FISHERY AND BIOLOGY OF DEEP-SEA CHONDRICHTHYANS OFF THE SOUTHWEST COAST OF INDIA

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June 2014

Declaration

I, Akhilesh K.V., do hereby declare that the thesis entitled **FISHERY AND BIOLOGY OF DEEP-SEA CHONDRICHTHYANS OFF THE SOUTHWEST COAST OF INDIA** is a genuine record of research work carried out by me under the guidance of **Dr. N.G.K. Pillai** (Former Head, Pelagic Fisheries Division, Central Marine Fisheries Research Institute, Kochi, India) in partial fulfilment for the award of Ph.D. degree under the Faculty of Marine Sciences, Cochin University of Science and Technology, Kochi and no part of the work has previously formed the basis for the award of any degree, diploma, associateship, or any other title or recognition from any University/Institution.

Akhilesh K.V.

Kochi-682 018

June 2014

Certificate

This is to certify that the thesis entitled **FISHERY AND BIOLOGY OF DEEP-SEA CHONDRICHTHYANS OFF THE SOUTHWEST COAST OF INDIA** submitted by Mr. **Akhilesh K.V.** (Reg. No. 3478) is an authentic record of research work carried out by him under my guidance and supervision at Central Marine Fisheries Research Institute, Kochi (Kerala) in partial fulfilment of the requirement for the award of Ph.D. degree in Faculty of Marine Sciences, Cochin University of Science and Technology, Kochi (Kerala) and no part of this has previously formed basis for the award of degree or associateship in any University or Institution.

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CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Chapter 1

General Introduction

Chapter 1

General Introduction

Class Chondrichthyes is one of the oldest groups of vertebrates, which survived for more than 400 million years since Devonian period, and the second largest class of fishes after Osteichthyes. Chondrichthyes can be differentiated from Osteichthyes (bony fishes) based on the presence of placoid scales, which has been replaced by scales in fishes and possessing simple internal skeletons formed of calcified cartilage and no true bones (Last and Stevens, 2009). The body forms of Chondrichthyes shares many similar characteristics, but is highly varied between orders, reflecting adaptations to lifestyle, habitat and environment (Compagno, 1999). Class Chondrichthyes is a monophyletic group and is divided into two subclasses, the Holocephali (*holo*=whole, *cephalic* =head) containing Chimaeras and the Elasmobranchii (*elasmo* =plate, *branchii* =gills) containing sharks, skates and rays. Elasmobranchii can be differentiated from chimaeras in having multiple paired gill openings (5-7), where as the latter have only single gill opening (Fowler *et al.*, 2005).

Chondrichthyans are a diverse taxonomic group; their systematic arrangements and phylogeny are mostly unresolved. Early taxonomic works such as that by Bigelow and Shroeder (1948) suggested that there are fundamental splits in batoids and sharks, while the recent studies (Compagno, 1977) suggested batoids are derived from sharks (such as saw sharks and angel sharks). The most discussed modern cladistic classifications of elasmobranchs are by Carvalho, 1996; Shirai, 1996; Compagno, 2001 and Compagno, 2005 (Table. 1). Recently genetic and molecular data has been widely used to make phylogenetic tree and to solve the issues related to chondrichthyan phylogeny, interrelationships, radiation and evolution (Douady, 2003; Puckridge *et al.*, 2013). Though there are several classifications presented for chondrichthyes (eg. Mould, 1997), most widely used and recognized classification is that of Compagno (2005).

Table 1.1. Orders of Class Chondrichthyes

Class	Subclass	Super order		Order	Common names
	Holocephali			Chimaeriformes	Chimaeras
		Squalomorphii		Hexanchiformes	Cow and frilled sharks
				Squaliformes	Dogfish sharks
				Squatiniformes	Angel sharks
				Pristiophoriformes	Saw sharks
		Galeomorphii		Heterodontiformes	Bullhead sharks
				Orectolobiformes	Carpet sharks
				Lamniformes	Mackerel sharks
				Carcharhiniformes	Ground sharks
Chondrichthyes	Elasmobranchii		Batoids	Rajiformes	Skates and guitarfish
				Torpedeniformes	Electric rays
				Pristiformes	Sawfishes
				Myliobatiformes	Stingrays

(Source: Compagno, 2001; Compagno, 2005; Ebert, 2013)

Global chondrichthyan fauna consist of approximately 1276 species, of which more than 100 species were described only in the recent years (Ebert *et al.,* 2013; Eschmeyer and Fong, 2014) and still new species are being discovered and described in each year. Chondrichthyans are found throughout the oceans and occupy diverse habitats in aquatic systems like freshwater lakes, rivers, estuaries, coastal waters, reefs, open-ocean and the deep-sea. Some chondrichthyan species are cosmopolitan and have wider distribution range in the oceans eg. Blue shark *Prionace glauca,* Whale shark *Rhincodon typus,* Pelagic stingray *Pteroplatytrygon violacea* and Tiger shark *Galeocerdo cuvier*. A few species are found in particular areas, isolated from other regions or endemic to certain localities eg. Pyjama shark *Poroderma africanum,* Maltese skate *Leucoraja melitensis,* Yellownose skate *Dipturus chilensis, Gummy* shark *Mustelus lenticulatus* etc.

Chondrichthyans are highly susceptible to over exploitation. Complex life history characteristics like slow growth, longevity, late sexual maturity and low fecundity together known as *K* selected life history strategies, make them vulnerable to fishing (Stevens *et al.,* 2000). Chondrichthyan life history and biology are poorly known and this limited information has made it difficult to determine the specific vulnerability to exploitation and has hampered conservation and management plans (Frisk *et al.,* 2001). A few elasmobranch species are known to exhibit geographic variability in their life history traits and may respond variably to exploitation (Kuparinen and Merila, 2007), thus warranting region specific management plans. The increased targeted fishery for elasmobranchs and their heavy bycatch in the commercial fishery have created an international concern over the sustainability of the group.

Chondrichthyan fishery of the world

Chondrichthyans have been important as food since immemorial times and have been used by Persians and Cretans in the coastal regions for over 5000 years (Vannuccini, 1999). They are currently important as food and processed/ pharmaceuticals products. In targeted elasmobranch fishery, sharks have more importance than skates, rays and chimaeras. One of the earliest account of targeted elasmobranch fishery in the world dates back to 18th century, harpoon fishery for Basking shark, *Cetorhinus maximus* off the western coast of Ireland was started in 1770s (Fowler, 1996) and spiny dogfish *Squalus acanthias* have been exploited for liver oil since 1870s (McFarlane and Beamish, 1987).

Commercial (targeted) exploitation of elasmobranchs started after First World War, for food and leather industry (Vannuccini, 1999). Fishery has grown steadily since 1920s, which made negative impact on the stocks (Walker, 1998). The discovery and demand of high Vitamin A content in elasmobranch livers prompted the increased exploitation in 1940s (Kroese and Sauer, 1998; Vannuccini, 1999; Stevens *et al.*, 2000). Elasmobranchs are exploited in commercial, artisanal and recreational fishing activities, but a major share occur as bycatch in commercial fishery. The significant increase in chondrichthyan fishery and trade is due to the great demand for shark fins, meat and cartilage, which has also prompted targeted and illegal, unreported and unregulated (IUU) fishing for sharks.

Globally there is an increasing concern over the unjudicious exploitation of apex predator of the ocean due to their particular *K* selected life history traits (Smith *et al.*, 1998). Over exploitation along with habitat destruction could lead to negative impact on stocks (Musick, *et al.,* 2000; Stevens, 2000; Musick and Ellis, 2005).

