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Population dynamics and stock assessment of grey sharpnose shark *Rhizoprionodon oligolinx* Springer, 1964 (Chondrichthyes: Carcharhinidae) from the north-west coast of India

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ABSTRACT

The life history and exploitation parameters of *Rhizoprionodon oligolinx* Springer, 1964 were assessed using commercial landing data of 2012-2015 from Mumbai waters of India to understand the population dynamics and stock status of the species. The average annual landing of the species was estimated to be 383 t, which formed about 9.1% of the total shark landings of Maharashtra. L_{∞}, K and t_0 estimated were 97.1 cm, 0.47 yr^{-1} and -0.79 yr respectively. Total mortality (Z), fishing mortality (F) and natural mortality (M) rates were estimated as 2.16 yr^{-1}, 1.48 yr^{-1} and 0.69 yr^{-1} respectively. The length at capture (L_{50}), length at female maturity (Lm_{50}) and male maturity (Lm_{50}) were estimated as 49.7, 62.3 and 59.5 cm respectively, which indicated that most of the sharks entered peak phase of exploitation before attaining sexual maturity. Length-weight relationship indicated allometric growth (b>3) for the species. The species was found to be a continuous breeder and showed peak recruitment during April. The current exploitation rate (E_{cur}) was found to be 0.68, which is lower than E_{max} estimated for the species using Beverton and Holt yield per recruit analysis. Thompson and Bell prediction model showed that at current exploitation level, the biomass (B) has reduced to 32% of virgin biomass (B0) where as, the spawning stock biomass (SSB) has reduced to 16% of the virgin spawning stock biomass (SSB0). Hence the exploitation level for the species should be reduced by 40% that will ensure the availability of SSB at a relatively safer 30% level to rebuild the stock for long term sustainability of the resource.

Keywords: Grey sharpnose shark, Growth parameters, Length-weight relationship, Maturity, Spawning stock biomass

Introduction

In the past there was no organised shark fishery in India and sharks were caught incidentally and formed bycatch in the gears. Till late 1960s (pre trawl period) the shark fishery was more or less neglected and the resource was not adequately studied for the reason that the shark flesh was less preferred as an edible meat owing to its pungent odour caused by the presence of trimethylamine. The rapid expansion of fisheries and globalised trade have emerged as the principal drivers of shark fishing to meet the rising demand for their meat, fins, liver and other products. This has led to indiscriminate fishing of the resource which is decimating their population as a result of which the global shark catch is in a declining phase (Bonfil, 1994; Hanfee, 1999, 2001; Vivekanandan, 2001).

The state of Maharashtra (19º 39' 47.8080'' N; 75º 18' 1.0548'' E) along the west coast of India is endowed with a 720 km long coastline and harbours rich elasmobranch diversity (Raje *et al*., 2002). The total number of elasmobranch species in Maharashtra is estimated to be 76 of which 3.8% are listed as Critically Endangered (CR), 5% as Endangered (EN), 25.2% Vulnerable (VU), 20.8% Near Threatened (NT), 8.8% of Least Concern (LC), 26.4% as Data Deficient (DD) and 10.1% as Not Evaluated (NE) (Purushottama *et al*., in press).

A few species of small/medium coastal sharks are caught regularly in targeted fisheries and as bycatch in waters off Maharashtra. The group presently includes the spadenose shark (*Scoliodon laticaudus*), grey sharpnose shark (*Rhizoprionodon oligolinx*), milk shark (*Rhizoprionodon acutus*), spot-tail shark (*Carcharhinus* *sorrah*), whitecheek shark (*Carcharhinus dussumeiri*) and hardnose shark (*Carcharhinus macloti*). Elasmobranch landing statistics for Maharashtra during the period 2012 to 2015 shows that among sharks, the landing was mainly contributed by *S. laticaudus* (72.5%) followed by *R. oligolinx* (9.1%). Apart from this, a major contribution was also made by *R. acutus* (3.8%), *Lamiopsis temminckii* (3.1%), *Sphyrna lewini* (2.2%), *C. macloti* (1.8%), *Carcharhinus limbatus* (1.5%), *C. sorrah* (1.0%), *Carcharhinus leucas* (0.5%), *Carcharhinus amblyrhynchoides* (0.4%), *Galeocerdo cuvier* (0.1%) and other sharks (3.9%). The sharks were mainly exploited by gillnetters (44.9%), trawlers (42.7%), *dol* netters (8.7%) and other gears (3.7%) in Maharashtra (CMFRI, 2013; 2014; 2015; 2016).

Of the seven species of the genus *Rhizoprionodon* Whitley, 1929, only two species *R. acutus* and *R. oligolinx* are known from the Arabian Sea (Ebert *et al.,* 2013). *Rhizoprionodon* spp. are identified by their long upper labial furrow and the second dorsal fin origin posterior to the origin of the anal and pre-anal ridges (Compagno, 1984; Compagno *et al.,* 2005). Elasmobranchs are mostly characterised by slow growth, large size, late maturity and production of few off-springs which is known as K selected life history strategy, which makes them vulnerable to fishing, with low generation turnover rates (Holden, 1974; Jennings *et al*., 1998; Ebert *et al*., 2008). High fishing mortality coupled with juvenile discards have already depleted some species, while endangering others (Stevens *et al*., 2000).

