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Population dynamics and stock assessment of spadenose shark *Scoliodon laticaudus* Muller and Henle 1839 along Gujarat coast of India

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Stock assessment of *Scoliodon laticaudus* Muller and Henle, 1839 was made along with analysis of its few biological characteristics from its commercial landings during 2012-2016 from Gujarat waters of India to understand the population dynamics and stock status of the species. The average annual landing of the species was 5442 t, which constituted about 67% of the total shark landings at Gujarat coast. L_{∞}, K and t_0 were estimated as 75.53 cm and 0.54/yr, and -0.4 yr, respectively. Total mortality rate, fishing mortality rate and natural mortality rate were estimated as 1.95 yr^{-1}, 1.04 yr^{-1} and 0.91 yr^{-1}, respectively. The length at capture (Lc_{50}) and length at maturity (Lm_{50}) were 39.74 cm and 35.79 cm, respectively, which indicate that most of the sharks are exploited after attaining the sexual maturity. Length-weight relationship showed that the growth was isometric. The species was a continuous breeder and showed peak recruitment during September. The current exploitation ratio (E_{cur}) was found to be 0.53, which is lower than $E_{0.1}$ estimated for the species using Beverton and Holt yield per recruit analysis. Thompson and Bell prediction model showed that maximum sustainable yield for *S. laticaudus* could be obtained by increasing fishing effort by almost 2.4 times higher than the present level which would deplete the spawning stock biomass (SSB) to 20%. Maximum economic yield could be obtained by increasing the fishing effort by 1.8 times which would also decrease the SSB, but to a comparatively safer 26.5% level. Considering 30% SSB as a precautionary management reference point, the effort could be increased by 50% exclusively for the sharks to increase the yield and revenue from fishery while maintain SSB at a safer 30% level.

[**Keywords**: Spadenose shark; Population parameters; Fishery management; Precautionary approach]

Introduction

Sharks, as the apex predators, play a crucial role in marine ecosystem and being in the top of food chain, are usually found in lower biomass[1,2]. Due to the ever-increasing demand for meat, fins, liver and other products, sharks are exploited at higher rate, which is adversely impacting their population. The global shark landings have already shown a drastic decline of nearly 15% during last decade[3]. In India, shark landings increased from 27,400 tonnes in 1961 to the highest of 75,000 tonnes in 1998, but since then the trend is highly fluctuating and is showing an overall decrease[4]. The contribution of shark landings to the total marine fisheries landing has also decreased from 3.4% in 1985 to 0.6% in 2014[5]. Gujarat, the largest maritime state in India, was contributing more than half of India's total shark landings during 2000[6], but the contribution has decreased dramatically during the recent years[5].

Scoliodon laticaudus, popularly known as spadenose shark, is a common species in the tropical Indian and western Pacific Ocean, where it forms large schools in shallow water. It is an amphidromous, demersal shark that inhabits the shallow waters at a depth range of 10 to 13 m[7]. There are a few earlier studies where attempts have been made to understand its reproductive biology[8] from Malaysian waters, food and feeding biology[9], reproductive and developmental biology[10,11], and morphometrics[12] from Chinese waters.

S. laticaudus is also a commercially important shark in north-west coast of India and in Gujarat it contributes predominantly to the total elasmobranch catch[13]. There are several scientific investigations in India where attempts have been made to study its systematic, taxonomy[14], length-weight relationship[15,16,17], food and feeding biology[18], reproductive and developmental biology[19,20,21,22,23], age and growth[16,24], and population dynamics[25,26,27]. Despite all these studies, there is a gap of information about the stock status of *S. laticaudus* from Gujarat coast of India except for the earlier study by Kasim[26] from Veraval coast of Gujarat. However, this study was conducted more than two decades ago and since then the fishery has undergone dramatic changes. Therefore, this study was undertaken to update the information about the stock status of the species so that proper management advisory can be provided for sustainable exploitation of the resource.

Materials and Methods

Weekly samplings were conducted for five years during January 2012 to December 2016 to collect data on catch, fishing effort and size composition of the shark from commercial landings at four major fish landing centres, namely, Veraval (20.905401°N; 70.375217°E), Mangrol (21.107787°N; 70.100019°E), Porbandar (21.640813°N; 69.596152°E) and Okha (22.444087°N; 69.056324°E) along the Saurashtra coast of Gujarat, India (Fig. 1). The total length (TL) was measured from tip of the snout to the posterior tip of tail, with tail flexed down to middle of each shark to the nearest 1.0 cm using a soft tape along the side of the body and the body weight was recorded to the nearest g using an electronic weighing machine (Sunrise SVT, India). Weekly length frequency data were raised to the estimated monthly shark landings of Gujarat collected using stratified multistage random sampling method by Fisheries Resources Assessment Division (FRAD) of ICAR-CMFRI, Kochi, India. The von Bertalanffy growth parameters[28] *viz*. asymptotic length (L_∞) and growth co-efficient (K) were estimated using monthly raised length frequency data in the ELEFAN 1 module of FiSAT II[29]. Age at length zero (t_0) was back calculated using modified von Bertalanffy growth equation suggested by Alagaraja[30] i.e., $t_0=1/K \log_e [1-(L_{t=0}/L_\infty)]$, where $L_{t=0}$ is length at birth. For the correct estimation of t_0, 15 cm was used as length at birth ($L_{t=0}$) which was ascertained from length of the largest embryo and smallest free-swimming individuals observed from the landing centres. The modal class progression analysis (MPA) was carried out to refine the growth parameters obtained from ELEFAN 1. The composite length frequency distribution for each month was decomposed to different cohorts by Bhattacharya methods[31]. The mean lengths of the cohort across different months were linked to generate 'length-at-age' data. A range of t_0 from -0.3 to -0.9 yr was used in the iteration to fit growth curve using the above-mentioned 'length-at-age' data. The $L_{t=0}$ as 15 cm and t_0 of less than 1 yr was used as the yardstick to select the most reasonable growth curve. The growth performance index (φ) was calculated from formula described by Pauly and Munro[32] i.e., $\varphi=\log_{10} K+ 2\log_{10} L_\infty$. Longevity ($t_{max}$) was estimated from the equation described by Pauly[33] i.e., $t_{max} = 3/K + t_0$. The length-weight relationship of *S. laticaudus* was established following Le Cren[34] i.e., $W=aL^b$.