The magnitude of the effects of fishing and habitat degradation on exploited elasmobranch groups will remain unnoticed until there is a major/ observable decline in the catch of the targeted/bycatch species. Most of the targeted elasmobranch fisheries are often called as boom and bust fisheries due to their short period of existence. Elasmobranch stock decline due to fishing/bycatch are reported around world such as; the Californian soupfin shark, *Galeorhinus galeus* fishery (Ripley, 1946), Irish Sea skate, *Dipturus batis* fishery (Brander, 1981), basking shark, *Cetorhinus maximus* and spiny dogfish, *Squalus acanthias* fishery (Holden, 1974). Oceanic whitetip *Carcharhinus longimanus* and Silky shark *Carcharhinus falciformes* fishery declined between 1950 and late 1990s respectively in Gulf of Mexico (Baum and Myers, 2004) and shark population of northwest Atlantic Ocean (Baum *et al.,* 2003) etc.

Global chondrichthyan catch data reported by Food and Agricultural Organization (FAO) shows that the catch has increased considerably, from 2,71,800 tonnes in 1950 to 8,22,000 tonnes in 1999 (Vannuccini, 1999) and steadily increasing since 1985 at an average rate of 2% per year (Stevens *et al.,* 2000). However, it’s only about 1% of the world's annual total marine fish catch (Walker, 1998). It is well known that most of the chondrichthyan catch data presented are possibly underestimates of actual fishery landings. Most of the chondrichthyan catch data does not include vast quantities caught as bycatch. Bonfil (1994) stated that bycatch alone represent 50% of the actual chondrichthyan catch. Poor monitoring and catch estimation in coastal nations lead to inaccurate catch data, which hampers the management measures.

Targeted elasmobranch fishery (mostly shark fishing) is conducted in 26 countries, of which the leading countries are Indonesia, India, Spain, Taiwan, Portugal and Japan, and the leading 20 fishing nations account for 80% of total world elasmobranch catch (Lack and Sant, 2011). The International Union for Conservation of Nature (IUCN), Red List of Threatened Species shows almost 30 % of all sharks are threatened or near threatened with extinction risk (Dulvy *et al.,* 2014). Due to the collapse of several elasmobranch fishery and understanding the role and importance of elasmobranchs in the ecosystem, Food and Agricultural Organisation (FAO) under the Code of Conduct for Responsible Fisheries (CCRF) in 1999 approved and adopted International Plan of Action (IPOA) for the Conservation and Management of Sharks (including all elasmobranchs); which recommended voluntary management of fisheries with the development of national shark plans and cooperation among regional fishing nations for ensuring sustainability of stocks. The Convention on International Trade on Endangered Species (CITES), also monitors the international trade of elasmobranchs and keep a check on the trade of endangered, protected species listed in CITES Appendix.

Chondrichthyan fishery of India

India is one of the leading chondrichthyan fishing nations in the world, positioned second after Indonesia (FAO, 2009). Chondrichthyan fishery resources consisting of sharks, rays and skates are exploited by different gears (longlines, trawl nets, drift gillnets and hooks and lines) in the Indian Exclusive Economic Zone (EEZ). Traditionally India has a long history of fishery; one of the earliest records of elasmobranch fishery was provided by Day (1863) from southwest coast (Kerala coast) of India.

Until 1980, elasmobranchs has been occasionally caught by different types of traditional crafts and gears in India, and they were considered only as bycatch. The commercial elasmobranch fishery of India has undergone several changes during the last three decades (since 1980) especially with regard to catch levels and species composition (Fig. 1.1), this change is due to the increased effort, multiday distant water fishing, new depth and area of fishing. Targeted elasmobranch fishing have been conducted in Indian waters employing gill nets, hooks and lines, long lines since 1990 (Bonfil, 1994; Hanfee, 1997, 1999). Nowadays multiday distant water targeted elasmobranch fishing is conducted all along the Indian EEZ.

During 2012 the estimated all India elasmobranch landing was 52602 tonnes (sharks 44.6 %, rays 51.5 % and skates 3.9%), of which major contributions were from states like Tamil Nadu and Maharashtra (Fig. 1.2). The fishery was dominated by species belonging to family Carcharhinidae, Dasyatidae, Alopiidae, Sphyrnidae and Mobulidae (CMFRI, 2013).

The International Convention on Biodiversity held at Rio (Brazil) in December 1992 emphasized the need for conservation and sustainable use of biodiversity. Considering multispecies and multi-gear fishery in India there is an essential need for evaluating the status of exploited elasmobranchs for their sustainable exploitation and management plan formulation. Formulation of elasmobranch management plan needs basic data on the fauna, their diversity, distribution, habitat, catch data and biological traits which all becomes the crucial information.

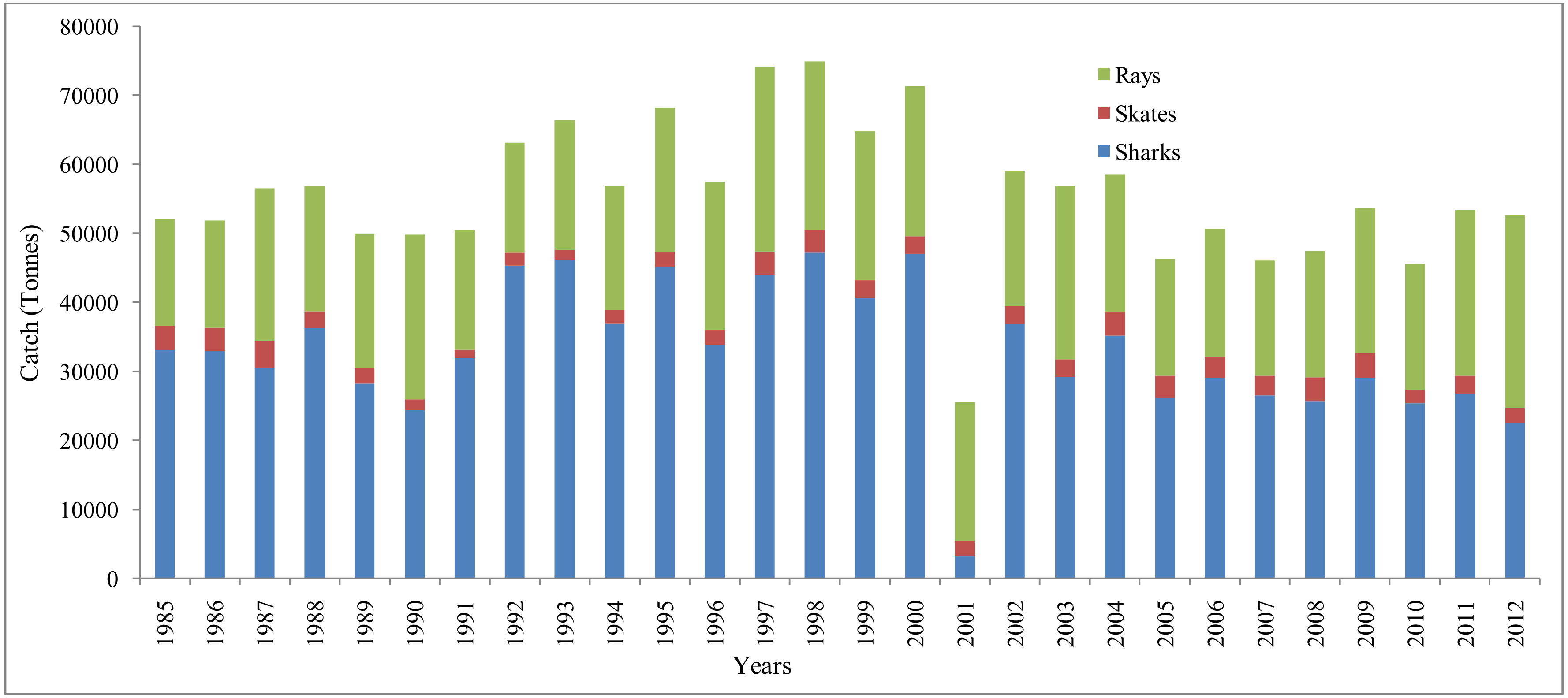

Figure 1. 1. Elasmobranch landings of India during 1985 to 2012 (Source: Srinath, 2008 and CMFRI Annual reports)