R. oligolinx is a commercially important shark in Maharashtra and is used both domestically and for export. When landed in large quantities, a portion is marketed in fresh condition owing to demand for fresh meat, a larger portion is processed for its high-quality meat, by filleting and salting and sold in local markets or traded to nearby regions/states where there is a high demand for salted meat. Majority of salted shark meat (60%) are sold to merchants/agents from the southern states of India like Andhra Pradesh, Karnataka, Kerala, Tamil Nadu as well as Telangana. Nearly 40% of salted shark meat and products are exported to Sri Lanka and Nepal. The liver of these sharks are removed and the oil is extracted along with other common shark species occurring in the region *viz., R. acutus*, *S. laticaudus*, *C. macloti*, *L. temminckii* and *C. sorrah*. However, since the resulting oil is of low quality, it is mostly used for the painting of wooden fishing boats as antifouling agent or used for local medicinal purposes. The fins (dorsal, pectoral and caudal) fetch good value ranging from USD 10-14 per kg.

Detailed study on the exploitation level and stock status of *R. oligolinx* is scarce in the region and elsewhere. Therefore, the present study was carried out to assess the exploitation and stock status of the species so that proper management advisory can be formulated to maintain the resilience of the species and sustainable harvest of the resource.

Materials and methods

Weekly data on catch and effort of fish landed in all major fish landing centres in different districts of Maharashtra was collected and raised to monthly and annual figures using the Stratified Random Sampling Technique (Alagaraja, 1984). Using the data of National Marine Living Resource Data Centre (NMLRDC) of ICAR-Central Marine Fisheireis Research Institute (ICAR-CMFRI), Kochi, the marine fish catch trends of the state was analysed for the period from 1996 to 2015. Data on length frequency of *R. oligolinx* was collected for 4 years during January 2012 to December 2015 at weekly intervals from Satpati, Sassoon Dock and New Ferry Wharf fish landing centres of Maharashtra (Fig.1). Total length (TL), length between tips of the snout to the posterior margin of upper caudal fin across the middle line were measured for each shark to the nearest cm using a measuring tape and the body weight (BW) was recorded to the nearest g using an electronic weighing machine (Axpert, India). A total of 711 fresh specimens of *R. oligolinx* in the size range 36.4 to 93.0 cm TL and weight range 200 to 2600 g for females and length range 34.5 to 93.0 cm TL and weight range 200 to 2100 g for males were collected randomly for analysis. The von Bertalanffy's growth parameters (von Bertalanffy, 1938) *viz.,* asymptotic length (L_∞) and growth co-efficient (K) were estimated using monthly raised data in the ELEFAN-I module of FiSAT II (Gayanilo *et al*., 2005). Age at length zero (t_0) was back calculated using modified von Bertalanffy's growth equation *i.e.* t_0=1/K $\log_e$ [1-($L_{t=0}$ / L_∞)]. For calculation of t_o, 30 cm was used as length at birth ($L_{t=0}$) which was assumed from length of the smallest free-swimming individuals observed from the fishery. The modal class progression analysis (MPA) was also carried out to refine the growth parameters obtained from ELEFAN-I following Bhattacharya's method. A range of k (0.2 to 0.6 yr^{-1}) were used in the iteration to fit the growth curve using the 'length at age data' generated from MPA analysis. The $L_{t=0}$ as 30 cm and t_0 of about 1 yr was used as the yardstick to select the most reasonable growth curve for the species. The growth performance index (φ) was calculated from formula as described by Pauly and Munro (1984) *i.e.,* $\varphi=\log_{10} K+ 2\log_{10} L_\infty$. Longevity ($t_{max}$) was estimated from the equation described by Pauly (1983) *i.e.,* $t_{max} = 3/K + t_0$. The length-weight relationship of *R. oligolinx* was established following the formula, $W = aL^b$ (Le Cren, 1951). After logarithmic transformation

