Trend in bycatch in the tuna longline fishery in India with reference to the biology of dominant species of pelagic sharks

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ABSTRACT

The bycatch contribute substantially to the longline catch in India. The exploratory tuna longline surveys conducted by Fishery Survey of India in the exclusive economic zone(EEZ) of India has indicated the abundance of these species. The study of the bycatch trend is utmost important so as to manage the tuna fishery effectively. In the present study along with the targeted catch i.e the tunas, 31 bycatch species i.e the bill fishes, pelagic sharks, rays, barracudas, dolphin fish, lancet fish etc. were recorded. The sharks dominate the bycatch groups in the Indian EEZ. The fishes caught by the four longliners i.e MFV *Matsya Vrushti*, MFV *Matsya Drushti*, MFV *Yellow Fin* and MFV *Blue Marlin* during 2010-19 were analyzed for finding out the distribution and abundance pattern of the tunas and the bycatch species. An aggregate hooking rate of 0.28%(number/100 hooks) and a catch rate of 33.6(kg/1000hooks) was recorded from the Indian EEZ. The dominant species of pelagic sharks occurring as bycatch were taken for in depth biological studies such as sex ratio, length frequency, length-weight, dietary analysis etc. This study will be useful for framing necessary guidelines for managing the tuna long line fisheries and to know more on the biology of the large pelagics.
(Key words: Bycatch, tuna longline, EEZ, longliner, hooking rate, catch rate, length– weight relationship, dietary analysis).

INTRODUCTION

Tuna fishery caters to major economic development, providing jobs and substantial revenue while ensuring food security in several countries along the coast of Indian Ocean (Andriamahefazafy, 2019). Longlining is generally aimed at harvesting the oceanic resources such as tuna and billfishes and is an eco friendly fishing method compared with other methods (e.g., bottom trawling, purse seining and gillnet fishing). The capture of non-targeted organisms that get hooked or entangled in fishing gear and commonly referred to as bycatch. Though the longline is a sound fishing technique but for some target species, regions, and seasons, bycatch levels can be high (Griggs & Baird 2013). Among the different bycatch species encountered in the longline fishery, the oceanic sharks are prominent. These studies on the bycatch play an important role in the management of the oceanic fishery worldwide. India is blessed with two LMEs i.e Arabian Sea large marine ecosystem to her west and Bay of Bengal large marine ecosystem to her east and both these LMEs offer abundant faunal diversity. Among the oceanic fauna caught by longlining, apart from the targeted species ie tunas, the common bycatch species includes sharks, billfishes, barracuda, seer fish, dolphin fish etc.

The composition of the tuna longline bycatch in India is well studied by various researchers (Bhargava *et al*., 2002, Somvanshi *et al*., 2005, John *et al*., 2005, Varghese *et al*., (2007, 2010a), Kar *et al*., 2011, Varghese and Vijayakumaran, 2013, Koya *et al*., 2019) etc. The Fishery Survey of India, Govt. of India has been assigned the job of surveying the entire EEZ of India and adjoining seas for the demersal, pelagic and oceanic fishery resources. In the present paper, the data collected from the exploratory tuna longline fishery operations along Indian EEZ is analysed to study the abundance and distribution of the oceanic resources and the composition of catch and bycatch status by taking into consideration the hooking rate and catch rate of the species. Sharks, being the major bycatch group in the tuna longline, a detailed study on the biology of the commonly occurring shark species was attempted in this paper.

MATERIALS AND METHODS

The tuna long line survey data collected by the FSI survey vessels i.e MFV *Matsya Vrushti* (OAL 37.5 m, GRT 465 t) & MFV *Yellow Fin* (OAL 35.7 m, GRT 310 t) in the west coast of India (Arabian Sea), MFV *Matsya Drushti* (OAL 37.5 m, GRT 465 t) and MFV *Blue Marlin* (OAL 35.7 m, GRT 310 t) in the east coast of India (Bay of Bengal and Andaman and Nicobar waters) (**Fig.1**) during the period of 2010-19 is used in the present study. The vessel *M.Drushti* and *M. Vrushti* operated monofilament longline with seven hooks per basket and the vessels *Blue Marlin* and *Yellow Fin* operated the conventional longline with 5 hooks per basket. Every month, these vessels were deployed for voyages of 20 days duration. Overall 3125 longline sets were made by deploying 1,646, 258 hooks averaging 527 hooks per day. The data, so collected was analyzed to study the catch composition, abundance and distribution of bycatch species and also some biological aspects such as length frequency, length weight, sex ratio and food & feeding etc. of eight species of sharks belonging to the family Carcharhinidae and Alopiidae. The hooking rate and catch rate (number of specimen caught per 100 hooks and weight per 1000 hooks) was used as a proxy of abundance as well as spatio-temporal variations in distribution. Length – weight relationship was calculated by the formula $W = a L^b$ (Le Cren, 1951, Froese, 2006), where 'W' is the weight in kg and 'L' is the pre caudal length in cm. The regression lines of both males and females were tested for significant difference by ANOVA (Snedecor and Cochran, 1967). Sexes were identified by the presence or absence of claspers.

Food and feeding studies of the sharks were carried out by examining the gut contents by occurrence method (Pillai, 1952). Identified lowest possible taxa for each prey items was compared with three indices i.e. the Shannon-Wiener index (*H'*), Margalef's richness index (d) and Pielou's evenness index (J'). Intensity of feeding activity was calculated by the vacuity index (VI), which was calculated as the percentage of empty stomachs (number of stomachs without prey/total number of stomachs) x 100 (Hyslop, 1980). The individual prey abundance data collected from eight species of sharks were used for the analysis using PRIMER 6 (Ver. 6.1.13, PRIMER-E Ltd.). The data were tested for resemblance of eight species of pelagic sharks using Bray-Curtis similarity test. The analysis of similarity (ANOSIM) was performed through ANOVA to find out the difference between prey groups. Cluster analysis was carried out with SIMPROF test to pool the samples through dendrogram plot using their resemblance of prey groups. A non-metric-multi dimensional scaling plot (nMDS) analysis was carried out on the overlaid cluster from dendrogram plot to depict the similarity and dissimilarity of eight species of pelagic sharks. The similarity percentage analysis (SIMPER) was calculated to examine the various groups of prey species of trophic guilds.

RESULTS

Distribution and abundance of bycatch:

During the survey period a total of 1,646,258 nos. of hooks were deployed in 121 squares (1º Lat × 1º Longitude) in the Indian EEZ. The survey results indicated that alongwith the targeted species 31 bycatch species were recorded which consisted of four species of billfishes, two species of seer fishes, two species of barracudas ,fourteen species of sharks, one species each of sickle pomfret, ribbonfish, ray, dolphin fish, lancet fish, escolar, oil fish and sunfish etc.(Table 1). A total number of 4,605 fishes weighing about 55,257 kg were caught of which 1257 number of tunas, 387 number of billfishes, 667 number of sharks , 450 number of rays and 1844 number of other varieties were caught (Table 2). The data was projected for three sectors i.e west coast of India (FAO Area 51) , east coast of India (FAO Area 57) and Andaman and Nicobar waters (FAO Area 57). The hooking rate and catch rate of the 11 major groups/species are shown. From the table 2 it can be seen that in the Indian EEZ the aggregate hooking rate(%) for all the species was 0.28 and the catch rate (kg/1000hooks) was found to be 33.6. The aggregate hooking rate obtained for the east coast of India was 0.31% followed by A&N waters (0.28%) and the west coast of India (0.24%). However the aggregate catch rate showed a different trend i.e 46.3 in the A&N waters followed by 33.6 in the west coast of India and 27.6 in the east coast of India.

For studying the year wise percentage composition and also the monthly hooking rate, the species recorded were broadly divided into four groups comprising of tuna (yellowfin tuna, skipjack tuna and other tunas), billfishes(marlins, swordfish, sailfish), elasmobranchs (sharks and rays) and others (dolphin fish, lancet fish, barracuda, escolar, oil fish and sun fish etc.). The year wise percentage composition of tuna and the bycatch during the years 2010-2019 was calculated by taking into consideration the total weight of the groups encountered which is shown in Figure 2**.** It could be seen that the tuna catch has shown an increasing trend and the percentage composition varied in between 6.7% and 66.9%. The share of billfishes varied in between 9.2% and 26.3% and the percentage of elasmobranchs was in between 11.0% and 61.4%. The hooking rate of tunas, billfishes , elasmobranchs and others during the periods 2010-19 is shown in Figure 3. The hooking rate of billfishes varied from 0.01%-0.03% and the hooking rate of elamobranchs was in between 0.03% and 0.14%. The other bycatch species contributed substantially to the catch and their composition varied in between 0.03% and 0.18%.

The month-wise variations of tunas, billfishes, elasmobranchs and other varieties are shown in the Figure 4(a,b,c,d). The figure indicated that abundance of the tunas in the Bay of Bengal was more during October-January (Figure 4.a). In the Arabian Sea, it was during December-April and in the A&N waters the dominance was noticed during the month of January and July. Overall a better hooking rate of tuna was noticed in the Bay of Bengal. The billfish catch indicated a better hooking rate in the Arabian sea than the Bay of Bengal and A&N waters respectively (Figure 4.b). Higher hooking rate for elasmobranchs was recorded in the Andaman Sea in all the months in comparison to the Arabian Sea and Bay of Bengal. The highest hooking rate was obtained during the month of May (0.39%) and June (0.31%) respectively. The dominance of elasmobranchs was noticed in the Arabian Sea during June-October. In the Bay of

Bengal the hooking rate of shark was found to be very poor in all the months (Figure 4.c). The hooking rate of the other varieties were more in the Arabian Sea followed by A&N waters and Bay of Bengal (Figure 4.d).