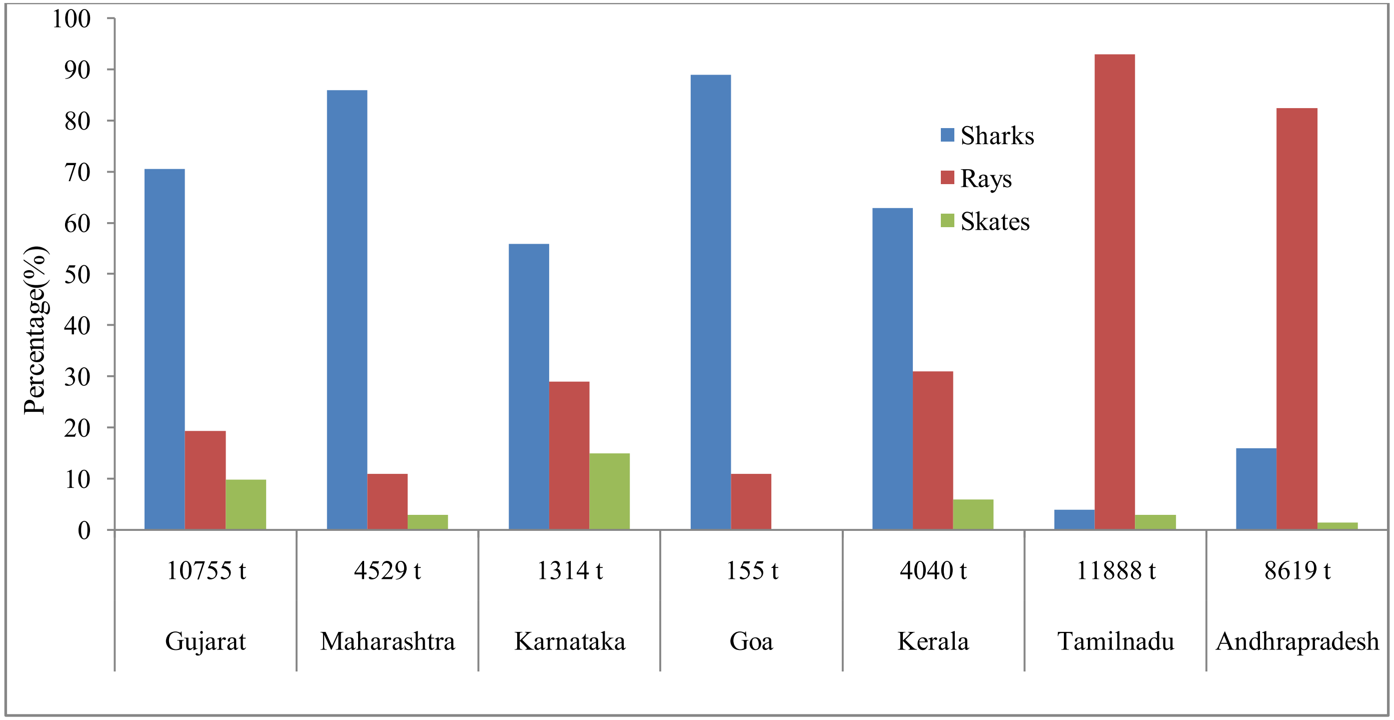

Figure 1. 2. State-wise elasmobranch landings of India during 2012 (CMFRI, 2013)

Deep-sea chondrichthyans

The International Union for Conservation of Nature (IUCN) defines deepwater chondrichthyans as those sharks, rays and holocephalans whose distributions are mostly at depths below 200 m (Kyne and Simpfendorfer, 2007). This depth is generally continental and insular shelf edge, and therefore, deepwater species are those occurring on or over the continental and insular slopes and beyond, including the abyssal plains and oceanic seamounts.

Nearly half (48.7%) of the global chondrichthyan fauna are inhabitants of deep-sea ie., 55.8% of shark species, 39.8% of batoid fauna and 93.9% of chimaeroids (Kyne and Simpfendorfer, 2007).

Most of the deepwater sharks belong to the Order Squaliformes (squaloid dogfishes) and Family Scyliorhinidae (catsharks). Deepwater batoid fauna is dominated by three skate families such as Arhynchobatidae, Rajidae and Anacanthobatidae (Kyne and Simpfendorfer, 2007). There is an overall lack of knowledge of the deep-sea fauna even at the most basic levels, in their diversity level to biology and biogeography due to sampling difficulties for such studies.

Chondrichthyans are generally considered to be *K* selected species which makes them vulnerable, however these characters are highly prominent in deepwater forms and hence they are more vulnerable to exploitation (Gordon, 1999; Clarke *et al.*, 2002; Fowler *et al.*, 2002; Simpfendorfer and Kyne, 2007; Kyne and Simpfendorfer, 2010). Chondrichthyans have an apex position in the trophic system (Cortes, 1999; Musick, 1999), mainly in mesopelagic and bathyal zone as top predators, therefore any depletion in the population or stock would have very significant effect on the overall ecosystem.

Deep-sea chondrichthyan fishery can be considered as old as that of deep-sea finfish fishery, since deep-sea finfish and crustacean fishery always brings deepwater chondrichthyans as bycatch. For example, when the French trawlers began to land deep-water teleost fishes such as *Coryphaenoides rupestris* and *Aphanopus carbo,* several deep-water sharks, including *Centroscymnus coelolepis* and leafscale gulper shark *Centrophorus squamosus* were also landed, together called *'siki'* fishery (Clarke *et al.,* 2002). Targeted deep-sea shark fishery has been reported from several countries; Namibian deepwater fishery for *Centrophorus squamosus, Deania quadrispinosum, Centroscymnus ceolopsis* and *Squalus mitsukurri* (Yano, 1991), Maldivian deep-sea fishing for *Centrophorus niakung, Centrophorus tessellatus* and *Centrophorus squamosus* with occasional bycatch of several other deep-sea sharks (Anderson and Ahmed, 1993), Azores handline fishery for *Dalatias licha* (Heessen, 2003), North east Atlantic deep-sea fishery for *Centrophorus squamosus, Centroscymnus coelolepis, Centroscyllium fabricii, Centroselachus crepidator* and *Deania calcea* (Kjerstad *et al.,* 2003), Indonesian targeted fishery for deep-sea sharks (White *et al.,* 2006 a), West and North of Great Britain and Ireland fishery targeting *Centrophorus squamosus* and *Centroscyllium coelolepis* **(**Brown and Magnus, 2005). Australian fishery for deep-sea sharks, *Centrophorus harrissoni* and *Centrophorus uyato* (Graham *et al.,* 2001).

In the Indian EEZ targeted deep-sea shark fishery was reported from Andaman waters since 1984 (Mustaffa, 1986). Soundararajan and Roy (2004) reported about the handlining for deep-sea sharks in Andaman waters during 1988-1992. Bycatch of deep-sea chondrichthyans, mostly gulper sharks, bramble shark and chimaeroids has been reported occasionally in the commercial fisheries along southern coasts since a very longtime (Mathew *et al.,* 1991). Since 2002, a targeted deep-sea shark fishery was reported along the southwest coast of India (Akhilesh *et al.,* 2011 a).

