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Population dynamics and stock assessment of milk shark, *Rhizoprionodon acutus* (Ruppell, 1837) along Gujarat coast of India

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Stock assessment of *Rhizoprionodon acutus* (Ruppell, 1837) was made along with a few biological characteristics in the commercial landings during 2012-2014 from Gujarat waters of India to understand the population dynamics and stock status of the species. L_{∞}, K and t_0 estimated were 93.8 cm, 0.32 yr^{-1} and -1.3 yr, respectively. Total mortality rate (Z), fishing mortality rate (F) and natural mortality rate (M) were estimated as 1.0 yr^{-1}, 0.39 yr^{-1} and 0.61 yr^{-1}, respectively. Length at capture (Lc_{50}) and length at maturity (Lm_{50}) were estimated as 50 cm and 61 cm respectively, which indicate that most of the sharks are exploited before attaining the sexual maturity. Length-weight relationship showed growth was isometric. The species was a continuous breeder and showed peak recruitment during May. The current exploitation ratio (E_{cur}) was found to be 0.39, 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 the current exploitation is reducing the virgin stock biomass (B_0) and spawning stock biomass (SSB) to 55% and 34%, respectively and hence, the exploitation level for the species could be increased by 20% which would increase the yield while maintaining the SSB at a relatively safer 28% level for its sustainability.

[Key words: milk shark, growth parameters, spawning stock biomass, resilient species]

Introduction

Sharks play a crucial functional role as the apex predators in marine ecosystem and being in the top of food chain, are usually found in lower biomass compared to those occupying lower trophic levels[1,2]. Sharks are targeted due to rising demand for their meat, fins, liver and other products that has led to indiscriminate fishing of the resource which is decimating their population. The global shark landing has come down from 893,000 tonnes in 2000 to 766,000 tonnes in 2011 registering a 15% decline in a decade[3]. In India, shark landing 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 shark landing in India was about 22,479 tonnes in 2014[5], which is about 70% lower than the historic highest landing of shark. The contribution of shark landing to the total marine fisheries landing has also decreased from 3.4% in 1985 to 0.6% in 2014[5]. Gujarat is the largest maritime state in India where a large fishery for shark was existed, which contributed more than half of India's total shark landings during 2000[6]. However, currently the shark landing in Gujarat has decreased to about 8016 tonnes[5].

Rhizoprionodon acutus, also popularly known as 'milk shark', is a medium sized shark that has been found to grow to a length little over 1 m. This is a pelagic shark which is usually found in in-shore water but has also been reported upto a depth of 200 m in tropical and sub-tropical estuarine and coastal waters[7,8]. This shark exhibits a conserved external morphology, which hampers its easy identification at the field level. This could be a reason for which there is a paucity of specific information about this species, though general information is available to some extent from Indian waters[9,10] as well as from foreign waters[7,11,12]. Though detailed study on reproductive biology of the shark from Oman waters[13,14] and diet composition of shark from Senegal waters[15,16] are available, information about the exploitation level and stock status is scarce. In India, studies on the population dynamics and status of the stock have been carried out from Chennai waters in south-east

coast[17] and from Veraval waters of north-west coast during the year 1979 to 1981[18]. However, the fishery has changed considerably in the last few decades, which warrants a fresh assessment of the resource. Therefore, the present study was carried out to assess the status of exploitation and stock of the species so that proper management advisory can be provided to maximize the yield while maintaining its sustainability.

Materials and Methods

Data on catch, effort and size composition were collected every week from January, 2012 to December 2014 from commercial landings at 4 major fish landing centres *i.e.,* 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 Saurashtra coast of Gujarat, India (Figure 1).

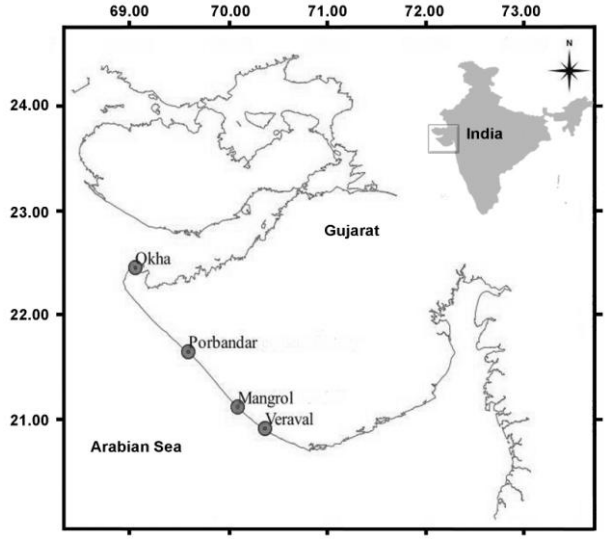

Fig.1-Map showing the location of the fish landing centres from which the samples for the present study were collected

