

Biological Aspects and Catch Trends of Elasmobranchs in the Inshore Waters of Goa, West Coast of India

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International Journal of Marine Science, 2014, Vol.4, No.45 doi: 10.5376/ijms.2014.04.0045

Received: 09 May, 2014

Accepted: 13 Jun., 2014

Published: 11 Aug., 2014

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Preferred citation for this article:

Hegde et al., 2014, Biological Aspects and Catch Trends of Elasmobranchs in the Inshore Waters of Goa, West Coast of India, International Journal of Marine Science, Vol.4, No.45 1–12 (doi: 10.5376/ijms.2014.04.0045)

Abstract Despite being the top predator, elasmobranchs are dwindling due to excessive fishing pressure. However, very few studies along Indian coasts have focused on their eco-biological aspects. The present investigation during 2006–2010 and comprising 158 trawl samples (220 h effort) along the nearshore fishing grounds of Goa revealed that the elasmobranch population comprised 10 species (2 sharks, 6 rays and 2 skates). Analysis of spatial variation revealed significant variations between the regions (abundance, $\alpha = 0.001$, $P = 0.000191$; weight, $\alpha = 0.001$, $P = 2.14E-08$) suggesting high catches along southern region, owing to lesser fresh water discharge due to absence of major estuarine system. Assessment of size class indicated that juveniles dominated the elasmobranch population with few stray occurrences of adults. Dietary analysis of the three commonly observed species revealed the dominance of teleosts (45.95% I_{RI}), followed by crustaceans (40.19% I_{RI}). Analysis of the catch trends (1969–2004) of elasmobranchs in this region indicated meagre contribution (0.05–5.04%) to the total marine fish landings of Goa. Further, the catch trends displayed decrease in recent times suggesting reduction in trophic level of the regional fishery perhaps caused by fishing out of carnivores coupled with increased catches of low trophic level fishes as evidenced in the present study. These findings have implications for the trophic web dynamics of the coastal waters, which in turn affect the coastal fisheries of the region.

Keywords Shark fisheries; Spatial variation; Temporal variations; Diets; Goa; India

Background

Goa situated on the central west coast of India with 105 km long coastline and about 10,000 km² shelf areas (Kurup et al., 1987) supports a wide array of demersal and pelagic ichthyofaunal diversity including elasmobranchs. Traditionally, the elasmobranch fisheries of Goan coast consisted of catches taken with beach seines (inshore), gill nets and hook-and-line (offshore). Mechanization of fishing vessels (1963) led to exploitation of bulk of the elasmobranchs as by-catch of bottom trawlers operating in the nearshore and offshore waters off Goa. Published literature (Raje et al., 2007) suggests that 38 species including 26 species of sharks, nine species of rays and three species of skates have contributed to the elasmobranch fishery of Goa during 1969–2004 (CMFRI, 1979; Kurup et al., 1987; Srinath et al., 2006) with an average annual landing of 461.78 mt per annum. Amongst the commercially exploited elasmobranchs, *Scoliodon laticaudus* (Müller and Henle, 1838) and *Sphyrna zygaena* (Linnaeus, 1758) attract lucrative

markets for dried products (Hanfee, 1997), however only large sized batoids are locally consumed. Large-scale discarding of elasmobranch juveniles and small sized individuals by trawlers might be the reason for the inaccurate estimation of species abundance and diversity.

Elasmobranchs being top predators play a major role in regulating the population size and dynamics of lower trophic level (LTL) fishes (Wetherbee and Cortés, 2004; Séret et al., 2010). Targeted fishing for elasmobranchs due to high demand for their meat, fins, liver and other products has resulted in increased global landings to the tune of 760,000 mt per annum (Stevens et al., 2000). Further, intrinsic biological traits such as slow growth rate, low fecundity (Holden, 1974; Jennings et al., 1998; Ebert et al., 2008), high fishing mortality coupled with juvenile discard push some species to depletion, while endangering others (Stevens et al., 2000). Although elasmobranchs have been traditionally exploited, the present rate of

elasmobranchs' exploitation seems to be highly unsustainable as there are serious concerns owing to drastically declining populations (Séret et al., 2010).

In response to global concerns over dwindling stocks of elasmobranchs as a result of overexploitation, studies pertaining to the biological traits of elasmobranchs (Cortés, 2000; Ebert et al., 2008; Abdurahiman et al., 2010), their population dynamics (Walker and Heessen, 1996; Walker and Hislop, 1998), status of exploitation (Compagno, 1990; Bonfil, 1994) and its effects on their stocks (Stevens et al., 2000; Stobutzki et al., 2002) have received attention of fisheries researchers recently (Stevens et al., 2000).

Rapid changes in demersal fishing effort as well as catch trends in the recent years along with alterations in water quality in the coastal waters and increased removal of elasmobranchs and their prey species have exacerbated the deleterious effects on the elasmobranchs populations. Hence, it was pertinent to evaluate the status of elasmobranch populations through continuous monitoring. Moreover, the elasmobranchs catch and their prey items would enable to assess the changes in their populations and its dependence on prey items. Against this background, an attempt have been made to provide baseline information on species composition, spatio-temporal variations in occurrence, size class and diet of dominant elasmobranch species collected from the fishing grounds of Goa in this communication. Further, an attempt has also been made to provide a better

insight into the status of exploitation and utilization of these resources based on elasmobranch landings of Goa during 1969–2004.

1 Results

1.1 Environmental variables

Sea Surface Temperature (SST) range during the entire study period was 26.02 – 31.03 °C with a mean value of 28.86 ± 1.14°C.

