Parameter	Value
Asymptotic length (L_∞) (cm L_F)	113.87
Growth co-efficient (K) (yr^{-1})	0.23
Length at first capture (L_c) (cm L_F)	15.49
Age at zero length (t_0) (years)	-0.0636
Length at recruitment (L_r) (cm L_F)	14.45
Lifespan (t_{max}) in years	12.98
Optimal fishing length (L_{opt}) (cm L_F)	68.30
Natural mortality (M) (yr^{-1})	0.46
Fishing mortality (F) (yr^{-1})	0.25
Total mortality (Z) (yr^{-1})	0.71
Exploitation rate (E)	0.35
Exploitation ratio (U)	0.18

derived was L_t = 113.87 $[1 - e^{-0.23\,(t + 0.0636)}]$ and the output of the monthly pooled growth curve is exhibited in Fig. 2. Growth performance index for the species was 3.47. Size (L_F) attained from first year to twelfth year are given in Fig. 3. Fishery was dominated by the 1 year old age group (24.7 to 42.9 cm L_F), as seen from their proportion (39.9% by number) in the landings. This was followed by the 2 year old age group (43.0 to 57.5 cm L_F) with 19% contribution by number to the landings. The share of 3 (57.6 to 69.0 cm L_F) and 4 (69.1 to 78.2 cm L_F) year old age groups by number to the fishery were 13.4 and 11.1%. The length converted catch curve is depicted in Fig. 4. Recruitment to the fishery was unimodal and occurred throughout the year, with a peak from February to May and this peak pulse produced 60.87% of the annual recruits. The corresponding ages, obtained by converting length into age using inverse growth equation, for L_r, L_c, L_{mean} and L_{opt} were 0.53, 0.57, 2.51 and 3.92 years respectively. VPA indicated that the main loss in the stock up to 22.4 cm L_F was due to natural causes. Fishing mortality increased thereafter, as fishes became more vulnerable, but never exceeded the natural mortality. The highest fishing mortality of 0.40 was recorded at 105.4 cm L_F (Fig. 5). The present exploitation rate (E=0.35) is less than the exploitation rate providing maximum yield (E_{max}=0.41), indicating the species to be currently underexploited.

Discussion

From the length composition, it is evident that all size ranges were represented in the fishery. The minimum and maximum L_Fs was 14.7 and 108.0 cm with a mean of