The shark fishery of Gujarat is mainly exploited by outboard gill netters (31%), mechanized gill netters (31%) and trawlers (27%)[5], which are operated at a depth range of 20 m to 140 m from the Kutch coast of western Gujarat to the Ratnagiri coast of south Maharashtra, a neighboring maritime state of Gujarat. A total of 684 fresh specimens of *Rhizoprionodon acutus* in the size range of 32-89.5 cm (TL) were collected randomly for the analysis. The major portion of the sample was collected from gill net landings (64%) and the remaining 36% from trawl landings. The total length (TL) *i.e.,* from tip of the snout to the posterior tip of tail, with tail flexed down to middle of each individual was measured 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 landings of *R. acutus* of Gujarat following the multistage stratified random sampling method adopted by Fisheries Resources Assessment Division (FRAD) of CMFRI, Kochi, India. The von Bertalanffy growth parameters[19] *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[20]. Age at length zero (t_0) was back calculated using modified von Bertalanffy growth equation suggested by Alagaraja[21] *i.e.,* $t_0=1/K \log_e [1-(L_{t=0}/L_\infty)]$, where $L_{t=0}$ is the length at birth . For the calculation of t_o, 32 cm was used as the length at birth ($L_{t=0}$) which was ascertained from the length of the largest embryo and the smallest free-swimming individuals observed from the fishery. 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[22]. The mean lengths of the cohort across different months were linked to generate 'length-at-age' data. A range of t_o (-0.8 yr to -1.4 yr) was used in the iteration to fit growth curve using the above mentioned 'length-at-age' data. The $L_{t=0}$ as 32 cm and t_0 >1 yr was used as the yardstick to select the most reasonable growth curve for the species from which the growth parameters *viz*. L_∞ and K were recalculated and used for further analysis. Growth performance index (φ) was calculated from formula as described by Pauly and Munro[23] *i.e.,* $\varphi=\log_{10} K+ 2\log_{10} L_\infty$. Longevity ($t_{max}$) was estimated from the equation described by Pauly[24] *i.e.,* $t_{max} = 3/K + t_0$. Length-weight relationship of *R. acutus* was established following of Le Cren[25] *i.e.,* $W=aL^b$.

The instantaneous total mortality rate (Z) was estimated by FiSAT II package using the length converted catch curve method[24]. The natural mortality rate (M) was estimated by Pauly's empirical formula[26] *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 $E= F/Z$[27]. The length structured cohort analysis of FiSAT II was used to obtain fishing mortality per length class.

For determining the length at first maturity (Lm_{50}), the maturity status of each shark was ascertained following the classification scheme proposed by Stehmann[28], based on ovarian and uterine condition for females and clasper calcification and testes development for males.

Table 1. Catch and effort of *Rhizoprionodon acutus* landed along Gujarat coast of India during 2012-2014

Year	Efforts (units)	Total marine landing(t)	Total commercial shark landing (t)	Percentage of shark landing total marine landing(t)	*Rhizoprionodon acutus*		
					Catch (t)	CPUE (Kg U^{-1})	% to total shark landing
2012	751105	690396	7598	1.10	31.15	0.041	0.41
2013	800993	705945	6573	0.93	46.60	0.058	0.70
2014	838464	713497	8009	1.12	18.42	0.021	0.23
Average	796854	703279	7393	1.05	32.05	0.040	0.44

The female sharks with ovaries not developed or partially developed but with maturing oocytes, and having undeveloped thin ribbon-like uteri were classified as immature. On the other hand the female sharks having well developed uteri and ovaries with mature oocytes were considered as mature. The male sharks having uncalcified or partially calcified claspers and undeveloped testes were considered as immature whereas, the sharks having well calcified claspers and developed testes were classified as mature sharks. The Lm_{50} was calculated using the logistic regression described by White[29] 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. Temporal spread was reduced by using the restructured data and normal distribution of the recruitment pattern was determined by maximum likelihood method using NORMSEP[30]. The midpoint of the smallest length group in the catch during the three-year period was taken as the length at recruitment (Lr). The length at first capture (Lc_{50}) was estimated by probability of capture routine in the FiSAT-II package. The probability of capture was approximated by backward extrapolation of the regression line of descending limb of the length converted catch curve[31].

The probability of capture of sequential length classes was regressed using a logit curve for the estimation of Lc_{50}.

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 the relative yield per recruit analysis method described by Beverton and Holt[32]. The equilibrium yield, standing stock biomass (B) and spawning stock biomass (SSB) at different fishing levels were predicted using the length based Thompson and Bell bio-economic model[33]. The price information of the species for different length classes were collected at monthly interval and such information were used in the Thompson and Bell bio-economic model[33] to estimate the equilibrium economic yield of the species. Information from the above stock assessment models were used to forecast the biological reference points for the sustainable exploitation of the resource.

Results

Fishery and Seasonal abundance

The annual average landing of *R. acutus* was 32.05 t during 2012-2014 with a catch rate (CPUE) of 0.040 kg per unit (Table-1). During this period *R. acutus* landings contributed 0.44% to the total shark landings of Gujarat. Fishery was at its peak in the first quarter of the year (January to March) after which the landings reduced. The fishery revived again during September to November after the monsoon fishing ban was lifted (Figure 2).

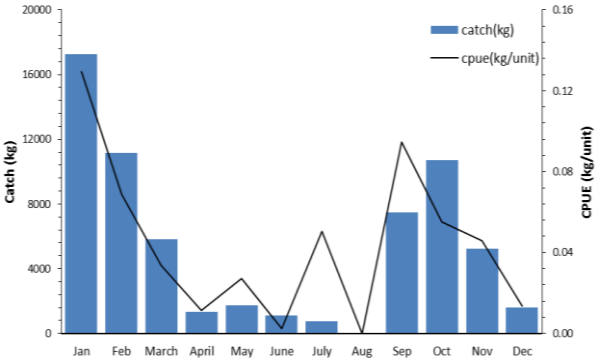

Fig.2-Month-wise catch (kg) and catch rate (kg/unit) of *Rhizoprionodon acutus* from Gujarat coast of India

Stock structure

A total of 684 sharks were collected for the study of which the females constituted 53% (n=363) and the males 47% (n=321) with an overall sex ratio (Male: Female) of 1:1.13. The mean TL of the female sharks *i.e.*, 55.98 ± 0.58 cm, was not found to be significantly higher than that of the male sharks *i.e.*, 54.77 ± 0.67 cm

(Independent t-test, P>0.01). The exploited *R. acutus* stock was represented by the female sharks in a TL range between 32 cm to 89.6 cm and was mainly dominated by individuals in the length group of 50-55 cm. The length range of the male sharks was between 33.5 cm and 89 cm but was dominated by comparatively smaller length group of 45-50 cm. The length frequency distribution for both the sexes was normal (Kolmogorov–Smirnov test, P>0.05) with a modal length at 52.5 cm (Figure 3).