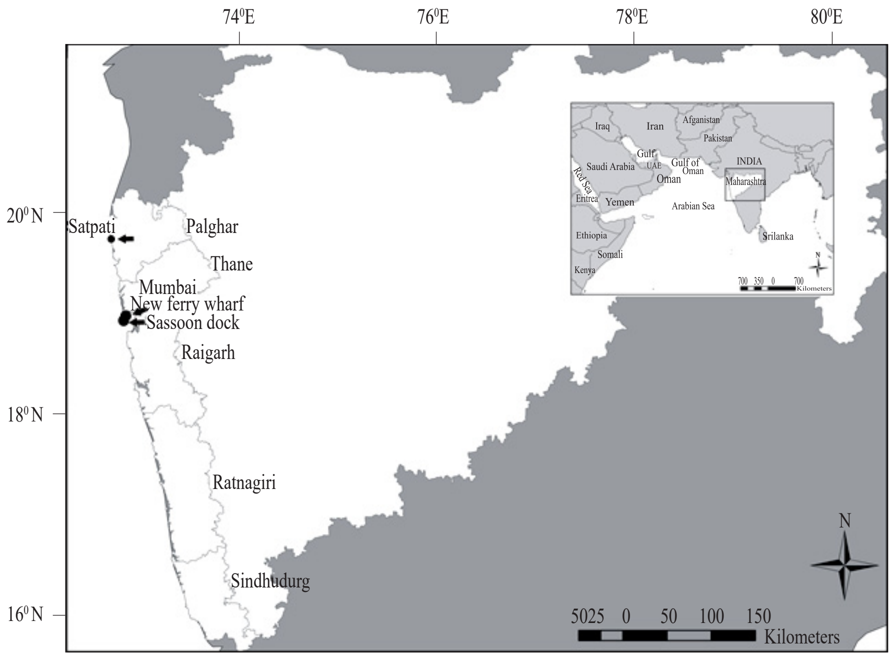

Fig. 1. Map of Maharashtra showing locations where the specimens of *R. oligolinx* were landed and an inset depicting political boundaries

of length and weight data, this equation may be expressed as: log W = log a + b log L, where, W is the weight of the fish in grams, L is the total length of the shark in cm, a is the intercept of the regression curve (coefficient related to body form) and b is the regression coefficient (exponent indicating isometric growth; Froese, 2006).

The instantaneous total mortality rate (Z) was estimated by FiSAT II package using the length converted catch curve method (Pauly, 1983). The natural mortality rate (M) was estimated by Pauly's (1983) empirical formula, $\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$ and the fishing mortality rate (F) was obtained as F = Z-M. The current exploitation rate (E_{cur}) was calculated as E = F/Z (Ricker, 1975). 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}), a total of 663 (females = 369; males = 294) specimens were used. The maturity status of each shark was ascertained following the classification scheme proposed by Stehmann (2002), based on ovarian and uterine condition for females and clasper calcification and testes development for males. The Lm_{50} was calculated using the logistic regression described by White (2007) as follows:

$$pL = [1+6^{\{-In(19)(L-Lm_{50})(L_{95}-Lm_{50})^{-1}\}}]^{-1}$$

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 matured. The SOLVER routine in Microsoft™ Excel was used to obtain maximum likelihood estimates of the parameters.

The recruitment pattern 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 (Pauly and Caddy, 1985). The midpoint of the smallest length group in the catch during the four year period was taken as length at recruitment (L_r). Length at first capture (L_{50}) was estimated by probability of capture routine in the FiSAT-II package (Pauly, 1987). The probability of capture of sequential length classes were regressed using a logit curve for the estimation of L_{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 relative yield per recruit analysis method as described by Beverton and Holt (1966). The equilibrium yield such as catch (Y) and revenue (INR), standing stock biomass (B) and spawning stock biomass (SSB) at different fishing levels were predicted using length based Thompson and Bell bio-economic model (Thompson and Bell, 1934). The data from above stock assessment models were used to forecast the biological reference points (BRPs) for the sustainable exploitation of the grey shapnose shark resource.

Results and discussion

Fisheries and utilisation

The marine fish landing scenario of Maharashtra was analysed for the last two decades and it revealed that landings marginally decreased by 0.8 times from an annual average of 3,70,385 t during 1996-2005 to 3,14,548 t during 2006 to 2015. The contribution of shark landings to the total marine fish landings marginally fluctuated on an average from 1.9% (7,085 t) during 1996-2005 to 1.7% (5,311 t) during 2006-2015. Shark catch in the state peaked at 14,186 t in 2002 and fell to 3,441 t in 2010.

R. oligolinx recorded during the study period were landed by mechanised gillnetters (18-20 m OAL) operating monofilament gillnet [70-100 m length (70-100 pieces), mesh size 90-110 mm] and multifilament gillnet [70 m length (50-60 pieces), mesh size: 80-110 mm] targeting pomfrets, seerfish and elasmobranchs at 40-50 m depth off north-west coast of India. Another variant of the gillnet (70 m length, mesh size: 220-270 mm) was exclusively employed for catching elasmobranchs, polynemids, large sciaenids and eels during December to May.

The estimated annual landings (2009-2015) of *R. oligolinx* in Maharashtra by gillnets ranged from 109 t in 2012 to 543 t in 2013. There was a 39% (2.4 times) increase in landings in 2015 compared to 2012. The catch and effort of gillnets from Maharashtra during 2012-2015 is given in Table 1. Landings of *R. oligolinx* in Maharashtra varied considerably across years and months with the greatest landings recorded in April 2013 during the study period (167 t, because of the high level targeted gillnet fishery and availability of sharks in the fishing grounds), followed by March 2013 (35.9 t), April 2015 (62 t), December 2013 (60.4 t) and September 2014 (49.5 t) (Fig. 2).