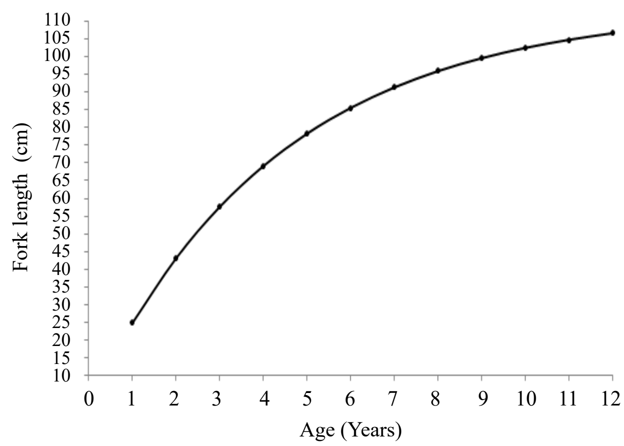

Fig. 3. Length-at-age for *S. putnamae* from western Bay of Bengal

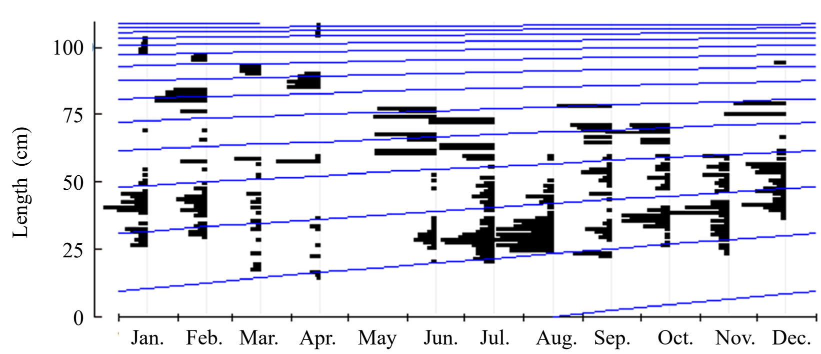

Fig. 2. Growth curve of *S. putnamae* from western Bay of Bengal

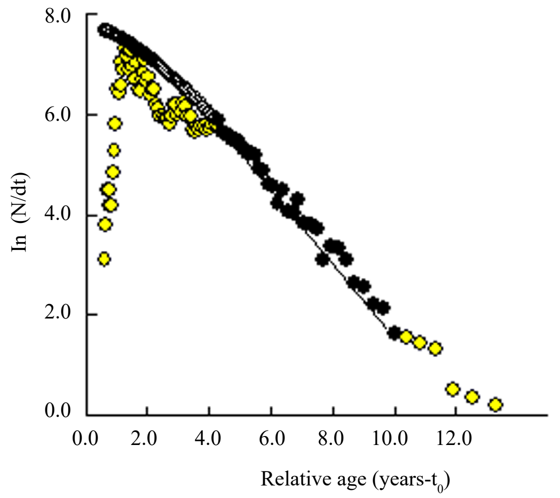

Fig. 4. Length converted catch curve for mortality estimation in *S. putnamae* (for Z = 0.71; M (at 27^{0}C) = 0.46; F = 0.25; E = 0.35)

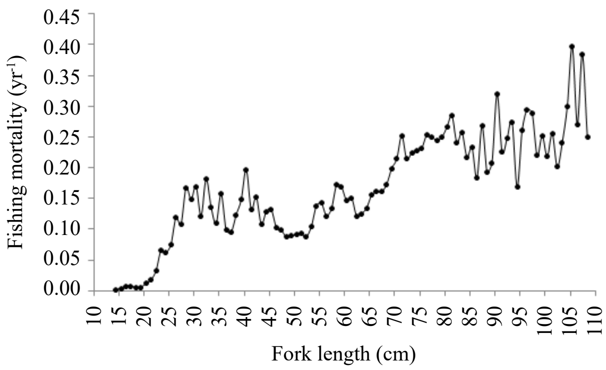

Fig. 5. Fishing mortality in different lengths for *S. putnamae*

50.8 cm. Maximum L_Fs reported till date for *S. putnamae* globally varies from 93 cm (Mohammadizadeh *et al*., 2010) to 100 cm (Rajesh *et al*., 2020). The present study recorded individuals larger than 100 cm L_F and the maximum L_F observed was 108 cm, weighing 5282 g, which is the highest ever length recorded for the species. The higher length is attributed to the difference in the area of the sampling as according to Whitehead *et al*. (1986), small barracudas are found close to coastal areas, while the large individuals are found in the open sea. Mean length was highest in April and lowest in August. Seasonal variations in the distribution of barracudas have earlier been observed by Somavanshi (1989), wherein small individuals are abundantly available in shallow waters during monsoon and large individuals in deeper waters during post and pre-monsoon. Fishing during monsoon months (July to October) along Bay of Bengal is mostly in inshore waters due to inclement weather conditions and sea state, whereas during post and pre-monsoon, weather conditions and sea state are favourable and fishing is carried out offshore in deeper waters.