1.2 Biological aspects

1.2.1 Species composition

A total of 10 elasmobranch species (Table 1) were observed in the inshore trawl catches. Among these, only three namely *C. griseum*, *H. walga* and *S. laticaudus* were found to occur in 16, 15 and 10 % of the trawl hauls, respectively (Table 1) indicating a sizeable contribution of these species to the total elasmobranch catch. However, the contribution of the other seven species was negligible (<0.05 %; Table 1) highlighting the rarity of their occurrence. Further, only seven species namely *S. laticaudus*, *C. griseum*, *H. walga*, *Himantura gerrardi* (Gmelin, 1789), *Aetobatus flagellum* (Bloch and Schneider, 1801), *Glaucostegus granulatus* (Cuvier, 1829) and *Rhinobatus obtusus* Müller and Henle, 1841 were found to occur off both North and South Goa; two others namely *Neotrygon kuhlii* (Müller and Henle, 1841), *Pastinachus sephen* (Forskål, 1775) were found off North and *Himantura uarnak* (Gmelin, 1789) was found only off South Goa.

Table 1 Species composition, occurrence and size range of elasmobranch species examined during the present study

Sr. No.	Species	N	Frequency of occurrence (%)	Size range (cm)	Lm (cm)*	Juveniles (n)	Adults (n)
1	<i>Chiloscyllium griseum</i> (Müller & Henle, 1838)	62	16.00	11 – 581	30.6–55.01	31	31
2	<i>Scoliodon laticaudus</i> (Müller & Henle, 1838)	10	15.00	15–571	32.6–58.41	84	24
3	<i>Himantura walga</i> (Müller & Henle, 1841)	63	10.00	5–372	19.8–35.42	45	18
4	<i>Aetobatus flagellum</i> (Bloch & Schneider, 1801)	10	0.05	20–1052	29.9–53.72	06	04
5	<i>Himantura gerrardi</i> (Gmelin, 1789)	07	0.03	9–282	73.8–132.4	07	00
6	<i>Glaucostegus granulatus</i> (Cuvier, 1829)	06	0.03	9–251	99.3–128.2	06	00
7	<i>Rhinobatus obtusus</i> Müller & Henle, 1841	05	0.04	20–301	37.5–67.31	03	02
8	<i>Himantura uarnak</i> (Gmelin, 1789)	03	0.02	22–352	73.8–132.4	03	00
9	<i>Pastinachus sephen</i> (Forskål, 1775)	01	0.01	352	68.2–1242	01	00
10	<i>Neotrygon kuhlii</i> (Müller & Henle, 1841)	01	0.01	142	29.2–52.42	01	00

Note: 1 total length 2 disc width

Quantitative analysis of trawl catch data collected during the present study revealed a meagre contribution from elasmobranchs (0.42 and 0.97 % by abundance and weight, respectively). Subsequently, the above data was assorted to represent 'pre-monsoon' and 'post-monsoon' seasons. The temporal trends revealed no marked differences between the seasons (Figure 1a, b). Further, analysis

of elasmobranch abundance and weight data between the two sites (North Goa and South Goa) revealed significant variations in both abundance ($\alpha = 0.001$, $P = 0.000191$) and weight ($\alpha = 0.001$, $P = 2.14E-08$). Similarly, annual landings of Goa (2006–2010; Directorate of Fisheries, Government of Goa; Figure 2) indicated greater contribution from South Goa ($\alpha = 0.01$, $P = 0.00295$).

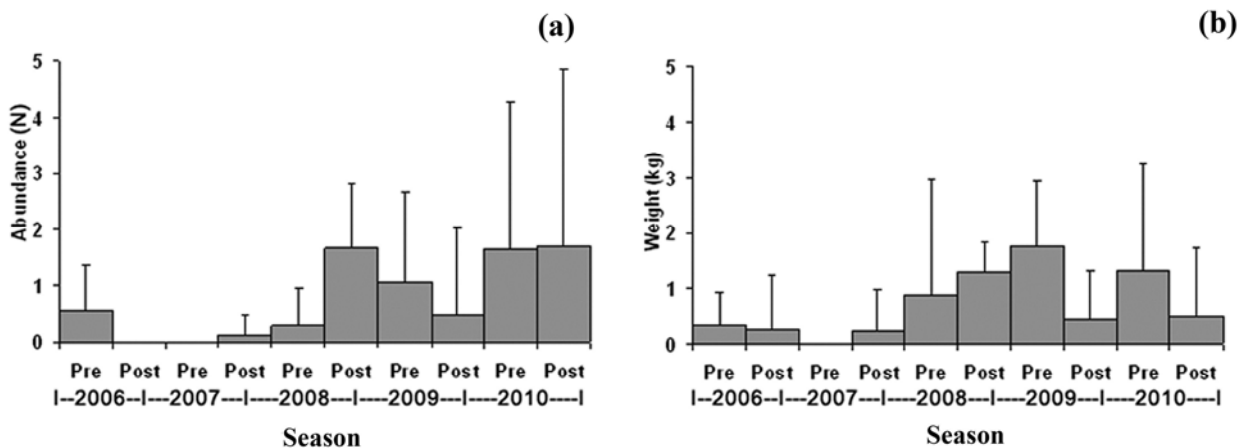


Figure 1 Seasonal variations in elasmobranch abundance (a) and weight (b)