Globally fishing has been extending to deeper waters and the fishing effort on deepwater chondrichthyans being targeted and also as incidental catch/bycatch has been increased significantly over time. Many deep-water chondrichthyans, which are taken as bycatch are often discarded at sea due to smaller size/ no commercial value, which is not accounted in the catch data. The lack of accurate catch data, poor taxonomic resolution, species identification and illegal fishing makes assessment of the global catch of deepwater chondrichthyans extremely difficult.

Knowledge on the deep-sea chondrichthyan fauna of is limited, which is considerably behind the knowledge available for coastal and pelagic chondrichthyans. So, there is an urgent need for creating more reliable information on diversity, life history, role and function of deep-sea chondrichthyans in the ecosystem from the geographic ranges of exploitation. Since very little information is available for the exploited deep-sea chondrichthyans in the Indian EEZ, formulation of management plans becomes difficult. In this context present study is taken up.

In this thesis chondrichthyans and elasmobranchs, Cochin and Kochi are used inter-changeably.

Objectives

Deep-sea chondrichthyans are considered highly vulnerable to exploitation. In India fishing has been extended to deeper waters and as a result several deep-sea fauna are being landed, moreover there exists a targeted fishery for the same. The available information on the chondrichthyan fauna, fishery and biology especially on deep-sea chondrichthyans from Indian EEZ are meagre. Considering the importance of these resources and for suggesting their sustainable exploitation levels, the present study was undertaken with the following objectives.

1. To review the chondrichthyan research from Indian waters.
2. To investigate the diversity of deep-sea chondrichthyans inhabiting the southwest coast of India and to prepare a taxonomic database with detailed morphometric data.
3. To generate a detailed account of deep-sea chondrichthyan fishery of southwest coast.
4. To study the life history and biological parameters of selected deep-sea sharks off the southwest coast of India.

This study will improve the existing knowledge on the chondrichthyans of Indian waters by developing a database on the deep-sea chondrichthyans off the southwest coast of India, their diversity, fishery trends, biological aspects and population parameters etc., which will be useful in formulation of sustainable deep-sea elasmobranch fishery management plans.

Chapter 2

Review of literature:

Review of chondrichthyan research in India

Chapter 2

Review of chondrichthyan research in India

Chondrichthyans are one of the major capture fishery resources of Indian EEZ and are being exploited by different types of crafts and gears for decades. Considering the multispecies, multi gear, year around, elasmobranch landings and a long history of elasmobranch fishery from India, there is an urgent need for evaluating the status of these vulnerable resources; which basically needs compilation of available information. Most of the research on chondrichthyans from India are related to diversity, taxonomy, fishery, biology and population dynamics and there are only limited attempts to review the earlier research works and none were of comprehensive in nature. The present chapter compiles and consolidates major research works on elasmobranchs from Indian waters.

Taxonomy and systematics

Elasmobranch taxonomy research from Indian waters dates back to centuries. Earliest ichthyologists who worked on elasmobranchs from Indian water are; Latham (1794) a British naturalist is considered to be the first to work on Indian elasmobranchs, and described *Anoxypristis cuspidata* from Malabar (Kerala). German naturalists Bloch and Schneider, in their publication *Systema Ichthyologiae* (1801), described several new elasmobranchs based on materials collected from the Coromandel coast of India (southeast coast), which includes *Aetobatus flagellum* and *Rhina ancylostoma*.

Following Bloch and Schneider, several researchers worked on Indian fauna during the colonial period viz; Shaw (1803); Russell (1803); Hamilton (1822); van Hasselt (1823); Cuvier (1829); Gray (1830-1835); Henle (1834); Cantor (1837); Müller and Henle (1838-1841); Swainson (1839); McClelland (1841); Blyth (1847); Gray (1851); Jerdon (1851); Dumeril (1852); Bleeker (1853); Cuvier (1853); Gronov (1854); Blyth (1860); Dumeril (1865); Day (1865); Gunther (1870); Day (1873); Day (1878); Alcock (1889); Alcock (1891); Alcock (1898); Alcock (1899); Lloyd (1908); Lloyd (1909) and Annandale (1909) who all contributed significantly to understanding elasmobranch fauna of Indian waters.

Several new chondrichthyans were described from Indian waters by early ichthyologists, however many of them were synonymised or considered to be invalid at present (Table 2.1). After 1940, only few new species were described from Indian waters of which few are with questionable/invalid /uncertain status viz. *Urogymnus asperrimus* var. *krusdeinsis* Chacko, 1944; *Carcharias watu* Setna and Sarangdhar, 1946; *Rhinoptera sewelli* Misra, 1946; *Proscyllium alcocki* Misra, 1950; *Chiloscyllium confusum* Dingerkus and De Fino, 1983 etc. Recent new species descriptions from Indian waters which are considered as valid are; deepwater scyliorhinid shark *Pentanchus investigatoris* Misra, 1962 from Andaman waters, bathypelagic shark *Cephaloscyllium silasi* (Talwar, 1974 a) from the deep waters off Kollam coast, Arabian Sea. Deep-sea shovel nose skate *Rhinobatos variegatus* Nair and Lal Mohan (1973), from Gulf of Mannar, *Heteronarce prabhui* Talwar (1981 a) from off Kollam, Arabian Sea. Cubelio *et al.* (2011) described a new shark *Mustelus mangalorensis* based on materials collected at Kochi.

One of the earliest compilations of chondrichthyan diversity in Indian waters was done by Day (1889) which reported 69 species. Misra (1947, 1952) reported 52 species from Indian waters, and in a more detailed work Misra (1969) reported 114 elasmobranch. Talwar and Kacker (1984) reported 76 chondrichthyans. Hanfee (2000) listed 98 elasmobranchs. Raje *et al.* (2002) listed 110 elasmobranch species from the Indian Seas. The recent guide for commercially important elasmobranchs of India (Raje *et al.*, 2007) listed 84 species occurring in the fishery giving their distribution pattern and fishery importance.

Chondrichthyan taxonomy research works of few researchers were limited to certain groups or regions/areas. Alcock (1889, 1898) concentrated mainly on deep-sea elasmobranchs. Setna and Sarangdhar (1946) worked on elasmobranchs from Bombay waters. Jones and Kumaran (1980) from Laccadive waters. Dutta and Roy (1977) provided details of elasmobranchs of Sunderbans. Venkataraman *et al.* (2003) prepared a field guide to identification of sharks of Indian waters. Sujatha (2002) provided details of batoids of Vizakhapatanam. Rajan *et al.* (2012) provided diversity of elasmobranchs in Andaman waters. Few research works listed elasmobranch species found in fishery; Joshi *et al.* (2008) and Akhilesh *et al.* (2011 a) from Kochi, Mohanraj *et al.* (2009) from Chennai and Hanfee (1999) from Tamilnadu and Kerala.

