INNSPUB

International Journal of Biosciences (IJB)
ISSN: 2220-6655 (Print) 2222-5234 (Online)
Vol. 1, No. 6, p. 14-26, 2011
http://www.innspub.net

RESEARCH PAPER
OPEN ACCESS

Studies on population structure, mortality, growth and exploitation level of smooth hammerhead *Sphyrna zygaena* (L) (Carcharhiniformes - Sphyrnidae) in the coastal region of Kerala, India

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Received: 06 October 2011
Revised: 27 October 2011
Accepted: 28 October 2011

Key words: *Sphyrna zygaena*, growth, rrecruitment, yield per recruit, exploitation.

Abstract

The hammerhead sharks (Sphyrnidae), have a circumglobal distribution in tropical and warm-temperate waters, and the smooth hammerhead, *Sphryna zygaena* is a globally exploited. The current population status of *S. zygaena* captured from the Kerala coast of Indian Ocean was assessed in terms of yield-per-recruit and biomass-per-recruit analyses during 2008-2009. The growth parameters, asymptotic length (L_∞) and growth coefficient (K) were estimated.The von Bertalanffy growth model resulted in growth parameters of L_∞ = 362.25 cm and K=0.23 year^{-1}. The average total, natural and fishing mortality coefficients were estimated as 0.35, 1.39 and 1.74 respectively appear to be appropriate for utilization of the stock. The present study reveals that the exploitation ratio of *S. zygaena* along the Kerala Coast of India is 0.8 and therefore the stock is overexploited. It can be concluded that *Sphyrna zygaena* is over exploited along the Kerala Coast and proper management steps have to be taken for maintaining the fishing effort of *S. zygaena* in the Indian ocean so as to result in higher economic yield thereby this fishery operates near biologically optimal level.

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Introduction

In fisheries science, `stock' first referred to any group of a fish species that was available for exploitation in a given area.(Milton and Shaklee, 1987). To manage a fishery effectively, it is important to understand the stock structure of a species and how fishing effort and mortality are distributed (Gavin and John,1999). An understanding of stock structure is vital to designing appropriate management regulations in fisheries where stocks are differentially exploited (Ricker, 1981).

The hammerhead sharks (Sphyrnidae),which have a circumglobal distribution in tropical and warm-temperate waters, are represented by two genera, i.e. Eusphyra and Sphyrna, that contain one and seven species, respectively (Compagno *et al.,* 2005) Hammerhead sharks, primarily great, *Sphyrna mokarran*, scalloped, *S. lewini*, and smooth, *S. zygaena*, are caught in a variety of fisheries including artisanal and small-scale commercial fisheries, bottom longlines as well as offshore pelagic longlines. Hammerheads are generally suffering high bycatch mortality (IUCN, 2008). Previous reports revealed that (Clarke *et al.,* 2004a, 2006a, 2006b), hammerheads are the second-most abundant species in the international fin trade. The combination of increasing exploitation and well-documented susceptibility of shark populations to collapse in response to overfishing has made conservation and management, an issue of urgent and international concern (Bonfil 1994; Weber and Fordham 1997; FAO 2000; Musick *et al.,* 2000a; NMFS 2001; Baum *et al.,* 2003).

There are only limited published biological data on *S. zygaena*, despite its widespread occurrence. In general, sharks have a combination of biological characteristics, such as slow growth, late maturation and low fecundity that make them extremely susceptible to overfishing (Stevens *et al.,* 2000). Recent studies have revealed a significant reduction in abundance of large predatory fishes, including sharks, in the Atlantic and in Indian Ocean (Baum *et al.,* 2003; Myers *et al.,* 2007). Fishing pressure can affect shark stock structure, diversity, and biological parameters, and in the worst of cases, could cause a species to become extinct (Stevens *et al.,* 2000). Smooth hammerhead is caught with a variety of gears, including with pelagic longlines, handlines, gillnets, purse-seines and pelagic and bottom trawls (Bonfil 1994, Maguire *et al.,* 2006). In the Indian Ocean and adjacent waters, information related with the biology, fishery and landings of sharks is scarce or non-existent. Still, management regulations are needed to help conserve this valuable fishery. There are no reports presently available on the population parameters, mortality and exploitation of *S. zygaena* from coastal waters of India. The knowledge of various population parameters and the exploitation level (*E*) of that population is required for the proper management of *S. zygaena* resources. The objective of the present study was to estimate the population characteristics and the exploitation level of *S. zygaena* to assess the stock position of the species from the Indian coastal waters.