BIOLOGY OF SHARKS

The abundance of the shark in the entire study area is shown in the figure 5(1°×1° grid). Higher hooking rate was noticed in the square 5°N-76°E(1.1%) followed by 10°N-72°E(1.0%), 5°N-90°E (0.8%), 15°N-81°E (0.8%) etc. Among the 14 species of pelagic sharks recorded from the Indian EEZ, detailed biological studies (length-frequency, sex ratio , length-weight and food and feeding) were carried out for 8 species comprising of 509 specimens. The morphometric details are given in table 3.

Length frequency studies:

The length frequency (pre-caudal length, PCL) studies of the dominant species of shark is shown in table 4 . It indicated that the dominant size range of the species *Alopias pelagicus* was 121-140cm followed by 141-160cm. In the case of *Alopias vulpinus* the range was 101-120cm followed by 121-140cm for male and 121-140cm & 141-160cm for female. Similarly the dominant size range of the species *Alopias suoperciliosus* was 141-160 cm. *Carcharhinus falciformis* were dominant at 61-80cm. The dominant size range of *Carcharhinus dussumieri* was 101-120cm and for *G.cuvier* it was 141-160cm.

Sex ratio:

The sex ratio of the shark is shown in the table 5. The dominance of male was noticed in all the three species of the family Alopiidae i.e *A.pelagicus*, *A.vulpinus* and *A.superciliosus*. Similarly male dominance was noticed for the species *C. falciformis.* It was also noticed that in all the three species of the family Alopiidae in higher size range the males were more and female population was less. In the species *C. falciformis* also similar trend was seen.

Length-Weight Relationship:

The length-weight relationship for eight species are given in table 6. The study indicated that the species *A.pelagicus, A.vulpinus and A.superciliosus* showed negative allometric growth. For the species *A.pelagicus* and *A.vulpinus*, the ANOVA indicated that the regression lines for male and female were not significantly different , hence a combined equation was worked out for both the species. However in the case of *A.superciliosus* the ANOVA indicated that the regression lines for male and female were significantly different (F=26.9). Hence a combined equation could not be worked out. Similarly the species *G.cuvier*, *C. dussumieri, P.glauca* have shown negative allometric growth and the species *C.falciformis* and *C.sorrah* showed positive allometric growth. The ANOVA doesn't indicate any significant difference between the regression lines for male and female, hence a combined equation was worked out for the above species.

Food and feeding pattern of dominant species of sharks:

The food and feeding pattern of the shark species is shown in figure 6(a-p). Three distinct groups of food items are noticed in *A. pelagicus* (figure 6.a,b) i.e., squid and octopus, teleost fishes and part of the constituents were in the semi digested form. Apart from this euphausiids and fish larvae also contributed to the diets. 36% of the stomachs were found to be empty. Teleost fishes are mainly euthynnus, gempylus, cubiceps etc. In the case of *A. vulpinus* (figure 6.c,d) 15% of the stomach were found to be empty and the preferred items were squid and octopus, teleost fishes , euphausiids etc. 15%-17% of the contents were found to be in a semi digested form. 11% of the stomach of *A. superciliosus* (figure 6.e,f) were found empty and the food comprised of teleost fishes followed by squid and octopus. 16%-22% of the contents of both male and female were found to be in semi digested form. 24% of the stomach of *C. falciformis* (figure 6.g,h) was found to be empty and gut contents indicated broadly two groups i.e squid and octopus and teleost fishes. 13%-20% of the contents were in semi digested form. In the case of the male specimens macroplastics were recorded in the gut contributing 4% to the constituents. The gut contents of *C.sorrah*, *C.dussumieri* , *G. cuvier* and *P.glauca* also indicated similar trend.

The prey items of the shark species were subjected to detailed statistical analysis by determining various biodiversity indices and CLUSTER analysis with SIMPROF test. The details are as under. The overall Shannon-Wiener index (*H'*), Pielou's index of evenness (*J'*) and Margalef's index richness (*d*) for the diet of eight species of pelagic sharks are given in table7. No much variation in the diversity indices was observed for the prey items of the eight species of pelagic sharks. However, the biodiversity indices (Shannon-Wiener index) of *G. cuvier, P.gluaca and A. pelagicus* indicated wide variety of food items followed by *A. superciliosus,* and

C. falciformis. Highest margalef's index of species richness was observed in *G.cuvier* and *C.falciformis* and highest pielou's index of evenness was noticed in *C.sorrah.*

In the present study, out of 509 shark specimens analysed, 23.18% were found to be having empty stomach resulting an overall vacuity index of 23.18%. The highest vacuity index was observed in *C. falciformis* (46.6%) and the lowest vacuity index was noticed in *A. superciliosus* (17.1%). The findings of the cluster analysis as resemblance dendrogram plot and nMDS analysis were shown in figure 7&8**.** The cluster analysis with SIMPROF test showed a resemblance of 84.1% indicating non-significant difference in prey preference of eight species of pelagic sharks (SIMPROF, p>0.05). The dendrogram plot showed the formation of two different clusters. The first cluster consisting of *C.falciformis, A.vulpinus, G.cuvier, P.glauca* and *A.pelagicus* indicates that the prey are mainly teleost fish group. The second cluster consisting of *C.dussumieri, , C.sorrah* and *A.superciliosus* indicates that the prey are squid and octopus group.

The nMDS plot supported the above pattern found in dendrogram. The nMDS plot clearly indicated two separate groups; first group consisting of *C.falciformis, A.vulpinus, G.cuvier, P.glauca* and *A.pelagicus* are grouped in the lower part of nMDS plot; second group consisting of *C. dussumieri, C.sorrah and A.superciliosus* are grouped in the upper part of the nMDS plot. The stress value which was overlying on the nMDS plot showed excellent separation of trophic groups. The analysis of similarity (ANOSIM) showed that two trophic groups were significantly different (Global *R*-statistic value=0.714; p<0.001) and in conformity with the results of the cluster analysis.

The abundance of the prey groups were studied by SIMPER analysis (table 8). The group-II showed the highest percentage of similarity (60.67%) with squid and octopus, other teleost fishes and semi digested fishes comprising 97% and the first group exhibited the second highest percentage of similarly (35.57%) with squid and octopus, other teleost fishes and semi digested fishes representing 96% of prey groups.

DISCUSSION

Monitoring and managing fisheries bycatch is being recognized as a major component of tuna fishery management worldwide. Bycatch has been identified as the most serious threat to many marine organisms, including marine mammals, birds, turtles and fishes (Lewison *et al*., 2014; Phillips *et al*., 2016). The unscientific and unchecked commercial fisheries negatively impact marine ecosystem beyond doubts (Pauly *et al*., 2005). Hence, the flow of fishery management policies were redirected from stock assessment to address various unintended consequences of fishing, such as habitat destruction, changes to ecosystem structure and incidental mortality (bycatch) of non-target species (Anon, 2003; Zhou *et al*., 2010).

Somvanshi *et al*.(2005) recorded 25 bycatch species in the Indian tuna longline survey. Moon *et al*. (2007) recorded 13 species of shark as bycatch of longline fishery by the Korean vessels in the Indian ocean and blue shark contributed 48.4% and silky shark 22.2% of the total shark catch. Huang and Liu (2010) recorded 40 bycatch species by Taiwanese vessels from the Indian ocean and the major bycatch species were swordfish, blue shark, sailfish, pomfret, and escolar. Peterson *et al*.(2010) recorded 26 species as bycatch of the South African pelagic longline fleet targeting tuna, *Thunnus spp.* and swordfish *Xiphias gladius*. Among them blue shark, *Prionace glauca* and short-finned mako shark, *Isurus oxyrinchus* were the most commonly caught species (69.2% and 17.2% respectively). Kar *et al*.(2011) recorded 30 bycatch species in the tuna longline survey conducted in the Indian EEZ around Andaman and Nicobar waters. Varghese and Vijayakumaran(2013) reported 60 species of large pelagics and sea turtle as bycatch in the tuna longline survey in India with Indo-Pacific sailfish, *I. platypterus*, the main bycatch species and sharks formed the largest group.

In the present study, 31 species contributed to the bycatch of Indian tuna longline fishery survey. Out of that 14 species of sharks were recorded and the shark catch contributed 14.5% by number and 39.9% by weight. Abundance of shark was well noticed in the A&N waters(0.08%) followed by the Arabian sea (0.06%). Higher catch rate of shark in the A&N waters (30.1) than the Arabian sea (10.9) and the Bay of the Bengal (2.4) indicates the catching of matured/fully matured species in the longline. The poor hooking rate of shark in the Bay of Bengal (0.009%) could be attributed to the use of circle hooks in the monofilament longline gear. It could be seen that the sharks are distributed evenly in the near shore and in the deeper waters in the east coast of India and A&N waters, however in the Arabian sea they were distributed away from the coast.