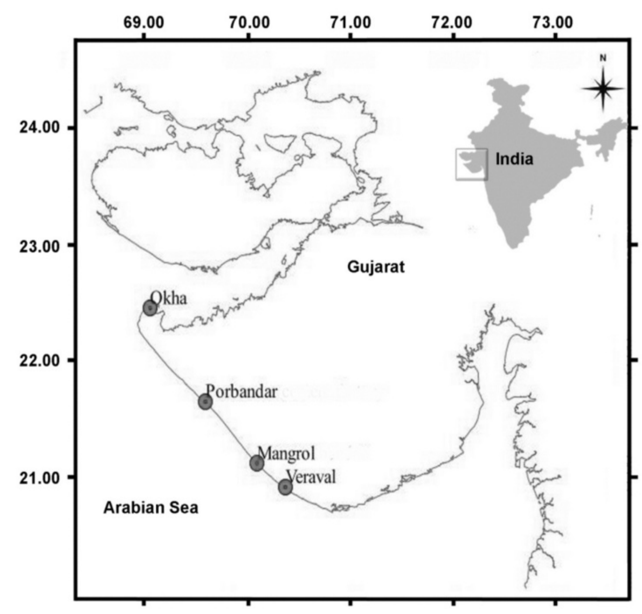

Fig. 1 — Location of sampling sites (fish landing centres) along Gujarat coast

The instantaneous total mortality rate (Z) was estimated by FiSAT II package using the length converted catch curve method[35]. The natural mortality rate (M) was estimated by Pauly's empirical formula[36] i.e., $\ln(M) = - 0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$, using the T value of 27.5 ^{0}C, and the fishing mortality rate (F) was obtained as F= Z-M. The current exploitation ratio (E_{cur}) was calculated as E= F/Z[37]. Length structured cohort analysis (VPA) of FiSAT II was used to obtain fishing mortalities per length class.

For determining length at first maturity (Lm_{50}), the maturity status of each shark was ascertained following the classification scheme proposed by Stehmann[38], based on ovarian and uterine condition for females and clasper calcification and testes development for males. The female sharks with undeveloped or partially developed ovaries and having undeveloped thin ribbon-like uteri were classified as immature. On the other hand, female sharks having well developed uteri and ovaries with mature oocytes were considered as mature. Male sharks having an uncalcified or partially calcified clasper and undeveloped testes were considered as immature, whereas sharks having a well calcified clasper and developed testes were classified as mature sharks. The Lm_{50} was calculated using the logistic regression described by White[39] as follows

$$pL = [1 + e^{\{-\ln(19)(L-Lm_{50})(L_{95}-Lm_{50})^{-1}\}}]^{-1}$$

where, pL is the proportion of sharks that are matured at length L; Lm_{50} and Lm_{95} are the lengths at which 50% and 95% sharks in the stock are mature. The SOLVER routine in Microsoft™ Excel was used to obtain maximum likelihood estimates of the parameters.

The recruitment of the stock was determined by backward projection on the length axis of the set of available length frequency data as described in FiSAT II[40]. The midpoint of the smallest length group in the catch during the three-year period was taken as length at recruitment (Lr). Length at first capture (Lc_{50}) was estimated by probability of capture routine in the FiSAT-II package[41].

The relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) at different exploitation levels were estimated by FiSAT II package using relative yield per recruit analysis method described by Beverton and Holt[42]. The equilibrium yield, standing stock biomass (B) and spawning stock biomass (SSB) at different fishing levels were predicted using length based Thompson and Bell bio-economic model[43]. The information from the above stock assessment models were used to forecast the biological reference points for sustainable exploitation of the resource.

Results

Fishery and seasonal abundance

With an annual average landing of 6364 t and catch rate (CPUE) of 0.76 kg per unit, *S. laticaudus* was the major contributor (67%) to the total shark landing of Gujarat during 2012-2016 (Table 1). The fishery of *S. laticaudus* attained its peak during the first quarter of the year registering the highest catch in March, after which the landings reduced gradually (Fig. 2). The fishery revived again after the 60-day fishing ban and showed increasing trend during the last quarter which continued till the end of first quarter of the year.