Materials and methods

The present study was based on the preliminary data collected from the Indian waters by scientific observers on onboard long line fishing trawl net using vessels targeting fish and tuna. Random sampling was done monthly between February 2008 and December 2009. Once captured, sharks were identified to the lowest taxonomic level possible species level by FAO manual (FAO, 1994). During the study, observers collected digital images of the shark species caught by the fishery to validate identification. The details of length, weight, sex were taken by following standard methods. The total length (TL) was measured from the most anterior part of the cephalofoil head to the farthest tip of the caudal fin, the total weight (*W*) of the fish was recorded to the nearest 10 using a spring balance (Zacharia and Nataraja, 2003). A total of 200 specimens of *S. zygaena* 55-185 cm TL were measured during the study period.

Estimation of growth parameters

Length-based stock assessment methods were used for the present study. Length data were grouped into 10 cm length groups. Subsequently the monthly length frequency distributions were analyzed using the FiSAT computer software as explained in detail by Gayanilo *et al.*,(1997). The parameters of von Bertalanffy growth function (VBGF), asymptotic length (L_∞) and growth co-efficient (K) were estimated using ELEFAN-1 routing incorporated into the FiSAT software. K-Scan routine was conducted to assess a reliable estimate of the *K* value.

The inverse von Bertalanffy growth equation (Sparre and Venema, 1992) was used to find the lengths at various ages. Then VBGF was fitted to estimates of length-at-age curve using non-linear squares estimation procedures (Pauly *et al.,* 1992). The VBGF is defined by the equation: $L_t = L_\infty[1 - e^{-k\,(t-t_0)}]$ **w**here L_t is the mean length at age t; L_∞ is the asymptotic length; t is the age of *S. zygaena* and t_0 is the hypothetical age at which length is zero (Newman, 2002).

Total mortality coefficient (Z) was estimated by using length converted catch curve method using ELEFAN II. Natural mortality rate (M) was estimated using Pauly's empirical relationship (Pauly, 1980)**;**

$\text{Log } M = -\ 0.0066 - 0.279 \text{ Log } L_\infty + 0.6543 \text{ Log } K + 0.4634 \text{ Log}_{10}\, T$

where M is the natural mortality, L_∞ the asymptotic length, K refers to the growth coefficient of the VBGF and T is the mean annual habitat temperature (°C) of the water in which the stocks live. Once Z and M were obtained, then fishing mortality (F) was estimated using the relationship;

$F = Z - M$

where Z is the total mortality, F the fishing mortality and M is the natural mortality. The exploitation level (E) was obtained by the relationship of Gulland (1965):

$F\,[E = /Z = F/\ F + M]$

The ascending left arm of the length-converted catch curve was used to analyze the probability of capture of each length class according to the method of Pauly,1992. By plotting the cumulative probability of capture against mid-length we obtain a resultant curve from which the length at first capture was taken as corresponding to the cumulative probability at 50%.

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. This routine reconstructs the recruitment pulse from a time series of length–frequency data to determine the number of pulses per year and the relative strength of each pulse (Nurul *et al.*,2009). Input parameters were L_∞, K. Normal distribution of the recruitment pattern was determined by NORMSEP (Pauly and Caddy, 1985) in FiSAT. To estimate length at recruitment (Lr) the midpoint of the smallest length group in the catch was taken as length at recruitment (Murty *et al.,* 1992).The estimated length structured virtual population analysis (VPA) and cohort analyses were done according to the FiSAT routine (Fry,1949; Pauly,1984; Jones,1984). The values of L_∞, K, M, F, a (constant) and b (exponent) for the species were used as inputs to a VPA analysis in the FiSAT routine. The t_0 value was taken as zero (Nurul *et al.,* 2009). The relative yield-per-recruit (Y/R) and relative-biomass-per recruit (B/R) values as a function of E were determined from the estimated growth parameters and probability of capture by length (Pauly and Soriano 1986). The relative Y/R and B/R were estimated by keeping the Lc constant. With the help of different exploitation ratios (E) on the 'X' axis and different sizes at first capture by using L_C/L ratios on 'Y' axis, isovalues of Y/R were plotted to generate the isopleths diagram. The calculations were carried out using the FiSAT software package. The input requirements in the procedure were the values of L_C/L_∞ and M/K. From the analysis, the maximum allowable limit of exploitation (E_{max}) giving maximum relative yield-per-recruit was estimated. Also E=0.1, the exploitation rate at which the marginal increase in relative yield-per-recruit is 10% of its value at E=0 and E =0.5, the exploitation rate corresponding to 50% of the unexploited relative biomass-per-recruit (B/R), were estimated.