The present study indicated a better tuna longline hooking rate from the Bay of Bengal followed by Andaman & Nicobar waters. Kar *et al*.(2011) reported the bill fishes catch as 10% both by number and weight and shark contributed 38% and 54% by number and weight respectively from the A&N waters. In the present observation however the billfish and shark catch from the A&N waters were 5.5% and 7.7% and 28.5% and 64.9% respectively. Varghese and Vijayakumaran (2013) reported a hooking rate of 0.22% for shark from the Andaman waters. In the present observation it was 0.08%. They also reported a hooking rate of 0.16% for sailfish from the northwest coast of India however in the present observation an aggregate hooking rate of 0.008% was recorded from the entire west coast of India. Somvanshi *et al*. (2009) reported hooking of pelagic stingray at a HR of 0.06 per 100 hooks in the tuna longline survey conducted in the seas around India during the period 2005-2007. Varghese and Vijayakumaran (2013) recorded HR for this species from the Andaman and Nicobar waters as 0.077%, followed by Bay of Bengal region (0.064%) and Arabian Sea (0.036%). In the present study it was 0.025%, 0.009% and 0.069% respectively. *C. hippurus* (Dolphin fish) was caught from the Indian seas at a hooking rate of 0.048 (Benjamin and Kurup (2012) and Varghese *et al*., (2013). In this study it was 0.021%.

Sinha *et al*. (2010) reported the mean pre caudal length for the species *A.pelagicus*, *A.vulpinus* and *A. superciliosus* as 134.6cm, 137.8cm and 141.2 cm respectively from the A&N waters. In the present study the PCL of *A.pelagicus* (male & female) were recorded at 135.4cm &128.9cm respectively. The PCL of *A.vulpinus* (male & female) were recorded at 136.0cm &135.1cm respectively and those of *A.superciliosus* (male &female) were recorded at 145.0cm & 151.7cm respectively. Kar *et al*.(2011) reported that the females of *A.pelagicus* and *A.vulpinus* are smaller than the male and the females of *A.seperciliosus* are larger than the male. The present study agrees well with the above studies.

Varghese and Vijayakumaran (2013) reported the ‘b’ value of the three species *A.pelagicus*, *A.superciliosus* and *A.vulpinus* as 2.48, 2.36, 2.50 respectively in the length weight relationship. In the present study for the species *A. pelagicus* and *A. vulpinus* the pooled ‘b’ was 2.83 and 1.84 respectively and the ANOVA indicated that the regression lines for males and female were not significantly different. Hence a combined length-weight equation was worked out for both the species. However in the case of *A.superciliosus* a pooled length-weight equation could not be worked out as the regression lines for males and females were significantly different (F=26.9). *C. sorrah*, *C.limbatus*, *C.dussumieri* and *G.cuvier* showed positive allometric growth (Varghese and Vijayakumaran,2013). In the present study *C.sorrah*

& *C.falciformis* showed positive allometry and *C.dussumieri* , *G.cuvier* and *P.glauca* showed negative allometry indicating increase in length is more in comparison to the weight.

The preferred food items of *C. limbatus* and *C.sorrah* are mainly pelagic fishes like mackerels and sardines (Devadoss, 1977a). Kar *et al*.(2011) observed the food items of the thresher sharks as squid, octopus, other teleost fishes such as parallepidids, gempylids, leognathids, sardines, mackerels and zoo plankton such as euphausiids and fish larvae etc. In the present study it could be observed that the dominant food items were squid and octopus as well as teleost fishes. 15%-43% of the constituents of the shark species were in semi digested form. Macroplastics was reported from the gut contents of *C. falciformis* (male) indicating the intrusion of plastic to the marine food web.

In the present study comparatively low values for index (*H'*) were noticed (1.61-1.809). Dominance of few varieties of prey species in the diet, such as squid & octopus and teleost fishes, indicates that the predatory fishes feed on the prey items occurring frequently in the area by selective hunting.

Cluster analysis of the diets revealed two distinct trophic guilds. The first cluster i.e "teleost fish group" (*C.falciformis, A.vulpinus, G.cuvier, P.glauca* and *A.pelagicus*) feeds mainly on mackerels, myctophids, sardines, flying fishes, some deep sea fishes and puffer fishes. The second cluster i.e "squid & octopus group" (*C.dussumieri, C.sorrah* and *A.superciliosus*) feeds mainly *Stenoteuthis oualaniensis* and *Octopus vulgaris.*

Conclusion:

The bycatch has a prominent role in the tuna longline fishery in India. The present observation on the bycatch trend (seasonal, annual, spatial) will definitely be useful for the researchers and the policy makers. Biological studies of the shark species like length frequency and length-weight relationship will help in studying the growth parameters of the sharks effectively. The information on food and feeding pattern of the sharks will be helpful in studying the marine food web effectively. More data on the biological parameters need to be acquired for studying the growth parameters effectively so as to understand the stock position.

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Table.1. Bycatch species recorded in the Indian EEZ during 2010-2019

FAMILY	SCIENTIFIC NAME	ENGLISH NAME
ISTIOPHORIDAE	*Istiompax indica*	Black marlin
	Makaira mazara	Blue marlin
	Istiophorus platypterus	Indo-Pacific sailfish
XIPHIDAE	*Xiphias gladius*	Swordfish
CORYPHAENIDAE	*Coryphaena hippurus*	Common dolphinfish
SCOMBRIDAE	*Acanthocybium solandri*	Wahoo
	Scomberomorus commerson	Narrow- barred Spanish mackerel
BRAMIDAE	*Taractichthys steindachneri*	Sickle pomfret
TRACHIPTERIDAE	*Zu elongatus*	Taper-tail ribbonfish
SPHYRAENIDAE	*Sphyraena jello*	Pickhandle barracuda
	Sphyraena barracuda	Great barracuda
ALOPIIDAE	*Alopias pelagicus*	Pelagic thresher
	Alopias superciliosus	Bigeye thresher
	Alopias vulpinus	Thresher
CARCHARHINIDAE	*Carcharhinus melanopterus*	Blacktip reef shark
	Carcharhinus macloti	Hardnose shark
	Carcharhinus sorrah	Spottail shark
	Carcharhinus falciformis	Silky shark
	Carcharhinus dussumieri	Whitecheek shark
	Carcharhinus leucas	Bull shark
	Galeocerdo cuvier	Tiger shark
	Prionace glauca	Blue shark
LAMNIDAE	*Isurus oxyrinchus*	Shortfin mako shark
SPHYRNIDAE	*Sphyrna zygaena*	Smooth hammerhead
	Sphyrna lewini	Scalloped hammerhead
DASYATIDAE	*Pteroplatytrygon violacea*	Pelagic stingray
GEMPYLIDAE	*Lepidocybium flavobrunneum*	Escolar
	Ruvettus pretiosus	Oilfish
MOLIDAE	*Mola mola*	Sunfish
RACHYCENTRIDAE	*Rachycentron canadum*	Cobia
ALEPISAURIDAE	*Alepisaurus ferox*	Long snouted lancetfish

Table .2. Percentage composition(by number & weight), hooking rate(%) and catch rate(kg/1000hooks) of fishes recorded in the tuna long line survey in the Indian EEZ during 2010-2019

Groups	Indian EEZ				Arabian Sea				Bay of Bengal				A&N Waters			
	Hooking rate (%)	% by number	Catch rate	% by weight	Hooking rate (%)	%by number	Catch rate	%by weight	Hooking rate (%)	% by number	Catch rate	% by weight	Hooking rate (%)	% by number	Catch rate	% by weight
Yellowfin tuna	0.063	22.7	12.1	36.0	0.032	13.3	8.9	26.9	0.109	35.2	17.5	63.1	0.021	7.7	6.5	14.0
Skipjack tuna	0.009	3.4	0.2	0.6	0.003	1.2	0.1	0.3	0.019	6.2	0.4	1.5	0.000	0.1	0.0	0.0
Other tuna	0.004	1.3	0.1	0.4	0.002	0.7	0.1	0.2	0.006	2.0	0.2	0.8	0.001	0.4	0.0	0.1
Sailfish	0.008	2.9	1.9	5.5	0.013	5.3	3.0	9.0	0.006	1.9	1.1	4.0	0.005	1.9	1.6	3.4
Marlin	0.004	1.6	1.6	4.9	0.004	1.8	2.4	7.3	0.006	2.0	1.7	6.1	0.001	0.3	0.3	0.7
Swordfish	0.011	3.9	1.8	5.5	0.020	8.2	3.5	10.6	0.005	1.5	0.7	2.4	0.009	3.3	1.6	3.5
Shark	0.041	14.5	11.4	33.9	0.056	23.0	10.9	33.1	0.009	2.9	2.4	8.7	0.079	28.5	30.1	64.9
Ray	0.027	9.8	0.9	2.7	0.025	10.1	0.5	1.4	0.009	2.9	0.8	2.8	0.069	24.7	1.9	4.0
Barracuda	0.003	1.2	0.2	0.6	0.001	0.5	0.1	0.3	0.002	0.7	0.1	0.3	0.009	3.4	0.6	1.3
Dolphinfish	0.021	7.4	0.9	2.7	0.034	13.8	1.5	4.7	0.020	6.6	0.8	2.9	0.001	0.5	0.1	0.1
Others	0.088	31.4	2.4	7.2	0.054	22.2	2.1	6.3	0.118	38.1	2.1	7.4	0.081	29.2	3.7	7.9
Total	**0.28**	**100.0**	**33.6**	**100.0**	**0.24**	**100.0**	**33.0**	**100.0**	**0.31**	**100**	**27.6**	**100**	**0.28**	**100.0**	**46.3**	**100.0**

Table 3. Sex wise details of morphometric parameters of eight species of pelagic sharks occurring in the Indian EEZ

