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Fishery, population characteristics and stock status of the bigeye thresher *Alopias superciliosus* Lowe, 1841 off Thoothukudi, south-east coast of India

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ABSTRACT

Fishery, population parameters and stock estimates of the bigeye thresher *Alopias superciliosus* Lowe, 1841 from the Thoothukudi coast of Gulf of Mannar Marine Biosphere Reserve (GoMMBR) was studied during the period 2015 to 2019. Results of the study reveals that the estimated annual average production of sharks from Thoothukudi region was 105 t of which the dominant shark species was *A. supercilious* (52.70%). The length of the sampled *A. supercilious* ranged between 108 and 265 cm. Results of the length-weight relationship showed negative allometric growth with b value of 2.66. The growth parameters *viz,* asymptotic length (L_∞), growth co-efficient (K) and arbitrary origin of growth (t_0) were estimated at 367 cm, 0.39 y^{-1} and 0.12 respectively. The mortality parameters *viz,* total mortality (Z), fishing mortality (F) and natural mortality (M) rates were estimated at 1.20, 0.70 and 0.50 y^{-1}, respectively. In Thoothukudi, the recruitment season of *A. superciliosus* was found during March and October showing optimal exploitation with exploitation rate (E) of 0.58 and the estimated exploitation ratio (U) was 0.54. The virtual population analysis (VPA) showed a fishing pressure on the 240 to 320 cm length group. The estimated annual catch and maximum sustainable yield (MSY) were 58 and 68 t respectively. The present study gives valuable baseline information on the fishery and population characteristics of this vulnerable and data deficit resource *A. superciliosus* off Thoothukudi.

Keywords: Growth and mortality parameters, Maximum sustainable yield, Recruitment overfishing, Virtual population analysis

Introduction

Thresher sharks are large lamniformes sharks belonging to the genus *Alopias* (Family: Alopiidae). These are extensive, migratory sharks with overlapping distribution from low shore waters to the high seas which are found in the temperate and tropical oceans of the world (Compagno, 2001). The family comprises three valid species *viz*, common thresher *Alopias vulpinus* (Bonnaterre, 1788), bigeye thresher *A. superciliosus* Lowe, 1841 and pelagic thresher *A. pelagicus* Nakamura, 1935 (Gruber and Compagno, 1981; Compagno, 1984). All the three species are listed as 'vulnerable' as per the International Union for Conservation of Nature (IUCN) in the Red List of Threatened Species and globally there is a continued decline in their populations (Amorim *et al*., 2009). The bigeye threshers are reported around the world; commonly distributed in the Indo-Pacific region, usually at low latitude and are considered relatively rare with local abundance in certain areas (Gubanov and dan Paramonov, 1993). Bigeye thresher exhibits slow growth with an estimated age at maturity of 12-13 years and fecundity is usually two pups per litter (Chen *et al*., 1997). Globally, the information on their biology, ecology, habitat and the landed catches of *A. superciliosus* was under-reported and limited (Chen *et al*., 1997). The Food and Agriculture Organisation of the United Nations (FAO) states that these species are considered fully exploited or overexploited globally (Maguire *et al*., 2016). The ecological risk assessments in terms of vulnerability to overfishing by the International Commission for Conservation of Atlantic Tunas (ICCAT) and the Indian Ocean Tuna Commission (IOTC) indicated that the bigeye threshers ranked second among 17 Indian Ocean elasmobranch species and first among 16 Atlantic species (ICCAT, 2009; Murua *et al*., 2018).

The sharks of the Indian Ocean region are considered overexploited based on the recent review of fisheries of this region (Yang *et al*., 2005). The information on the thresher sharks is mainly from the large meshed gillnet fisheries operating off Indian and Sri Lankan coasts which includes other shark landings since the 1980s (Ross, 1999). In the Atlantic Ocean, this species has to be discarded in the sea as capture is prohibited and therefore trends in the landings data are largely lacking (Young *et al*., 2016).