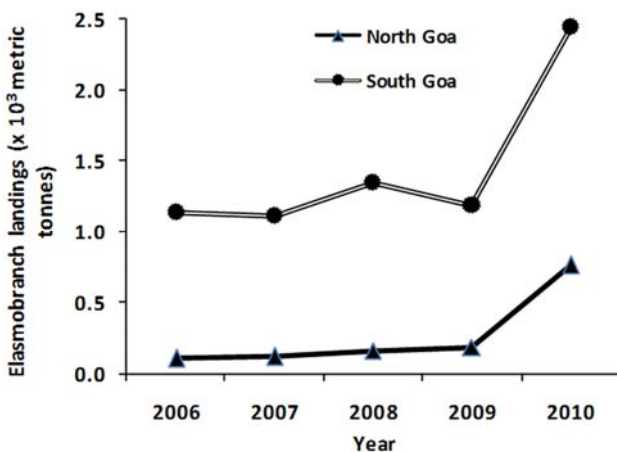


Figure 2 Elasmobranch landings along North Goa and South Goa) during 2006-2010

1.2.2 Size class and life stages

The observations on the size and their comparison with L_m values (Froese and Pauly, 2011) indicated that 72% specimens were juveniles, whereas only 28% were adults (Table 1). Species wise data indicated that *S. laticaudus*, *H. walga*, *A. flagellum* and *R. obtusus* were dominated by juveniles, *C. griseum* was represented equally by juveniles and adults, and the other five species were represented exclusively by juveniles (Table 1).

1.2.3 Diet analysis

Among the 165 guts examined, 27.27, 26.06 and 46.67% were empty, partially filled and gorged, respectively. The percentage of empty stomachs in *S. laticaudus*, *C. griseum* and *H. walga* was found to be 17, 31 and 31, respectively. Analysis of their stomach contents revealed 13 prey items (Table 2). The order of prey importance for all the observed specimens was teleosts (45.95% I_{RI}) followed by crustaceans (40.19% I_{RI}) and molluscs (13.83% I_{RI}). The Indian Oil sardine, *Sardinella longiceps* was the most important prey item of the elasmobranchs (Table 2). Further, analysis of the stomach contents revealed that crustaceans (58.85% I_{RI}), teleosts (81.50% I_{RI}) and cephalopod molluscs (55.79% I_{RI}) dominated the diets of *S. laticaudus*, *C. griseum* and *H. walga*, respectively (Table 2).

Gut content analysis of different size groups of *S. laticaudus* (Table 3) revealed that crustaceans (96.65 % I_{RI}) were the major prey item of small individuals (15–25 cm). Medium sized individuals fed on a mixed diet of crustaceans (60.05% I_{RI}), teleosts (33.14% I_{RI}) and molluscs (6.79 % I_{RI}). The diet of large individuals was dominated by teleosts (94.72% I_{RI}), whereas crustaceans were absent.

Table 2 Index of Relative Importance of individual prey items in elasmobranch diet

Sr.No.	Prey items (Faunal group-wise)	Index of Relative Importance (%)		
		<i>S. laticaudus</i> (N=71)	<i>C. griseum</i> (N=42)	<i>H. walga</i> (N=52)
I. Crustaceans				
1.	<i>Penaeus monodon</i>	4.58	0.00	0.00
2.	<i>Parapenaeopsis stylife</i>	16.11	0.00	0.00
3.	<i>Metapenaeus dobsoni</i>	9.86	12.85	0.00
4.	Mysis	1.40	0.00	4.81
5.	Unidentified prawn	11.08	0.00	23.65
6.	<i>Miyakea nepa</i>	15.82	0.00	15.73
II. Teleosts				
1.	<i>Sardinella longiceps</i>	12.83	71.03	0.00
2.	<i>Stolephorus commerso</i>	3.90	10.47	0.00
3.	Unidentified clupeid	3.45	0.00	0.00
4.	<i>Trichiurus lepturus</i>	3.93	0.00	0.00
5.	Unidentified teleost	10.52	0.00	0.00
III. Molluscs				
1.	<i>Uroteuthis duvauceli</i>	0.00	0.00	55.79
2.	<i>Sepiella inermis</i>	6.47	5.63	0.00

 Table 3 Diet matrix of *S. laticaudus* with prey items arranged in size groups indicating ontogenic shift

Sl. No.	Prey Items	Size Class		
		10–25	26–40	41–57
I.	Crustaceans	95.65	60.05	0.00
1	<i>Penaeus monodon</i>	0.00	12.78	0.00
2	<i>Parapenaeopsis stylifera</i>	17.39	0.00	0.00
3	<i>Metapenaeus dobsoni</i>	4.34	0.00	0.00
4	Mysis	39.13	0.00	0.00
5	Unidentified prawn	17.39	4.07	0.00
6	<i>Miyakea nepa</i>	17.39	43.19	0.00
II.	Teleosts	4.34	33.14	90.72
1	<i>Sardinella longiceps</i>	4.34	9.53	41.4
2	<i>Stolephorus commersonii</i>	0.00	0.00	11.5859
3	Unidentified clupeid	0.00	9.53	0.00
4	<i>Trichiurus lepturus</i>	0.00	8.40	9.27
5	Unidentified teleost	0.00	5.66	28.45
III.	Molluscs	0.00	6.79	9.27
1	<i>Uroteuthis duvauceli</i>	0.00	0.00	0.00
2	<i>Sepiella inermis</i>	0.00	6.79	9.27

Levins' diet breadth index (B) revealed that the all three elasmobranchs *H. walga* (0.76), *S. laticaudus* (0.67) and *C. griseum* (0.53) are generalised feeder which feeds on multiple prey items. Further, estimation of diet overlap among these species indicated the highest overlap between *S. laticaudus* and *H. walga* (65.61%), followed by *S. laticaudus* and *C. griseum* (34.00%). There was no overlap (0%) between *C. griseum* and *H. walga*. The trophic level of the elasmobranchs ranged between 3.75 (*C. griseum* and *S. laticaudus*) and 4.05 (*H. walga*).