Stock structure

A total of 711 sharks were collected for the study of which females constituted 55.7% (n = 369) and males 44.3% (n = 294) with an overall sex ratio (male: female) of 1:1.2 and 48 unsexed specimens (Fig. 3). *R. oligolinx* females ranged from 36.4 to 93.0 cm TL (mean±S.E. = 68.0±0.3) and 200 to 2600 g in total weight (mean±S.E. = 1520.2±21.8). Males ranged from 34.5 to 93.0 cm TL (mean±S.E. = 62.4±0.4) and 200 to 2100 g in total weight (mean±S.E. = 1082.6±14.7). The χ^2 test revealed significant differences ($p<0.001$) in length frequency distributions between females and males, with more females between 66 and 70 cm TL and more males for the 61-65 cm TL size class. The size range of *R. oligolinx* observed in the gillnet fishery of Maharashtra (27.0-93.0 cm TL) differs slightly from those reported from other regions by Moore *et al*. (2012) in Kuwait waters (45-85 cm TL for females and 45-64 cm TL for

Table 1. Catch and effort of *R. oligolinx* in gillnet from Maharashtra coast of India during 2012-2015

Year	Effort (h)	Total marine landings (t)	Elasmobranch landings (t)	Total commercial shark landing (t)	Percentage of shark landing to total marine landing	*Rhizoprionodon oligolinx*		
						Catch (t)	CPH (kg h^{-1})	% to total shark landing
2012	1,45,9431	3,14,834	4,159	3,889	1.2	109	0.075	2.8
2013	2,26,7515	3,64,340	5,476	4,550	1.2	543	0.24	11.9
2014	2,47,4190	3,44,648	5,779	4,780	1.4	237	0.096	4.9
2015	2,07,8132	2,64,891	4,474	3,548	1.3	258	0.12	7.3
Average	2,06,9817	3,22,178	5,062	4,192	1.3	287	0.13	6.7

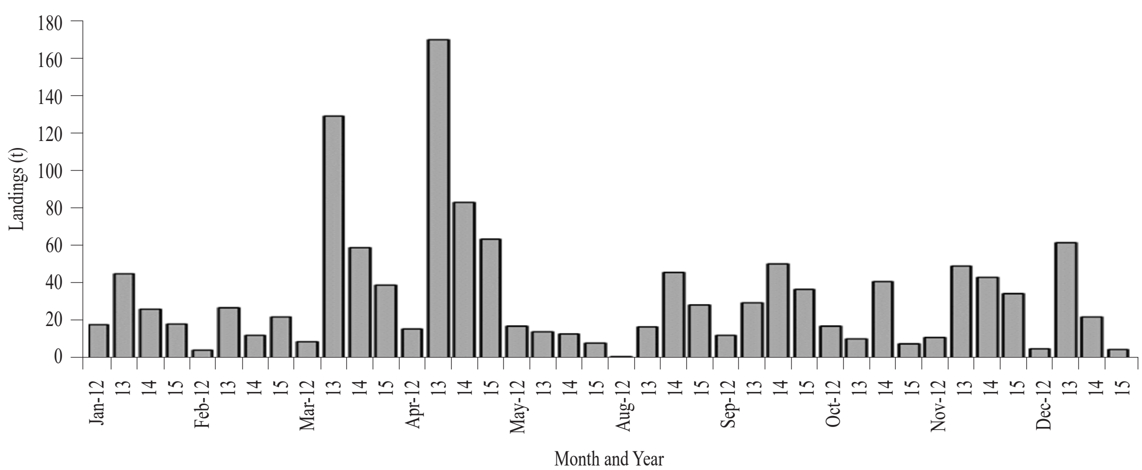

Fig. 2. Monthly estimated landings of *R. oligolinx* in gillnet along Maharashtra from January 2012 to December 2015 (Mechanised fishing ban/closed season was observed during June and July along the west coast of India)

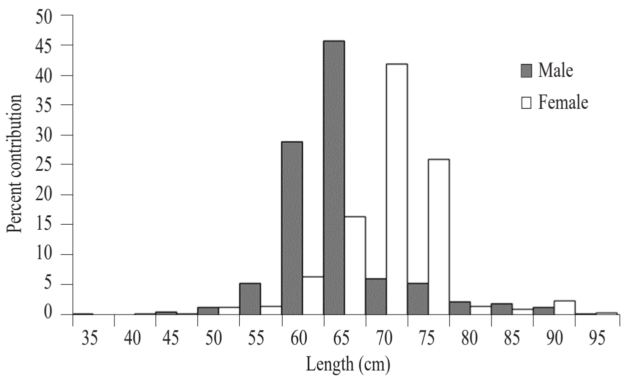

Fig. 3. Total length (TL)-frequency histogram of *Rhizoprionodon oligolinx* [Female (n = 369); males (n=294)] along Maharashtra coast

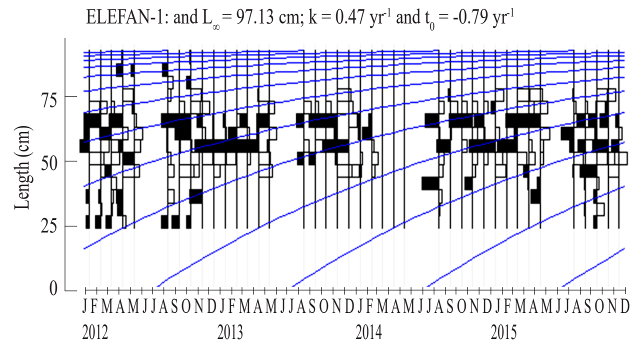

Fig. 4. von Bertalanffy's equation fitted growth curve of *R. oligolinx* using ELEFAN-I