Growth, mortality and exploitation parameters

In the present study, no significant difference (Independent t-test, P>0.01) was observed between the mean TL of male (40.41±0.45 cm) and female sharks (40.67±0.42 cm). The stock of *S. laticaudus* was dominated by female sharks that belong to the length range of 45 to 50 cm, whereas, the male fraction of the stock was dominated by relatively smaller sharks in the length range of 35 to 40 cm. The length frequency distribution for *S. laticaudus* (both the sexes combined) showed mean and modal lengths as 40.56 ± 0.31 and 47.5 cm, respectively. The estimated growth parameter for *S. laticaudus* by using ELEFAN-I and MPA is given in Table 2. The L_∞ and K estimated by ELEFAN-I were 76.13 cm and 0.54 yr^{-1} which resulted in t_0 of -0.41 yr. On the other hand, the MPA using t_0 in a range of -0.3 to -0.9 yr resulted in L_∞ values from 71.73 to 84.70 cm and corresponding K values from 0.62 to 0.34 yr^{-1}

Table 1 — Catch and effort for *S. laticaudus* landed along Gujarat coast during 2012-2016

Year	Effort (Boats)	Total landings (t)	Total shark landings(t)	Contribution of sharks to landings (%)	*Scoliodon laticaudus*		
					Catch (t)	CPUE (kg/ boat)	% to total shark landings
2012	751105	690396	7598	1.1	5166	0.69	68.0
2013	800993	705945	6573	0.9	4465	0.56	67.9
2014	838464	713497	8009	1.1	6693	0.80	83.6
2015	951543	721556	13040	1.8	8670	0.91	66.5
2016	817623	745846	13883	1.9	6825	0.83	49.2
Average	831946	715448	9821	1.4	6364	0.76	67.0

Table 2 — von Bertalanffy growth parameters of *S. laticaudus* from Gujarat coast

Growth parameters	ELEFAN-I t_0=-0.41* (yr)	MPA						
		t_0=-0.3 (yr)	t_0=-0.4 (yr)	t_0=-0.5 (yr)	t_0=-0.6 (yr)	t_0=-0.7 (yr)	t_0=-0.8 (yr)	t_0=-0.9 (yr)
L_∞ (cm)	76.13	71.73	75.50	78.51	81.08	83.21	83.41	84.70
K (yr^{-1})	0.54	0.62	0.54	0.48	0.43	0.39	0.37	0.34
VBGF fitted L_0 (cm)	15.00	12.20	15.00**	16.80	18.50	20.00	21.40	22.40
t_{max}(yr)	5.15	4.54	5.15	5.75	6.37	6.99	7.31	7.92

ELEFAN-I: Electronic Length Frequency Analysis-I method; MPA: Modal class Progression Analysis method; VBGF: von Bertalanffy growth curve (equation); L_∞: Maximum theoretical length the animal can reach; K: growth coefficient; t_0: time when length of the animal is theoretically zero; L_0: Length of the animal at birth and t_{max}: Longevity of shark
* VBGF fitted t_0 calculated using L_∞, K and observed L_0 i.e. 15 cm obtained from ELEFAN-I
** VBGF fitted L_0 calculated using L_∞, K and and t_0 -0.4 yr obtained from MPA and is equal to observed L_0 of the study

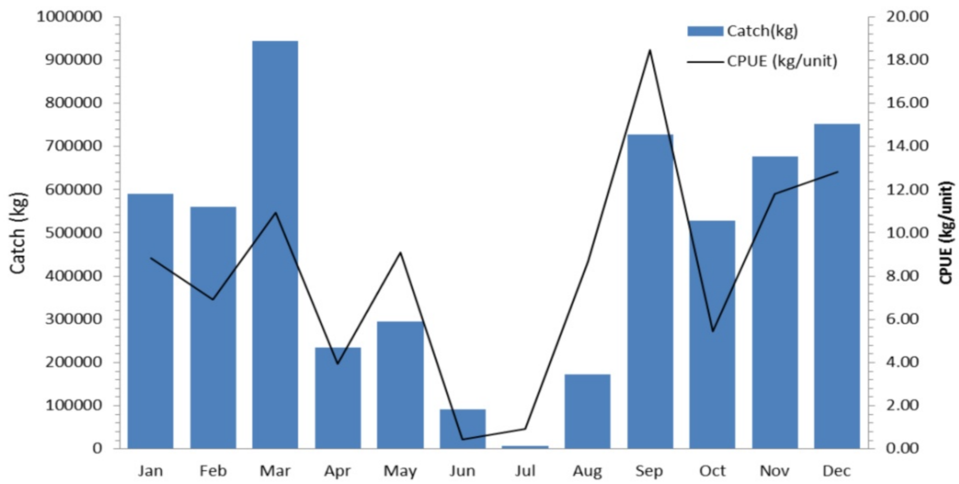

Fig. 2 — Month-wise catch (kg) and catch rate (kg/unit) of *S. laticaudus* from Gujarat coast

(Fig. 3). The L_∞ and K values of 75.50 cm and 0.54 yr^{-1} respectively obtained using t_0 of -0.4 yr (Fig. 4) from MPA were selected as the best fitting estimates of growth parameters for *S. laticaudus,* as the von Bertalanffy growth curve modeled using the above parameters resulted a length at birth ($L_{t=0}$) which was same as that of the observed value i.e. 15 cm (Figs 3 & 4). The growth performance index and t_{max} of *S. laticaudus* were calculated to be 3.44 and 5.15 yr, respectively. The growth curve constructed using these parameters showed that *S. laticaudus* grows to a TL of 40.27 cm in 1st yr, 55 cm in 2nd yr, after which the growth slows down considerably registering a TL of 63.58 cm in 3rd yr, 68.59 cm in 4th yr and 71.50 cm in 5th yr.