Species	Sex	Pre-caudal length (cm)	Weight range (kg)	Mean length (cm)	Mean weight (kg)
Alopias pelagicus	Male	50-165	02-67	135.3	40.1
	Female	53-165	02-75	128.9	38.1
A.vulpinus	Male	100-175	25-63	136.0	42.1
	Female	85-163	13-66	135.1	43.2
A.superciliosus	Male	88-257	16-74	145.0	44.8
	Female	102-205	20-110	151.7	59.5
Carcharhinus falciformis	Male	52-226	13-78	109.0	29.2
	Female	68-220	12-70	106.8	24.5
C.dussumieri	Male	87-107	06-11	99.3	8.3
	Female	99-110	08-10	102.7	8.7
C.sorrah	Male	56-160	10-54	105.3	37.5
	Female	89-180	17-53	136.3	35.3
Galeocerdo cuvier	Male	109-205	19-77	154.3	38.0
	Female	152-208	32-61	176.7	47.0
Prionace glauca	Male	158-197	28-42	182.4	37.8
	Female	170-187	29-42	177.5	35.3

Table 4. Length frequency distribution (%) of eight species of pelagic sharks in the Indian EEZ

Pre caudal length (cm)	*A.pelagicus*		*A.vulpinus*		*A.superciliosus*		*C.falciformis*		*C.dussumieri*		*C.sorrah*		*G.cuvier*		*P.glauca*	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
41-60	1	1	--	--	--	--	8	--	--	--	25	--	--	--	--	--
61-80	1	1	2	--	--	--	25	32	--	--	25	--	--	--	--	--
81-100	--	7	5	4	2	--	23	28	--	66	--	25	--	--	--	--
101-120	11	19	59	18	10	4	20	24	66	34	--	25	25	--	--	--
121-140	56	47	32	41	22	19	10	4	34	--	25	--	--	--	--	--
141-160	29	23	2	32	51	43	8	4	--	--	25	--	50	33	20	--
161-180	2	2	--	5	13	24	2	4	--	--	--	50	--	34	20	75
181-200	--	--	--	--	--	5	2	--	--	--	--	--	--	--	60	25
201-220	--	--	--	--	--	5	2	--	--	--	--	--	25	33	--	--
221-240	--	--	--	--	--	--	--	4	--	--	--	--	--	--	--	--
241-260	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--

Table 5. Size wise sex ratio of eight species of pelagic sharks in the Indian EEZ

Pre caudal length	*A.pelagicus*	*A.vulpinus*	*A.superciliosus*	*C.falciformis*	*C.dussumieri*	*C.sorrah*	*G.cuvier*	*P.glauca*
41-60	1:1	--	--	--	--	--	--	--
61-80	1:1	--	--	1:0.8	--	--	--	--
81-100	0	1:1	--	1:0.78	--	--	--	--
101-120	1:0.8	1:1.3	1:0.2	1:0.7	1:0.5	--	--	--
121-140	1:0.39	1:0.26	1:0.36	1:0.3	--	--	--	--
141-160	1:0.36	1:0.37	1:0.36	1:0.3	--	1:1	1:0.5	--
161-180	1:0.50	1:1	1:0.83	1:1	--	--	--	1:1.5
181-200	--	--	--	--	--	--	--	1:0.33
201-220	--	--	--	--	--	--	1:1	--
221-240	--	--	--	--	--	--	--	--
241-260	--	--	--	--	--	--	--	--
Sex ratio	**M:F= 1:0.46**	**M:F= 1:0.42**	**M:F= 1:0.37**	**M:F= 1:0.63**	**M:F= 1:1**	**M:F= 1:1**	**M:F= 1:0.70**	**M:F= 1:0.80**

Table 6. Length-Weight relationship (a, b, r &F value) of eight species of pelagic sharks in Indian EEZ

Species	Sex	a	b	r^2	F
Alopias pelagicus	Male	0.00005	2.77	0.90	1.57
	Female	0.00001	2.89	0.96	
	Pooled	0.0001	2.83	0.94	
A.vulpinus	Male	0.0037	1.67	0.92	1.53
	Female	0.0015	2.04	0.93	
	Pooled	0.0040	1.84	0.83	
A.superciliosus	Male	0.0031	2.16	0.84	26.9
	Female	0.0012	2.61	0.93	
	Pooled equation couldn't be worked out				
C.falciformis	Male	0.00001	3.04	0.96	0.05
	Female	0.00000	3.25	0.99	
	Pooled	0.00001	3.12	0.97	
C.dussumieri	Male	0.0009	2.46	0.94	0.87
	Female	0.0008	2.11	0.94	
	Pooled	0.0008	2.38	0.94	
C.sorrah	Male	0.0006	3.32	0.92	2.20
	Female	0.0005	3.25	0.93	
	Pooled	0.0004	3.28	0.92	
Galeocerdo cuvier	Male	0.0005	2.20	0.92	0.001
	Female	0.0018	1.95	0.95	
	Pooled	0.0006	2.15	0.94	
Prionace glauca	Male	0.0002	1.86	0.92	0.82
	Female	0.0004	2.04	0.91	
	Pooled	0.0003	1.89	0.91	

Table 7. Biodiversity indices for the prey items of eight species of pelagic sharks in the Indian EEZ

Sample	S	N	d	J'	H'(log2)
Alopias pelagicus	4	269	0.5362	0.7907	1.581
Alopias vulpinus	4	246	0.5449	0.8051	1.61
Alopias superciliosus	3	223	0.3699	0.8594	1.362
Carcharhinus falciformis	4	51	0.763	0.8199	1.64
Carcharhinus dussumieri	3	20	0.6676	0.865	1.371
Carcharhinus sorrah	3	22	0.647	0.9432	1.495
Galeocerdo cuvier	4	17	1.059	0.9046	1.809
Prionace glauca	4	51	0.763	0.8609	1.722

S: total species; *N:* total individuals; *H':* Shannon-Wiener index; *d:* Margalef's index of richness; and *J':* Pielou's index of evenness

Table 8. SIMPER analysis of prey groups of Average similarity and dissimilarity between two groups

Prey groups	Average similarity	% Contribution
Group-I	35.57	
Squid and Octopus	13.20	37.12
Other teleost fishes	12.06	33.91
Semi digested fishes	8.88	24.97
Group 2	60.67	
Squid and Octopus	27.35	45.08
Other teleost fishes	21.41	35.29
Semi digested fishes	10.11	16.67
Prey groups	**Average dissimilarity**	**% Contribution**
Group 1 & 2	68.94	
Other teleost fishes	28.39	41.18
Squid and Octopus	19.55	28.35
Semi digested fishes	15.56	22.56

Fig.1 Study area & sampling stations(Indian EEZ)

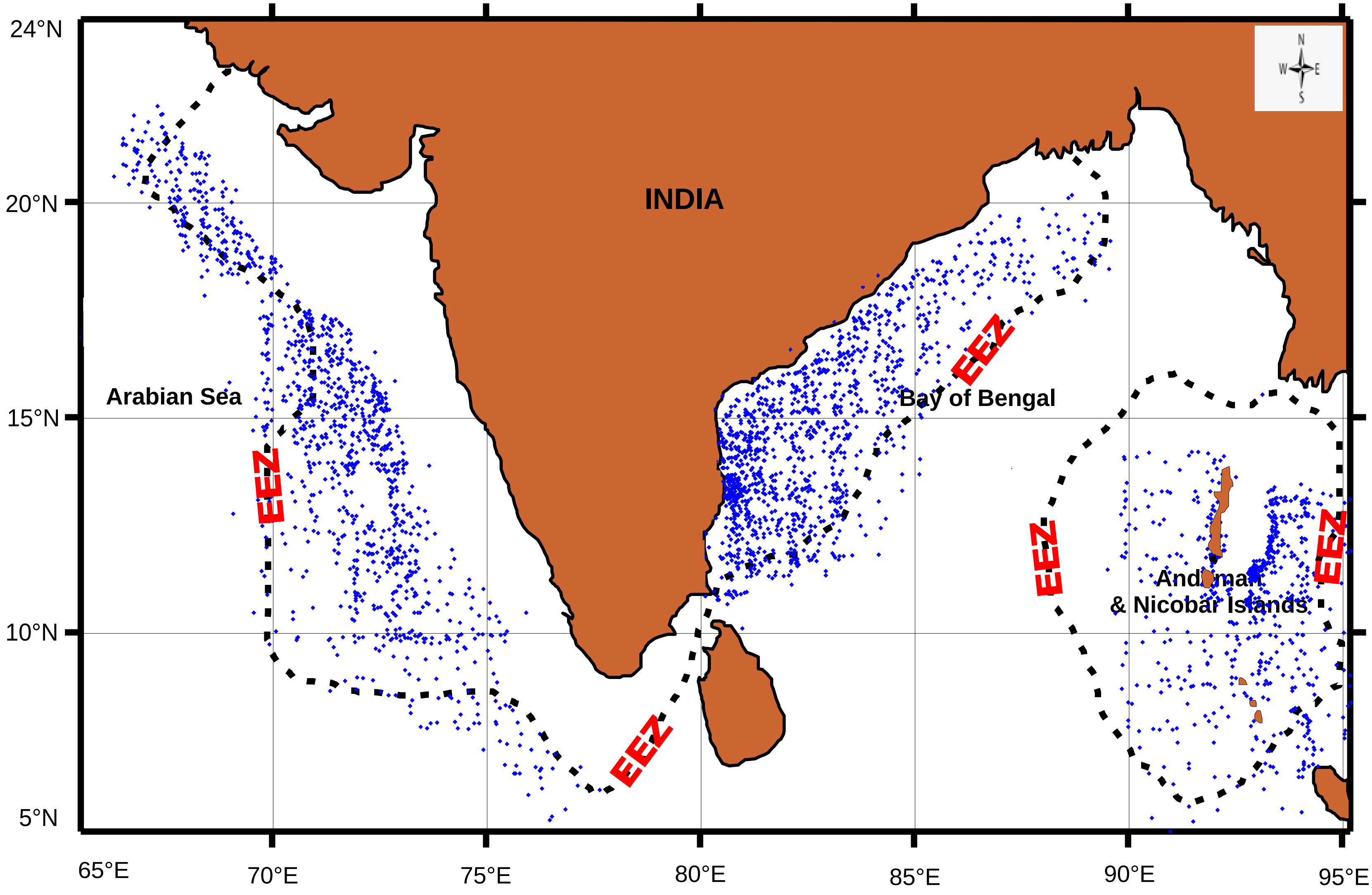


Fig.2. Percentage composition of tuna and bycatch during 2010-19 in the Indian EEZ