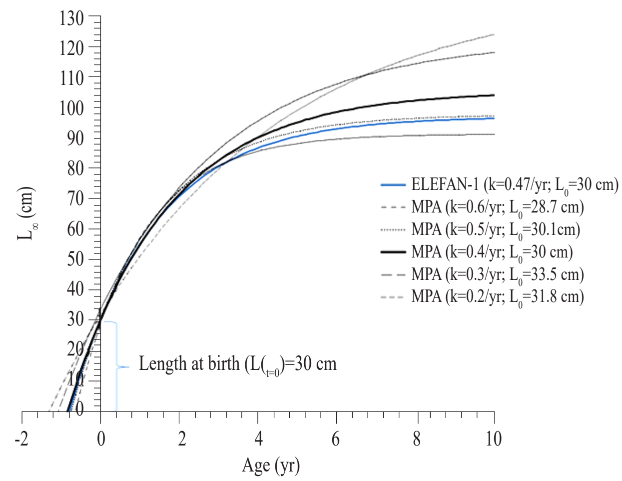

Fig. 5. Comparision of reconstructed VBGF growth curve fitted using growth parameters obtained from ELEFAN-I and MPA

males) and White (2007) in Indonesian waters (26 -65 cm TL for females, 29.5-52.0 cm TL for males).

Growth, mortality and exploitation parameters

The L_∞ and K as estimated by ELEFAN-I were 97.13 cm and 0.47 yr^{-1} (Table 2, Fig. 4) which resulted in a t_0 of -0.79 yr. The MPA using k in the range of 0.2 to 0.6 yr^{-1} resulted in L_∞ values from 91.5 to 138.5 cm and corresponding t_0 values from -1.3 to -0.63 yr^{-1} (Fig. 5). The L_∞ and K values of 106.9 cm and -0.4 yr^{-1} respectively, obtained using t_0 of -0.89 yr in MPA were selected as the most appropriate estimates of growth parameters (Fig. 6) as the modeled length at birth ($L_{t=0}$) of 30 cm obtained using these growth parameters was same as that of the observed $L_{t=0}$. The growth curve constructed using von Berttalanffy's growth (VBG) parameters showed that the shark grows to a TL of 54.8 cm in 1st yr, 71.5 cm in 2nd yr, 82.7 cm in 3rd yr, after which the growth slows down considerably registering a TL of 90.2 cm in 4th year, 95.2 cm in 5th yr, 98.6 cm in 6th yr and 100.9 cm in 7th year (Fig. 5). The growth performance index and t_{max} of the species was found to be 3.65 and 6.6 yr respectively. 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 $L_{t=0}$. The length at birth ($L_{t=0}$) in the present study was estimated as 30 cm. This is found to be close to that of *R. acutus* in the same genus, where $L_{t=0}$ has been mentioned as 30 cm from south-east and north-west coasts of India (Krishnamoorty and Jagadish, 1986; Sen *et al*., 2017). The maximum length (L_{max}= 93.0 cm) observed in the present study was, however, found to be higher than the earlier reported length of 85.0 cm TL from Kuwait waters (Moore *et al*.,

Table 2. Growth parameters of *R. oligolinx* from Maharashtra coast of India during 2012-2015

von Bertalanffy's Growth parameters	ELEFAN-I	MPA				
	k=0.47 (yr^{-1})	k=0.2 (yr^{-1})	k=0.3 (yr^{-1})	k=0.4 (yr^{-1})	k=0.5 (yr^{-1})	k=0.6 (yr^{-1})
L_∞ (cm)	97.13	138.50	122.56	105.50	97.84	91.48
t_0 (yr)	-0.79	-1.30	-1.06	-0.84	-0.74	-0.63
VBGF fitted L_0 (cm)	30.0	31.8	33.5	30.0	30.2	28.7
T_{max}	5.59	13.70	8.94	6.66	5.26	4.37

ELEFAN-I: Electronic Length Frequency Analysis-I method; MPA: Modal class progression analysis method; VBGF: von Bertalanffy's growth curve (equation); L_∞: Maximum theoretical length the animal can reach; K: curvature parameter; t_0: Time when length of the animal is theoretically zero; $L_{t=0}$: Length of the animal at birth

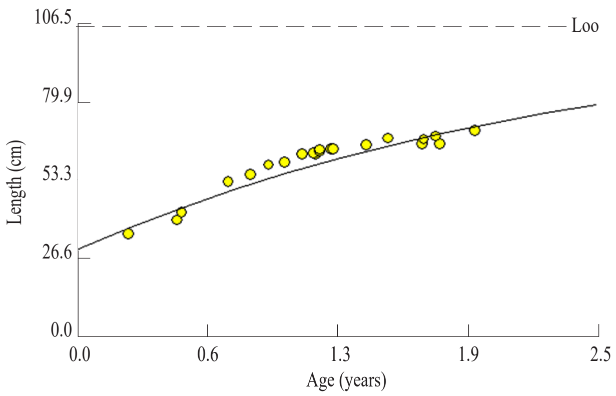

Fig. 6. Modal class progression analysis (MPA) growth curve obtained using length at age data by decomposing cohorts in Bhattacharya's method

2012) and 65.0 cm TL in Indonesian waters (White, 2007). The growth performance index (φ) and longevity obtained in the present study were 3.65 and 6.6 yr respectively, which indicate that the estimation of L_∞ and K is realistic (Compagno, 1984).