The natural (M), total (Z), fishing (F) mortality rates and current exploitation ratio (E_{cur}) for *S. laticaudus* were 0.91 yr^{-1}, 1.95 yr^{-1}, 1.04 yr^{-1} and 0.53, respectively (Fig. 5). The length based cohort analysis showed that F exceeded M when the shark attained 47.5 cm TL (Fig. 6).

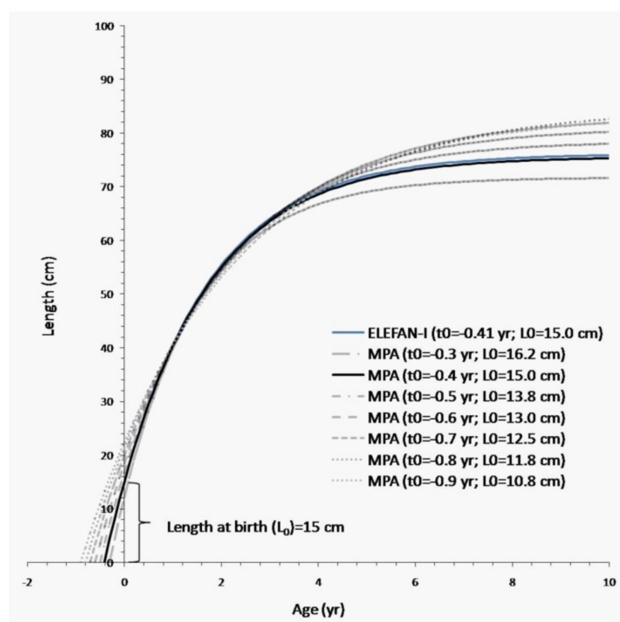

Fig. 3 — Comparison of reconstructed VBGF growth curve using growth parameters of *S. laticaudus* obtained from ELEFAN-I and MPA

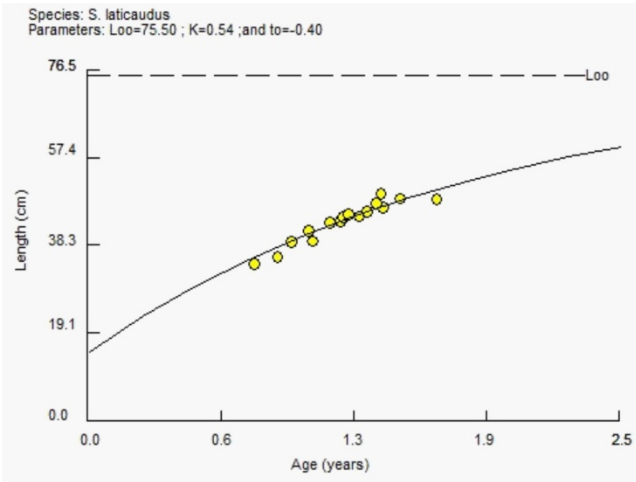

Fig. 4 — Modal class progression analysis (MPA) growth curve of *S. laticaudus* obtained using 'length-at-age' data

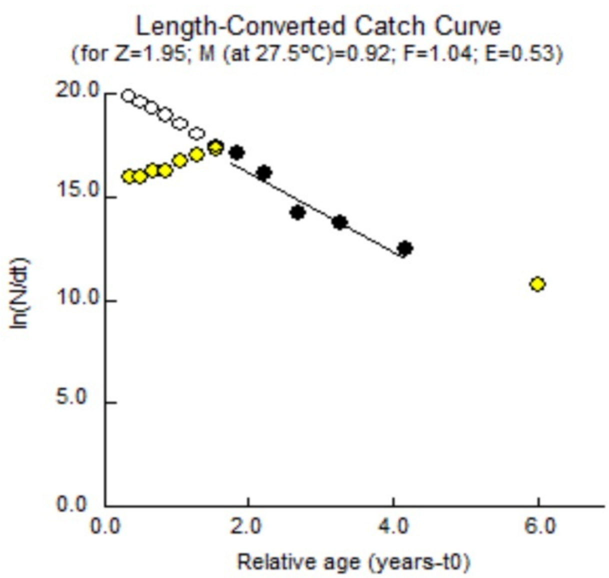

Fig. 5 — Mortality and exploitation parameters viz., M. F, Z and E of *S. laticaudus* from Gujarat coast

Length-weight relationship

The length-weight relationships for male, female and sex pooled data of *S. laticaudus* are given below:

Male W= 0.0063 TL $^{2.82}$ (r^2=0.96, n=543)

Female W= 0.0037 TL $^{2.98}$ (r^2=0.94, n=734)

Sex pooled W= 0.0047 TL $^{2.91}$ (r^2=0.98, n=1277)

Where, W is weight in g and TL is total length in cm. Analysis of covariance (ANCOVA) test revealed that the slope was found to be significantly (P≤0.01) higher for the female compared to the male sharks, whereas the intercept of the male was found to be