In addition, carcass removal especially in offshore and high seas fisheries has been reported from the Indian Ocean region (Anderson and Simpfendorfer, 2005). In India, the reports on occurrence of *Alopias* species from mechanised drift gillnetters operating from Thoothukudi coast was documented for *A. pelagicus* (Ranjith *et al*., 2014b) and *A. superciliosus* (Gouthaman *et al*., 2014). Globally, studies on the age and growth of *A. superciliosus* was reported by a few authors (Liu *et al*., 1998; Cortes *et al*., 2010; Tsai *et al*., 2010; Cao *et al*., 2011; Fernandez-Carvalho *et al*., 2011) and there are no reports from the Indian waters. In addition, no information is available on the population dynamics and stock assessment of *A. superciliosus*. Hence, the present study was undertaken to assess the population characteristics and stock stauts of *A. superciliosus* and to find out the extent of fishing pressure on this resource exploited along the Thoothukudi coast, in southern India.

Materials and methods

The data on the catch and effort of sharks for a period of five years from 2015 to 2019 from different fishing gears operating along the Thoothukudi region (Fig. 1), collected by the Fisheries Resource Assessment Division (FRAD), ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), India was used for this study. The total length (TL) to the nearest 0.1 cm and individual weight (W) was measured to the nearest gram following the method described by Compagno (1984). The length-weight relationship was studied following the method described by Le Cren (1951). The length-frequency distribution data of *A. superciliosus* comprising 1,675 specimens collected from Thoothukudi, through random sampling technique on a weekly basis was used for estimating the age, growth and mortality parameters and further for stock assessment studies. For the growth studies, the length data was grouped into 5 cm class intervals and the raised monthly frequency distribution was calculated following Sekharan (1962). FiSAT II program was utilised for assessing the age and growth (Gayanilo *et al*., 2005). Asymptotic length (L_∞), growth curvature (K) and arbitrary origin of growth (t_0) values were investigated by non-parametric scoring of von Bertalanffy growth function (VBGF) fit utilising ELEFAN-1 for the time frame January 2015 to December 2019. Length converted catch curve method was used for estimating the instantaneous total mortality rate (Z) (Pauly, 1983). Natural mortality (M) was assessed by Pauly's equation considering 28°C as the mean yearly temperature (Pauly, 1984). Coefficient of fishing mortality (F) was determined utilising the relationship Z=F+M. Length structured virtual population analysis (VPA) was used to find out the size of each length group. Recruitment pulses were analysed from the length frequency data. Total stock (Y/U) and annual stock (Y/F) were estimated using annual catch (Y), where Y is yield, U is exploitation ratio and F is fishing mortality. Exploitation rate (E) was estimated as E= F/Z and exploitation ratio (U) was estimated using the equation U=F/Z (1-e^{-z}) (Sparre and Venema, 1992). Maximum sustainable yield (MSY) was estimated as per Gulland (1956). Yield isopleth diagrams of *A. superciliosus* were derived by FiSAT using L_{50}/L_∞ and F/Z values.