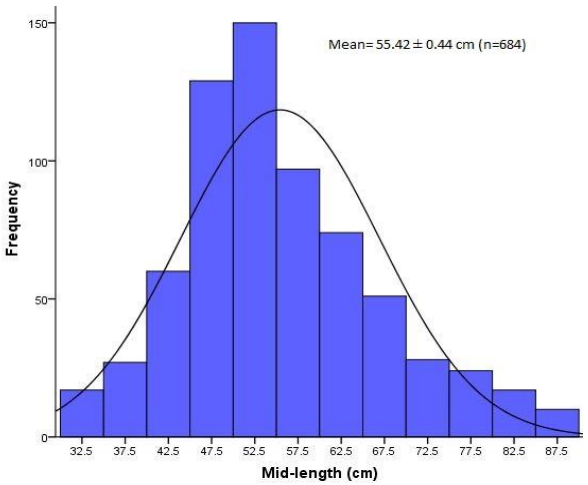

Fig.3-Stock structure of *Rhizoprionodon acutus* from Gujarat coast of India

Growth, Mortality and Exploitation Parameters

Estimated growth parameter for *R. acutus* by using ELEFAN-I and MPA is given in Table 2.

The L_∞ and K estimated by ELEFAN-I were 94.3 cm and 0.5 yr^{-1} (Figure 4) which resulted a t_0 of -0.83 yr. MPA using t_0 in a range of -0.8 to -1.4 yr resulted in L_∞ values from 89.4 to 94.9 cm and corresponding K values from 0.30 to 0.42 yr^{-1} (Figure 5).

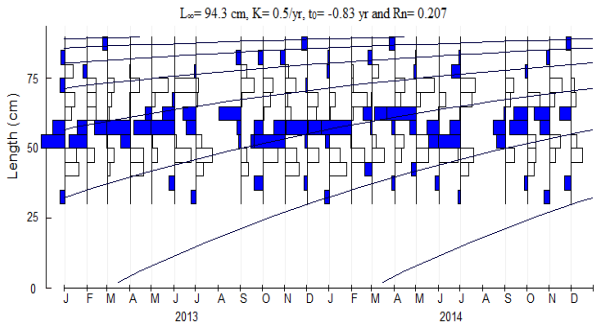

Fig.4-von Bertalanffy equation fitted growth curve of *Rhizoprionodon acutus* using ELEFAN-I

The L_∞ and K values of 93.8 cm and 0.32 yr^{-1} respectively, obtained using t_o of -1.3 yr in MPA were selected as the most befitting estimates of growth parameters (Figure 6) as the von Bertalanffy growth curve constructed using the above parameters resulted $L_{t=0}$ which was same as that of the observed value *i.e.,* 32 cm and these values were used for the subsequent analysis. Growth curve constructed using these growth parameters obtained from MPA showed that the shark grows to a TL of 48.93 cm in 1st yr, 61.22 cm in 2nd yr, 70.14 cm in 3rd yr, after which the growth slows down considerably registering a TL of 76.62 cm in 4th year, 81.22 cm in 5th yr, 84.75 cm in 6th yr, 87.23 cm in 7th year and 89.03 cm in 8th year (Figure 5). Growth performance index (φ) and longevity (t_{max}) of the species were found to be 3.44 and 8.08 yr, respectively.

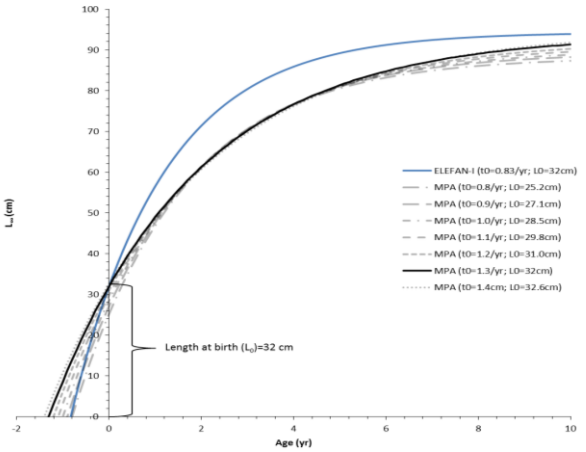

Fig.5-Comparison of reconstructed VBGF growth curve constructed using growth parameters obtained from ELEFAN-I and MPA

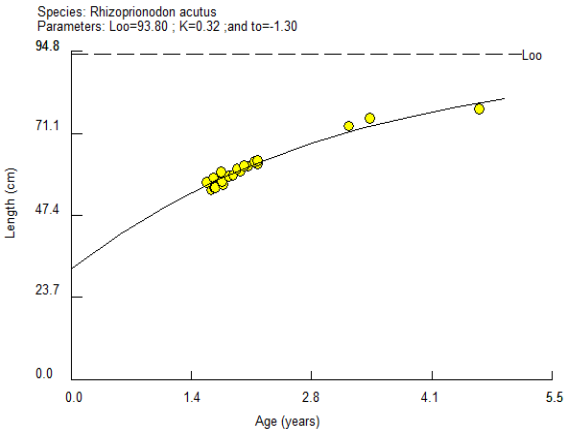

Fig.6. Modal class progression analysis (MPA) growth curve obtained using 'length-at-age' data

The natural mortality rate (M), the total mortality rate (Z), the fishing mortality rate (F) and current exploitation ratio (E_{cur}) were 0.61 yr^{-1}, 1 yr^{-1}, 0.39 yr^{-1} and 0.39 respectively (Figure 7). The length based cohort analysis showed that F exceeded M when the shark attained 82.5 cm TL (Figure 8).