1.3 Catch trends (1969–2004)

Analysis of the elasmobranch annual catch landings of Goa during 1969–2004 indicated highly variable figures (461.78 ± 363.33 mt), and their contribution to the total marine fish landings of the region during this period ranged between 0.05 and 5.04%. Elasmobranch landings during the above period did not show any particular trend (Figure 3). The initial post-mechanization period (1969) was marked with very low landings (138 mt), followed by a substantial

increase up to 1280 mt in 1979 ($R = 0.898$) and a reduction up to 29 mt in 2000 ($R = 0.786$). However, the production increased discernibly up to 1353 mt in 2004 ($R = 0.999$). Comparison of the above trends with the annual marine landings of Goa revealed an inverse relationship (Figure 3).

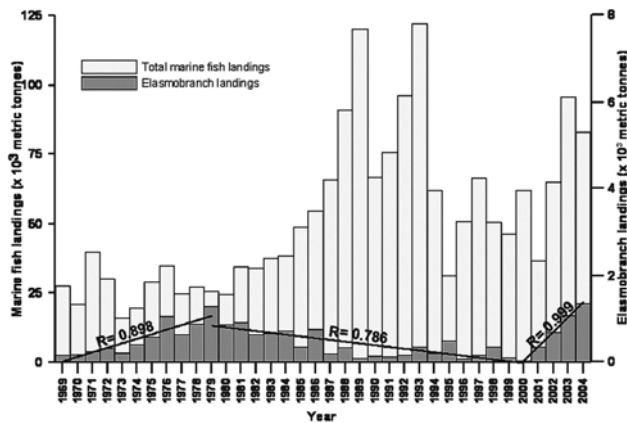


Figure 3 Landings of elasmobranchs and total marine fish landings of Goa during 1969-2004

Although, data on the elasmobranch fishery of Goa is available since 1969, assorted group-wise landings data for sharks, skates and rays is available only for the period 1981–2004. It is evident (Figure 4) that sharks were the major group and their landing trends influenced those of the total elasmobranchs during the above period. Rays occurred largely as incidental by-catch of bottom trawls and their contribution was negligible except during 2002–2004 (Figure 4).

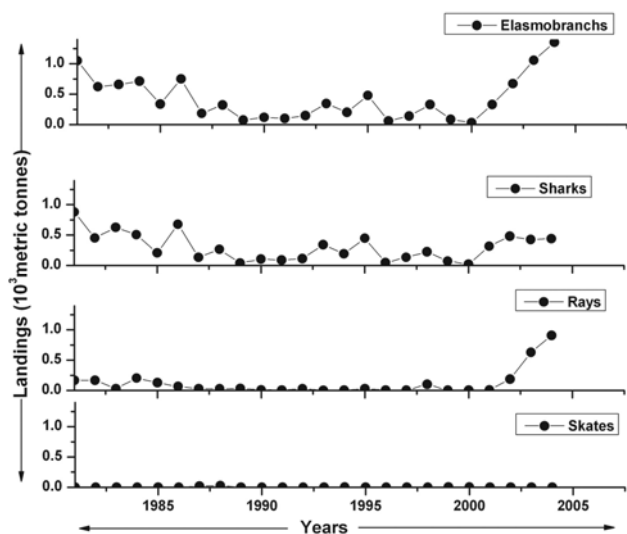


Figure 4 Catch trends of elasmobranchs including sharks, skates and rays for Goa coast (1981–2004)

Further investigation into the causes of reduction in elasmobranchs landings of Goa during 1969–2004 was done by comparing trends of their percentage contribution to the total marine fish landings with those of LTL and other HTL fishes. The graph (Figure 5) shows an inverse relationship between the trends of elasmobranchs and other HTL fishes, whereas it showed a direct relationship with LTL fishes. Hence, the data were split into two periods i.e. the initial period (1969–1979) with discernible increase in the contribution of elasmobranchs (Figure 6 a) and the later period (1979–2004) with gradual reduction (Figure 6 b). The initial upsurge in elasmobranch contribution (Figure 6b) was found to be noteworthy ($R = 0.932$) and corresponded with concomitant increase in other HTL fishes ($R = 0.953$) and reduction in LTL fishes ($R = 0.961$). On the other hand, reduction in the contributions of both elasmobranchs and other HTL corresponded with negligible increase in LTL percentage (Figure 6 b).

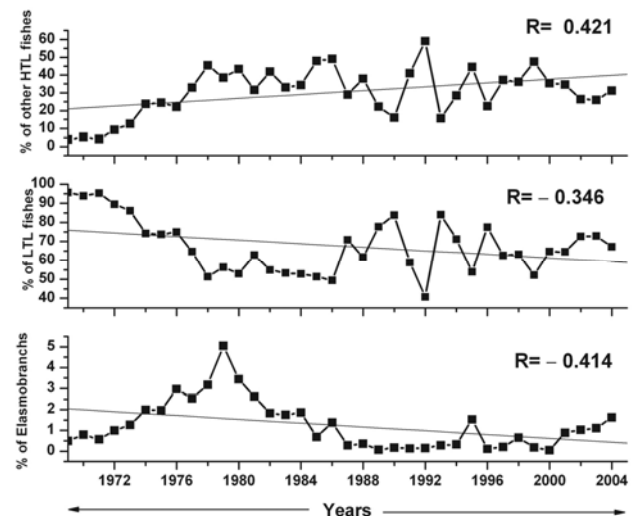


Figure 5 Trends in landings of elasmobranchs, other higher trophic level fishes and lower trophic level fishes of Goa during 1969–2004

Elasmobranch landings data collected from two principal jetties (Malim, North Goa and Betul, South Goa) indicated that two species namely *S. zygaena* and *S. laticaudus* formed the major bulk of the sharks landed at the respective jetties whereas, *C. griseum* was landed in meagre quantities along the entire region. It was further observed that the above species were mainly caught by bottom trawlers operating along the inshore waters between 20 and 80 m depths. In addition, large pelagic sharks (*Carcharhinus* spp.)