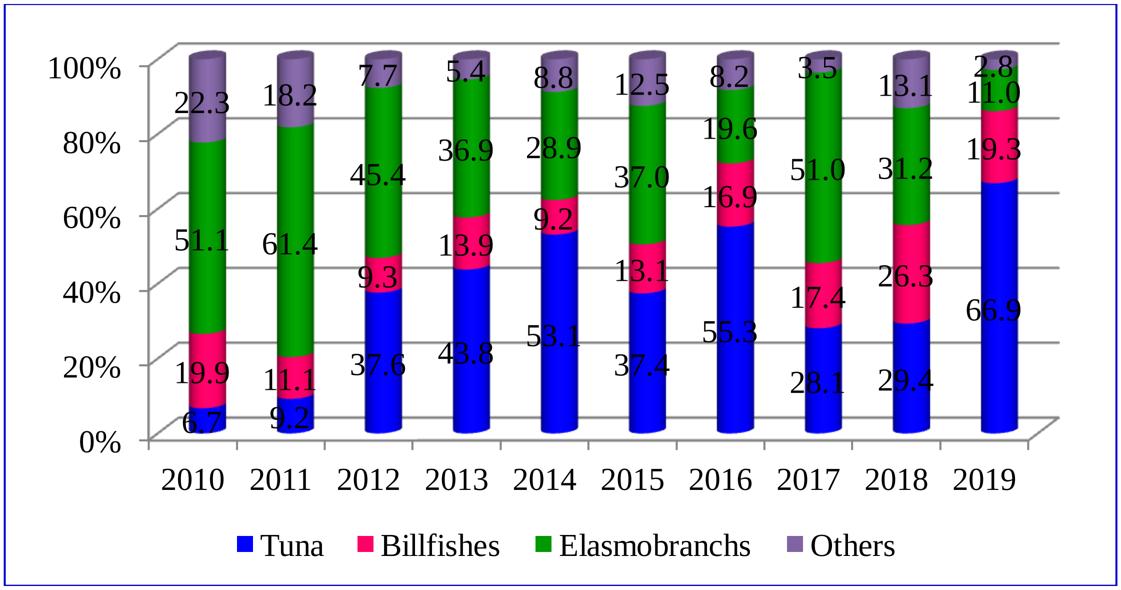


Fig.3. Hooking rate of tuna and bycatch during 2010-19 in the longline survey conducted in the Indian EEZ

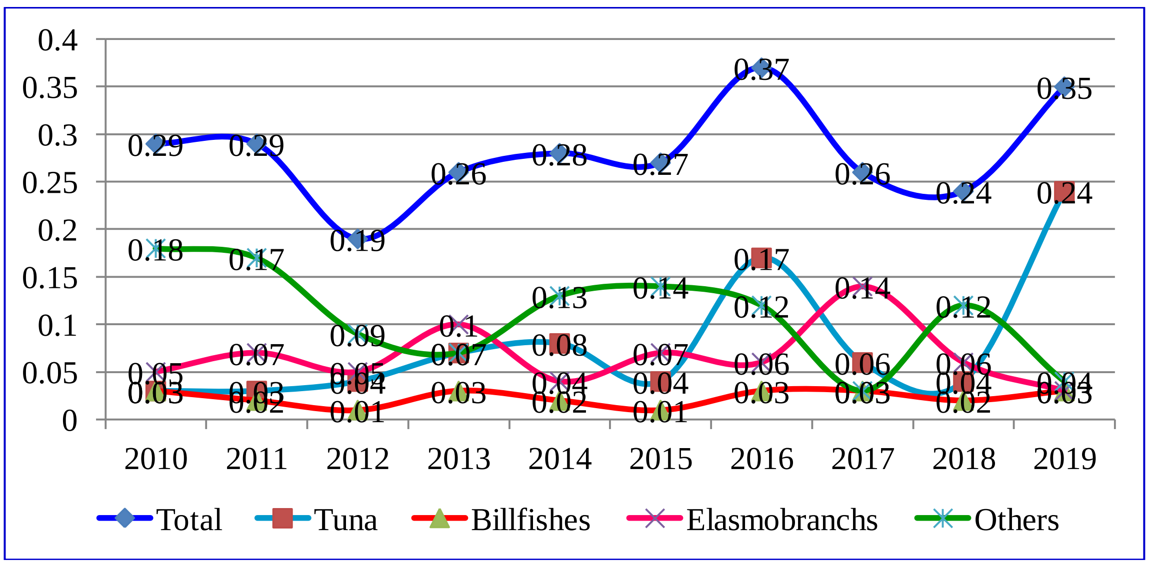


Fig.4.a. Hooking rate of tuna in the longline survey conducted in the Indian EEZ

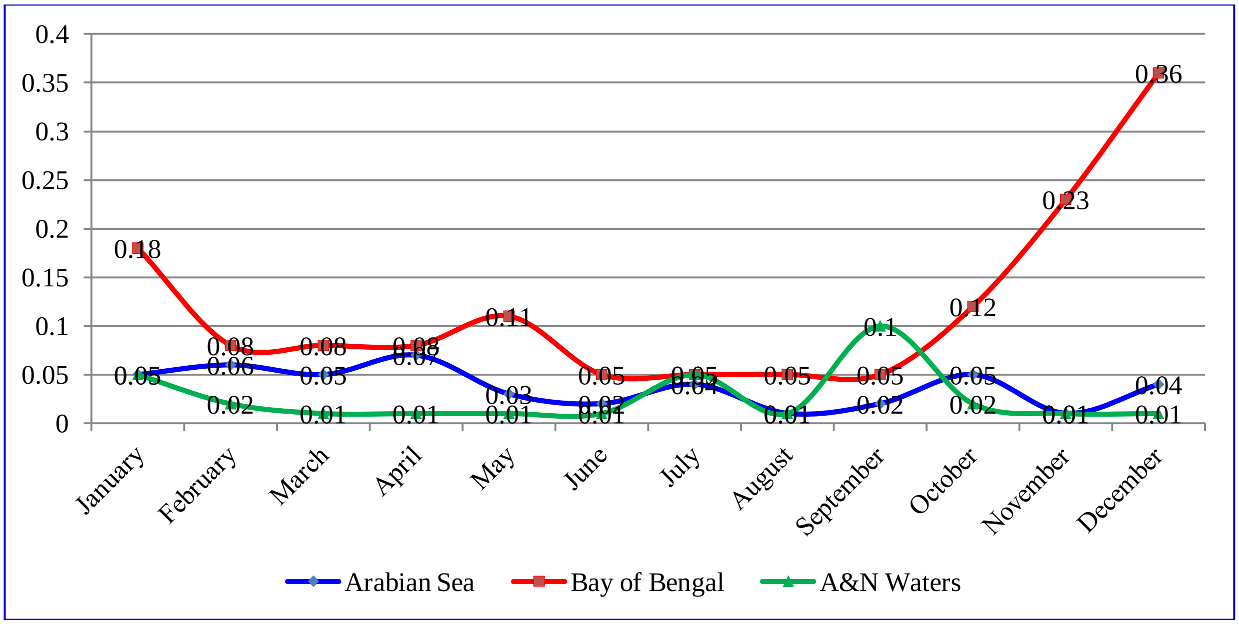


Fig.4.b. Hooking rate of billfishes in the longline survey conducted in the Indian EEZ