Studies are unravelling the elasmobranch diversity of India and several species are continuously being added to the fauna. Only in few publications (taxonomy and morphometric notes, distributional records and rare occurrences) detailed taxonomic descriptions and identification keys were provided. The major studies on elasmobranch taxonomy from India are; Chaudhuri (1911) provided details of freshwater stingrays of the Ganges. Raj (1914 a) provided details of *Neotrygon kuhlii*. Prashad (1920) provided taxonomic details of torpedo rays. Setna *et al.* (1948) provided description of *Scoliodon laticaudus*. Setna and Sarangdhar (1949 a) provided systematic account of *Rhizoprionodon acutus, Hemipristis elongatus* and *Torpedo zugmayeri*. Kewalramani and Chhapgar (1957) reported *Taeniura melanospila*. Silas (1969) and Silas *et al.* (1969) reported *Echinorhinus brucus, Neoharriotta pinnata* and *Atractophorus armatus* from southwest coast. Silas and Prasad (1969) reported deep-sea shark, *Squalus fernandinus* from the southwest coast of India. Nair and Lal Mohan (1971) reported *Echinorhinus brucus* from east coast of India. Nair and Lal Mohan (1972) reported *Centrophorus armatus* from east coast. Silas and Selvaraj (1972) gave detailed description of the bramble shark *Echinorhinus brucus.* Nair and Soundararajan (1973 a) reported deep-sea stingray *Plesiobatis daviesi* from Gulf of Mannar. Nair *et al.* (1974) gave a detailed account of four pelagic sharks of the family Carcharhinidae. Talwar (1974 b) provided taxonomic account of *Sphyrna lewini* from east coast. Nair and Soundararajan (1976) reported sting ray *Dasyatis microps* from Gulf of Mannar. Rajagopalan and Meiyappan (1976) redescribed *Negaprion acutidens* from Lakshadweep. Talwar (1976) provided taxonomic account of *Rhizoprionodon oligolinx*. Devadoss and Natarajan (1977) reported hammerhead shark, *Sphyrna zygaena.* James (1980) provided a detailed taxonomic account of *Himantura maginata* from Gulf of Mannar. Silas and Selvaraj (1980) provided taxonomic notes on *Neoharriotta pinnata*. Talwar (1981 a) gave account of electric rays of the genus *Heteronarce* (Torpedinidae) and described one new species. Talwar (1981 b) worked on torpedoes of Indian waters. Talwar (1981 c) provided additional descriptions of type specimens of scyliorhinid shark *Bythaelurus hispidus.*

Compagno and Talwar (1985 a) reported *Heptranchias perlo* for the first time from Indian coast. Compagno and Talwar (1985 b) provided generic relationship and status of the scyliorhinid catshark, *Cephaloscyllium silasi.* Silas and Selvaraj (1985) reported *Dasyatis centroura* for the first time from Indian waters. Devadoss (1987) gave detailed description of *Chiloscyllium griseum*. Devadoss (1988 a) reported fantail ray *Taeniura melanospila*. Mathew *et al*. (1991) reported *Centrophorus granulosus* from Indian seas. Ramaiyan and Sivakumar (1991) prepared an identification guide to the sharks, skates and rays of Parangipettai coast. Sujatha (2002) provided details of batoid fishes off Visakhapatnam. Devaraj and Gulati (2004) provided morphometry of the duskyshark, *Carcharhinus obscurus* from the west coast of India. Dholakia (2004) provided field identification key to seven elasmobranchs. Soundararajan and Roy (2004) reported deep-sea sharks, *Centrophorus acus* and *Squalus megalops* from Andaman waters. Nair (2006) reported *Rostroraja alba* from the west coast of India. Nair (2007) provided taxonomic account of *Raja miraletus*. Akhilesh *et al*. (2008, 2009) provided morphometric characteristics of stingrays *Pteroplatytrygon violacea* and *Plesiobatis daviesi*. Akhilesh *et al*. (2010) reported deep-sea sharks, *Deania profundorum, Hexanchus griseus* and *Centrophorus squamosus* from the west coast. Deepu *et al*. (2010) provided taxonomic account of *Etmopterus pusillus*.

Akhilesh *et al*. (2011 b) redescribed *Halaelurus quagga* from the southwest coast of India. Babu *et al.* (2011) reported *Hexatrygon bickelli* from south west coast of India. Zacharia *et al.* (2011) reported *Pteroplatytrygon violacea* from east coast of India. Kumar *et al*. (2012) reported *Alopias pelagicus* from Laccadives. Suresh and Raffi (2012) reported *Neoharriota pinnata* from Nagapattinam. Balakrishnan *et al*. (2012) commented on scalloped hammerhead *Sphyrna lewini* from Kakinada coastal waters. Akhilesh *et al*. (2013 a) reported velvet dogshark, *Zameus squamulosus* from Indian waters. Akhilesh *et al*. (2013 b) and Kizhakudan and Rajapackiam (2013) reported crocodile shark *Pseudocarcharias kamoharai* from Kochi and Chennai respectively. Benjamine *et al*. (2014) reported ornate eagle ray *Aetomylaeus vespertilio* from south-eastern Arabian Sea. Akhilesh *et al.* (2014) provided taxonomic account of *Cephaloscyllium silasi*. Bineesh *et al*. (2014) confirmed the occurrence of *Rhynchobatus australiae*, *Aetomylaeus vespertilio, Dasyatis microps* and *Himantura granulata* from the southwest coast of India. Ramachandran *et al*. (2014) reported *Echinorhinus brucus* from Laccadive Seas. Gowthaman *et al.* (2014) reported *Alopias superciliosus* from Gulf of Mannar.

Several instances of regional occurrences, short descriptions with diagnostic characters have been published in newsletters, magazines, popular articles of fisheries institutes like; Fishery Survey of India (FSI), Zoological Survey of India (ZSI), Central Marine Fisheries Research Institute (CMFRI) and universities etc. and only important are included in this review.

Studies on the distribution, biogeography, bathymetry, migration and abundance of elasmobranchs in Indian waters are limited; Misra and Menon (1955) reported the distribution of the elasmobranchs and chimaeras of the Indian region in relation to the mean annual isotherms. Mathew *et al*. (1996) provided distribution pattern and abundance of elasmobranchs of the Indian EEZ as revealed by FORV *Sagar Sampada* surveys. Somvanshi *et al.* (2009) studied the distribution pattern of pelagic stingray *Pteroplatytrygon violacea* in the Indian EEZ. Sinha *et al*. (2010) provided spatio-temporal distribution, abundance and diversity of oceanic sharks occurring in Andaman waters

Fishery

India has a long history of elasmobranch fishery. An early account of fishery was given by Day (1863), who reported that several species of sharks and rays (mainly dog sharks, carcharhinids hammerhead sharks and occasionally large sharks) including *Myliobatis* sp., *Pristis* sp. were observed in fishery. Sharks are caught by hooks and line and are rarely eaten fresh, but are used in salted and dried form. Shark meat is considered to be good to pregnant ladies (and the common name milk shark - *Palsoora* in native named for its powers to increase lactation).

Day (1863; 1865) reported that shark and ray livers were used for oil extraction, which is used in the Government hospitals as a substitute for cod-liver oil. During that period elasmobranch liver oil was manufactured at Cochin which later shifted to Calicut. Day (1863) stated that shark fishing was one of the major occupations in the Bombay region and also for the people of west coast of India. Shark catch from all along the coast were shipped to Bombay and then exported to China and other parts of world (Anon, 1856). Several other earlier researchers like Day (1878), Günther (1880), Thurston and Rangachari (1909) and Thurston (1913) also reported about the elasmobranch fishery of Kerala and commented that products like dried fish, fish maws, shark-fins, fish oil were exported to Sri Lanka, southeast Asia, China, Japan and Europe.

Detailed account of elasmobranch fishery was given by several researchers; Ayyangar (1922) provided details of Laccadive Sea fisheries. Hornell (1925, 1938) provided details of elasmobranch fishery of Coramandal and Malabar coast. Pillay (1929) commented on the elasmobranchs observed in the fishery along Kerala coast.

Sorley (1932) provided details about fisheries of Bombay. John (1946) provided details of shark fishing off Madras. Devanesan and Chidambaram (1948, 1953) commented on fishery of Madras. Chidambaram and Menon (1946) discussed about the shark fishery of Madras. Bal and Banerji (1951) reported that, during 1949 at Cudallore (Tamilnadu) rays formed 15% of total catch. Chopra (1951) listed major species occurring in the Indian fishery. Bhimachar and Venkataraman (1952) provided details of species occurring in the Malabar coast and commented that *Scoliodon laticaudus* is the most dominant species. Jones and Sujansingani (1954) provided details of elasmobranchs in Chilka lake fishery. Panikkar (1956) reported that elasmobranchs contributed 4.16% of all India marine production during 1950-54. Gokhala (1957) commented on fishing gears of Sourashtra region. John *et al*. (1959) reported on the elasmobranchs collected during fishing experiments off Madras. Jones and Kumaran (1959) discussed about the fishing industry of Minicoy Island.