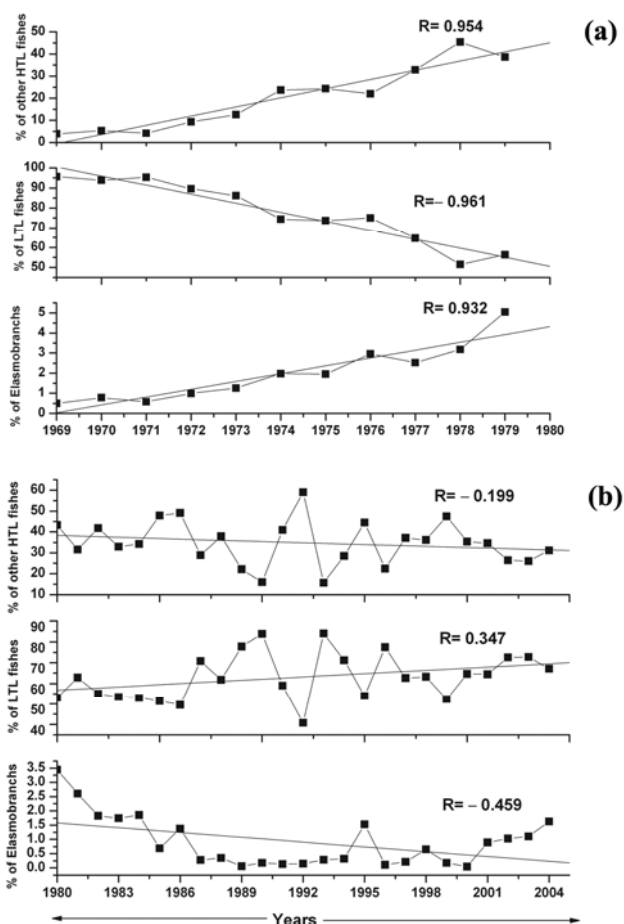


Figure 6 Trends in landings of elasmobranchs, other higher trophic level fishes and lower trophic level fishes of Goa (a) during 1969–1979 and (b) during 1980–2004

weighing up to 250 kg were occasionally landed by large mechanized vessels operating hook and line at 50–80 m depths. However, in recent times legislative ban on hook-and-line fishing has probably reduced the landings of these sharks. At present, these fishes are rarely caught in purse seines.

2 Discussion

The present observations indicated that a total of 10 species represent Goan inshore fishing grounds. Among these, only three species namely *S. laticaudus*, *C. griseum* and *H. walga* were found to be more frequent in their occurrence. Published literature (Froese and Pauly, 2011) suggested that the above species were the common inhabitants of estuarine and inshore shelf waters across the Indo-Western Pacific region. Further, the present study area along the west coast of India is highly productive (Madhupratap et al., 2001) and supports wide array of prey items consisting of demersal teleosts and epibenthic

invertebrates (Ansari et al., 1995; Padate et al., 2010) and is characterized by diverse habitats (Rao and Rao, 1974; Rodrigues et al., 1998), which provide suitable niches to elasmobranchs. The observed frequency of occurrence of these fishes in trawl catches indicated that they were subjected to intensive fishing. Available data on the fishing effort suggested that there has been a considerable rise in the number of boats operating along the Potential Fishing Zones (PFZ) in this region (Department of Fisheries, Government of Goa, 2007; Padate et al., 2009). It is mandatory to note that the other seven species were rare in abundance and occurred only in trawl catches operated in the vicinity of submerged rock reefs. It is apparent that these species preferred such habitats (Froese and Pauly, 2011) and stray individuals might have been incidentally trapped in the trawl net. The inherent biological traits such as slow growth and maturity, low fecundity and slow doubling time (Hoenig and Gruber, 1990; Stevens et al., 2000; Frisk et al., 2005; Froese and Pauly, 2011) might be the cause of their less abundance in the tropical coastal waters. However, higher elasmobranch diversity observed in the present investigation, as compared to earlier published literature (Prabhu and Dhawan, 1974; Ansari et al., 1995), could be due to intensive trawl sampling among varied habitats (estuaries, mangroves, submerged rocky patches, coral reefs and nearshore waters).

Quantitative analysis of the trawl catches revealed that the elasmobranchs contributed only 0.97% by weight, which could be attributed to the capture of juveniles of these organisms. The inshore fishing grounds off Goa serve as the primary nursery areas for juveniles of elasmobranchs (Ansari et al., 1995). Further, their reduced abundance suggests that elasmobranchs constitute an incidental by-catch of bottom trawlers (mostly designed to catch demersal prawns and ground fish), due to their ecological niche (Stobutzki et al., 2001). A comparative analysis of the present data with earlier reports (CMFRI, 1979; Kurup et al., 1987; Srinath et al., 2006) suggested that in recent years elasmobranchs' contribution to the overall trawl catches was distinctly less. This could be due to increased fishing effort as evidenced by the number of trawlers operating in this area, which are responsible for indiscriminate removal of juveniles of these species. Simultaneously, the data generated by the CMFRI is mainly based on the landings from all

fishing gears (trawlers, purse seines, long line and gill net) operating off the Goan coast.