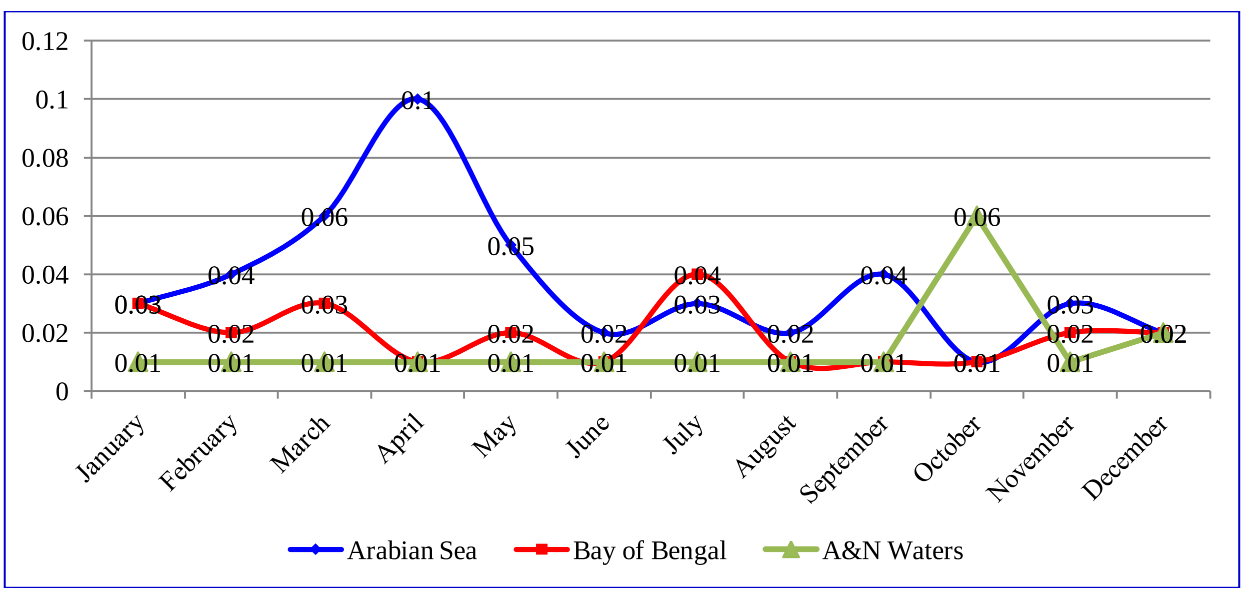


Fig.4.c. Hooking rate of elasmobranchs in the longline survey conducted in the Indian EEZ

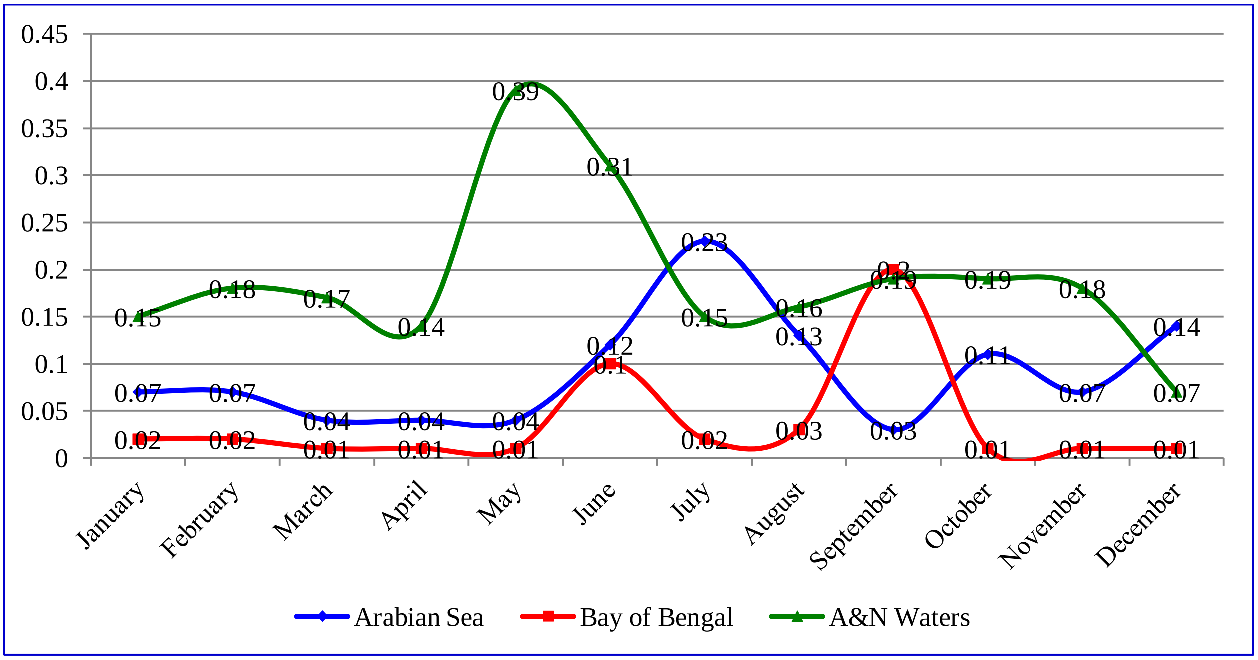


Fig.4.d. Hooking rate of other species in the longline survey conducted in the Indian EEZ

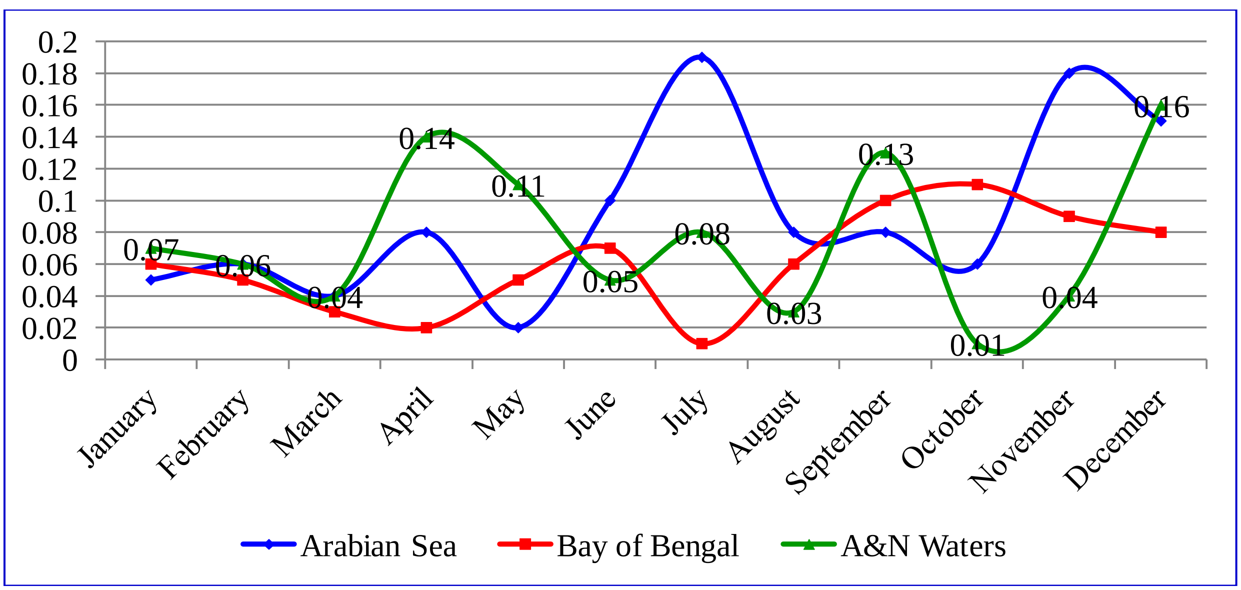
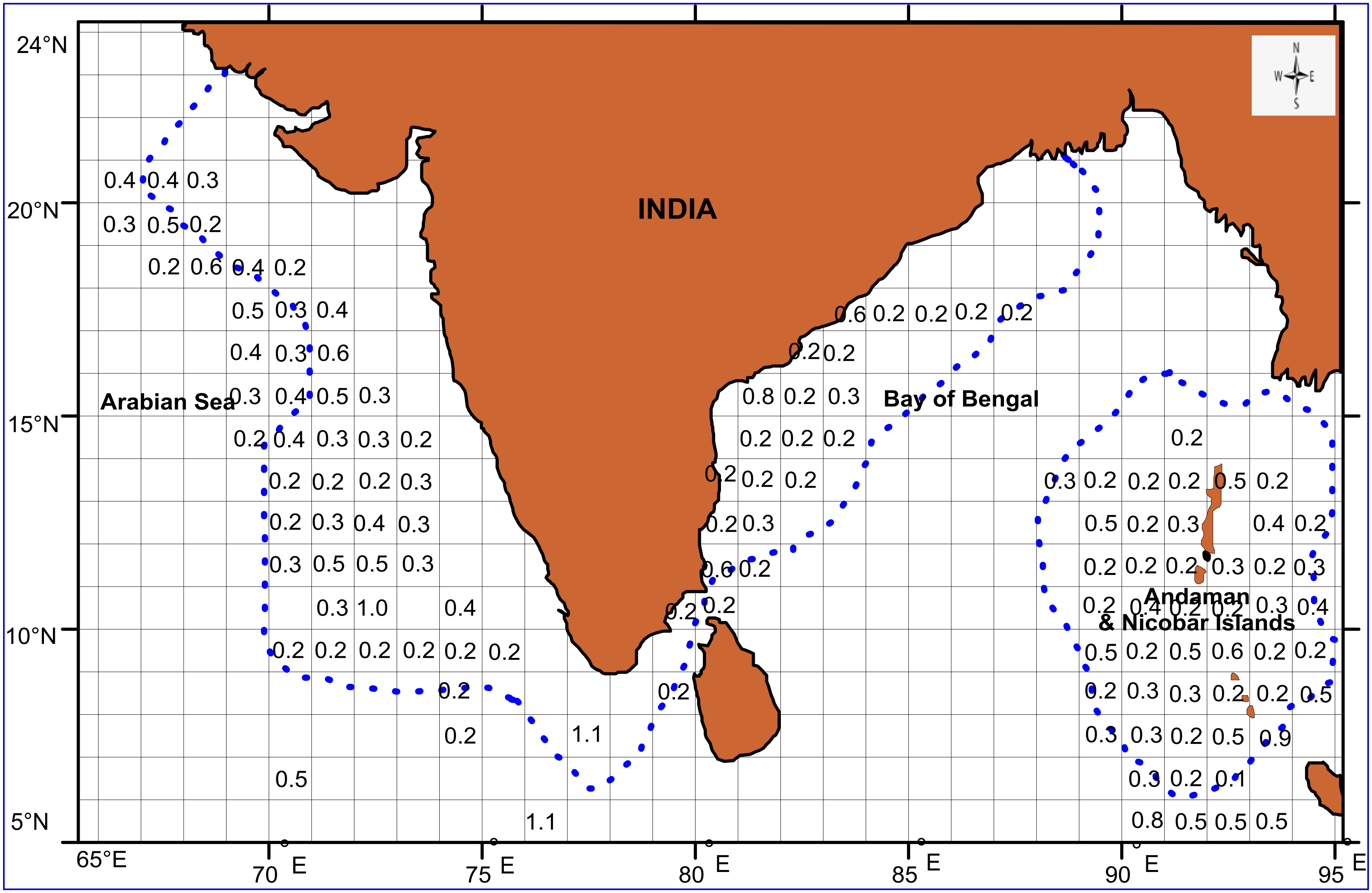