Kaikini (1960) gave details of Malwan fisheries. Thyagarajan and Thomas (1962) provided details of crafts and gears used in elasmobranch fishing at Madras. Balasubramanyan (1964) provided details of baits used in elasmobranch fishery. Nagabhushanam (1966) reported on the elasmobranch resources of Andhra and Orissa coast. Deshpande *et al*. (1970) provided details of shark longlining in Veraval. James (1973) suggested that sharks, rays and skates are potential fishery resources in the east coast of India. Kartha *et al*. (1973) studied the bottom drift long line fishery off Veraval. Pai and Pillai (1973) provided area wise catch and effort of trawl surveys in the southeast coast. Jhingran (1975) gave an account of commercially important elasmobranchs. Devadoss (1978) studied the batoid fishery of Cuddalore. Pillai and Honma (1978) studied the seasonal distribution of the pelagic sharks taken by the tuna longliners in the Indian Ocean.

Silas and Selvaraj (1980) suggested *Neoharriota pinnata* as a potentially important deepwater resource. Rao and Krishnamoorthi (1982) studied the diurnal variation in the demersal fish catches in the Bay of Bengal during 1959-60. Koya (1982) reported on ray fishing of the Kalpeni Island. Rajan (1982) described economics of shark long lining. Nishida and Sivasubramaniam (1983) commented that some deep-sea spiny sharks caught by hook and line from 200-400 m depths, have become economically valuable in Sri Lanka and India, because of their high valued liver oil used in the manufacture of cosmetics. Devadoss (1984 a) studied the skate and ray fishery off Calicut.

Silas *et al*. (1984) reported the importance of small scale fisheries and elasmobranch resources based on drift gillnet fishery off Kochi. Dholakia and Vasavda (1985) provided details of shark landings of Gujarat and Saurashtra. Deep-sea shark fishery was reported from Andaman waters in 1984 (Mustaffa, 1986). Appukuttan and Nair (1988) commented on the elasmobanch resources of east coast. Devadoss *et al*. (1989) presented status and future prospects of elasmobranch fishery in India. Kumaran *et al*. (1989) reported that drift long lines locally known as *'Bayp'* for the capture of sharks and other large fishes are found in all the islands except Minicoy. Harpoons are used for the capture of rays (*Manta birostris*, *Aetobatus narinari* and *Dasyatis* spp.) and sharks from the open seas around the islands. Sukumaran *et al*. (1989) provided details of shark long lining at Malpe.

Kasim (1991) gave an account of shark fishery of Veraval coast. Dahlgren (1992) reported that a directed shark fishery occurs in the east coast depending upon seasonality and availability of targeted species. Mathew (1992) provided details of

Scoliodon laticaudus fishery from Maharashtra waters. Joel and Ebenezer (1993) commented on targeted long-lining for sharks. Vivekanandan and Zala (1994) studied the whale shark fishery of Veraval. Devadoss (1996) commented on shark fishing in India. Marichamy *et al.* (1996) studied about the ray fishery of Tuticorin. Rao (1998) reported on the hooks and line fishery for sharks at Janjira-Murud (Maharashtra) by migrated fishermen from Kanyakumari. Devadoss *et al*. (2000) provided details of elasmobranch resources of India. Pillai and Biju (2000) provided details of pelagic shark fishery in the Indian seas emphasising on their exploitation and trade.

Bhargava *et al*. (2002) commented on pelagic shark bycatch in the tuna longline fishery. Jayaprakash *et al*. (2002) studied the drift gillnet fishery for large pelagics and bycatch of pelagic sharks at Kochi. Raje *et al*. (2002) gave a detailed account of elasmobranch fisheries of India. In certain areas of Tamilnadu coast large meshed bottom set gillnets called *Thirukkuvalai* are operated for ray (*Thirukkai*) fishing (Raje *et al*., 2002). Nair and Venugopal (2003) reported on targeted shark fishery in Kerala. John and Neelakandan (2003) discussed about the oceanic shark bycatch in tuna long line fishery. Raje and Joshi (2003) gave an account of Indian shark fishery. Pravin *et al*. (2004) reported on targeted fishery for whale sharks. Titto D'Cruz (2004) provided historic and socioeconomic aspects of fishermen. Dholakia (2004) provided an outline of Indian elasmobranch fishery, giving special reference to Gujarat. Srinath *et al*. (2006) reported yearly catch data of elasmobranchs from Indian coastal states since 1985. Varghese *et al*. (2007) studied about the bycatch of sharks in the tuna longline surveys. Joshi *et al*. (2008) commented on the changing shark fishery at Kochi. Vivekanandan and Sivaraj (2008) provided details of Indian elasmobranch fishery. John and Varghese (2009) reported about the declining catch per unit effort for oceanic sharks in the Indian EEZ.

Mohanraj *et al*. (2009) studied elasmobranch fishery of Chennai. Zacharia and Kandan (2010) provided details of skate and ray fishery at Tuticorin. An account of deep-sea shark fishing from south west coast was provided by Akhilesh *et al*. (2011 a). Kar *et al*. (2011) provided details of elamsobranch bycatch in tuna longline fishery around Andaman and Nicobar islands. Rajan *et al*. (2012) provided species composition of elasmobranch fishery in Andamans. Sajeevan and Sanadi (2012) reported on elasmobranchs as a major oceanic resources in Andamans as suggested earlier by John and Somvanshi (2000), John *et al*. (2005) and Somvanshi *et al*. (2008). Akhilesh *et al.* (2013) provided landing data of deep-sea shark, *Echinorhinus brucus* at Kochi.

Biology

Understanding the life history, biological aspects including reproductive biology and maturity are essential for the proper management plan creation of exploited species. The major studies on chondrichthyan biology from Indian waters are by: Day (1889) described characters of the young ones of *Rhinobatos annandalei, Rhynchobatus djiddensis, Himantura uarnak* and *Gymnura micrura*. Alcock (1890) made observations on the gestation in *Carcharhinus dussumieri, Carcharhinus melanopterus, Himantura bleekeri, Aetomylaeus nichofii* and *Eusphyrna blochii*. Wood-mason and Alcock (1891, 1892) studied gestation in rays. Alcock (1892 a) made observations on uterogestation in *Himantura bleekeri*. Alcock (1892 b) studied on the embryonic history of *Gymnura micrura.* Southwell (1910) gave description of intra uterine embryos of *Anoxypristis cuspidata.* Sewell (1912) reported egg capsule and embryo of *Rhinochimaera* sp. Raj (1914 a) commented on *Neotrygon kuhlii*. Raj (1914 b) provided details of *Chiloscyllium griseum* breeding.Southwell and Prasad (1919) reported on the intra-uterine embryos of elasmobranchs. Prashad (1920) described about the gravid uterus and embryos of *Narcine timlei.* Thillayampalam (1928) gave detailed account of *Scoliodon*.