Results

Growth parameters

K scan values and the VBGF parameters L_∞ and for the period 2008-09 were estimated as K=0.23 year^{-1}; L_∞=362.25 cm respectively is as shown in Fig. 1A and Fig. 1B. For these estimates through ELEFAN I the response surface (Rn) was 0.258 for the curve. The computed growth curves superimposed on the restructured length- frequency histograms with those parameters is as shown in Fig.1B. The black and white bars are positive and negative deviation from the "weighted" moving average of three length classes and they represent pseudo-cohorts.

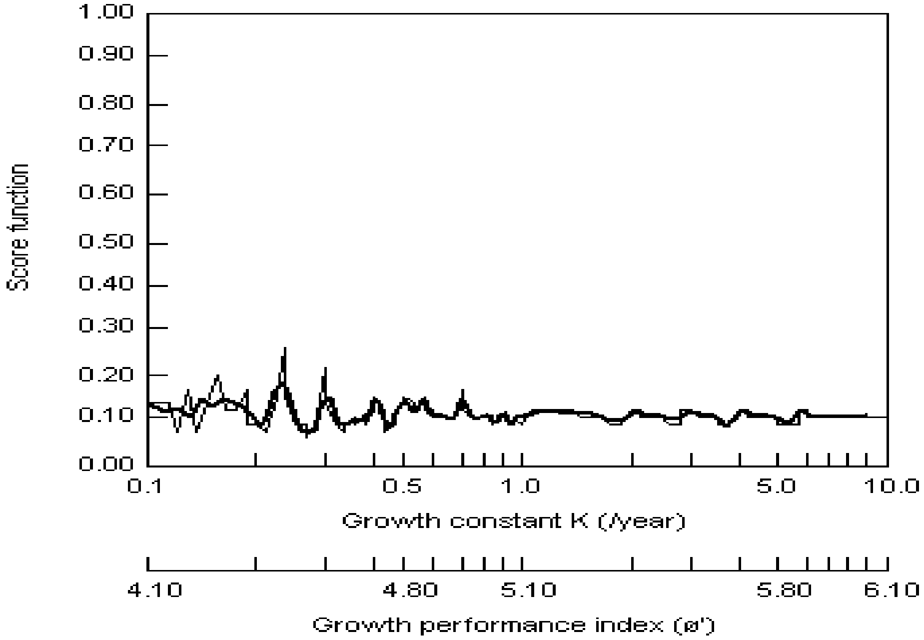

Fig. 1A. Estimation K of *S. zygaena* in the coast of Kerala.

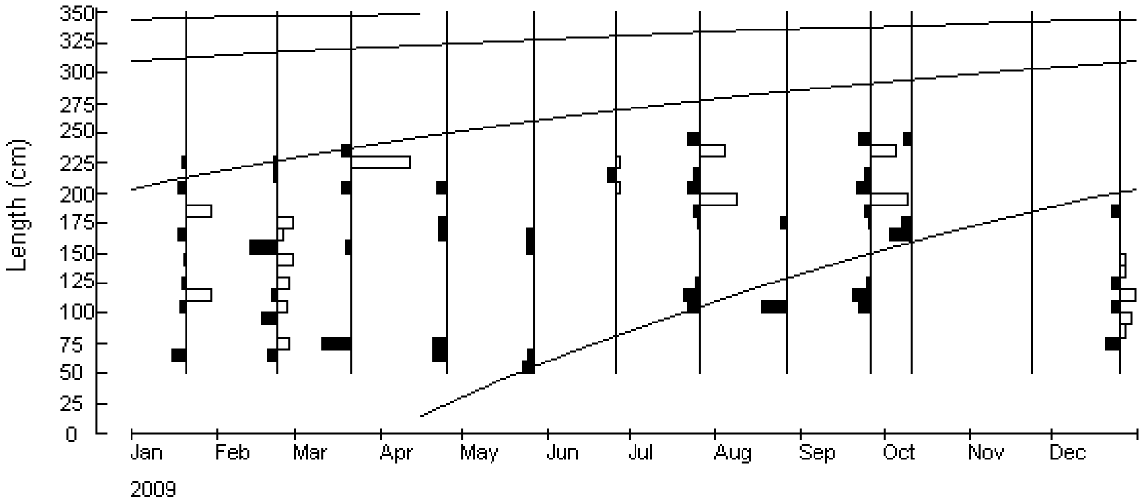

Fig. 1B. Von Bertalanffy Growth curve for *S. zygaena* by ELEFAN I superimposed on the restructured length-frequency diagram (L=362.25cm and K=0.23 year^{-1}; C=0, WP=0 and R_n=0.258).