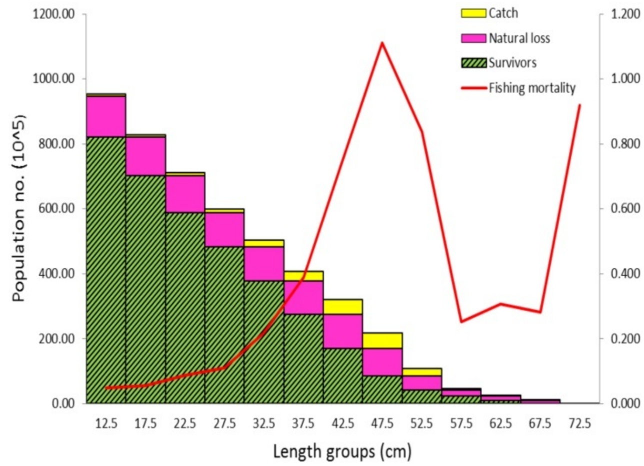

Fig. 6 — Length structured cohort analysis of *S. laticaudus* from Gujarat coast

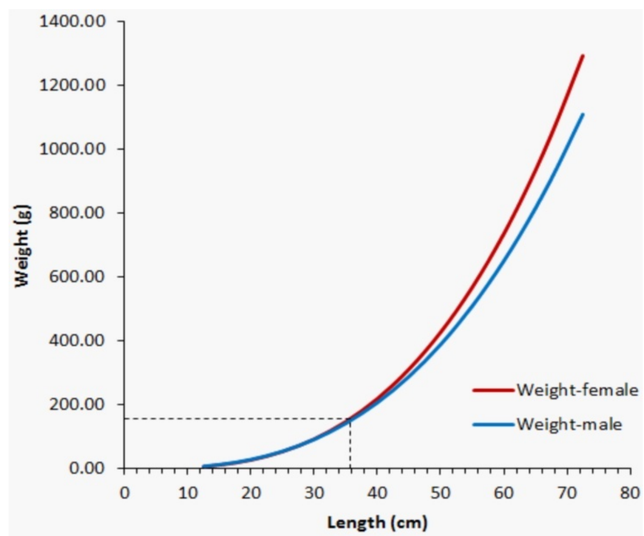

Fig. 7 — Difference in length-weight relationships between male and female *S. laticaudus* from Gujarat coast

significantly (P≤0.01) higher than the female sharks. This indicates that the weight varies significantly between males and females sharks (Fig. 7). The relationship between body-weight for the sex pooled data showed that growth is isometric (Fig. 8).

Maturity, recruitment and gear selectivity

Mature and pregnant females were recorded throughout the fishing period. A rise in number of mature females with visible eggs in their ovary was observed during March and April followed by October and November. Increase in number of pregnant females carrying near term embryos (15 cm) was observed during June and July, which was also

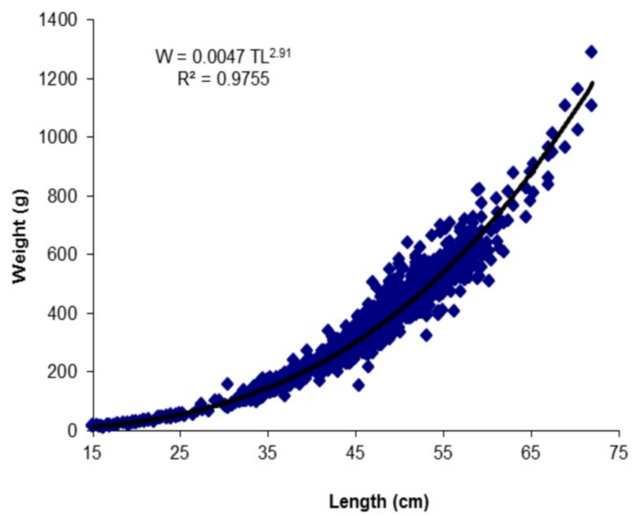

Fig. 8 — Length-weight relationship in *S. laticaudus* from Gujarat coast

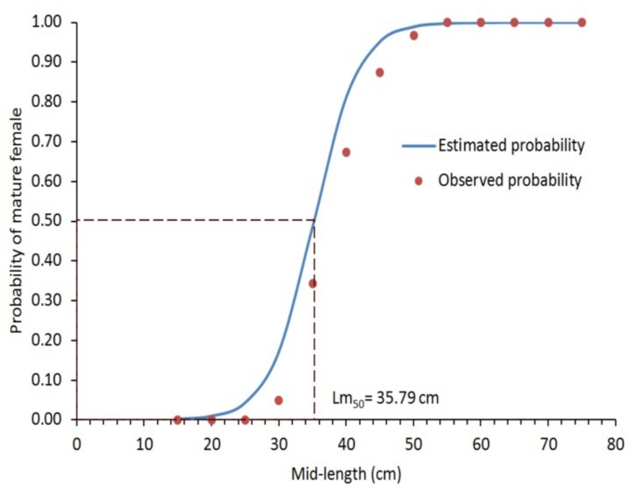

Fig. 9 — Length at maturity (Lm_{50}) of female of *S. laticaudus* from Gujarat coast

followed by an increase in number of postpartum females during August and September. Maturity study revealed that 50% of the female sharks mature between TL of 34.85 cm and 36.12 cm with a mean length of 35.79 cm (Fig. 9). Therefore, all females smaller than 36 cm were considered as juveniles while those above 36 cm as adults. The male *S. laticaudus* matures almost in similar size range of 32.76 to 34.85 cm TL with a mean length of 33.73 cm (Fig. 10). All males over a size of 34 cm had calcified and elongated claspers. The recruitment pattern demonstrated that *S. laticaudus* juveniles were recruited to the fishery throughout the year with peaks during September (18.32%) and August (16.51%) (Fig. 11). Logistic regression of the probability of