Fig.5. Abundance Indices(hooking rate in %) in 1° lat. × 1° long. of sharks during 2010-19



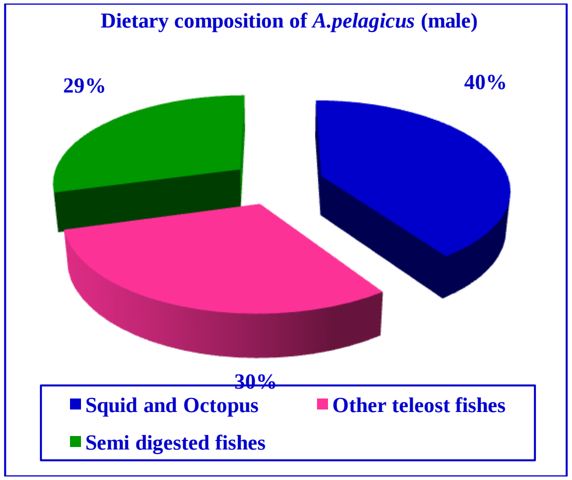


Fig.6.a

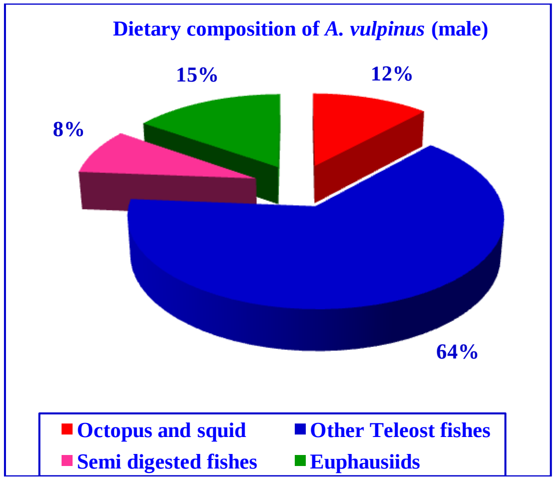


Fig.6.c

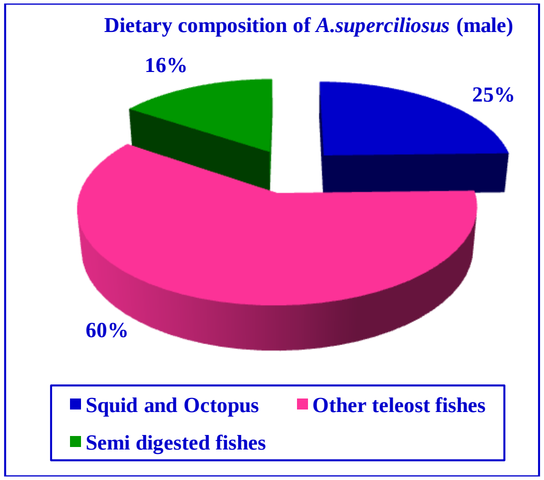
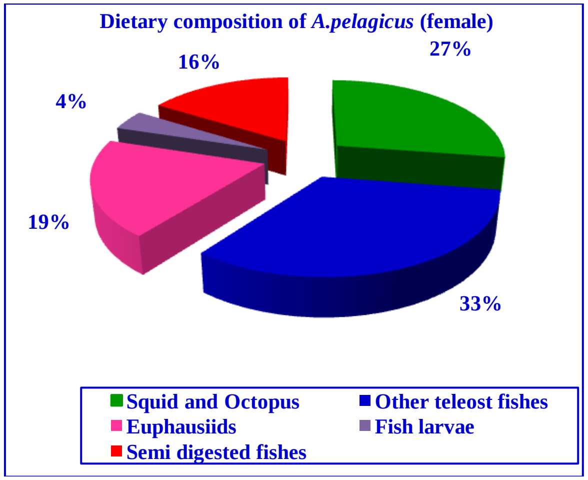


Fig.6.e



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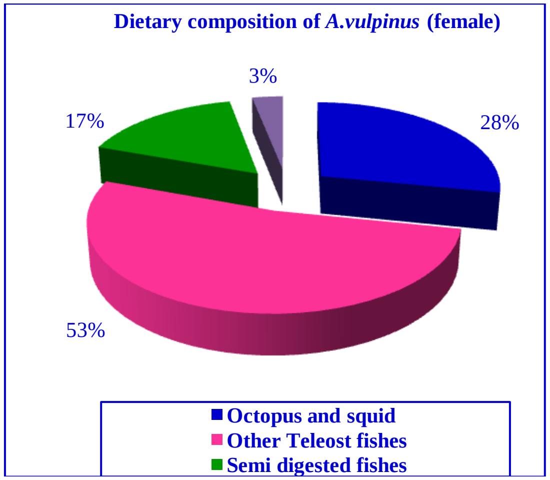