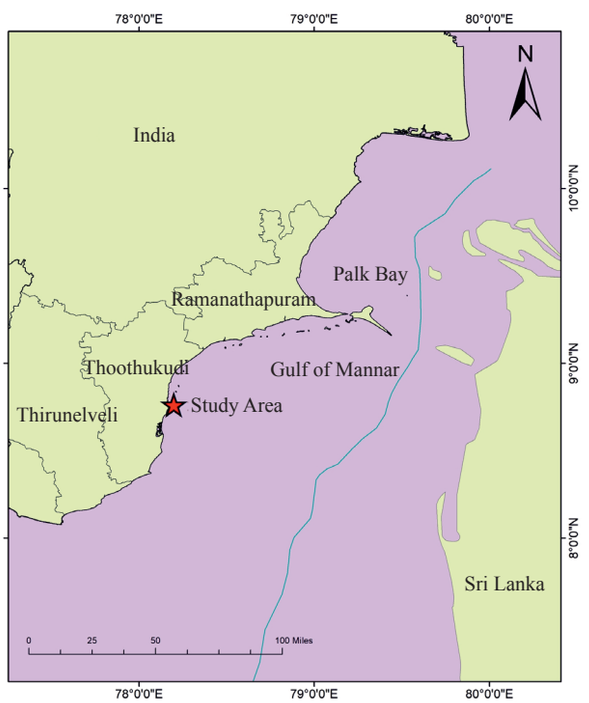

Fig. 1. Map showing the location of study area

Results and discussion

Fishery of sharks

In the Gulf of Mannar Marine Biosphere Reserve (GoMMBR) region of Tamil Nadu, sharks are a non-targeted fishery whereas they are caught by non-mechanised and mechanised crafts as a bycatch in fishing gears like trawls, hook and lines and gillnets. In Thoothukudi region of GoMMBR, the major chunk of the *Alopias* species are caught mainly in the large meshed drift gillnets (locally known as Paruvalai) and hook and line (Kannan *et al*., 2013, Sivadas *et al*., 2013, Ranjith *et al*., 2014a). In recent years, Tharuvaikulam, Threspuram and Punnakayal coastal villages of Thoothukudi have emerged as the most important shark landing centres where sharks are landed occasionally as bycatch along with scombrids and large pelagics. In addition, fishermen from Kombuthurai fishing village of Thoothukudi, who are the migrant fishermen from Kanyakumari target sharks by hook and line fishing but very recently due to lack of

catch they shifted the target to pelagics like carangids, seer fishes, barracudas and other large pelagics.

Shark fishery along the study region does not form any pattern and shows wide variation in the landings. The highest landing of sharks was recorded in 2016 at 219 t with an average of 123 t; after which the fishery showed a declining trend (Fig. 2). Manojkumar *et al*. (2019) observed that though sharks occur in small quantities in the entire marine fish landings off Thoothukudi coast, bigeye thresher support an important fishery from the region.

The catch rate of sharks ranged from 0.10 to 0.49 kg unit^{-1} with an average of 0.79 kg unit^{-1} during the study period. The catch rate of sharks in gillnet units ranged between 0.09 kg unit^{-1} (2018) and 0.72 kg unit^{-1} (2016) whereas in hook and line units it ranged between 0.09 kg unit^{-1} (2016) and 0.28 kg unit^{-1} (2017), with an average of 0.18 kg unit^{-1}. In trawl, the catch rate fluctuated between 0.07 kg h^{-1} (2018) and 0.09 kg h^{-1} (2016) with an average of 0.08 kg h^{-1} (Fig. 3).