The natural mortality rate (M), total mortality rate (Z), fishing mortality rate (F) and current exploitation rate (E_{cur}) were found to be 0.69 yr^{1}, 2.16 yr^{1}, 1.48 yr^{1} and 0.68 respectively (Fig. 7). The Length based cohort analysis showed that F exceeded M when the shark attains 55 cm TL (Fig. 8).

Length-weight relationship

The length-weight relationship for different groups (male, female and pooled data) is given below:

Females : $W = 0.000717663 \times TL^{3.466747}$ (R^2= 0.909, *n*=279)

Males : $W = 0.015313967 \times TL^{2.709603}$ (R^2= 0.907, *n*=186)

Pooled : $W = 0.00102409 \times TL^{3.377588}$ (R^2= 0.924, *n*=465)

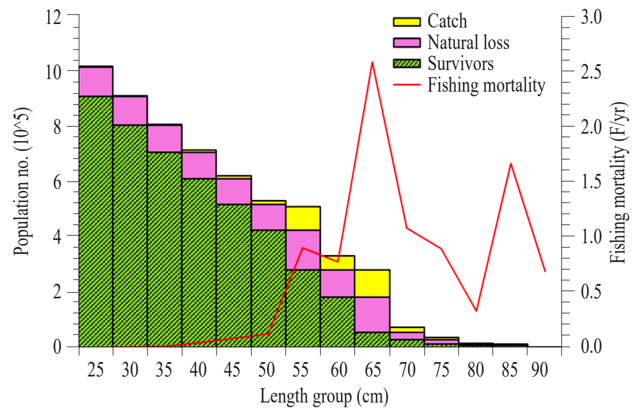

Fig. 8. Length structured cohort analysis of *Rhizoprionodon oligolinx*

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 line between male and female. The slope of the female was found to be significantly ($p<0.05$) higher in female compared to male whereas, the intercepts of male was found to be significantly ($p<0.05$) higher than the female. This suggests that the weight of the animals for a particular length varied significantly between males and females. Males tended to be heavier than females till a particular body length (TL) (approximately 60 cm TL), after which females become heavier than males. The relationship between length-body weights for the pooled data is given in Fig. 9 which shows that growth is allometric. Our results are in agreement with earlier reports where males were reported to be heavier than females (Machado *et al*., 2001; Loefer and Sedberry, 2003; Henderson *et al*., 2006). Whereas, in females the onset of sexual maturity increases demand of energy for reproduction, such as gonad development, egg formation and gestation which might trigger shifts in the feeding habits (Alonso *et al*., 2002). To match reproductive energy

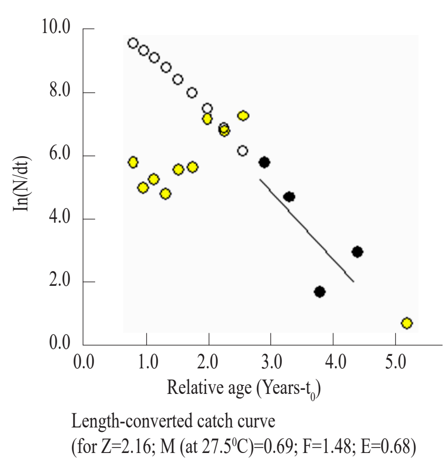

Fig. 7. Mortality parameters *viz.* M. F, Z and E of *Rhizoprionodon oligolinx*

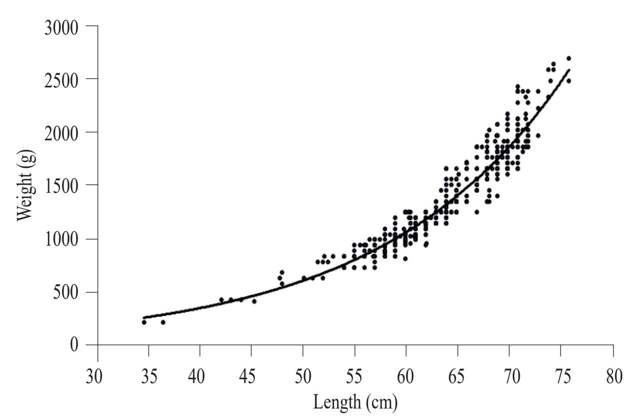

Fig. 9. Length-weight (L *v.* W) relationship of *Rhizoprionodon oligolinx* for both sexes combined

demand, a quantitative as well as qualitative change in diet may be expected (Fishelson *et al*., 1987) which possibly affects the body weight of the females.