Aiyar and Nalini (1938) made observations on the reproductive system, egg-case and breeding habits of *Chiloscyllium griseum* from Madras. Mahadevan (1940) made preliminary observations on the structure of the uterus and the placenta of *Rhizoprionodon acutus* and *Carcharhinus dussumieri*. Nalini (1940) provided structure and function of the nidamental gland of *Chiloscyllium griseum*, and commented on the formation of the egg-capsule. Samuel (1943) provided details of corpusluteum in *Rhinobatus granulatus.* Sarangadhar (1943, 1945) provided biological details of *Galeocerdo cuvier*. Prasad (1945 ab) provided the structure, phylogenetic significance and function of the nidamental glands of some elasmobranchs of the Madras coast. Prasad (1945 c) studied about the teeth succession in elasmobranchs, and provided details of teeth arrangement in the embryos of *Chaenogaleus macrostoma, Chiloscyllium griseum, Rhinobatus granulatus, Himantura uarnak* and *Narcine brunnea.* Samuel (1945) studied on the corpus luteum in *Chiloscyllium griseum*. Setna *et al.* (1948) studied developments of *Scoliodon sorrakowah*. Setna and Sarangadhar (1949 b) studied the development of *Chiloscyllium griseum, Anoxypristis cuspidata* and *Rhynchobatus djiddensis*. Setna and Sarangdhar (1950 ab) commented on the breeding habit and development of elasmobranchs from Bombay waters.

Prasad (1951) made observations on the formation of egg-cases of some ovoviviparous and viviparous elasmobranchs and the probable mode of their formation. George (1953) studied the air-breathing habits in *Chiloscyllium.* Sarangdhar (1954) made comparative observations on the placenta and foetal nutrition in elasmobranchs and mammals. Chandy (1955) studied the nervous system of *Dasyatis.* Krishnan (1959) made studies on histochemical aspects of egg capsules of *Chiloscyllium griseum.* Menon and Kewalramani (1959) studied on the physiological aspects of digestion in three species of elasmobranchs. Ganguly *et al.* (1962) commented on the organization of myometric musculature in the guitar fish *Rhinobatos granulatus*. Balakrishnan (1963) described an egg capsule, tentatively assigned to *Neoharriotta pinnata.* Thomas (1965) made observations on the heart of *Chiloscyllium indicum*. James (1966) studied the biology of butterfly ray, *Gymnura poecilura* from the Palk Bay and Gulf of Mannar. James (1963, 1970) studied biology of *Rhinoptera javanica*.

Silas and Selvaraj (1972) provided a detailed description of embryo of bramble shark *Echinorhinus brucus*. Nair and Soundararajan (1973 b) reported occurrence of hermaphroditism in the electric ray, *Narcine timlei*. Nair and Appukuttan (1973) commented on the food of deep sea sharks *Halaelurus hispidus*, *Eridacnis radcliffei* and *Iago omanensis.* Devadoss (1974) provided details of little known electric ray *Narke impennis*. Nair and Appukuttan (1974) made observations on the developmental stages of *Eridacnis radcliffei* from Gulf of Mannar. Nair (1976) studied age and growth of *Scoliodon laticaudus* from Bombay waters. Devadoss (1977) worked on the elasmobranchs of Portonovo (Tamilnadu) coast. Appukuttan (1978) studied on the developmental stages of hammerhead shark *Sphyrna (Euphyra) blochii* from the Gulf of Mannar. Devadoss (1978 b, 1983 a) studied maturation and breeding habit of *Dasyatis* (*Amphotistius*) *imbricatus* from Porto Novo. Devadoss (1978 b) studied the feeding habits of rays, *Dasyatis uarnak*, *Dasyatis alcockii* and

Pastinachus sephen. Devadoss (1979) studied about the maturity, breeding and development of *Scoliodon laticaudus* from Calicut. Devadoss (1982) reported on the embryonic stages of the mottled ray, *Aetomylus maculatus* providing details of breeding season. Devadoss (1984 b) made observations on the maturity, breeding and development of *Scoliodon laticaudus* off Calicut coast. Ghate (1984) observed black coloration on the olfactory sacs of *Scoliodon* caught off Bombay. Waghray (1985) studied olfactory organ and its sexual dimorphism in the electric ray, *Narcine timlei*. Devadoss (1986, 1987) studied on the biological aspects of shark *Chiloscyllium griseum*. Krishnamoorthi and Jagadis (1986) studied the biology and population dynamics of shark, *Rhizoprionodon acutus* in Madras waters. Appukuttan and Nair (1988) provided biological aspects of selected elasmobranchs from east coast. Devadoss (1988 b) provided an account on breeding and development of sharks. Kulkarni *et al*. (1988) studied length weight relationship of *Scoliodon laticaudus* and *Carcharhinus limbatus* from Karnataka. Devadoss (1989) studied length-weight relationship and food and feeding habits of *Scoliodon laticaudus*.

Arumugam *et al*. (1990) provided details of chimaeroid egg capsule collected off Tuticorin. Joel and Ebenezer (1991) reported on the fecundity of *Echinorhinus brucus*. Kasim (1991) studied population dynamics of *Scoliodon laticaudus* and *Rhozoprionodon acutus*. Mathew and Devaraj (1997) studied the biology and population dynamics of the shark *Scoliodon laticaudus* in the coastal waters of Maharashtra. Devadoss and Batcha (1997) reported hermaphroditism in *Mustelus mosis* from Madras coast. Devadoss (1998 a) worked on growth and population parameters of shark *Scoliodon laticaudus* from Calicut coast. Devadoss (1998 b) made observations on the breeding and development in batoid fishes.

Kasim *et al*. (1999) studied the age, growth and mortality of *Carcharhinus sorrah.* Marichamy *et al*. (1999) studied the age and growth of *Himantura bleekeri* off Tuticorin

Devadoss *et al*. (2000) compiled information on the length-weight relationship, age and growth for elasmobranchs from Indian waters. Raje (2000) provided length-weight relationship of five species of rays from Mumbai. Jagadis and Ignatius (2003) succeeded in captive breeding and rearing of grey bamboo shark, *Chiloscyllium griseum*. Raje (2003) studied the biology of four species of rays off Mumbai waters. Devaraj and Gulati (2004) studied biology of dusky shark, *Carcharhinus obscurus* from the west coast of India. Soundararajan and Roy (2004) studied biology of deep-sea sharks, *Centrophorus acus* and *Squalus megalops* from Andaman waters. Raje (2006) studied the biological aspects of five species of skates of Mumbai. Castro *et al*. (2007) studied population genetic structure of whale shark *Rhincodon typus*. Chembian (2007) reported *Rhinochimaera atlantica* spawning ground in the Gulf of Mannar. Raje (2007) studied biology of *Himantura bleekeri* and *Amphiotistius imbricatus.* Ravi *et al*. (2008) provided spine structure of scaly stingray, *Himantura imbricata*. Raje and Zacharia (2009) investigated the biology of nine species of rays from Mumbai. Somvanshi *et al*. (2009) studied the biology of pelagic stingray *Pteroplatytrygon violacea*.

Abdurahiman *et al*. (2010) provided trophic positions of *Carcharhinus limbatus* and *Rhynchobatus djiddensis*. Kumari and Raman (2010) assessed Whale shark habitats in the north-eastern Arabian Sea using satellite remote sensing. Chembian (2010) reported wedge bank area as possible spawning ground of *Raja* *miraletus*. Kizhakudan *et al*. (2010) studied the biology of the scaly whipray *Himantura imbricata*. Borrel *et al*. (2011 a) worked on the trophic ecology of elasmobranchs caught off Gujarat using stable isotopes. Borrell *et al*. (2011 b) worked on stable isotope profiling in whale shark to suggest segregation and dissimilarities in the diet depending on sex and size. Kar *et al*. (2011) provided details of biology and length weight relation of thresher sharks from Andaman waters. Manjusha *et al*. (2011) studied population structure and exploitation level of smooth hammerhead *Sphyrna zygaena* in the coastal waters of Kerala. Veena *et al*. (2011) reported case of leucism in *Scoliodon laticaudus* from Mangalore. Akhilesh *et al*. (2012) reported on the biology of *Eridacnis radcliffei*. Raje *et al*. (2012) studied the relation between body size and reproductive biology of elasmobranchs from Mumbai. Anandhakumar (2012) worked on mating behaviour and breeding of the grey bamboo shark, *Chiloscyllium griseum* in captivity. Akhilesh *et al*. (2013 cd) studied the biology of deep-sea sharks *Bythaelurus hispidus* and *Echinorhinus brucus* from the southwest coast of India. Fofandi *et al*. (2013) studied the biology of *Scoliodon laticaudus* from Saurashtra coast. Shrikanya and Sujatha (2014) studied the reproductive biology of the mottled electric ray, *Torpedo sinuspersici* from Visakhapatnam.