Mortality parameters

The estimated mortality parameters Natural mortality (*M*), Fishing mortality (*F*) and Total mortality (*Z*) were 0.35, 1.39 and 1.74 respectively. According to Sparre and Venema (1993) the fishes with moderate *K* values are characteristic with moderate natural mortality, and it is related to age and size of fish. *K* value in the present study is 0.23 year^{-1} and the corresponding *M* value is 0.35. Therefore the M/K ratio is found to be 1.52. The fishing mortality (*F*) was calculated by subtraction of *M* from *Z* and it was found to be 1.39 where *M* was 0.35 and *Z* was 1.74. Fig. 2 represents the catch curve utilized in the estimation of *Z*. The darkened quadrilateral represents the points used in estimating Z through least square line regression. The blank circles represent points either not fully recruited or nearing L_∞ and hence not considered for the calculation. Good fit to the descending right hand limits of the catch curve was considered.

Virtual population analysis

Results of the VPA using the length frequency data for the year showed that fishing mortality (*F*) was maximum in the size group of 200-255 cm (Fig. 3).

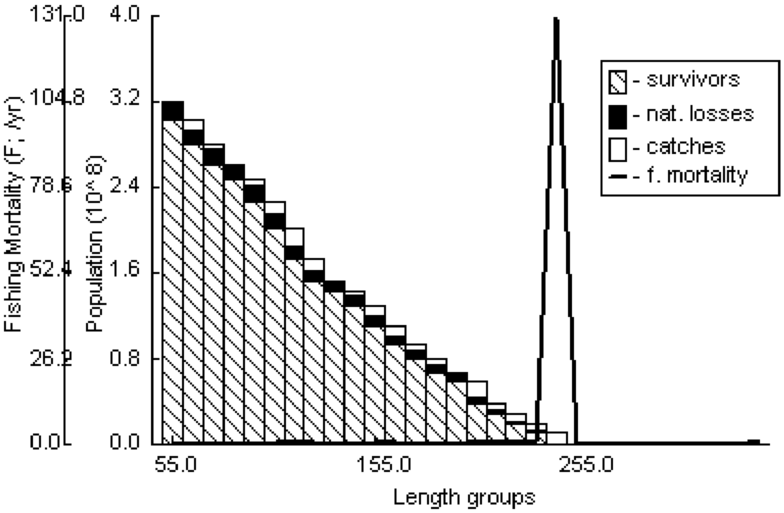

Fig. 3. Length – structured Virtual Population Analysis of *Sphyrna zygaena* for the year.

Recruitment pattern

Results of the analysis of recruitment pattern are shown in Fig. 4. The peak of normal distribution was inferred by NORMSEP program for determining the recruitment pattern (Pauly and Caddy, 1985).This can be interpreted as two recruitment peaks throughout the year, one around March and the other around June. The percent recruitment varied from 17.85% (April) to 21.85% (July). (Fig. 4).

Relative Yield Per Recruit (Y/R) and Biomass Per Recruit (B/R)

The Relative yield per recruit (Y/R) and Biomass per recruit (B/R) were determined as a function of L_C/L_∞ and *M/K* where it was 0.40 and 1.52 (Fig. 5). The plot of yield per recruit (*Y/R*) against *E* is shown in (Fig. 5) where the maximum (*Y/R*)' was obtained at E_{max}= 0.60 as the exploitation rate increases beyond this value, relative yield per recruit decreases towards zero level. Both of *E*= 0.1 (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* and *E*= 0.5 (the exploitation level which will result in a reduction of the unexploited biomass by 50%) were estimated. E_{max} value was found from the yield-per recruit and biomass per recruit model (Fig. 5). The estimated values of *E*=0.1 and *E*=0.5 were 0.51 and

0.33 respectively. The results indicated that the present levels of *E* and *F* were higher value, which give the maximum (*Y/R*) so that it indicates that it is overexploited in nature.