Length-weight relationship

The length-weight relationships for the male, female and both sexes are given below.

Male: $W = 0.0097\ TL^{2.80}$ (r^2=0.97, n=321)
Female: $W = 0.0027\ TL^{3.12}$ (r^2=0.96, n=363)
Sex Pooled: $W = 0.0049\ TL^{2.97}$ (r^2=0.96, n=684)

Table 2. Growth parameters of *Rhizoprionodon acutus* from Gujarat coast of India

von Bertalanffy Growth parameters	ELEFAN-I t_0=-0.83* yr	MPA						
		t_0=-0.8 yr	t_0=-0.9 yr	t_0=-1.0 yr	t_0=-1.1 yr	t_0=-1.2 yr	t_0=-1.3 yr	t_0=-1.4 yr
L_∞ (cm)	94.3	88.25	89.36	90.17	91.2	92.3	**93.80**	94.92
K (yr^{-1})	0.5	0.42	0.4	0.38	0.36	0.34	**0.32**	0.3
VBGF fitted L_0 (cm)	32	25.2	27.1	28.5	29.8	31	**32****	32.6
T_{max}(yr)	5.17	6.34	6.60	6.89	7.23	7.62	**8.08**	8.60

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; $L_{t=0}$: Length of the animal at birth
*VBGF fitted t_0 calculated using L_∞, K and observed $L_{t=0}$ *i.e.*, 32 cm obtained from ELEFAN-I
**VBGF fitted $L_{t=0}$ calculated using L_∞, K and and t_0 -1.3 yr obtained from MPA

Where, W is weight in g and TL is total length in cm. Analysis of covariance (ANCOVA) test was performed to check the similarity of regression lines of the male and female sharks. Slope was found to be significantly ($P \leq 0.05$) higher for female sharks compared to male sharks whereas, the intercept of the male sharks was found to be significantly ($P \leq 0.05$) higher than the female sharks. This suggests that the weight for a specific length varies significantly between males and females. The males tend to be heavier than the female until 60 cm TL after which the females become heavier than the males (Figure 9). Here it should be noted that the body weights of the pregnant females are inclusive of pups weight growing inside the bodies. The relationship between the body length and weight for the sex pooled data shows that growth is isometric (Figure10).

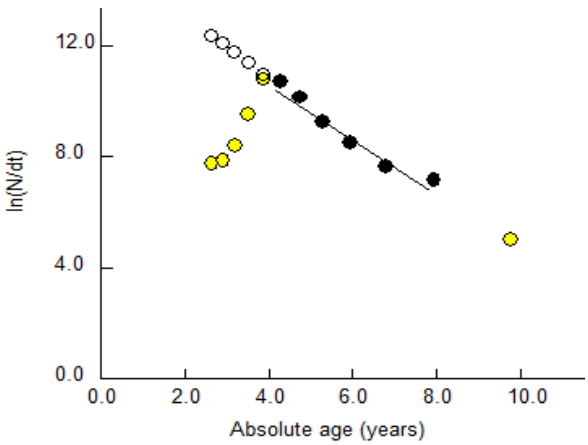

Fig.7-Length converted catch curve showing the mortality parameters *viz.*, M, F & Z and exploitation ratio *i.e.*, E of *Rhizoprionodon acutus* from Gujarat coast of India

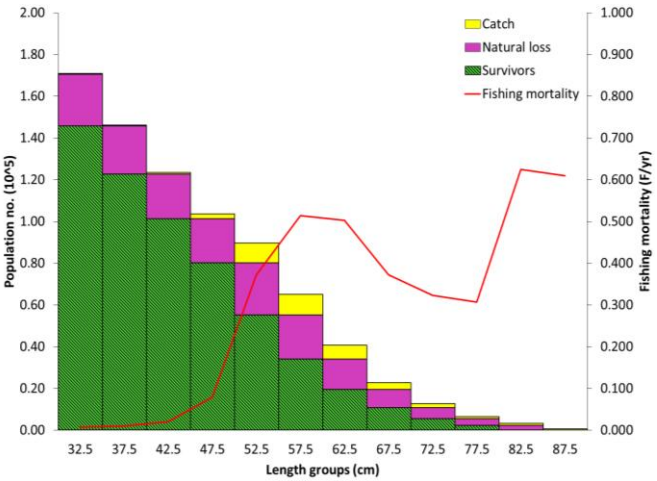

Fig.8-Length structured cohort analysis of *Rhizoprionodon acutus* from Gujarat coast of India

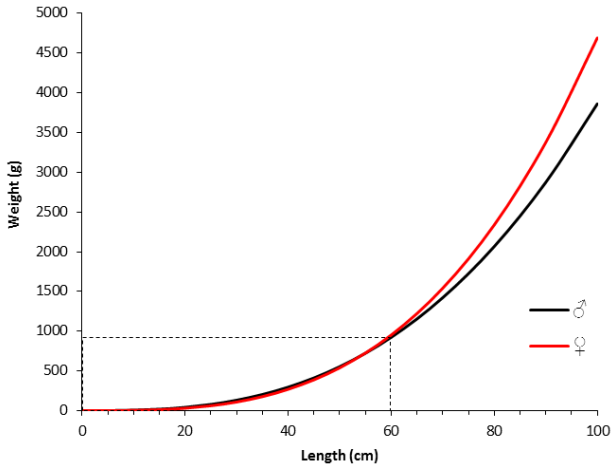

Fig.9-Difference in length-weight relationship between male and female *Rhizoprionodon acutus* from Gujarat coast of India

