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Demographics of a heavily exploited deep water shark *Echinorhinus* cf. *brucus* (Bonnaterre, 1788) from the south-eastern Arabian Sea

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ABSTRACT

In the absence of direct consumption importance and considering as low value bycatch, many vulnerable non-target species, especially slow growing deep water fauna, are overlooked in tropical fisheries research and management. The bramble shark *Echinorhinus* cf. *brucus* (Bonnaterre, 1788) is one such species, subjected to a significant non-targeted deepwater fishery off southern India. A length frequency based stock assessment of bramble shark caught in trawl fisheries from the south-eastern Arabian Sea suggests that, *E.* cf. *brucus* is a moderately slow growing (K=0.12 year^{-1}) and moderately long lived shark species (T_{max} = 25 years, L_{∞}= 333 at corresponding age of 55 years) which is overexploited (M=0.17, Z=0.39) in the region. In view of resilience capacity and vulnerability of deep sea fisheries, improved research and monitoring programmes are urgently required to ensure a sustainable future for India's expanding deep sea and distant water fisheries.

Keywords: Bycatch, Deep sea, Indian Ocean, India, Population dynamics, Shark fishery, Sustainability

Introduction

Deep sea chondrichthyans are highly vulnerable to overexploitation due to their unique life history and biological traits (Hutchings, 2002; Simpfendorfer and Kyne, 2009). Information on exploitation, population dynamics, biology, ecology and distribution of most exploited deep water species are unavailable making fishery managers highly concerned about their sustainability and extinction risk (Graham *et al.,* 2001; Clarke *et al.,* 2003; Garcia *et al.,* 2008 ; Kyne and Simpfendorfer, 2007, 2010), especially in the wake of shark declines in many of the world's marine waters (Dulvy and Forrest, 2010; Worm *et al.,* 2013; Dulvy *et al.,* 2014). However, knowledge gaps on many elasmobranchs especially deep sea shark fauna and rare species are quite high from Indian Ocean region mostly due to lack of research effort and geographic/ habitat range bias (Ducatez, 2019). Conservation and management of deep sea shark fauna in Indian Ocean or elsewhere is often limited by lack of information on catch, stock, effort and biology.

The bramble shark *Echinorhinus* cf. *brucus* (Bonnaterre, 1788) a poorly known deepwater shark, with a reported maximum size (L_{max}) of 318 cm TL, occurring mostly at 200-1200 m depths and occasionally in shallow waters, from the Gulf of Aden to the Sea of Oman, Pakistan, India, Maldives, Sri Lanka, Bay of Bengal and Andaman Sea, in the northern Indian Ocean (Naylor *et al.,* 2012; Akhilesh *et al.,* 2013; Henderson *et al.,* 2016; Kumar *et al.,* 2018; Fernando *et al.,* 2019).

Along the southern coasts of India, where the continental shelf is narrow and fishing occurs in deepwater, *E.* cf. *brucus* occurs mainly as bycatch in various gears (mostly trawls) and since 2002 it has been a major bycatch in the gulper shark (*Centrophorus* spp.) longline fishery (Akhilesh *et al.,* 2011, 2013). Elsewhere in the world, echinorhinid shark species are rarely caught in huge quantities possibly due to inaccessible fishery habitat (except in southern India). Hence no studies have been carried out either on the biology (Akhilesh *et al.,* 2013), or the stock parameters of the members of Echinorhinidae, hindering the development of management strategies.

Most deep sea sharks from the Arabian Sea and the larger Indian Ocean region are assessed as Data Deficient (DD) in the IUCN Red List assessments, due to limited information on population status or trends (Jabado *et al.,* 2017). In the Regional Red List assessment of chondrichthyan species occurring in the Arabian Sea and adjacent waters (ASR), *Echinorhinus* cf. *brucus* is assessed as Vulnerable (VU) (Jabado *et al.,* 2018), due to the high fishing pressure in the region and Data Deficient (DD) in the global assessment (Paul, 2003). Global Red List assessments often underestimate the local population status when the species has restricted or patchy distribution/population range and regional fishing pressures are alarmingly high than expected or compared to elsewhere in the known distribution range. In this paper, we provide the first estimate on the demographics of the deep sea shark *E.* cf. *brucus,* from the Indian waters, which will help inform future management actions and update global and regional conservation assessments.