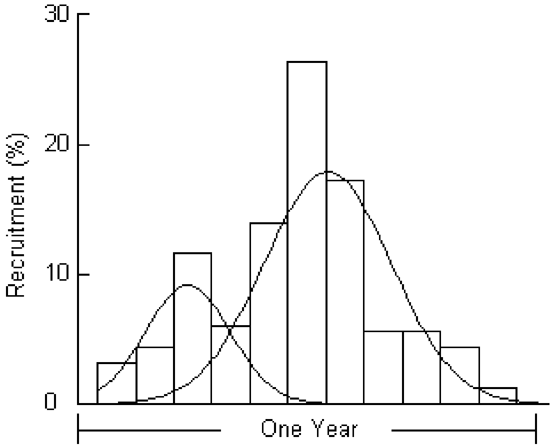

Fig. 4. Annual recruitment pattern of *Sphyrna zygaena.*

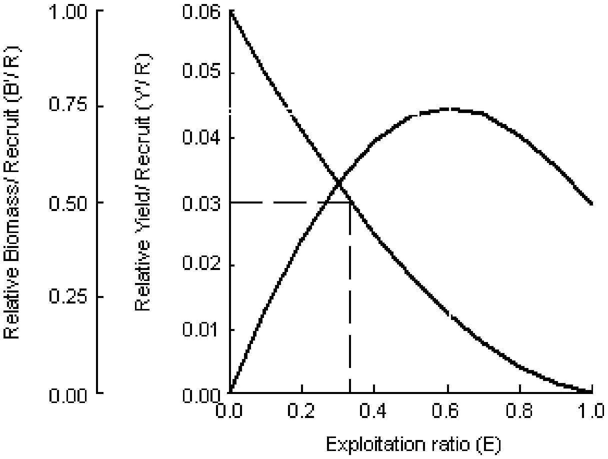

Fig. 5. Relative Yield/recruit and Biomass/recruit (Knife- edge selection) of *Sphyrna zygaena.*

Discussion

Concerns over the status and conservation of elasmobranch populations around the world are being raised at an international level. Elasmobranch vulnerability to directed fishing pressure and indirect losses due to bycatch is well established (Baum and Myers, 2004). This vulnerability is regarded as a direct consequence of inherent elasmobranch life history characteristics, which feature a pattern of slow growth, late maturity, long gestation, low fecundity, and long life, resulting in a slow intrinsic rate of population increase (Pratt and Casey, 1990; Cortes, 2000). Worldwide, many elasmobranch populations are now depleted and some are considered threatened or critically endangered (Fowler et al., 2002). The long-term ecological effects of depleted elasmobranch populations are largely unknown but likely to be far-reaching (Cortes, 1999; Stevens et al., 2000).

Elasmobranchs are ecologically important components in virtually every marine habitat (Compagno, 1990b). Actively predaceous sharks, in particular, may play important roles in controlling population size and species diversity of their prey (Cortes, 1999). Increasing evidence suggests that indirect effects of fishing affect the composition and diversity of elasmobranch and total fish assemblages through trophic interactions (Stevens et al., 2000). A cost-effective way to foster elasmobranch conservation among citizens and the government officials is development of education programmes that increase awareness of the value of elasmobranchs as a living resource and their vulnerability to overfishing (Castro et al., 999).

Sharks constitute an important predator group in marine ecosystems and consequently play an essential role on energy exchange within the highest trophic levels (Wetherbee and Cortés, 2004). For centuries, humans have conducted fishing for sharks in a sustainable manner by the use of artisanal fishing methods (FAO, 1998). Recently, modern technology in combination with an increase demand for sharks products have resulted in increasing effort and yield of shark catches, as well the expansion of fishing areas (Bonfil, 1994).

Hammerhead sharks can also be considered as a complex of three species: scalloped (*Sphyrna lewini*), great (*Sphyrna mokarran*), and smooth hammerheads (*Sphyrna zygaena*). The current status of hammerhead sharks is of concern (Myers *et al.,* 2007). Compagno (1984) reported that the species reaches a maximum size of 370–400 cm TL. Stevens (2000) reported that off the east coast of Australia males mature at about 250–260 cm TL and females at about 265 cm TL. Although few data are available on the Smooth Hammerhead's life-history characteristics, it is a large hammerhead shark and presumably at least as biologically vulnerable as *S. lewini*. The smooth hammerhead is a coastal-pelagic and semi-oceanic and occurs on the continental shelf, to 200 m depth (Ebert 2003) and viviparous mode of reproduction with females giving birth to live young (Hayes *et al*., 2007).