Analysis of temporal variations using ANOVA did not reveal any significant differences between the seasons. It appears that all the three common elasmobranchs (*S. laticaudus*, *C. griseum* and *H. walga*) were residents of this region. Further, the lack of seasonal differences in their occurrence could be attributed to minor fluctuations in the water temperature ($\mu = 28.86 \pm 1.14$ °C). On the other hand, the observations made on the elasmobranch abundance between the two sampling sites showed marked differences. The northern part of the present study area is characterized by the presence of large estuaries, whereas the absence of a large estuary in the southern part highlights the role of fresh water intrusion in adjacent coastal region. This implies that due to the presence of a large estuarine system and the transient nature of elasmobranch population during most of the year, they occurred in less abundance in the northern region. On the other hand, absence of a large estuary in the southern region resulted in less freshwater discharge to the inshore shelf waters, which might be the reason for higher catches from this region. Published reports (Froese and Pauly, 2011) suggest that most of the presently recorded elasmobranchs undertake amphidromous migration.

Analysis of size class among the observed elasmobranchs indicated that juveniles dominated the population during most of the sampling duration, except December-January, suggesting that the inshore region functions as perennial nurseries for young-of-the-year and juveniles (Ansari et al., 1995). However, the occasional capture of adults along the estuarine channel during the post-monsoon season (December–January) suggested that they undertook amphidromous migration.

Elasmobranchs are voracious predators that frequent the inshore coastal waters primarily due to availability of abundant prey resources. Analysis of degree of fullness of gut content revealed low proportion of empty guts in *S. laticaudus* suggesting high feeding intensity as compared to *C. griseum* and *H. walga*. Relatively high I_{RI} values for teleosts in the elasmobranch diet were influenced by I_{RI} data of *S. laticaudus* and *C. griseum*. The dominance of natantian

decapods in the diet of *S. laticaudus* along with comparable proportion of teleosts suggested that it is a non-selective predator. It is essential to note that the inference drawn here could be biased as most of the analyzed samples were juveniles. Devadoss (1989) suggested that during post-parturition, when the fishes are unable to move fast owing to limited strength, they feed on epibenthic fishes and invertebrates. On the other hand, high proportions of a single prey group (clupeoid fishes and cephalopod molluscs) observed in the case of *C. griseum* and *H. walga*, respectively suggested that these species are specialized feeders. Further, high proportions of crustaceans and pelagic teleosts in the diet of *S. laticaudus* and *C. griseum* suggested a benthic-pelagic mode of foraging, whereas the dominance of decapods and squids in the ray diet suggested that it is an epibenthic feeder. Elasmobranchs are known to adapt to various feeding strategies depending upon the type and degree of specialization in respect of habitat, prey items and morphology (Wilga et al., 2007).

Gut content analysis of different size groups suggested that juveniles of *S. laticaudus* preferably fed on small crustaceans (Mysis and small sized *Miyakea nepa*), medium sized individuals fed on a mixed diet of large crustaceans (prawns and *M. nepa*) and variety of teleosts, whereas adults preferred teleosts. A similar observation made by Abdurahiman et al. (2010) indicated that juveniles mostly feed on epibenthic crustacean and slow moving organisms whereas adults feed on benthic and pelagic teleosts. It is known that carnivorous fishes become more ichthyophagous with size and age (Renones et al., 2002). This could be attributed to the differences in locomotion and ability to catch prey at different life stages (Devadoss, 1989) suggesting a tendency for an ontogenic shift in the diet.

Diet breadth (B) analysis for the above three species suggested that they were generalist feeders, which consumed a wide array of prey items including penaeid prawns, stomatopods, clupeoid fishes and cephalopods. Published literature (Ellis et al., 1996; Raje, 2003; Navia et al., 2007; Gutteridge et al., 2011) suggested that epibenthic crustaceans, cephalopod molluscs and teleosts were the common prey items of elasmobranchs worldwide. Diet overlap between species is related to the degree of competition among organisms under conditions of limited resource

availability (Odum, 1971). High percentage of diet overlap between *S. laticaudus* and *H. walga* suggested that both the species were generalist feeders of epibenthic crustaceans. However, despite occupying similar trophic levels, the low degree of diet overlap between *S. laticaudus* and *C. griseum* suggested that availability of wide array of prey items could have resulted in resource partitioning among these species (Burrell, 1992). Secondly, differences in mouth morphology, dentition and or feeding behaviour may influence degree of competition towards resource utilization (Scrimgeour and Winterbourn, 1987).

Despite being the top predators in the marine ecosystem, elasmobranch populations are dwindling. The meagre contribution of elasmobranchs to the total marine fish landings of Goa during 1969–2004 despite the increased fishing effort suggests the absence of an organized elasmobranch fishery off Goa. The reported figures could be inaccurate as elasmobranchs form incidental by-catch of bottom trawlers, purse seines and gill nets, and depending on their size, they are either utilized or discarded. Moreover, Illegal, Unreported and Unregulated (IUU) fishing of demersal species is known to occur during the monsoon ban period, when fishing vessels from neighbouring states harvest catches in the coastal waters off Goa and land them in their respective home states (Pramod, 2010). However, such catches are not evaluated. An inverse relationship between the total marine fish landings and elasmobranch landings suggested that much of the fishing effort was concentrated towards the exploitation of LTL (sardines, mackerels, prawns) and other HTL fishes (tuna, perch-like fishes, flatfishes). The fishing effort in terms of mechanized vessels operating along the Goan shelf waters has increased from only four vessels in 1963 to 1152 in 2004 (Directorate of Fisheries, Government of Goa) suggesting that the expansion of marine fishery resulted in exploration of deeper waters (> 40 m depth), which support substantial stocks of HTL and LTL organisms (Rodionov, 2005). Among the three groups listed by the CMFRI – sharks, skates and rays, the former dominated the elasmobranch landings during the post-mechanization period. This is mainly due to the contribution of trawlers, purse seines and gill nets those harvested large quantities of *S. laticaudus* and *S. zygaena* at 30-50 m depths off Goa. On the other hand, relatively meagre catches of

batoid fishes during the above period may be attributed to discarding of under-sized juveniles back into the sea, owing to lack of commercial value (personal observation). Secondly, there is no record of the discarded fraction of the elasmobranch by-catch that resulted in poorly documented batoid fish catches. Bonfil (1994) opined that lack of authentic information on biological aspects of elasmobranch by-catch across the globe stemmed out of inadequate recording of elasmobranch catches.