Materials and methods

Length data (TL) of 3679 individuals of *E.* cf. *brucus* was collected from the trawl landings at Cochin Fisheries Harbour (Kerala), India during 2009-2011 (excluding the month of July due to the closed season). For each individual, the total length (measured from the anterior most part of the head with mouth closed to the farthest tip of the caudal fin upper lobe and recorded to nearest centimetre), weight and sex were recorded. Pooled length frequency data for the period 2009-11 were grouped into 10 cm intervals. Growth, mortality and exploitation levels were estimated from the length-frequency data using FiSAT II software (Gayanilo and Pauly, 1997; Gayanilo *et al.,* 2005). Asymptotic length (L_∞) and growth constant (K) were further used to estimate other parameters. Based on L_∞ and K, the growth performance index (φ) and potential longevity ($3/K$) were determined (Munro and Pauly, 1983). Instantaneous total mortality (Z) was estimated from the length-converted catch curve (Pauly, 1984); natural mortality (M) was determined using Pauly's empirical formula (Pauly, 1980), with ambient temperature used as 15ºC for the habitat; fishing mortality (F) was calculated as F = Z-M and exploitation rate (E) as E = F/Z. Length-converted catch curve was then used to determine the length at first capture (L_c), Length-structured virtual population analysis (VPA) was performed (Pauly, 1984). Exploitation rates that retains 50% of the biomass (E_{50}) and maximum yield per recruit (E_{max}) were then predicted using relative yield per recruit (YR^{-1}) and relative biomass per recruit (BR^{-1}) analysis using knife-edge selection (Pauly, 1984).

Results and discussion

Fishery for *E.* cf. *brucus* in the south-west coast of India exploits all size classes in the stock. Asymptotic length (L_∞) was estimated as 333 cm TL and growth coefficient (K) was estimated at 0.12 $year^{-1}$ (Table 1), similar to those of other deep water chondrichthyans (Cortes, 2000). Comparative growth coefficient study of chondrichthyans (Cailliet, 1990; Cailliet and Goldman, 2004) suggest that a wide range of K values (0.034 $year^{-1}$ for *Squalus acanthias* (Ketchen, 1975), 0.05 $year^{-1}$ for *Dipturus pullopunctata* (Walmsley-Hart *et al.,* 1999) and 1.3 $year^{-1}$ in *Rhizoprionodon taylori* (Simpfendorfer, 1993) can be used to interpret life history traits, with most deep sea chondrichthyans having a low K value like 0.12 $year^{-1}$ for *Squalus megalops* (Avsar, 2001) and 0.088-0.092 $year^{-1}$ for *Alopias superciliosus* (Liu *et al.,* 1998). Based on the VBGF growth coefficient values (Fig. 1), *E.* cf. *brucus* in south-eastern Arabian Sea is considered to be a moderately slow growing species (Branstetter 1987; Branstetter and Musick, 1994). The values of L_∞ and K estimated by ELEFAN were considered for the calculation of lengths attained by *E.* cf. *brucus* at quarterly intervals using von Bertalanffy's growth formula. The total length attained by *E. brucus* were 150, 233, 278, 303 cm at the end of 5, 10, 15, 20 years of its life span respectively and for the maximum size (L_{max}) observed 318 cm TL the respective

Table 1. Growth, mortality and exploitation parameters of *E.* cf. *brucus* from south-eastern Arabian Sea