Fig.6.d

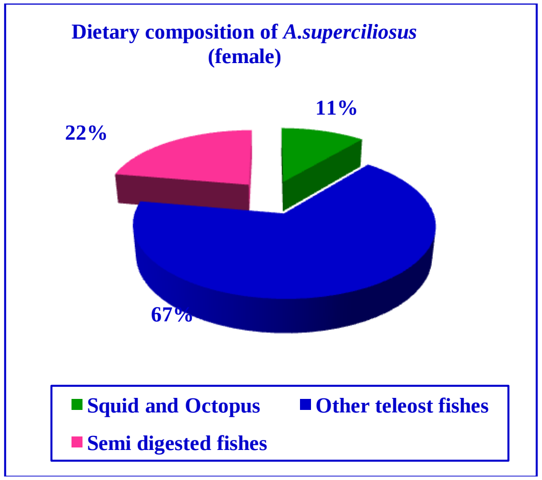

Fig.6.f

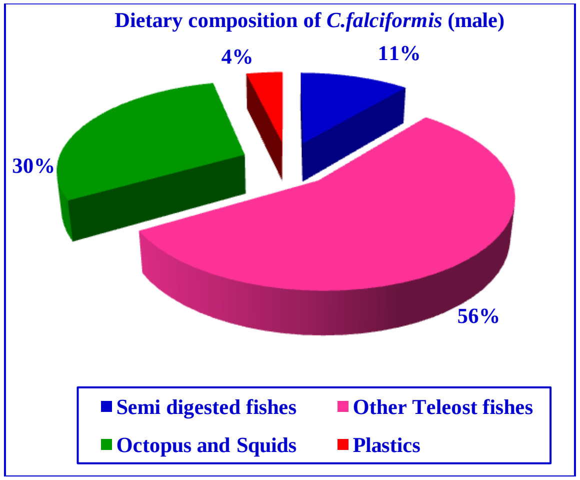

Fig.6.g

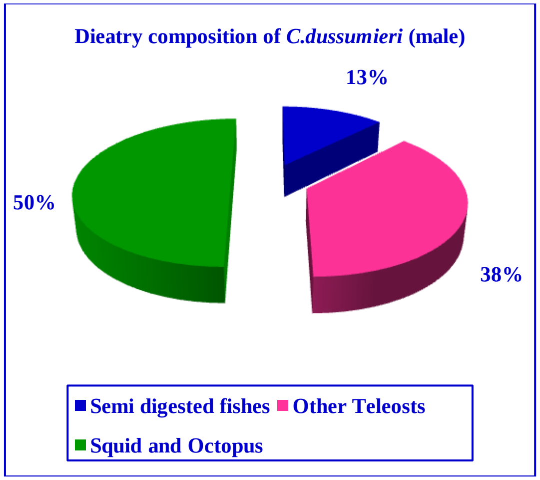

Fig.6.i

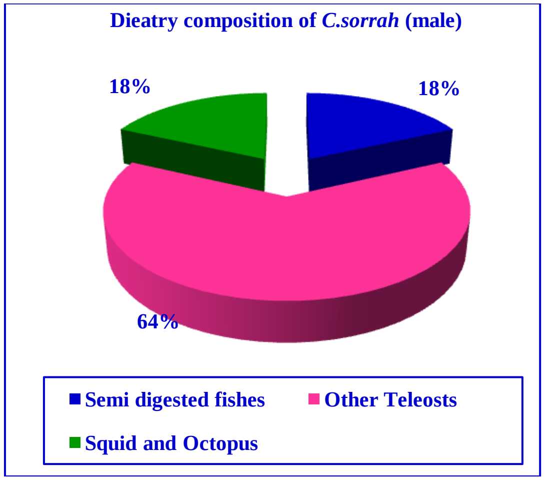

Fig.6.k

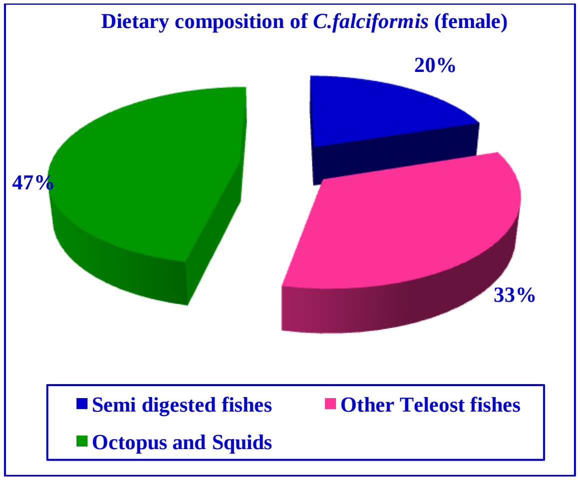

Fig.6.h

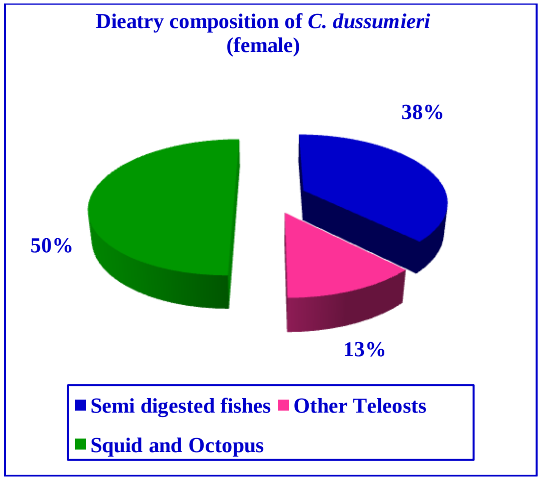

Fig.6.j

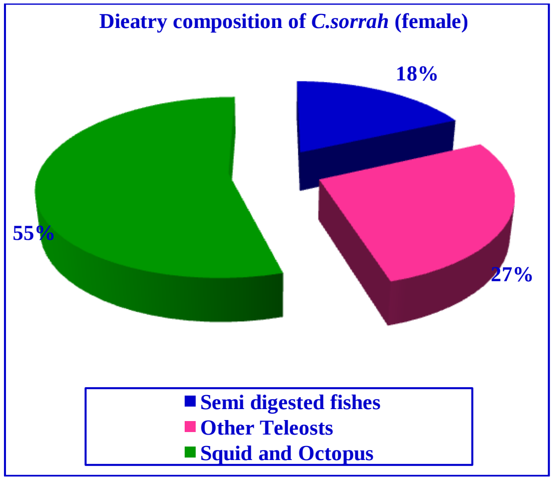

Fig.6.l

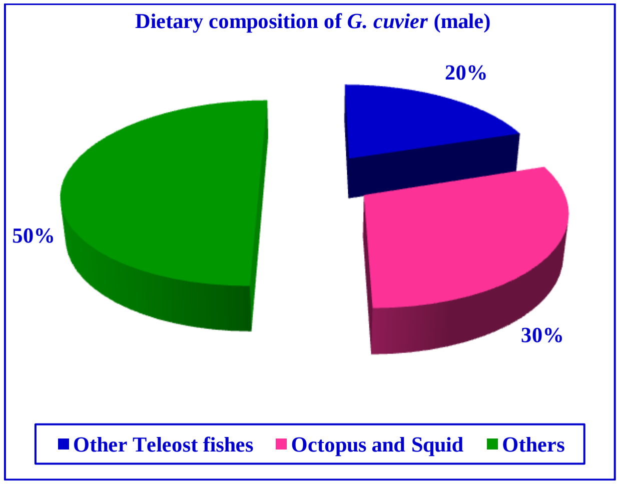

Fig.6.m

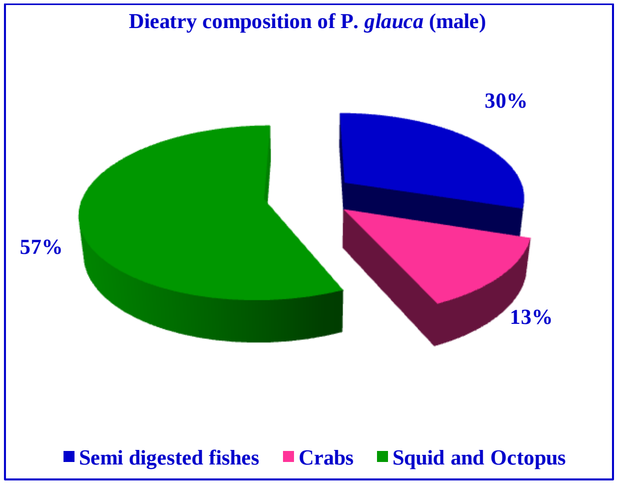

Fig.6.o

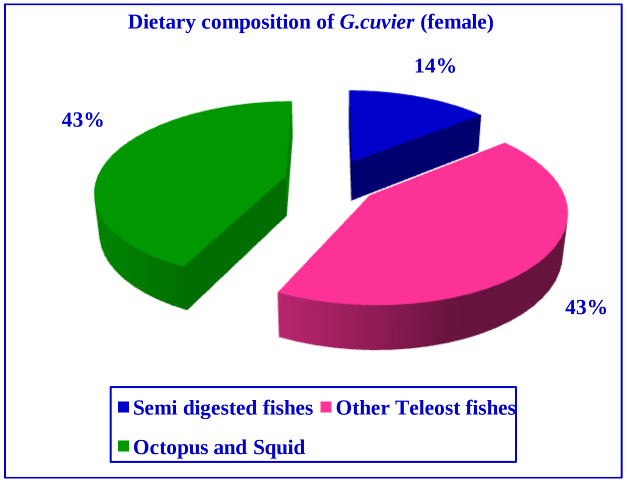

Fig.6.n

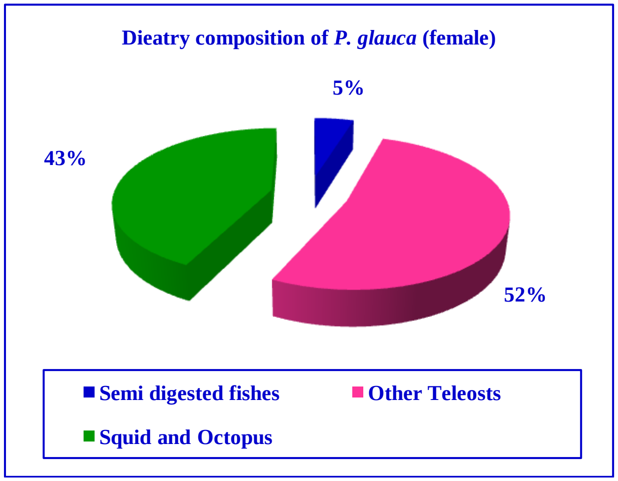

Fig.6.p

Fig. 7. Dendrogram plot showing the grouping of eight species of pelagic sharks through CLUSTER analysis with SIMPROF test using their resemblance in terms of prey preference

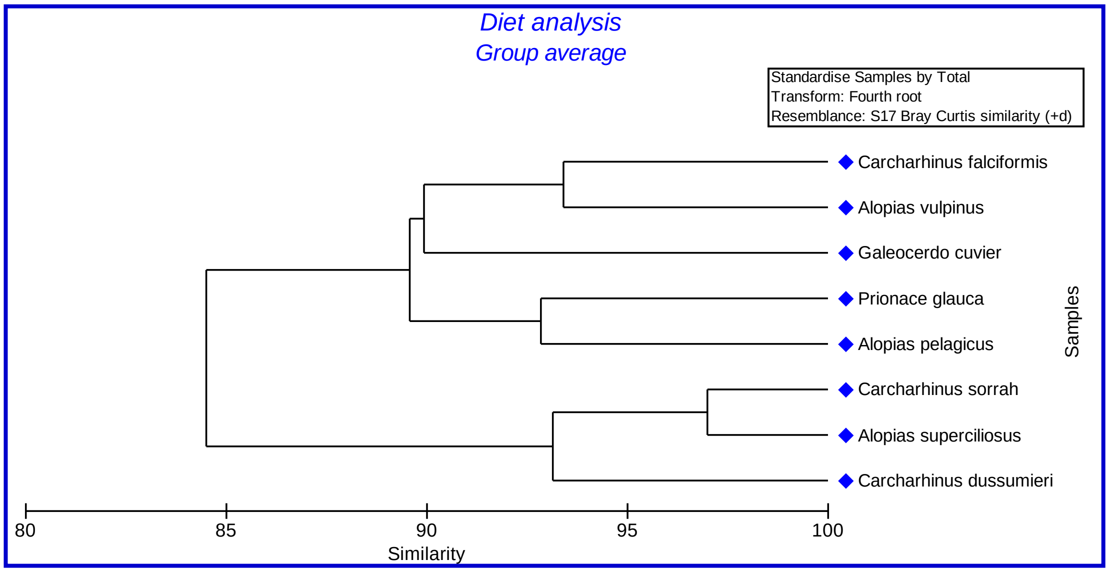

Fig 8. Non-metric multi-dimensional scaling (nMDS) plot with overlaid cluster from dendrogram plot of eight species of pelagic sharks in Indian EEZ