Decreasing trends of elasmobranchs and LTL fishes with a simultaneous increase in other HTL fishes during 1969–2004 suggested shift in the fishing effort. A significant variations in trends of these resources during 1969–1979 suggested that although the quantum of fishing with traditional crafts and gears did not vary substantially, further expansion of the mechanized fishery during this period led to increased harvesting of HTL fishes from deeper waters (up to 80 m depth). The recent catch trends (1979–2004) displaying decrease in elasmobranchs and other HTL fishes with a simultaneous increase in LTL fishes resulted in decrease in the Marine Trophic Index along this region.

Despite the increase in fishing effort in the shelf waters (30–80 m depths) that supported the bulk of the elasmobranch landings (personal observation), there was no increase in their catches corresponding to increase in HTL fishes (Figure 6) suggesting the role of the biological attributes of these species. The 38 elasmobranch species listed by the CMFRI as bulk contributors towards the elasmobranch fishery off the Southwest coast of India are known to be long-lived with slow growth rate, late maturity and low fecundity (Raje et al., 2007). All the above attributes make these species highly vulnerable to the ever-increasing fishing effort. Most of the individuals caught in demersal fishing gear are young-of-the-year and juveniles, which are discarded back into the sea and whose recruitment to the coastal ecosystem depends on their survival rate. However, there is no documentation of survival of these under-sized individuals. Further, there is no assorted data on species and gear available for landings of large sharks.

3 Materials and Methods

3.1 Study site

The 105 km long coastline of Goa is aligned NNW-SSE, faces the Arabian Sea with diverse

bathymetry (Wagle, 1993) and habitats (Rodrigues et al., 1998). The coastal waters receive perennial nutrient-rich freshwater influx from the adjoining estuaries, particularly the Mandovi-Zuari estuarine complex (15°25'N-15°31'N and 73°45'E-73°59'E; Qasim and Sen Gupta, 1981).

The present study area (Figure 7) comprised (i) inshore fishing grounds (sand-silt substratum), lower regions of Mandovi-Zuari estuaries (clayey substratum), Aguada and Mormugao bays (mixed substratum interspersed with submerged rocky patches) situated between 15°28'N-15°32'N and 73°45'E-73°57'E, and (ii) fishing grounds off the mouth of Sal estuary (15°00'N-15°16'N and 73°00'E-74°41'E) comprising two different habitats i.e. silty substratum towards the north of the mouth and submerged rock outcrops towards the south. In addition, occurrence of tropical reef fishes in the inshore trawl catches during the present study suggested the presence of coral reef patches towards the south of the estuary (Padate et al., 2010).

3.2 Sample collection

Sample collection involved participation in fishing trips onboard commercial fishing trawlers to collect fishes (both elasmobranchs and teleosts). Samples collected from 158 bottom trawls (total fishing effort of 220 h) during 2006-2010 formed the study material. Seasons were defined as monsoon (June–September), post-monsoon (October–January) and pre-monsoon (February–May). Sampling was not carried during the monsoon due to a fishing ban (Goa Marine Fishing Regulation Act, 1981). Geographical position of each sampling station was recorded with 12-Channel Geographical Positioning System (GPS) and sampling depth was obtained from Naval Hydrographic Chart No. 2022. Trawl net with 20 m head and foot rope lengths, and mesh sizes of 25, 15 and 9 mm at mouth end, middle and cod end, respectively was towed at an estimated speed of 2–3 knots.

Initially, the trawl catch was examined for species composition. In the case of trawl hauls, five sub-samples, each weighing approximately 1 kg were randomly picked. Out of the 158 trawl hauls, 128 yielded catch in excess of 30 kg, hence only these were subjected to sub-sampling.

3.3 Auxiliary data

Sea surface temperature (SST) data was obtained from Group for High Resolution Sea Surface Temperature (GHRSSST) Level 4 (AVHRR) Advanced Very High Resolution Radiometer, Path Finder, available at POET.PODAAC website.

3.4 Species identification and size

Taxonomic identification involved meristic counts and morphometric measurements up to the nearest 0.01 cm using vernier callipers. Life stage of specimens was determined by comparing the present morphometric data with published data on length at first maturity (L_m) (Froese and Pauly, 2011; Palomares and Pauly, 2011). For this comparison, two morphometric parameters namely Total Length (for sharks and skates) and Disc Width (for rays) were used for comparison.