The L_∞ value obtained from study as 362.25 cm TL and K value obtained from study as 0.23 year^{-1} obtained in the present study (L= 362.25, K= 0.23 are similar to the values of the growth parameters of *Sphyrna Lewini* obtained from South Africa, (Chen *et al.,* 1990). This should be due to the limited published biological data on *S. zygaena*, despite its widespread occurrence.

This study also elucidate that the recruitment pattern of *S. zygaena* shows two recruitment peaks per year. The highest (21.85%) and lowest (17.85%) percent recruitment was observed in the months of July and April (Fig. 4). It is seen that *S. zygaena* spawns in surface waters and their reproductive season is extensive with frequent multiple spawning and viviparous with a yolk-sac placenta; size at birth 50 to 61 cm (Compagno, 1984). According to Fabio *et al.,* (2005) from Brazil that the occurrence of this species occurred all year long were recognized as three seasonal size-class patterns (1) between October and March, the juveniles were more frequent; (2) from April to July, adults were most common; and (3) from August to September, neonates were most numerically abundant. Such patterns were associated with reproductive tactics that may reduce intra-specific and inter-specific competition with hammerhead shark neonates (*S. lewini*), probably result in reduced natural mortality of the offspring during their first few months (Fabio *et al.,* 2005; Piercy *et al*., 2007). In earlier studies the high correspondence between modal length classes and the half year classes suggests that the population of *Sphyrna zygaena* is made up of two cohorts each year, as a consequence of two separate and well-defined recruitment periods. On the other hand, the modal progression analysis of the size distribution of *S.zygaena* caught in 1995 shows four size classes (Castro *et al.,* 1999).

The Relative yield per recruit (Y/R) and Biomass per recruit (B/R) were determined as a function of L_C/L_∞ and M/K in the present study were 0.28 and 1.5. According to Sparre and Venema (1992) the fishes with moderate K values are characteristic with moderate natural mortality, and it is related to age and size of the fish. K value in the present study is 0.40/year and the corresponding M value is 0.60. Therefore the M/K ratio of *S. zygaena* is found to be 1.5. The M/K ratio is found to be constant among the closely related species (Beverton and Holt, 1959) and the M/K ratio in fishes generally falls within the limit of 1.5-2.5. Hammerheads have relatively moderate productivity depending on the species (Cortés 2002). Species-specific stock assessments for hammerheads are generally lacking but some studies have reported large declines in relative abundance. In light of limited catch statistics, analysis of trade data for shark products has been proposed as a means of tracking relative extraction rates and warning of potential declines not documented by catch data (Clarke, 2004a). Recent studies have shown that for the few sharks for which long-term catch data are available on a regional level, several species appear to be in severe decline (>50%, Baum *et al.,* 2003). Such large declines even in areas where some management is practiced (e.g., the northwest Atlantic) have led to concerns that the same or even greater declines have occurred in regions where catch goes largely unrecorded and management is minimal or non-existent (Bonfil 1997; Castro *et al.,* 1999; Baum *et al.,* 2003). A recent assessment for a hammerhead complex (i.e., *S. lewini*, *S. mokarran*, and *S. zygaena*) in the northwest Atlantic Ocean found about a 70% decline in abundance from 1981 (Jiao *et al.,* 2008). According to Maguire *et al.,* (2006), the state of exploitation for species is unknown except scalloped hammerheads, which are reported as fully- to over exploited. The most recent IUCN red list assessments lists the most of the species of Sphyrnidae as Endangered globally (IUCN 2008).