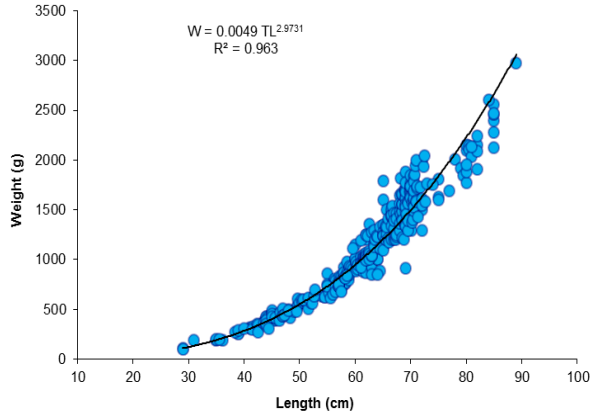

Fig.10-Length-weight relationship between male and female *Rhizoprionodon acutus* from Gujarat coast of India

Maturity, Recruitment and Gear selectivity

The mature and pregnant females were recorded throughout the fishing period. However, the maximum percentage of mature and pregnant females was reported during March to May. The maturity study revealed that, 50% of the female sharks mature between TL of 59.74 cm and 62.73 cm with a mean length of 61.28 cm. (Figure 11). The male sharks also mature almost in the similar size range of 59.85-63.10 cm TL with a mean length of 61.53 cm (Figure 12). Annual sex ratio between male and female sharks was 1:1.13.

The recruitment pattern demonstrated that the shark juveniles were recruited to the fishery continuously throughout the year with peak during May (16.18%) and June (13.12%) (Figure 13). The length at recruitment (Lr) for shark was found to be 32 cm. Logistic regression of the probability of capture for the sequential length classes obtained from length converted catch curve analysis revealed that 50% of the sharks in the stock become vulnerable to gears at TL of 49.92 cm (Lc_{50}) (Figure 14).

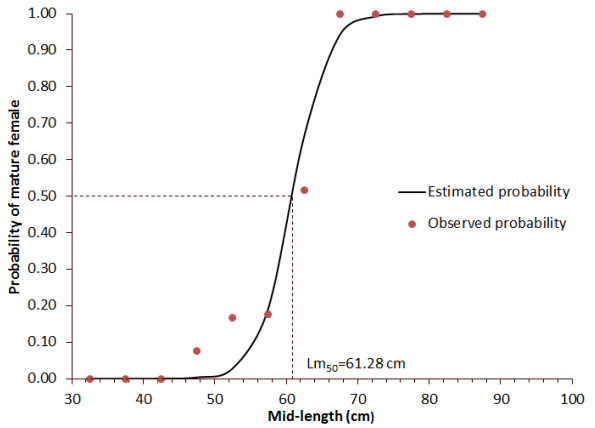

Fig.11-Length at maturity (Lm_{50}) of female of *Rhizoprionodon acutus* from Gujarat coast of India

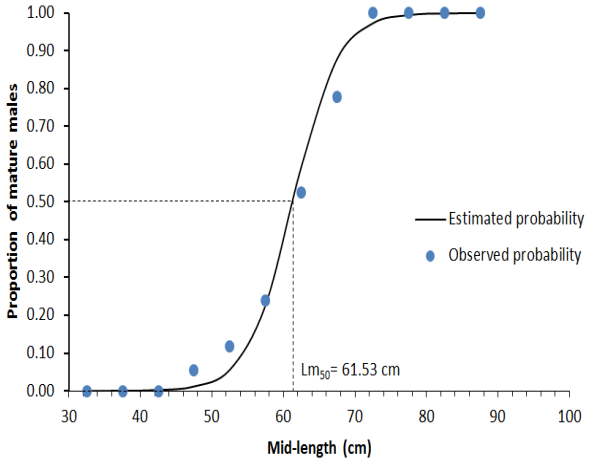

Fig.12-Length at maturity (Lm_{50}) of male of *Rhizoprionodon acutus* from Gujarat coast of India

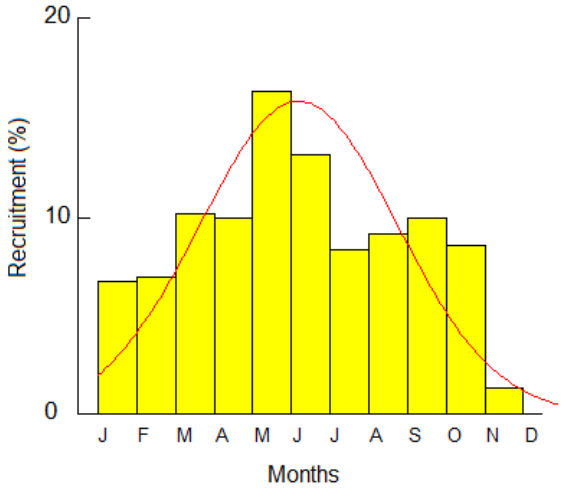

Fig.13-Recruitment pattern of *Rhizoprionodon acutus* from Gujarat coast of India

The Lc_{25} and Lc_{75} were calculated as 47.08 cm and 52.77 cm respectively.