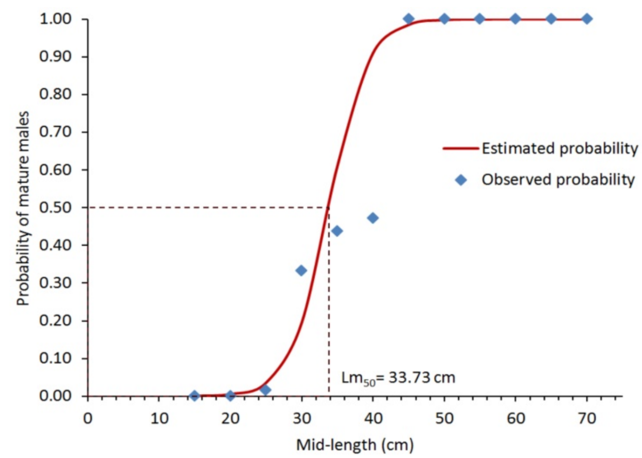

Fig. 10 — Length at maturity (Lm_{50}) of male *S. laticaudus* from Gujarat coast

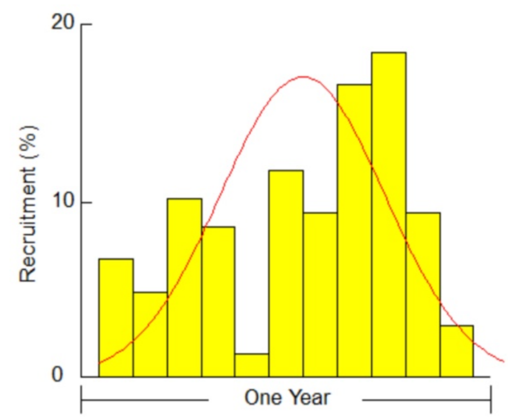

Fig.11 — Recruitment pattern of *S. laticaudus* from Gujarat coast

capture for sequential length classes of *S. laticaudus* obtained from length converted catch curve analysis revealed that 50% of the sharks in stock become vulnerable to gears at TL of 39.74 cm (Lc_{50}) (Fig. 12). The length at recruitment (Lr) for shark was found to be 15 cm.

Stock assessment

The relative Y/R and B/R analysis of *S. laticaudus* using selection ogive procedure of FiSAT II is shown in Figure 13. The Lc_{50}/L_{∞} and M/K values of 0.526 and 1.703 were used as input parameter for the analysis. The analysis indicated that the exploitation rate which maximizes the yield per recruit (E_{max}) was 0.70 for *S. laticaudus*. The level of exploitation at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a very low value of E ($E_{0.1}$) was 0.57 for the species. The exploitation level which could result 50%

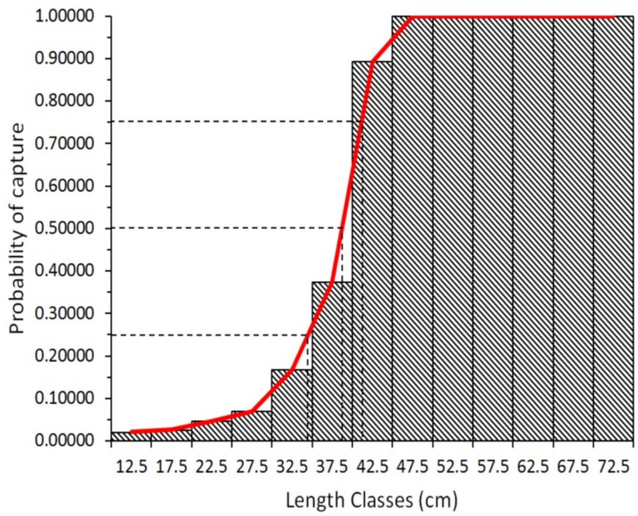

Fig .12 — Length at capture (Lc_{50}) of *S. laticaudus* from Gujarat coast

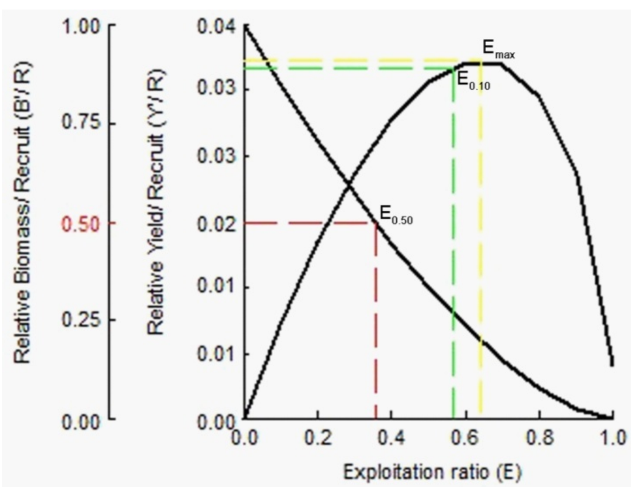

Fig. 13 — Stock status of *S. laticaudus* from Gujarat coast using Beverton and Holt's relative Y/R model

reduction of B/R compared to virgin biomass ($E_{0.5}$) was 0.36 for *S. laticaudus*.