Parameter	Value
L_∞, Asymptotic length (cm)	333
K, Growth coefficient (y^{-1})	0.12
t_o (y^{-1})	-0.06
ϕ', Growth performance index	4.12
Z, Total mortality (y^{-1})	0.39
M, Natural mortality (y^{-1}) at 13	0.17
F, Fishing mortality (y^{-1})	0.22
E, Current exploitation rate	0.56
E_{max}, Maximum yield per recruit	0.39
L_c, Length at first capture (cm)	199

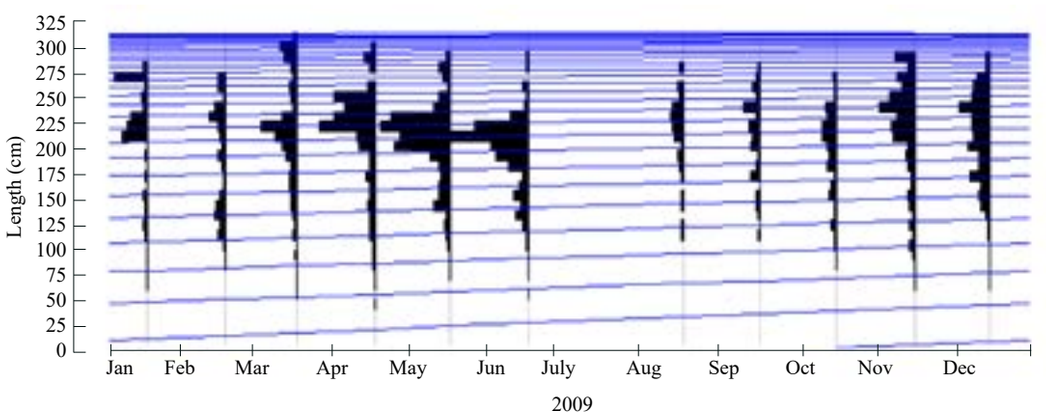

Fig. 1. von Bertalanffy growth curve drawn on restructured length-frequency data of *E.* cf. *brucus* from south-eastern Arabian Sea, where positive points (black bars) are shown. The points were computed and used to identify the growth curve which passes through the largest number of positive points by avoiding negative points. (L_∞ = 333 cm and K = 0.12 $year^{-1}$)

age was 26 year and for attaining L_∞ the age would be 55 years. Age at maturity is 187-189 cm TL at 7 years. Following Pauly (1979), t_0 was estimated as -0.06 year^{-1}.

The phi prime growth performance Index (Φ) which is one of the parameters that determines a relationship between L_∞ and K, was estimated at 4.12. Most deep sea chondrichthyans have low natural mortality (M) due to low predation and high juvenile survival rate, butjl vulnerability to fishing gear will be very high if most individuals and all size class of population is vulnerable to fishing. The natural mortality coefficient, M (0.17) is similar to those obtained for other deep sea sharks like *Etmopterus pusillus* and *E. spinax* (0.17–0.26 year^{-1} and 0.21-0.42 year^{-1}) (Coelho and Erzini, 2005). For deep water species, it is desirable that the value of fishing mortality (F) as less or equal to M as a precautionary approach and even very low fishing mortality levels are enough to lead to overexploited state of deep sea sharks (Graham *et al.,* 2001; Devine *et al.,* 2006; Morato *et al.,* 2006). The F value estimated (0.22) in this study is higher than M, indicating increasing levels of exploitation of the species.

The exploitation rate (E) and exploitation ratio (U) values were estimated as 0.56 and 0.40. Exploitation rate (E) is slightly above the optimum value of E (0.5) suggesting evidences of overexploitation, supported by the observations of declining fishery (Akhilesh *et al.,* 2013). In the present study, the knife-edge procedure gave E_{max} of 0.39. As E is 0.56, the fishery is considered as "over fished" (Gulland, 1971). It was observed that the gulper shark fishery in southern India declined due to unprofitability and high juvenile catch and this could be applicable to *E.* cf. *brucus* also. The higher E (0.56) compared to E_{max} obtained in the study may perhaps be due to bycatch of all size classes in vessels operating in deeper waters. The population status can be estimated based on ratio of, Z/K *ie.,* >1 indicates that the population is mortality dominated and if less than 1 it is growth dominated (Pauly, 1984). However, the Z/K of 3.25 estimated in the present study, indicates that the population is highly mortality (Fishing mortality) dominated.