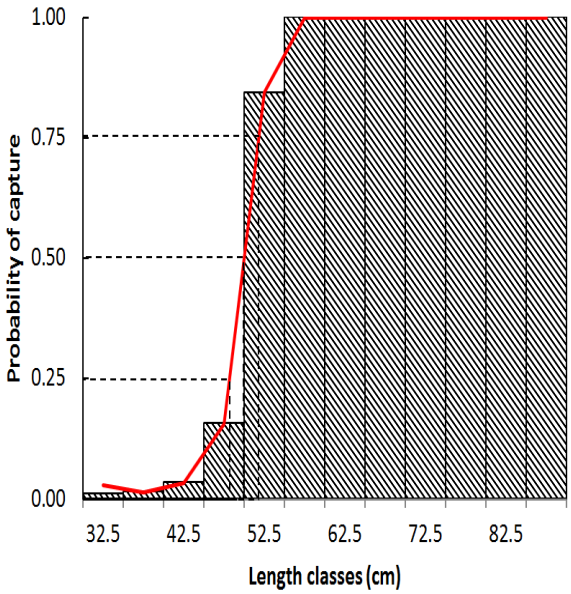

Fig.14-Length at capture (Lc_{50}) of *Rhizoprionodon acutus* from Gujarat coast of India

Stock assessment

The relative Y/R and B/R analysis of *R. acutus* were estimated using knife edge selection procedure of FiSAT II (Figure 15). Lc_{50}/L_{∞} as 0.533 and M/K as 1.906 were used as the input parameter for the analysis. The analysis indicated that, the exploitation rate which maximizes the yield per recruit (E_{max}) was 0.75. 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 0.62. The exploitation level which will result in the reduction of B/R to 50% compared to virgin biomass ($E_{0.5}$) is 0.37.

The yield (Y), biomass (B) and spawning stock biomass (SSB) at different fishing levels predicted using length based Thompson and Bell bio-economic model is summarized in Figure 16. Analysis showed that, maximum sustainable yield (MSY) could be obtained by increasing fishing effort by almost 5 times higher than the present level whereas, the maximum economic yield (MEY) could be obtained at a fishing effort as high as 2.4 times than the present level of fishing. However, such an increase in the present exploitation level to achieve MSY and MEY could decline the SSB to an alarming low level of 1.45% and 10.38%, respectively. The present exploitation level is reducing the SSB to 34% and therefore, the exploitation level should be increased by 20% which would maintain SSB at 28% as the precautionary reference point to ensure stock regeneration.

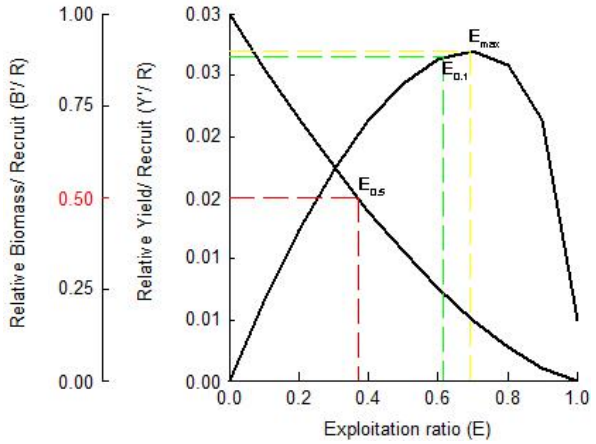

Fig.15-Stock status of *Rhizoprionodon acutus* using Beverten and Holt's relative Y/R model from Gujarat coast of India

Discussion

Analysis of the catch data during 2012-14 revealed that the contribution of *R. acutus* to the Gujarat fishery is very low. The CPUE was also found to be very low which clearly indicates that *R. acutus* is not a targeted resource in the fishery.

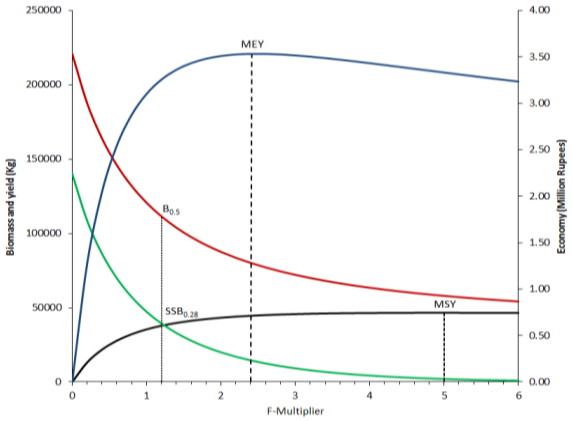

Fig.16-Stock status of *Rhizoprionodon acutus* using Thompson and Bell model from Gujarat coast of India

According to the recent data, the shark landing of Gujarat is mainly contributed by *Scoliodon laticaudus* (83.2%) followed by *Carcharhinus sp*. (14%). Apart from this, a minor contribution was also made from *Sphryna* sp. (1.4%), *Mustelus mosis* (0.8%), *Rhizoprionodon* sp. (0.2%), *Centrophorus* sp. (0.2%) and *Loxodon* sp. (0.2%)[5]. Fishery in Gujarat waters is mainly exploited by gears like trawl nets, gill nets and bag nets which target resources such as ribbonfish (*Trichiurus lepturus*), threadfin breams (*Nemipterus japonicus*), squids (*Loligo duvauceli*), cuttlefish (*Sepia inermis*) and prawns (penaeid and non-penaeid). Sharks like *R. acutus* are caught as by-catch. However, the current annual average landing of the shark from Gujarat *i.e.,* 32.05 t has decreased substantially from the earlier reported landings of 281 t during 1979-1980 and 92 t during 1980-1981 from Veraval alone, which is the major landing centre of Gujarat[18]. One of the possible reasons for this decline could be due to the fact that a considerable fraction of the catch for the species are landed elsewhere outside Gujarat depending on market demand pattern, scope of export as well as social issues. It has also been noticed that sharks beyond the territorial water (12 nautical miles) are exploited by fishermen of neighboring as well as distant maritime states due to lack of expertise and interest of the local fishermen. Due to these reasons, it is difficult to estimate the amount of sharks caught off Gujarat coast. Therefore, the present study is mainly deriving the conclusion from the landing of the resource on Gujarat coast.