Fish stock assessment uses information on population parameters for efficiently managing the resource and predicting stock responses to current and future management measures. With markings on scales, vertebrae and other hard parts for direct determination of age found not reliable for tropical large pelagics, length frequency was examined in the present study to arrive at age and growth. According to Pauly (1987), for reliable estimates on age and growth, the sample size of the population should be 1500 or more, which has been satisfied with 2482 individuals being sampled over a period of 33 months. Growth and mortality estimates for other barracuda species is presented in Table 2. Some barracuda species *viz*., *S. jello*, *S. picuda*, *S. afra*, *S. viridensis* and *S. novaehollandiae* grow to large sizes and live for many years, as evident from their values of asymptotic length, growth co-efficient and natural mortality. Other species *viz., S. obtusata*, *S. sphyraena*, *S. chrysotaenia* and *S. flavicauda* are small and live for a few years. *S. putnamae* with L_∞, K, M and t_{max} of 113.87 cm, 0.23 yr^{-1}, 0.46 yr^{-1} and 12.98 years belonged to the former. Fishes of relatively larger sizes exhibit slow growth and low natural mortality and live longer and the same was observed for *S. putnamae*. However, long lived species with slow growth are vulnerable to overfishing and therefore, needs careful monitoring and management (Udoh *et al*., 2015). *S. afra* is known to live for 30 years (Ayo-Olalusi and Ayoade, 2018), whereas *S. obtusata*, *S. chrysotaenia* and *S. flavicauda* has longevity ranging from 3-6 years (Kasim and Balasubramaniam, 1990; El-Ganainy *et al*., 2017). Substantial differences in growth are observed at the individual, population and cohort levels; which are usually genetic but are also highly dependent on physical (temperature, salinity, levels of dissolved oxygen and photoperiod), biotic (food availability and quality, competition and age and maturity) and general environmental conditions (Sparre and Venema, 1998). Growth performance index was 3.47, close to that estimated for *S. afra* but different from other barracuda species. In general, the growth performance index value ranges from 2-4 in finfishes and is constant for a species, family, or similar taxonomic group (Abdul *et al*., 2012). However, variations observed worldwide for barracudas are because of the inter-species differences in sizes and growth rates, environmental conditions and different fishing intensities.

Fishery in the Bay for *S. putnamae* was mostly dominated by 1-4 year old length classes, constituting more than 80% of the landings by number. Similarly, for *S. chrysotaenia* and *S. flavicauda* (El-Ganainy *et al*., 2017)

Table 2. Growth and mortality estimates for other barracuda species

Species	L_∞ (cm)	K (yr^{-1})	t_0 (years)	Ø	M (yr^{-1})	F (yr^{-1})	Z (yr^{-1})	Authors
Sphyraena jello	148.4	0.1	0.009	-	-	-	-	Edwards *et al*. (1985)
Sphyraena obtusata	47.0	1.04	-0.009	-	1.59	1.24	2.83	Kasim and Balasubramaniam (1990)
Sphyraena novaehollandiae	97.4	0.23	-	-	-	-	0.73	Bertoni (1994)
Sphyraena jello	168.0	0.40	-0.0448	-	0.6	1.23	1.82	Kasim (2000)
Sphyraena picuda	152.1	0.33	-0.1085	-	0.5	2.51	3.01	Kasim (2000)
Sphyraena chrysotaenia	27.14	0.39	-1.41	2.46	0.39	0.66	1.05	Allam *et al*. (2004)
Sphyraena flavicauda	44.58	0.29	-0.82	2.77	0.32	0.49	0.81	Allam *et al*. (2004)
Sphyraena sphyraena	55.27	0.12	-3.25	2.58	0.20	0.59	0.79	Allam *et al*. (2004)
Sphyraena viridensis	100.64	0.09	-0.83	2.95	-	-	-	Allam *et al*. (2004)
Sphyraena chrysotaenia	26.41-28.55	0.31-0.36	-(1.54-1.66)	2.4				Rim *et al*. (2009)
Sphyraena obtusata	34.2	0.7	-	2.92	1.35	1.54	2.89	Najmudeen *et al*. (2015)
Sphyraena chrysotaenia	29.37	0.48	-1.02	2.62	-	-	-	El-Ganainy *et al*. (2017)
Sphyraena flavicauda	41.21	0.39	-1.14	2.82	-	-	-	El-Ganainy *et al*. (2017)
Sphyraena afra	192.68	0.1	-	3.57	0.24	1.05	1.29	Ayo-Olalusi and Ayoade (2018)