The length at first capture (L_c) in the present study is estimated at 199 cm TL (Fig. 2). Several researchers reported that sexual maturity in *E. brucus* occurs between 182 and 231 cm TL in females and 150 and 187 cm TL in males (Barrul and Mate, 1996; Compagno *et al.,* 2005; Henderson *et al.,* 2007; Akhilesh *et al.,* 2013). However, the length at first capture in the present study (199 cm) falls within the broad maturity size range indicating, most of the members in the stock are not getting chance to support next recruitment. The ratio of L_m/L_∞ estimated as 0.57 for females and 0.56 for males, indicates that *E.* cf. *brucus* is a moderate maturing species (Compagno, 1984; Liu *et al.,* 2015). F for the species estimated based on length cohort analysis shows an increasing trend for the large size groups. The recruitment pattern of *E.* cf. *brucus* shows a continuous one with a single peak per year. The highest (17%) and lowest (1%) percent recruitment takes place in May and January (Fig. 3) respectively.

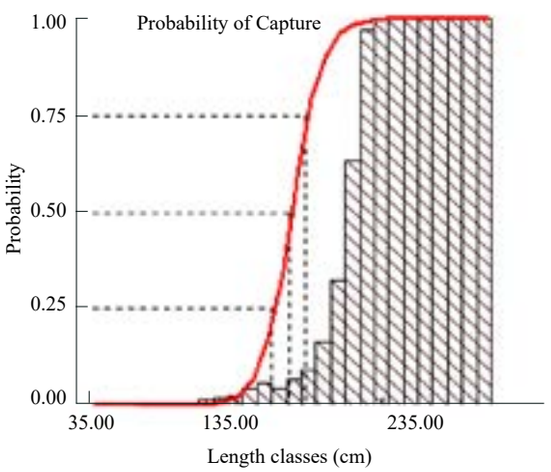

Fig. 2. Probability of length at capture of *E.* cf. *brucus* from south-eastern Arabian Sea. L_{25}=183 cm; L_{50}=199 cm, L_{75}= 216 cm.

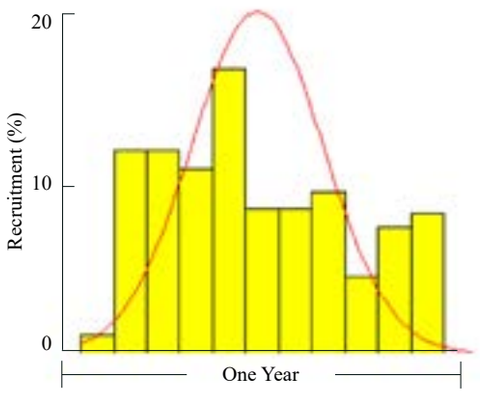

Fig. 3 Computed monthly recruitment pattern of *E.* cf. *brucus* from south-eastern Arabian Sea for a period of one year.

The relative yield per recruit (Y/R) and biomass per recruit (B/R) determined as a function of L_c/L_∞ and M/K (Fig. 4). In the yield contours (isopleth diagram), L_c/L_∞, E and M/K ratio are compared to determine the fishing status and the stock can be classified into four quadrants (Pauly and Soriano, 1986). In the present study, with an L_c/L_∞ of 0.6 and *E* of 0.56, the stock belongs to quadrant C which implies that large specimens are caught at higher efforts. *E.* cf. *brucus* fits under this category

which suggests that the efforts must be stabilised and possibly reduced, as a management measure. The M/K was estimated as 1.4. The M/K ratio is found to be constant among the closely related species and the M/K ratio in fishes generally falls within the limit of 1.5-2.5 (Beverton and Holt, 1959). The results of the present study reinforce the need for monitoring the fishing effort on *E.* cf. *brucus* population along the south-west coast of India.