Maturity, recruitment and gear selectivity

Mature and pregnant females were recorded throughout the entire fishing period. Maximum percentage of mature and pregnant females was reported during November to April. Maturity study revealed that, female *R. oligolinx* matured between 60 and 65 cm, with 50% maturity occurring at 62.3 cm TL (Fig. 10). Males matured at a lower size range (55.0-60.0 cm) and 50% maturity occurred at 59.5 cm TL (Fig. 11). The annual sex ratio between male and female sharks was 1:1.2.

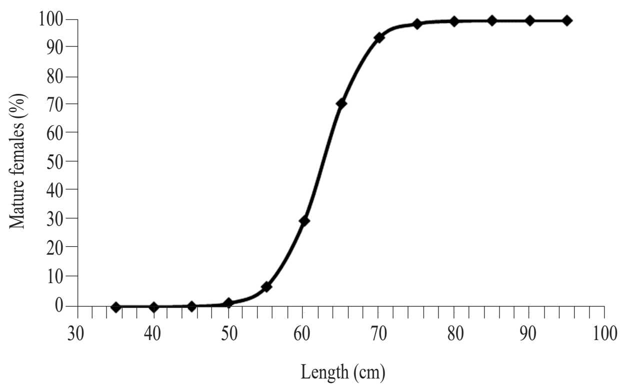

Fig. 10. Estimated length at maturity (Lm_{50}) for female *Rhizoprionodon oligolinx*

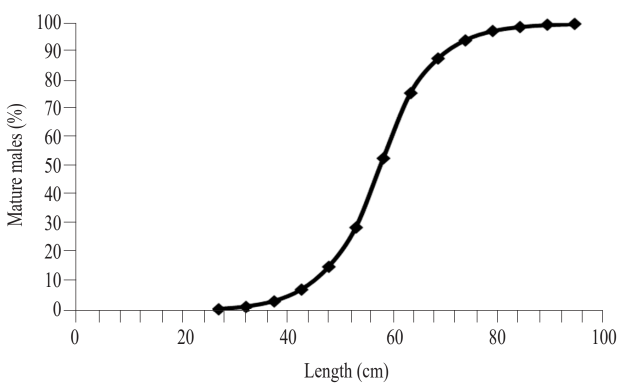

Fig. 11. Estimated length at maturity (Lm_{50}) for male *Rhizoprionodon oligolinx*

The recruitment pattern demonstrated that shark juveniles were recruited in the fishery continuously throughout the year with a peak during the month of April (16.1%) (Fig.12). The length at recruitment (L_r) for shark was found to be 30 cm. Logistic regression of the probability of capture for sequential length classes obtained from length converted catch curve analysis revealed that 50% of the sharks become vulnerable to gear at the total length of 49.7 cm (L_{50}) (Fig.13).

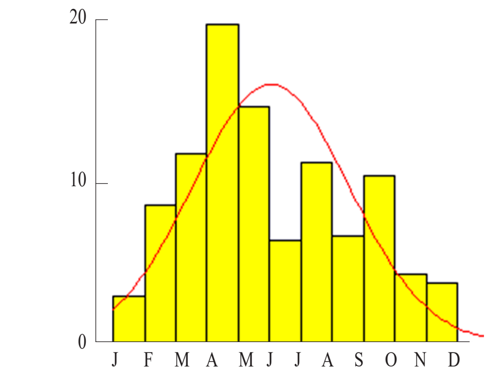

Fig.12. Monthly recruitment pattern of *R. oligolinx*

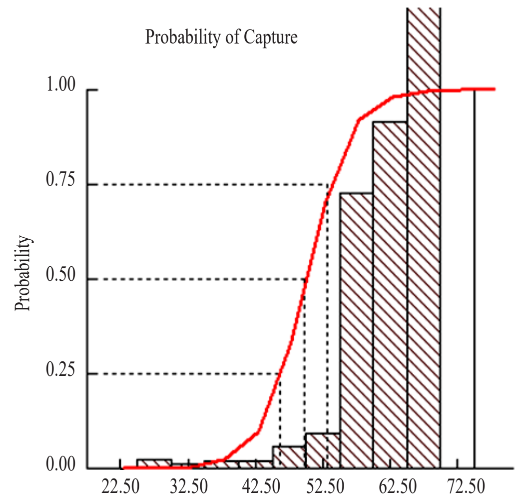

Fig.13. Length at capture (L_{50}) of *R. oligolinx*

The L_{25} and L_{75} were also calculated as 46.1 cm and 53.2 cm respectively. The L_{m50} of males at maturity determined in this study, 59.5 cm TL, is larger than previously reported for this species. Springer (1964) reported that males matured as small as 38 cm TL while Appukuttan and Nair (1988) estimated length at maturity of males at 29-38 cm TL. Males were found to mature at 43-45 cm TL, with L_{m50} at 53.0 cm in Indonesia (White, 2007), Lm_{50} at 53.0 cm TL in Kuwait, (Moore *et al.,* 2012) and 55.0 cm TL in Bahrain (Moore and Pierce, 2013). In this study, the reproductive load (L_{m50}/L_{∞}) ratio was found to be 0.64. The ratio is comparatively lower than the value of 0.77 suggested by Holden (1974) for elasmobranchs. Similarly, the ratio is also found to be higher than the value of 0.51 suggested by Devaraj (1983) for tropical elasmobranchs. Interestingly, the ratio in the present study is found to be in agreement with the findings of Krishnamoorty and Jagadis (1986) for *R. acutus* from east coast of India and that of Sen *et al.* (2017) from north-west coast of India. Besides, other species in this genus reported so far indicated an L_{m50}/L_∞ ratio ranging from 0.61 to 0.64 (Springer 1964).