and *S. novaehollandiae* (Bertoni, 1994), age groups of 2 and 3 years constituted the bulk of the catches. The maximum growth rate in length was observed during the first year of life, after which the annual increment decreased with increasing age. Lengths and ages at first capture (15.49 cm L_F and 0.57 years) and recruitment (14.45 cm L_F and 0.53 years), as observed for *S. putnamae* are in accordance to that reported for other barracuda species; 17.24 cm (1.17 years) and 16.3 cm (0.94 years) for *S. chrysotaenia* (Allam *et al*., 2004); 19.67 cm (1.15 years) and 19.2 cm (0.82 years) for *S. flavicauda* (Allam *et al*., 2004); 25.44 cm (1.77 years) and 21.2 cm (0.69 years) for *S. sphyraena* (Allam *et al*., 2004) and 18.15-23.5 cm (0.47-1.64 years) and 10.0-16.5 cm (0.22-0.93 years) for *S. obtusata* (Kasim and Balasubramaniam, 1990; Najmudeen *et al*., 2015). With zero age groups being recruited into the fishery and forming a sizeable catch, it is inferred that along the Bay, the spawning grounds for *S. putnamae* are probably their fishing grounds. Also, lower capture sizes imply that substantial numbers are removed by fishing before they grow large enough to mature and spawn and contribute significantly to the stock biomass. This could potentially result in growth and recruitment overfishing in the future. This is further corroborated by the fact that mean length in the sampled individuals is smaller than the optimal fishing length indicating the stock to be under spawning stress. However, mean age recorded (2.51 years) is higher than 1.29 and 1.74 years observed for *S. chrysotaenia* and *S. flavicauda* respectively, and similar to 2.56 years observed for *S. sphyraena* (Allam *et al*., 2004). Optimal fishing age earlier reported for *S. obtusata* ranges from 0.89-1.30 years (Kasim and Balasubramaniam, 1990; Najmudeen *et al*., 2015), much lower than 3.92 years observed for *S. putnamae*.

Year-round recruitment with a single peak from February to May was observed in the Bay of Bengal for *S. putnamae*. Recruitment pulses coupled with recruitment age indicate the species to breed throughout the year. The present study, confirms the findings of Pauly (1980), who stated that tropical fish species are recruited into the fishery round the year. However, in contrary, for *S. obtusata* and *S. afra*, bimodal recruitment pattern was observed (Najmudeen *et al*., 2015; Ayo-Olalusi and Ayoade, 2018).

Beverton and Holt (1956) stated that the natural mortality coefficient of a fish is directly related to the growth coefficient and inversely related to the asymptotic length and the life span. The same was observed for *S. putnamae* from Bay of Bengal, wherein the species exhibited a low rate (0.46) of natural mortality. Natural mortality coefficient varies with the age of the species and also with predator abundance in the respective environment (Pauly, 1980; 1983). The ratio M/K explains the relationship between natural mortality and physiological factors. For *S. putnamae*, the ratio was 2.0, well within the normal range of 1-2.5 (Beverton and Holt, 1959). The ratio Z/K (Barry and Jegner, 1989) is used to determine the predominance of growth on mortality, with a ratio equal to 1 implying the population to be in a steady state and with a ratio much higher than 2 implying the stocks to be overexploited. The Z/K ratio was 3.1 indicating the population to be mortality dominated. Exploitation rate is used to assess the status of stocks, either using E_{opt} equal to 0.5 or using estimated E_{max} (Gulland, 1969; 1971). For *S. putnamae*, along the western Bay of Bengal, current exploitation (0.35) is lower than both, E_{opt} and E_{max}, indicating the stocks to be underexploited. Fishing mortality increased with an increase in the size of the fish. This is because, while smaller individuals were exploited only by trawlnetters, larger individuals were exploited by a combination of trawlnetters, gillnetters and hooks and lines.

The present study estimated the population parameters for sawtooth barracuda, *S. putnamae* from the western Bay of Bengal. The information generated on growth, mortality and exploitation status is the first global report for the species. With slow growth and low natural mortality and high asymptotic length and lifespan, the species, though presently underexploited, is highly vulnerable to fishing pressure. Presently, the size and age of exploitation is smaller than the optimum and lower than the biological limits, substantiating the fact that the population is under stress and this, needs to be addressed by enhancing their capture sizes beyond the desired level. Again, in a multi-species multi-gear fishery, as existent in the Bay, there is no targeted fishing which exclusively catches the sawtooth barracuda, therefore, taking into account all the above, a precautionary approach needs to be adopted. The shallow coastal waters are the nursery grounds for the young ones and spatio-temporal protection of these nursery grounds would ensure stronger and larger recruitment sizes into the population. Also, mesh sizes of semi-pelagic trawlnetters, which capture small sized individuals in nearshore waters, have to be increased for increasing exploitation sizes.

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