The yield (Y), biomass (B) and SSB at different fishing levels predicted using length-based Thompson and Bell bio-economic model is summarized in Figure 14. The analysis shows that maximum sustainable yield (MSY) for *S. laticaudus* could be obtained by increasing fishing effort by almost 2.4 times higher than the present level which would deplete the SSB to 20%. On the other hand, the economic yield can be maximized (MEY) by increasing the fishing effort by1.8 times which would decrease the SSB to a safer 26.5%. In case of *S. laticaudus* fishery, the fishing effort could be

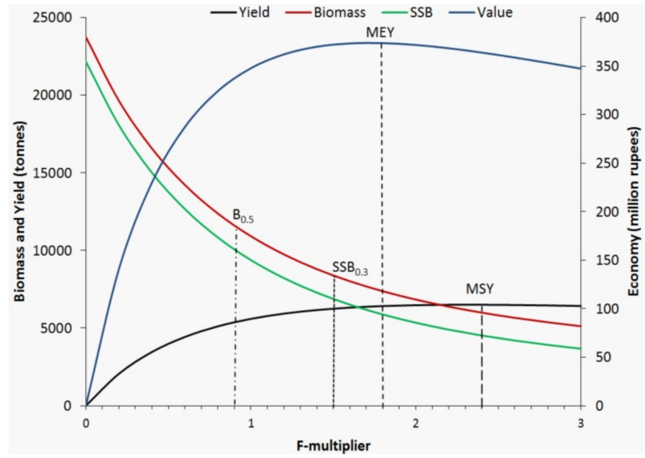

Fig. 14 — Stock status of *S. laticaudus* from Gujarat coast using Thompson and Bell model

increased by 50% to increase the yield and revenue from fishery while maintaining SSB at a much safer 30% level. However, to conserve the biomass at 50%, the fishing effort needs to be decreased by 10%.

Discussion

Analysis of catch data during 2012-16 revealed that *S. laticaudus* contributes predominantly to Gujarat shark fishery. The species contributes nearly 67% to the total shark landings of the state which is well corroborated by the recent landings data from CMFRI[5]. Moreover, the fishery of spadenose shark appeared to be relatively stable without much decline during the study period. The sharks are, however, not targeted by the fishery which is clearly evident from their meager contribution (1.37%) to the Gujarat fisheries and are caught incidentally by the gears targeting other fishery resources like ribbonfishes, sciaenids, threadfin breams, catfishes and tunas. It is also pertinent to mention that a portion of the shark stocks beyond the territorial waters of Gujarat is targeted by the fishing fleets operating from the distant southern maritime states of India and is landed outside Gujarat. During the present study, it was observed that the sharks are predominantly exploited by gill nets (60%) followed by trawl nets (40%).

The maximum length (L_{max}=71.8 cm) of *S. laticaudus* observed in the present study was slightly higher than that was reported by Setna and Sarangdhar[20] and Mathew and Devaraj[25] from Mumbai waters, but comparatively lower than the earlier reported L_{max} *i.e.*, 74 cm from Madras waters[47] and Indonesian waters[48], 75 cm from Myanmar waters[49] and 76 cm from Indian waters[50]. There is even a report about this shark growing to a length of 120 cm[51]. The present estimates of L_∞ of *S. laticaudus* was found to be higher than the earlier report of Kasim where L_∞ was reported as 74.9 cm and 68 cm for female and male sharks, respectively; whereas, the present estimate of K was found to be lower than that of female sharks (0.88 yr^{-1}) and male sharks (1.08 yr^{-1}) from Mumbai waters of north-west coast of India[26]. The estimates of growth parameters were also found to be comparatively higher than earlier report of Devadoss, where L_∞, K have been reported as 71.5 cm 0.36, respectively for females and 67.6 cm and 0.41 for males sharks from Calicut waters of south-east coast of India[21].

In the case of viviparous sharks where the gestation period is usually long, t_0 plays a crucial role in correct estimation of growth parameters. In the present study, since there was no direct evidence about t_0 values used for selection of growth parameters, the largest embryo size and the smallest free-swimming individuals observed in the present study were used to ascertain the length at birth (L_0). The observed length at birth i.e., 15 cm for *S. laticaudus* was used to fit the von Bertalanffy growth curve using various estimates of growth parameters to find out the best growth parameters that confirm with the earlier reported gestation period (t_0). The present L_0 for *S. laticaudus* was found to be in agreement with the observation of Compagno and Niem[44] and close to the earlier reports where, it has been reported as 14 cm from Mumbai[18,21,45,46] and Calicut waters[21,22]. The growth parameters were estimated by ELEFAN-I and MPA routines of FiSAT-II. The growth parameters for *S. laticaudus* obtained by ELEFAN-I resulted a t_0 of -0.41 yr which was marginally lower as there are earlier studies where the gestation period for the species was generally mentioned as five to six months[52,53]. Therefore, MPA was carried out using a range of t_0 inputs from -0.3 yr to -0.9 yr to refine the growth parameters obtained from ELEFAN-I. The L_∞ and K values of 75.50 cm and 0.54 yr^{-1} obtained were selected as the final estimates because of the back calculated value of t_0 (i.e., -0.40 yr) by using L_0 as 15 cm matched with the t_0, which was used as one of the inputs in MPA. However, the gestation period obtained in the present study was not found to be in agreement with earlier report of Mathew and Devaraj[25] who reported it as four months (-0.33 yr). The gestation period calculated in the earlier work[25] simply do not reconcile with the estimation of t_0 (-0.01 yr) which is very low for any shark. The estimation of t_0 (-0.012 yr for male sharks and 0.012 yr for female sharks) for *S. laticaudus* from Veraval waters by Kasim[26] appears to be unreasonable on the same rationale. Strangely, in another study, the t_0 was reported as 0.59 yr which is incomprehensible as it simply implies that the embryos were born with negative lengths[16]. Though, a gestation period of 6.8 month (t_0 = -0.57 yr) appears to be little higher[24], this is the only earlier estimate for *S. laticaudus* that is close to the result of the present study.