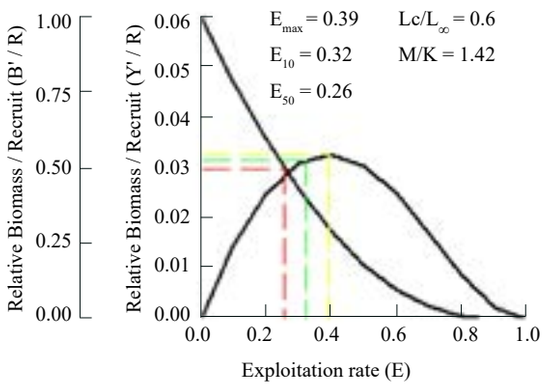

Fig. 4. Stock status of *E.* cf. *brucus* from south-eastern Arabian Sea, using Beverten and Holt's relative Y/R analysis

Virtual population analysis (VPA) revealed that all size groups are caught in the fishery and fishing mortality (F) rate increases from 80 cm TL (Fig. 5). The fishing mortality (F) increases to maximum of 0.20 - 0.23 at 221-230 cm TL, subsequently decreases to 0.18 - 0.19 at 261-270 cm TL and abruptly increases to 0.26 - 0.28 at 291-300 cm TL. However, for the recruitment size class (45-105 cm TL, 1-3 year class), the average fishing mortality is 0.15 whereas average total mortality is 0.17 suggesting fishing pressure in juveniles are also quite high which lead to growth overfishing. The reason for a sudden increase in F in larger size class is possibly due to larger sized sharks coming as bycatch and are retained in the fishery. Fishing mortality exceeds natural mortality from 224.5 cm TL onwards. The mean F from the fully recruited groups (221 - 320 cm TL) was 0.28. There is both growth and recruitment overfishing in *E.* cf. *brucus* bycatch fishery in the southern Arabian Sea region and will affect the population turnover rates leading to ecosystem overfishing. This would need a lot of time for recovering from the impact.

In all coastal states of India, fleet sizes currently in operation are greater than the estimated optimum fleet sizes (Sathianandan *et al.,* 2008) and no restriction is imposed on reducing efforts. Therefore, the only means of reducing the fishing pressure will be implementing additional

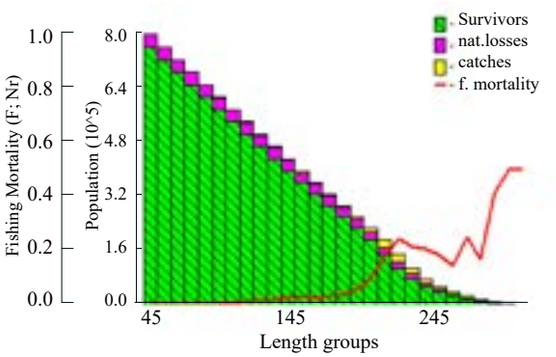

Fig. 5. Length structured VPA analysis of *E.* cf. *brucus* from south-eastern Arabian Sea, based on current fishing mortality

closed fishing seasons in addition to the existing closed season (June 15 to July 31 for west coast), extending closed seasons, declaring non-fishing zones in coastal and deep sea waters as well as moratorium on entry of new fishing vessels. With the current social and political scenarios in Indian fisheries sector, advocating most of the management efforts are becoming tough unless there is a strong political will to implement the same.