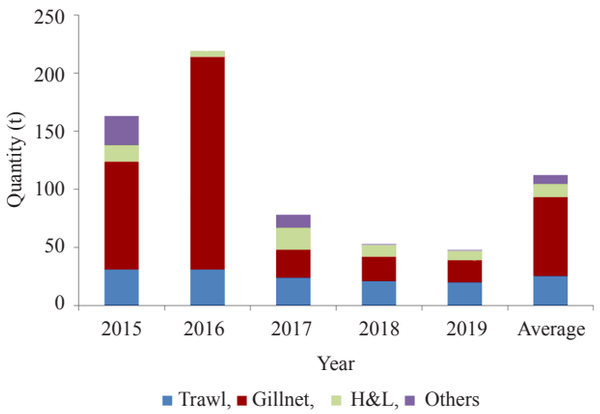

Fig. 2. Quantity of sharks landed at Thoothukudi

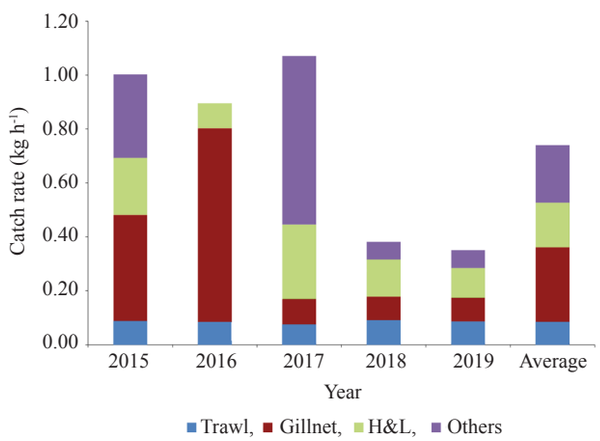

Fig. 3. Catch rate of sharks at Thoothukudi

Species composition

The Gulf of Mannar is rich in elasmobranch diversity and elasmobranchs are being regularly exploited in this region (Raje *et al*., 2007). Eleven species of sharks were recorded during the study period, whereas along the coast of Tamil Nadu and Kerala coasts about 30 to 40 species of sharks belonging to 15 genera occurs and only very few occur in the commercial fishery (Kasim, 1991). Raje *et al*. (2007) reported 110 elasmobranch species belonging to 42 genera which include 66 species of sharks, 8 species of guitar fishes, 4 species of sawfishes and 32 species of rays from Indian waters. During the present study, *A. superciliosus* dominated the catch forming more than 52.71% of shark landings and the other species contributing to the shark landings were *Chiloscyllium griseum* (8.03%), *C. indicum* (7.87%), *Carcharhinus melanopterus* (6.77%), *C. brevipinna* (6.02%), *C. sorrah* (4.61%), *Loxodon macrorhinus* (4.46%), *Scoliodon laticaudus* (3.41), *Rhizoprionodon acutus* (3.34%) and *A. pelagicus* (2.70%), but their landings were too meagre (Fig. 4). Among the thresher sharks, *A. superciliosus* form a good fishery in Thoothukudi region throughout the year. Hanfee (1999) revealed that shark fishery is multispecies in nature and no species dominates in other states of India. In an earlier study from Thoothukudi coast, shark fishery was mainly supported by families of Carcharhinidae, Echinorhinidae, Hemiscyllidae, Alopidae, Sphyrnidae and Squalidae wherein the family Carcharhinidae alone represented 45.1% of shark catch and family Hemiscyllidae represented 30.6% of shark catch (Abdussamad *et al*., 2006). The present study reports the dominance of bigeye thresher, *A. superciliosus* that has been caught by the drift-gillnets operated along the Thoothukudi region. Landings of thresher sharks was reported from Thoothukudi waters of Gulf of Mannar (Gowthaman *et al*., 2014; Ranjith *et al*., 2014b). Sudarsan *et al*. (1988) identified the existence of pelagic sharks in the potentially rich fishing grounds along the Gulf of

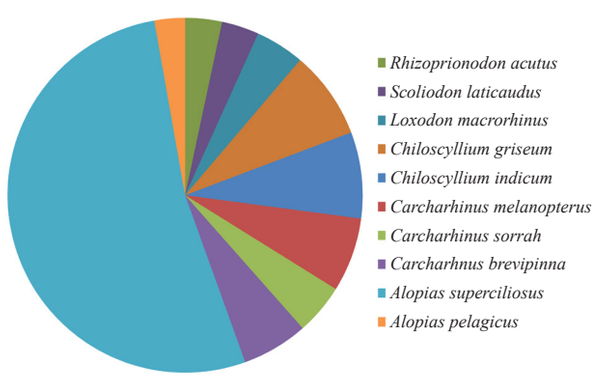

Fig. 4. Species composition of sharks landed and Thoothukudi

Mannar, Tamil Nadu. Manojkumar *et al*. (2019) observed that increase in landings or shift in biomass of pelagic sharks was mainly by the landing of bigeye thresher shark *A. superciliosus* along the Thoothukudi region.