Stock assessment

The relative Y/R and B/R analysis of *R. oligolinx* were estimated using selection ogive procedure of FiSAT II (Fig. 14). L_{50}/L_∞ of 0.471 and M/K of 1.725 were used as the input parameter for the analysis. The analysis indicated that, the exploitation rate which maximises yield per recruit (E_{max}) is 0.70. However, since the analysis does not give any consideration to the biomass, it is advisable to use a considerable safer management reference point (Clark, 1991) such as $E_{0.1}$ which is 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 estimated to be 0.57. The exploitation level which will

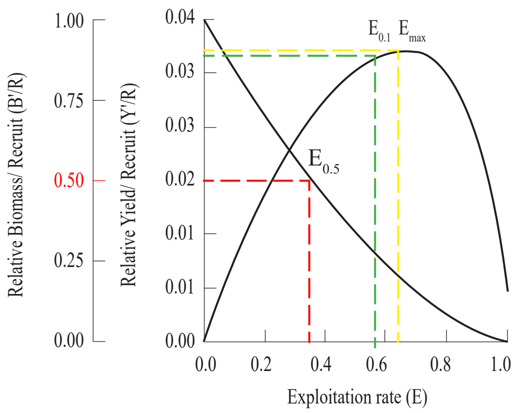

Fig. 14. Stock status of *Rhizoprionodon oligolinx* using Beverten and Holt's relative Y/R analysis from Maharashtra coast

result in the reduction of B/R to 50% compared to virgin biomass ($E_{0.5}$) was 0.35. Sen *et al*. (2017) calculated E_{cur} as 0.39, which was found to be very low compared to $E_{0.1}$ and advised that fishing effort for *R. acutus* can be increased to achieve the target reference point (TRP) in Gujarat waters. However, the increase in fishing effort in the multispecies and multigear regime exists in Gujarat waters would be detrimental for the other commercial important fishery resources in the region (Sen *et al*., 2017).

While assessing the stock status, it is always advisable to follow some precautionary management reference points such as spawning stock biomass (SSB) to minimise the risk resulted from the uncertainties involved in the assessment of life history parameters due to the inherent limitations and assumptions in assessment methodologies (Rosenberg and Repestro, 1996; Sen *et al.,* 2017). Therefore, Thompson and Bell bio-economic model was used to simulate the impact of fishing on the yield (Y), biomass (B) and spawning stock biomass (SSB) at different fishing levels. The analysis showed that, the present level of fishing has already depleted the virgin stock biomass (B_0) and spawning stock biomass (SSB_0) to 32 and 16% respectively (Fig. 15).

The maximum sustainable yield (MSY) could be obtained by increasing fishing effort by 40% which will further deplete the B_0 and SSB_0 to 27 and 10% respectively that could be dangerous for stock regeneration. On the other hand, the present fishing level needs to be reduced by 20% to maximise the economic yield (MEY) which will also ensure a SSB level of 22% that could be comparatively safer for the replenishment of the stock. However, considering the low fecundity of the species, the fishing pressure should be reduced by 40% to maintain the SSB at a prescribed safe level of 30% that would ensure the availability of adequate spawners to rebuild the stock for long term sustainability of the resource (Mace and Sissenwine, 1993).

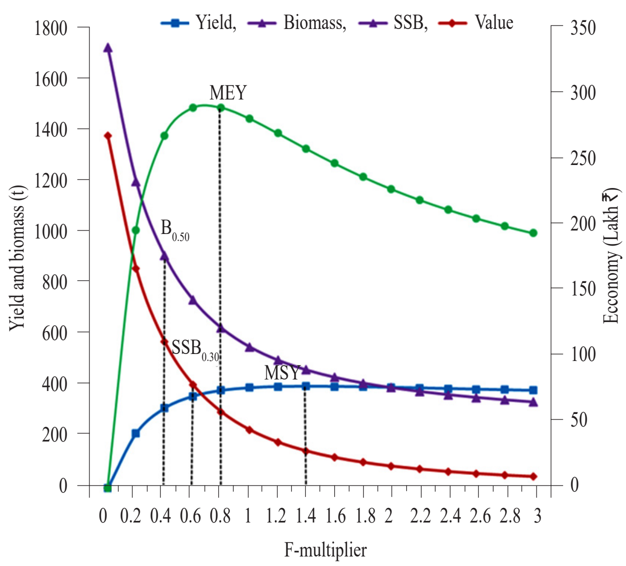

Fig.15. Stock status of *R. oligolinx* using Thompson and Bell analysis from Maharashtra coast

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