The length-weight relationship of *S. laticaudus* revealed that though growth is isometric, the males are slightly heavier than females till the shark reaches 36 cm (TL) after which females become heavier than males of same length. This is found to be in agreement with the earlier reports where females were reported to be heavier than males[16,25,26]. On the contrary, in some other studies, body weights between the sexes were not found to be significantly different[15,17,18]. The size at first maturity (Lm_{50}) for female and male *S. laticaudus* were found to be in agreement with the findings of previous studies where Lm_{50} has been described as 33 to 35 cm for females and 24 to 36 cm for males [16,21,51]. Contrary to the present finding there is a report where the size at first maturity has been reported as 57.3 cm for female sharks and 57.9 cm for male sharks from Zhejiang province of China[12] which appears to be very high for a fast growing small shark species like *S. laticaudus*. This present study indicates that *S. laticaudus* attains maturity between 9 to 10 months which appears to be little early compared to the previous reports where the shark has been estimated to mature at one or two years of age [16,26]. The Lm_{50}/ L_∞ ratio is found to be 0.48 in the present study. The ratio is low compared to the ratio suggested by Holden[54] for elasmobranchs; however, it is found to be in agreement with the calculated ratios from few previous studies[16,51]. The length at capture (Lc_{50}) was estimated to be 39.74 cm for the species which is higher than the length at maturity for both females and males. This implies that the shark enters into peak phase of exploitation by the completion of first year after birth and almost two months after attaining sexual maturity. Therefore, the fishery seems to be adequately sustainable as the sharks are getting the opportunity to breed before entering into peak phase of exploitation. The exploitation ratio was found to be 0.53 which indicates that *S. laticaudus* fishery is optimally exploited.

S. laticaudus with K values between 0.2 and 0.5 yr^{-1}, could be considered as fast growing shark species[55]. The species could be anticipated to sustain a reasonable intensity of targeted exploitation compared to its larger and slow growing counterparts due to its unique life history characteristics such as faster growth, earlier maturation and annual reproduction cycle. The Beverton and Holt relative yield per recruit analysis revealed that maximum Y/R could be obtained at an exploitation ratio (E_{max}) of 0.70 for *S. laticaudus*. However, as the analysis does not give any consideration for the biomass[56], operating the fishery at E_{max} could critically decrease the biomass. Therefore, it is advisable to use a precautionary management reference point like $E_{0.1}$. In the present study, E_{cur} was found to be lower than the $E_{0.1}$ which indicates that there is still scope to increase fishing effort for this species.

Another precautionary management reference point used to minimize the risk due to uncertainty in stock assessment is SSB, which ensures the availability of sufficient number of spawners to replenish the stock[57]. In the case of stocks, where the resilience is low and information on spawning stock recruitment relationship is unclear, the SSB should be maintained at least at 30% to prevent recruitment overfishing[58]. The exact mechanism by which sharks rebuild the stock despite having low fecundity is yet to be established, but it is believed to adopt some sort of compensatory density dependent population regulation, where the sharks increase their fecundity to circumvent the population decline from targeted over-exploitation[54-59]. Excessive removal of sharks from the habitat due to over-exploitation also improves the survival chance of the juveniles due to decrease in territorial behavior, reduced competition for resources and decreased vulnerability for cannibalism and predation[60,61]. The survival of sharks also enhanced due to viviparity in sharks, as the young sharks are given birth at a well-grown condition.

Thompson and Bell yield and stock prediction showed that yield of *S. laticaudus* fishery could be maximized (MSY) from the current equilibrium yield by deploying a fishing effort 2.4 times higher than the present level which would drastically decrease the SSB to 20% of the initial level. This resulted SSB at MSY could be detrimental for the long-term sustainability of the stock as it could lead to recruitment over fishing where there would not be adequate spawners to rebuild the stock for future exploitation. The analysis also showed that the revenue from fishery could be maximized (MEY) by increasing the fishing effort 1.8 times higher than the present level which would also decrease the SSB, but to a comparatively safer level of 26%. Moreover, any increase in fishing effort beyond MEY could lead to growth overfishing, as the revenue from catch will not increase despite the increase in catch due to the smaller exploited sharks which will not fetch good market price. In the present study, an increase in fishing effort by 50% could be considered safer as it will not decrease the SSB below 30% level. However, a general increase in fishing effort in multispecies and multigear fisheries of Gujarat could be detrimental for other valuable fishery resources and therefore, care should be taken while arriving at appropriate management reference point for the species. If effort has to be increased to increase sustainable yield from the shark, then the number of dedicated units targeting the shark fishery such as hook and lines and large meshed gill nets should only be increased.

Conclusion

The present study reveals that the spadenose shark fishery seems to be adequately sustainable as it is getting the opportunity to breed before entering into peak phase of exploitation. Since the Indian fisheries is a multi-gear multi-species fishery, the selective fishing effort for the sharks, by deploying gears like gill netters and hook and lines for the targeting of shark, could be increased to enhance the yield.

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