Length-weight relationship

The length-weight relationships of *A. superciliosus* were derived based on analysis of 285 males in the range of 110-265 cm (8.2-126 kg) and 208 females in the range of 108-238.2 cm (12.5-78.5 kg). The relationships were derived by the least square method and the regression equations obtained for males and females are:

Female: $W = 0.000100058L^{2.5140}$ ($r = 0.9614$)

Male: $W = 0.00001972L^{2.8140}$ ($r = 0.9564$)

The analysis of covariance showed that there was no significant difference at 5% level between sexes and the equation derived for pooled sexes as:

$W = 0.000069745L^{2.6630}$ ($r = 0.9651$)

Age, growth and mortality parameters

The study reveals presence of multiple modes in the monthly length frequency data whereas traceable modes for two consecutive months were used to assess the growth of cohorts from 2015 to 2019 (pooled data) of *A. superciliosus* (Fig. 5). The estimated growth parameters of *A. superciliosus* are shown in Table 1. Asymptotic lengths (L_∞) and growth coefficient (K), were 367 cm and 0.39 respectively. The estimated maximum lifespan was found to be 21.5 years. The von Bertalanffy's growth function (VBGF) plot is represented in Fig. 4. Fernandez-Carvalho *et al*. (2011) got higher values from North-east tropical Atlantic and the estimated growth parameters from length data of *A. superciliosus* were, L_∞ = 206 cm (male); 293 cm (female) and K = 0.18 (male) and 0.60 $year^{-1}$ (female). Factors explaining the relationship between natural mortality coefficient and growth coefficient (M/K) was 1.28 which is well within the normal range of 1 to 2.5, as suggested by Beverton and Holt (1959). The generalised VBGF growth equation for *A. superciliosus* and mortality parameters and exploitation rate are shown in Table 1. Life span of this species was estimated as 21 years. Average natural mortality (M) was found to be 0.50 y^{-1} and average fishing mortality coefficient (F) was 0.70 y^{-1}. Estimated exploitation rate (E) was 0.58 Estimated 'Z' value by length converted catch curve method was 1.20 as shown in Table 2. Since, the natural mortality rate of this species is high, fishing mortality may have severe consequences for their populations (Dulvy *et al*., 2008), with declines occurring even at relatively low levels of fishing mortality (Stevens *et al*., 2000). It could be inferred that fishing mortality was higher compared to natural mortality and the same trend was evident in Atlantic waters (Dulvy *et al*., 2008). A comparison indicating the von Bertalanffy growth (VBGF) parameters from studies carried out worldwide for *A. superciliosus* is given in Table 3.

Table 1. Growth, mortality and population parameters of *A. superciliosus* exploited off Gulf of Mannar, south-east coast of India

Population parameters	Values
Asymptotic length (L_∞, cm)	367
Growth coefficient (K $year^{-1}$)	0.39
Arbitrary origin of growth (t_0)	0.12
Growth coefficient (M/K)	1.28
Annual total mortality rate (Z)	1.20
Annual fishing mortality rate (F)	0.70
Annual natural mortality rate (M)	0.50
Length at first capture (L_C, cm)	120
Annual exploitation rate (E)	0.58
E_{50}	0.28
E_{max}	0.54

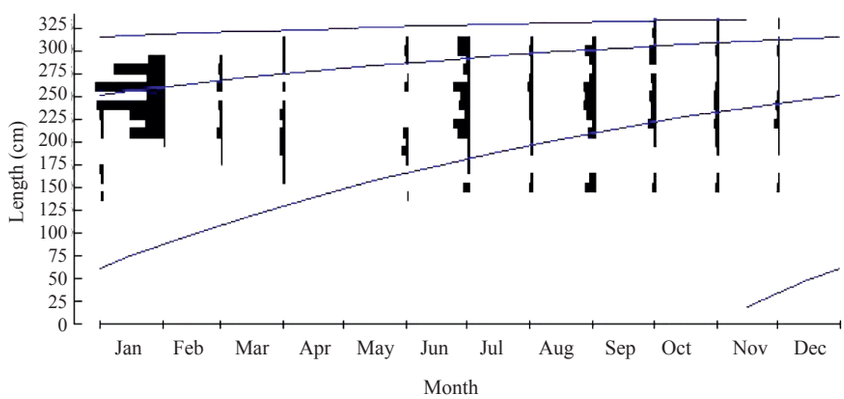

Fig. 5. Plot of FiSAT analysis of *A. superciliosus* exploited off Thoothukudi

Table 2. Mortality parameters and exploitation rate of *A. superciliosus* off Thoothukudi coast