In the present study, the data on length frequency of exploited stock followed a normal distribution (Kolmogorov-Smirnov test, $P \geq 0.05$).

Analysis revealed that the catch is predominantly constituted by individuals of length between 50 and 55 cm (mid-length=52.5cm and mean length=54.4 cm). This could be due to the selectivity of the fishing gears, which subjected the sharks to higher exploitation at a size of 50 cm and above (Lc_{50}). Female sharks were marginally (but not significantly) higher in number than the male sharks. Length at birth ($L_{t=0}$) in the present study was estimated as 32 cm. Since direct estimation of $L_{t=0}$ was beyond the scope of present study, the largest embryo size and smallest free swimming individuals were used to ascertain the $L_{t=0}$. This is found to be close to the earlier report where $L_{t=0}$ has been mentioned as 30 cm from Chennai waters of south-east coast of India[17]. This is also found to be in the range of $L_{t=0}$ *i.e.,* 25 to 39 cm which was earlier described by Compagno[17]. The $L_{t=0}$ for *R. acutus* has also been reported in the range of 32.5 to 50 cm along Senegal coast[14]. Maximum length (L_{max}=89.6 cm) observed in the present study is however, found to be lower than the earlier reported length *i.e.,* 108 cm from Chennai waters[17]. Surprisingly, there is also a report of this shark growing to a length of 178 cm from Australian waters[34].

The estimates of growth parameters in the present study differ from the earlier report of Kasim[18] from Veraval waters, where L_∞ and K have been reported as 105 cm, 0.56/yr for male and 106 cm, 0.60/yr for females. L_∞ and K for the species have been reported as 100 cm and 0.2/yr, respectively from Chennai waters[17]. In the case of viviparous sharks where the gestation period is usually long, t_0 plays a crucial role in the selection of appropriate growth parameters. Since there is no direct evidence about t_0, the observed length at birth *i.e.,* 32 cm was used to fit the von Bertalanffy growth curve. The t_0 thus estimated from growth parameters obtained by ELEFAN-I was -0.83 yr, which is low compared to the earlier reported t_0 of 1 year[7,11]. Therefore, MPA was carried out using a range of t_o (-0.8 to -1.4 yr) as input parameter to refine the growth parameters obtained from ELEFAN 1. The L_∞ and K values of 93.8 cm and 0.32/yr obtained by fitting the growth curve using 'length-at-age' data derived from decomposed cohorts were selected as the final estimates as the back calculated t_o using von Bertalanffy growth equation matched with the t_o that was used as one of the inputs in MPA. This also found to be in concurrence with the earlier reports, where the gestation period has been found to be more than a year[13,17]. However, t_o obtained in the present study was not found to be in agreement with t_o reported by Kasim (1991) as -0.053 yr for male shark and -0.056 yr for female shark from Veraval which are very low for a viviparous shark like *R. acutus*. The growth performance index (φ) and longevity obtained in the present study were 3.44 and 8 yr respectively, which indicate that the estimation of L_∞ and K is reasonable[7].

The estimated natural mortality rate (M) is important to understand rate of stock decay. But 'M' is a difficult parameter to estimate for an exploited resource. The widely used Pauly's empirical formula[26] resulted M of 0.61/yr. Length converted catch curve showed a total mortality rate (Z) of 1.00/yr which implies that fishing mortality rate (F) realized due to the present fishery is only 0.39/yr. This indicates that about 63% of the shark stock is reduced every year of which 46% reduction is solely contributed by mortality due to natural causes such as predation, shortage of prey, disease, senility *etc*. whereas, fishery contributes only 17% of the stock decay. Estimated M is reasonable as the M/K ratio was found to be 1.91 which falls within the range (1-2.5) proposed by Beverton and Holt[35]. Exploitation ratio was 0.39, which indicates that the resource is underexploited mainly because it is not targeted.

The length weight relationship of *R. acutus* shows that, though growth is isometric, the males are heavier than the females up to 60 cm TL after which the females becomes heavier than the males of same length. This is found to be in contrary to the earlier reports where the male sharks of some species of genus *Rhizoprionodon* were reported to be heavier than female sharks[13,36,37]. Increase in the body weight of the female above 60 cm may be due to the onset of sexual maturity (Lm_{50}) which considerably increases the weight of the reproductive structures in females compared to the males as well as add new weight in the form of growing pups inside the body of females.

The size at first maturity (Lm_{50}) for the females and males was found to be 61.28 cm and 61.53 cm respectively which is smaller than that reported from Oman[13] (64·7 cm LT), Indonesia (71·8 cm LT) and other locations in the Indo-West Pacific[29]. The current estimate is in agreement with Moore *et al*. who found Lm_{50} as 61.7 cm for the male shark from Persian Gulf[38]. Similarly, in another study, Lm_{50} for the species has been reported as 60 cm[39] from the same coast. This present study indicates that *R. acutus* attains maturity by the end of 2nd year which agrees well with the earlier report where this species has been reported to mature at an age of 2nd or 3rd year[7].