According to Gulland (1971) the Exploitation ratio (E) will be more than 0.5 for the stocks supposed to be over fished. In the present study, it could be seen that E=0.8 which is very high than the optimum E of 0.5. It can be concluded that *Sphyrna zygaena* is over exploited along the Kerala Coast and proper management steps have to be taken for maintaining the fishing effort of *S. zygaena* in the Indian ocean so as to result in higher economic yield thereby this fishery operates near biologically optimal level. It was observed that a standardized catch-rate index of a hammerhead complex (i.e., *S. lewini, S. mokarran, and S. zygaena*) from commercial fishing data in the U.S. pelagic longline from observer data between 1992-2005 estimated a decline of 89% (Baum *et al.,*2003; Anislado and Robinson 2001). Scalloped hammerhead sharks are often targeted by some semi-industrial, artisanal and recreational fisheries and are a bycatch in industrial fisheries (pelagic longline tuna and swordfish fisheries and purseseine fisheries) in the Indian Ocean. *S. lewini* is captured in various fisheries throughout the western Indian Ocean. Countries with major fisheries for sharks include the Maldives, Kenya, Mauritius, Seychelles and United Republic of Tanzania (Young, 2006). Sharks are considered fully- to over-exploited in these waters (Young, 2006.)

Pratt and Otake (1990) suggests research in several categories of reproductive data that may be useful in managing fisheries. Catch rate declines for "hammerheads", a group consisting primarily of three, large-bodied species: (*Sphyrna lewini*, *S. mokarran* and *S. zygaena*) have been estimated as high as 89% since 1986 in the northwest Atlantic (Baum *et al.,* 2003), and these species are part of a large coastal shark complex that is considered overfished and managed under a quota system by the United States (NMFS, 2006). These three species are caught incidentally in large numbers worldwide by multi-species fisheries and harvested locally in many regions for their meat (Rose, 1996). Accompanying the recognition that many sharks are especially *sensitive* to exploitation due to their life history characteristics (slow growth, late maturity, low fecundity), and that different species have varying natural capacities to respond to fishing pressure (Smith *et al.,* 1998; Musick *et al.,* 2000b; Corte´s 2002), is the realization that conservation and management measures are needed on a species specific rather than group-specific basis to prevent the unrecognized overexploitation of any single species (Walker *et al.,*2005; FAO 2000; NMFS 2001). Within the hammerheads, for example, the schooling nature of *S. lewini* and *S. zygaena* makes them vulnerable to fisheries because they concentrate in often predictable locations and are thus easily caught in large numbers. *S. mokarran* tends to be more solitary, but has a lower reproductive potential because it reproduces biennially as opposed to annually as do *S. lewini* and *S. zygaena* (Castro *et al.,*1999).

Concerns about shark population sustainability in the face of growing exploitation for fins and other products, and the consequences of large-scale apex predator removal on marine ecosystems have prompted calls for worldwide implementation of management and conservation measures for sharks (FAO 1998, 2000; Musick *et al.,* 2000a). An important requirement for such measures to be effective is the availability of reliable information on shark catch and trade on a species-specific basis, data that has been largely missing for most shark species. This feature, together with the substantial catches of *S. zygaena* and the Sphyrna relative yield suggests that this species is likely to be maximum exploited may be due to over overfishing in Indian waters. Furthermore, the removal of large numbers of this apex predator will presumably be affecting the trophic structure in the waters in which it is fished. There is no published report on recruitment of *S. zygaena* from Indian waters. The overexploitation (E = 0.8) of this species in the Indian waters may be due to over fishing. Relative yield per recruit (Y/R) and biomass per recruit (B/R) suggested that the E=0.8 should be reduces to obtain maximum (E_{max} = 0.3) sustainable exploitation rate for this species. Hence, necessary measures should be developed for the sustainable management and conservation measures for sharks. Concerns about shark population sustainability in the face of growing exploitation for fins and other products, and the consequences of large-scale apex predator removal on marine ecosystems have prompted calls for worldwide implementation of management and conservation measures for sharks. It is therefore, concluded that the proper management may be taken to decrease the fishing effort to bring the catch to maximum sustainable yield levels (MSY) for sustaining the smooth hammer head fishery.

The present study gives an insight to the exploitation ratio of *S. zygaena* and associated population parameters in the Kerala Coast of Indian waters. Further detailed study is required to elucidate role of overfishing in deep sea *Sphyrna zygaena* groups, the recruitment, mortality and associated population parameters since it is essential for effective management of *S. zygaena* in the face of growing exploitation and the consequences of large-scale apex predator removal on marine ecosystems. Despite the above uncertainties a part of the above results could be attributed on a long-term effect of human actions (i.e. increasing of marine deep sea fishing) which modify the increase of fishing mortality in the sea species populations.

Acknowledgments

We wish to thank the Ministry of Earth Sciences, Govt. of India, New Delhi for their financial assistance. The authors are grateful to Diana Benjamin, Rajisha R and all others who were helped in the work.

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