Year	F	M	Z	E = F/Z
2015	0.7	0.49	1.19	0.59
2016	0.8	0.52	1.32	0.61
2017	0.6	0.48	1.08	0.56
2018	0.7	0.5	1.20	0.58
2019	0.71	0.50	1.18	0.60
Average	0.70	0.50	1.20	0.60

Recruitment pattern, virtual population analysis and yield per recruit

The recruitment pattern of *A. superciliosus* showed a distinct peak with maximum recruitment during February to April contributing to 46% of total recruitment (Fig. 6). Highest recruitment took place in March (18%) and the lowest in July (4%). In equatorial Pacific coast, *A. pelagicus* was recruited with a peak during April to July (Romero-Caicedo *et al*., 2014), However, in the present study, one major peak was observed from February to April in Thoothukudi coast of Gulf of Mannar**.** The major recruitment season coincides with the coastal monsoon ban in the south-east coast of India. The results of the length structured VPA employed to recognise the level of mortality on various length groups of *A. superciliosus* are shown in Fig. 7. Fishing pressure on *A. superciliosus* was found more in the length group of 240 to 320 cm. Liu *et al*. (1998) and Tsai *et al*. (2010) assessed the stock status of the pelagic thresher shark in the waters off eastern Taiwan and north-western Pacific using spawning-per recruit models and VPA and the results indicated that with heavy fishing, the stock stands overexploited. The annual catch and annual stock exploitation ratio estimated for *A. superciliosus* are presented in Table 4. MSY for *A. superciliosus* off Thoothukudi waters is estimated as 58 t. Tsai *et al.* (2010) revealed the total mortality in MSY increased due to fishing. The mean size of pelagic threshers in the commercial catch declined since 1994, showing a further warning sign that overfishing is occurring in north-western Pacific. The yield per recruit for *A. superciliosus* from Thoothukudi waters is shown in Fig. 8. The L_c/L_∞ for the present exploitation ratio (0.54) of *A. superciliosus* is 0.00142 and it has been inferred that maximum sustainable yield can be possible keeping the exploitation rate and $L_c/L\infty$ at 0.050 and 0.48 respectively.

Table 3. Comparison of age and growth parameters of *A. superciliosus* in studies carried out worldwide

Sl. No.	Study	Sex	Size range (TL, cm)	Sample size (N)	VBGF parameters (L_∞) cm	K (y^{-1})	Max observed age (years)	Region
1.	Present study	Pooled	105-362	315	367	0.39	22	Bay of Bengal
2	Pescas (2014)	Male	94-260	241	245.6	0.09	25	Atlantic
		Female	102-265	258	284.2	0.06	25	
3.	Fernandez-Carvalho *et al*. (2011)	Male	101-210	42	206.0	0.18	17	NE Tropical Atlantic
		Female	115-242	73	293.0	0.06	22	
4.	Liu *et al*. (1998)	Male	NA-213.5	214	235.5	0.09	20	NW Pacific (Taiwan)
		Female	NA-256.5	107	241.7	0.09	21	