On a long-term basis, reducing L_c/L_∞ is suggested so that length at first capture can be increased from the current level and effort reduction. As a precautionary measure in fishery management, the Government of Kerala has implemented a minimum legal size (MLS) for utilisation/ trade of important commercially exploited species and this could also be expanded to include commonly exploited long-lived fish species that occur as bycatch species as well. However, effective implementation of MLS in a tropical multispecies fishery is a management challenge that requires enforcement of mesh size regulations, demarcation of spawning/breeding/nursery grounds and implementation of no-take zones in participatory approach.

Bycatch and their utilisation for commercial purposes is a major challenge in the Indian fisheries sector. With depleting near shore resources, bycatch utilisation and commercialisation can lead to target fishery of commercially lesser important species and juveniles for non-consumption purposes (Lobo *et al.,* 2010). In the recent years. commercial utilisation of consumable fish catch and bycatch has increased (Aswathy and Narayanakumar 2013). In the deep sea shrimp trawl fishery targeting *Plesionika* spp., *Heterocarpus* spp., *Solenocera* spp., *Metapenaeopsis* spp. and *Aristeus* spp., operating at depths from 200-700 m in southern coasts of India, huge quantity of *E.* cf. *brucus* are being landed as bycatch along with several other

deep sea sharks and utilised (Akhilesh *et al.,* 2011; Akhilesh and Ganga, 2013). Available catch records and preliminary evidence from the current study shows that *E.* cf. *brucus* in the deep waters off southern India are under high fishing pressure (Akhilesh *et al.,* 2013), however it is a well-known fact that for most deep sea bycatch taxa only limited time series data on catch and effort is available in India. Low productivity and high exploitation of deep sea fauna are a matter of high concern (Norse *et al.,* 2012). Generating information on Data Deficient groups are important for reducing extinction risk by management interventions. Limited information from bramble shark fisheries has indicated that serious harvest related declines have taken place in parts of the north-east Atlantic Ocean (Quero and Cendrero, 1996; Quero, 1998). Similarly, Ali and Sinan (2014) showed that targeted fishery for the deep sea gulper sharks in Maldives led to rapid declines within four years of exploitation. Similarly, in the southern coasts of India, targeted deep sea shark fishery expanded rapidly, due to demand for liver oil and within few years, fishery landings declined in number and size leading to non-profitable venture and closure of fishery, but still bycatch continues. Gibson *et al.* (2008) reported that the reduced availability of stocks, rather than falling market values, as the major reason for deep sea shark fisheries becoming unprofitable. which is partially applicable to south Indian deep sea shark fishery too. The market demand for shark meat is quite high in southern India. The expanding fisheries and their shark bycatch provides reasonable incentives for bringing the deep sea sharks too, at whatever sizes and quantity caught.

Trends in exploitation can be used as a proxy to improve our understanding of the population status. To achieve sustainable fishery through rational exploitation, it is essential to have reliable data on population parameters and life history traits of exploited taxa. Considering the highly vulnerable nature of deep sea chondrichthyans, it is very much essential to estimate basis of fisheries management science such as the growth, maturity, population parameters and mortality for effective management and supporting policy decisions. Studies from elsewhere have shown that slow growing species can be harvested sustainably with good science-based management measures and catch restrictions limiting to a portion of the stock (Rago and Sosebee, 2009; Wallace *et al.,* 2009; Simpfendorfer and Dulvy, 2017). However, it is known that length-based growth and population models have limitations (Laslett *et al.,* 2004; Pardo *et al.,* 2013) due to natural variability in productivity factor, changes in fishing systems and operation details. Notwithstanding these limitations, precautionary approaches can be made based on the current preliminary results and available information. In most tropical countries, fisheries management policies give little priority for certain categories of fishes such as juveniles exploited/low quality high value fishes used for fishmeal and deep sea fishes. Deep water bycatch species often fall in category of high conservation concern. Detailed studies (fisheries independent and dependent) on deep water fauna and their ecological characters in addition to continuous monitoring of expanding deep sea fisheries in tropical countries are required for developing management strategies as well as to reduce the extinction risks

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