3.5 Diet analysis

A total of 165 guts belonging only to three species *Scoliodon laticaudus*, *Chiloscyllium griseum* (Müller and Henle, 1838) and *Himantura walga* (Müller and Henle, 1841) were analyzed for their feeding habits, due to insufficient number of specimens of the other

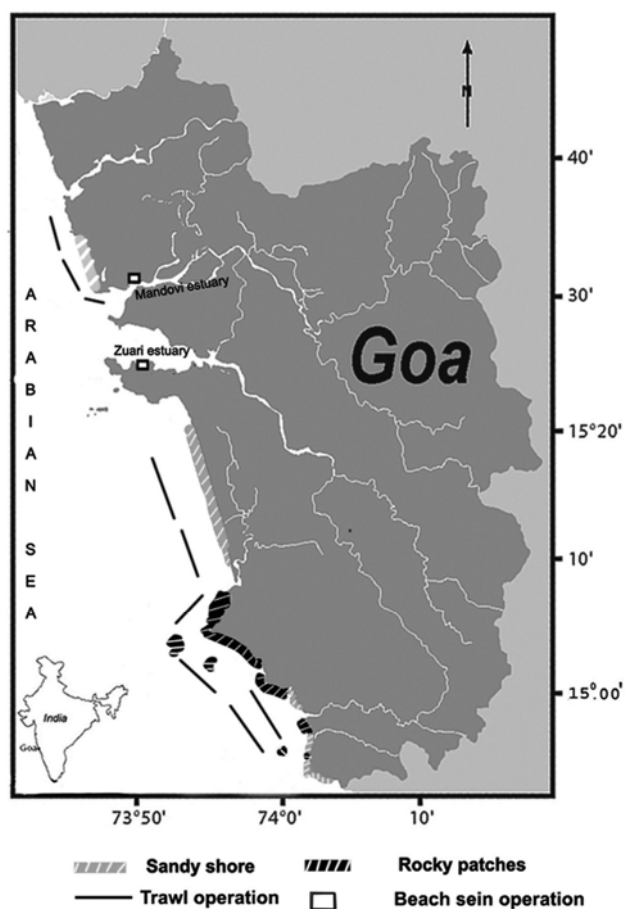


Figure 7 Map of the study area indicating sampling sites

species. Body parameters (length, weight) of the specimens were measured, followed by removal of the gut, which was subsequently weighed and preserved in 70% alcohol. Degree of fullness of stomach was categorized as empty, partially filled or full following Hyslop (1980) and the contents were examined under microscope. Stomach contents were identified up to the lowest possible taxon following FAO species identification sheets (Fischer and Bianchi, 1984; Carpenter and Niem, 1998).

Further, only *S. laticaudus* was selected to assess ontogenic shift in the diet as both juvenile and adult specimens were available. These samples were categorized into three different size groups namely small (10–25 cm, juveniles), medium (26–40 cm, sub adults), large (41–57 cm, adults) and the percent Index of Relative Importance (I_{RI}) for each prey item for the all size groups was calculated.

3.6 Data analysis

Species abundance and weight data from all the five sub-samples of each trawl haul were summed up to represent a single sample and standardized to 60-min trawl in view of the variability in trawling duration. Subsequently, spatio-temporal trends of elasmobranch abundance and weight were computed and comparisons by season and site were analyzed by ANOVA (Sokal and Rohlf, 1987) using the Microsoft Excel 2007 program.

Stomach content data was compiled and Index of Relative Importance " I_{RI} " (Pinkas et al., 1971) was computed to evaluate the importance of each prey item.

$$I_{RI} = (\% N_i + \% W_i) \times \% FO_i$$

where N_i , W_i and FO_i represent percentage of number, weight and frequency of occurrence of prey "i", respectively.

Index of diet breadth " B " of a species (Levins, 1968) was computed to establish the level of specialization of each examined species and to identify whether it is a generalist or specialist feeder.

$$B_i = [(\sum_j p_{ij}^2)^{-1} - 1] (n-1)^{-1}$$

where, B_i is Levins' standardized index for predator "i", p_{ij} is the proportion of the diet of predator "i" that is made up of prey "j", n is the number of prey items.

Dietary similarity index " S " (Linton et al., 1981) was computed to evaluate the extent of diet overlap between the commonly observed species.

$$S = 100 (1 - \frac{1}{2} \sum |P_{xi} - P_{yi}|)$$

where, P_{xi} and P_{yi} are the proportions of the diets of the species examined 'x' and 'y' respectively, of prey 'i'.

Trophic level of the species was computed to assess the position of the examined species in the food web (Christensen and Pauly, 1992).

$$TL_i = 1 + \sum_{j=1}^n (DC_{ij} \cdot TL_j)$$

where, TL_i is the trophic level of the species "i", DC_{ij} is the proportion of the prey species "j" in the diet of "i", TL_j is the trophic level of the prey species.

3.7 Collection and analysis of fishery data

Marine fish landing data of Goa for the periods 1969–2004 (CMFRI) and 2006–2010 (Directorate of Fisheries, Government of Goa, 2011) were obtained and the trends in overall elasmobranch fisheries of Goa as well as assorted data for sharks, rays and skates were compared with fishing effort (number of fishing vessels) for the above period. Subsequently, the elasmobranch trends during 1969–2004 were compared with trends of other higher trophic level (HTL) and lower trophic level (LTL) species during the same period.

Authors' contributions

MRH and VPP carried out sampling for the study along the potential fishing grounds off Goa, followed by taxonomic identification of elasmobranchs and their seasonal distribution. MRH also carried out the dietary analysis of the biological samples and interpreted the same. VPP interpreted the overall results of the current work and discussed the same in the manuscript. CUR planned, designed and participated in the field work and guided in interpreting the manuscript.

Acknowledgements

The authors are grateful to the Ballast Water Management Programme, India executed by the National Institute of Oceanography (CSIR), India for Directorate General of Shipping, Ministry of Shipping, Government of India. The first author was supported by University Grants Commission (UGC), Government of India. We thank the crew of the trawlers for allowing us to collect samples for the study. The regional data on fish landings (2006-2010) was made available by the

Directorate of Fisheries, Government of Goa and is gratefully acknowledged.

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