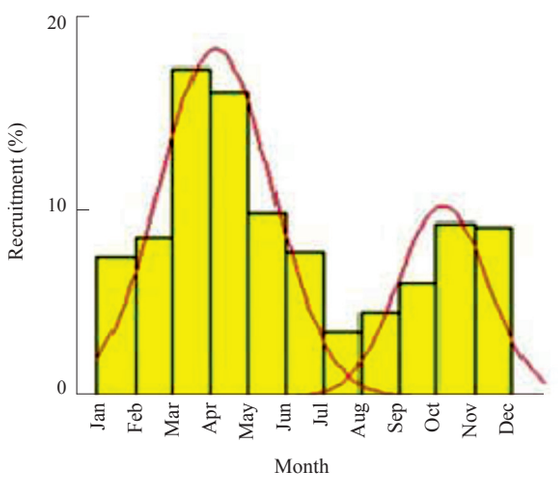

Fig. 6. Recruitment pattern of *A. superciliosus* exploited off Thoothukudi

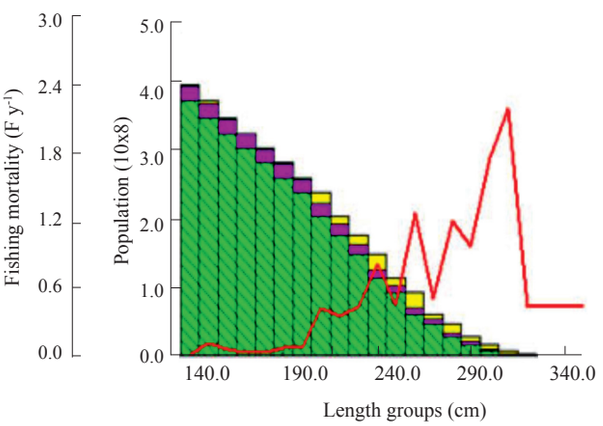

Fig. 7. Length structured virtual population analysis of *A. superciliosus* exploited off Thoothukudi

Table 4. Exploitation ratio, total stock and annual stock of *A. superciliosus* off Thoothukudi coast

Year	Annual catch (t)	Exploitation ratio (U)	Annual stock (t)	Total stock (t)
2015	53	0.54	76	98
2016	97	0.53	121	183
2017	50	0.53	84	94
2018	71	0.53	102	133
2019	68	0.53	98	128
Average	68	0.54	96	126

The study also suggests that the fishing effort for *A. superciliosus* could be reduced by decreasing the number of boats or reducing the fishing duration to 3-4 h. The present study reveals that the stock of *A. superciliosus* is overexploited off Thoothukudi coast and there is a probability of depletion in the stock of this species in future.

India is a signatory to Convention on International Trade in Endangered Species of wild fauna and flora (CITES), the Convention on Migratory Species (CMS) wherein bigeye thresher shark, *A. superciliosus* is listed as 'Vulnerable' in the IUCN's Red List (Amorim *et al*., 2009) and comprehensive worldwide stock assessment wanting; in spite of lack of catch data. Moreover, in tune with the global concern in the population of bigeye thresher sharks, efforts have been initiated by ICAR-CMFRI to assess the status of the species in Indian waters. Further to this, ICAR-CMFRI has been recognised by CITES as the Scientific Authority for Non Detriment Findings (NDF) assessment of CITES listed species including *A. superciliosus* from Indian coast. In this contest, the present study provides valuable baseline information on the population characteristics and stock status of *A. superciliosus* along Thoothukudi coast of India for further management of the vulnerable species.

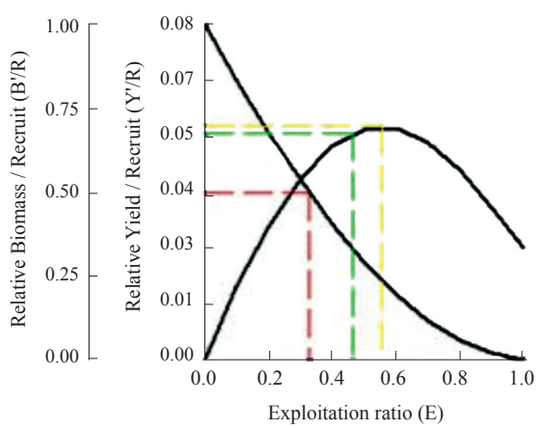

Fig. 8. Yield/Biomass recruitment of *A. superciliosus* exploited of Tuticorin

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