The $Lm_{50}/L\infty$ ratio is found to be 0.65 in the present study. Ratio is comparatively lower than that suggested by Holden for elasmobranchs *i.e.*, 0.77[40]. Interestingly, the ratio in the present study is found to be in agreement with the finding of Krishnamoorty and Jagadis for the species from Chennai coast of India[17]. Furthermore, other species in this genus reported so far indicated a $Lm_{50}/L\infty$ ratio ranging from 0.61 to 0.64[39]. The length at capture (Lc_{50}) is estimated as 49.9 cm which is less than the length at maturity of both females and males. This implies that the shark enter into the peak phase of exploitation immediately after completion of the 1st year of birth and almost a year before attaining the sexual maturity. Hence, the unintentional exploitation of juvenile sharks as by-catch may pose a risk of the growth overfishing and unsustainability of the resource in future if proper regulation for mesh size regulation is not practiced. Nevertheless, according to Branstetter and Musick[41] scheme of growth classification, *R. acutus*, with a K value between 0.2 to 0.5 yr^{-1}, could be considered as a fast growing shark species. Though it is a k-selected species, its peculiar life history characteristics of relatively faster growth and reproduction throughout the year make it as one of the most productive shark species and therefore, could be anticipated to sustain a reasonable intensity of targeted exploitation compared to its larger slow growing counterparts.

"Selection ogive" was used for the relative yield per recruitment analysis as assumption for "knife edge selection" are rarely met in real situation, especially for *R.acutus* which is exploited by both selective as well as semi-selective gears. The analysis revealed that maximum Y/R could be obtained at an exploitation ratio (E_{max}) of 0.75. However, exploitation of stock at E_{max} can decrease the biomass to a critically low level and hence should not be necessarily used as a target reference point (TRP). Therefore, as a precautionary approach, it is recommended that the exploitation should be reduced to a level where the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a very low value of E ($E_{0.1}$) which was found to be 0.62 and this may be used as a relatively safe TRP. In the present study, E_{cur} (0.39) is found to be very low compared to $E_{0.1}$, which indicates that the fishing effort for the species can be increased to achieve the TRP. However, the analysis does not give any consideration for the spawning stock biomass (SSB) which is essential to maintain the recruitment for the future[42].

Therefore, Thompson and Bell yield and stock prediction model[33] was used to evaluate the impact of increase in effort on total biomass (B), spawning stock biomass (SSB) and revenue from the fishery. Analysis shows that yield could be maximized to 46,560 kg (MSY) from the current equilibrium yield of 35,401 kg by deploying a fishing effort 5 times higher than the present level. However, the fishing effort at this high level could drastically decrease the SSB to a critical low level of 1.5%. The analysis also showed that the revenue from the fishery could be maximized to 3.53 million rupees (MEY) from the current equilibrium revenue of 3.10 million rupees by increasing the fishing effort 2.4 times from the present level. But fishing effort at this level could decrease the SSB to 10.38%. The resulted SSB at MSY and MEY could be detrimental for the long-term sustainability of the stock owing to the low reproductive potential of the species. This could lead to the recruitment over-fishing, as there will not be adequate spawners left to rebuild the stock for future exploitation. Moreover, any increase in the fishing effort beyond MEY could lead to growth overfishing as revenue from catch will not increase despite the increase in the catch.

Due to uncertainties involved in the assessment of life history parameters, it is wise to use precautionary management reference points such as SSB, even in situations where the relationship between spawning stock and recruitment cannot be established statistically[43]. In the present study, the relationship between the spawning stock and the recruitment has not been studied and hence it will be difficult to ascertain the safe SSB level for the species. However, according to the earlier study, it has been found out that the SSB in a stock, which is having an average resilience, should not be reduced below 20%. But in the case of stocks, where the resilience is low, the SSB should be maintained at 30% to prevent recruitment overfishing[44]. The exact mechanism by which sharks despite having low fecundity rebuild the stock is not clear, though it is believed to adopt a sort of compensatory density dependent population regulation, where the fecundity of the shark increases when it is overfished[45,46]. Similarly, under the low density condition, the survival of juveniles improves due to decrease in the territorial behavior, reduced competition for resources and decreased vulnerability for cannibalism and predation[47&48]. The viviparous mode of reproduction also plays the trick, where the young ones are given birth at a well-grown condition, which maximizes their chances of

survival. In the present study, an increase of fishing effort by 20% could be considered safe as it would only decrease the SSB to 28%.

However, the increase in fishing effort in the multispecies and multigear fishery of Gujarat, would be detrimental for the other valuable fishery resources such as *Pampus argentius*[49], *Pseudosciana diacanthus* and *Otolithoides biauritus*[50]. Therefore, care should be taken while arriving at management reference point for the species. *R. acutus* is not a target resource in Gujarat and is mainly landed as by-catch in trawls and gill nets fishing. If effort has to be increased to increase sustainable yield of milk sharks, then number of dedicated units targeting shark fishery such as hook and line and large meshed gill nets could be increased. Future study should also be envisaged to identify the shark breeding and feeding grounds and overall distribution of the species along the Gujarat coast so that exclusive targeting of the sharks for fishing can be carried out by Gujarat fishermen to improve the yield from the fishery in a sustainable manner.

Conclusion

The decrease in *R. acutus* landing, observed in the present study, could be more likely due to the change in the exploitation pattern towards other easily exploitable abundant resources and because of the changes in landing pattern for the shark due to social issues rather than the actual depletion of stock as it appears to be a relatively resilient shark species from its life history parameters. Presently, despite the fact that some portion of shark catch is missing from Gujarat landings, the species can be assumed underexploited and hence, the exploitation level can be increased marginally by deploying exclusively efforts targeting the shark resources such as large meshed gill nets and hook and lines. Considering the prevailing fishing pressure on other valuable fishery resources at Gujarat coast and SSB of the species as a precautionary reference point, exploitation level could be increased by 20% to improve the sustainable yield.

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