Reports on abnormality, morphometric variation and occasional observations on huge sizes, food and feeding, fecundity, hermaphroditism also had become research subjects and been published in reputed national journals and magazines (Arulprakasam, 1960; Bensam, 1965; Devadoss, 1983).

Elasmobranch parasitology and bacteriology also become an important research topic and the major studies from India are viz.: Rangenaker (1950, 1957);

Samuel (1952); Velankar and Kamasastri (1955); Pillai (1963 ab, 1964, 1968); Sinha *et al*. (1971); Hameed and Pillai (1973); Kumar (1990); Lakshmi and Sarada (1993); Sarada *et al*. (1993); Rajyalakshmi (1995); Vijayalakshmi and Sarada (1995,1996); Bullard and Jensen (2008); Bikash and Buddhadeb (2010) and Khadap and Dandwate (2012) etc.

Biochemistry and processing

Processing is one of the most important post harvest process in fisheries benefitting millions of people and producing high economic benefits. Major elasmobranch biochemistry and processing related studies are provided here. The earliest account of elasmobranch liver oil industry from India date back to 1852 (See Iyengar, 1950; Chopra, 1951) and the principal species exploited for their liver are *Galeocerdo cuvier, Carcharhinus melanopterus, Sphyrna blochii,* and *Anoxypristis cuspidatus*. Day (1889) recorded shark liver oil industry (from sharks and saw fishes) in the west coast based at Calicut in 1854. Rajagopal (1942) reported on vitamin A in shark liver oil. Aiyar (1943) gave details of sharks and shark-liver oil industry from India. John (1943) provided details of shark liver oil industry in India. Gajjar (1944) worked on the chemical composition of shark liver oil from Bombay. Kini and Chidambaram (1947) conducted studies on the liver oils of elasmobranchs of southern India. Samuel (1951) reported on elasmobranch fisheries and provided details of shark liver oil industry. Pathak *et al*. (1952) studied the fatty acid contents of Indian shark liver oil. Gupta *et al*. (1953) investigated on unsaturated fatty acids of liver oil from *Galeocerdo cuvier*. Setna (1954) provided details of sharks and shark liver oil industry in India. Ghanekar and Bal (1955) worked on the enzymes of elasmobranchs from Bombay. Bal and Ghanekar (1956) worked on Lipases of

Scoliodon sorrakowah and *Rhynchobatus djiddensis.* Ghanekar *et al*. (1956) studied Amylases of *Scoliodon sorrakowah* and *Sphyrna blochii*. Ambe and Sohonie (1957 abc) investigated on the proteins of sharks and skates and commented on their nutritive value. Bose *et al*. (1958) reported on shark meat processing. Kamasastri (1959) studied chemical properties and changes during storage of some ray liver oils. Kandoran *et al*. (1965) reported on curing of sharks and rays. Kamdar *et al*. (1967) studied on shark liver oil and its residues. Sastry and Ramachandran (1965) investigated the protein components of Elastoidin. Mathen (1970) worked on the quality and shelf life of dried shark products. Ramachandran *et al*. (1974) described shark fin processing technologies for extraction of fin rays. Solanki and Venkataraman (1978) described ice storage characteristics of fresh and brined shark fillets. Chandran (1980) reported on handling and processing of sharks in Lakshadweep. Devadoss (1984 c) commented on the nutritive values of sharks, skates and rays from Portonovo coast. Parab and Rao (1984) studied the distribution of TMAO in sharks. Dholakia and Vasavda (1985) reported on commercial shark liver oil production in Gujarat. Ghadi and Ninjoor (1989) explained about the biochemical and sensory evaluation of shark spoilage.

Ramachandran and Solanki (1991) studied the processing and storage characteristics of semi-dried products from shark. Sankar and Solanki (1992) worked on changes in nitrogen fractions in the elasmobranch fillets during salting. Venugopal *et al*. (1994) studied gelation of shark myofibrillar proteins by weak organic acids. Venugopal *et al*. (1997) described thermostable water dispersion of shark meat and its application on protein powder preparation. Ramachandran and Sankar (1990, 1992) described the processing and frozen storage characteristics of elasmobranch fillets. Vannuccini (1999) and Varma (1999) commented on the shark processing and its trade. Mathew and Shamasundar (2002) worked on effect of ice storage on the functional properties of proteins from shark *Scoliodon laticaudus* meat. Mathew *et al*. (2002) worked on the effect of water washing on shark *Scoliodon laticaudus* meat proteins. Mathew *et al*. (2008 ab) studied the analgesic and anti-inflammatory activities of liver oils of four shark species from Indian EEZ and lipid profile of liver oil of *Neoharriota pinnata* from Arabian Sea. Ravitchandirane and Yogamoorthi (2008) studied on the analgesic and anti-inflammatory properties of crude extracts of sting ray, *Dasyatis zugei*. Ravichandirane *et al*. (2012) studied the analgesic and anti–inflammatory properties of crude extracts of ray, *Narcine brunnea*. Sathyan *et al*. (2012) identified a putative antimicrobial peptide Himanturin from round whip ray *Himantura pastinacoides*. Ravitchandirane *et al*. (2013) investigated on the characterization of bioactive compounds from sting ray, *Dasyatis jenkinsii*. Kalidasan *et al*. (2014) studied the antimicrobial and anticoagulant activities stingray *Himantura imbricata*.

Trade

Historically, one of the earliest accounts of elasmobranch trade was given by Günther (1880) who stated that, in 1845-46, 8770 cwt (=446.4 tonnes) of shark fins were exported from Bombay to China. Day (1878) observed that sawfish fins being exported from India to China. Fins of sharks and rays, along with fish-maws were exported from Karachi to Bombay during 1872 from where they were re-exported to China. Shark fins were used in soup preparation, which is a delicacy in southeast Asia. Grades were used while exporting, shark fins (eg. *black* is used for pectoral, ventral and anal fins which is of low price and *white* for dorsal fin which has more gelatin and price). Skins of *Pastinachus sephen* and some sharks were converted into shagreen (Day, 1889). Shark meat was consumed, along the Malabar coast and was considered as nourishing food for mothers after child birth, while in Bombay they were largely purchased by African sailors (Day, 1889).

John (1943) provided details of shark liver oil industry in India. Jones and Sujansingani (1954) reported the trade from Chilka to Bengal during 1949. Since 1960s, a fairly substantial demand for fresh, salted, and dried shark meat has emerged in the South Indian states of Kerala and Tamil Nad (Frej and Gustafsson, 1990).

Hanfee (1997) studied the trade in shark and shark products in India. Hausfather (1999) analyzed shark landings based on shark fin exports. Vannuccini (1999) gave a detailed account of shark utilization in India. The details of Indian shark fishery industry were provided by Varma (1999). Rajapackiam *et al*. (2007) reported on the utilization of gill rakers of lesser devil ray *Mobula diabolus*. Dhaneesh and Zacharia (2013) commented on the shark fishery of India.

Marine Products Export Development Authority (MPEDA), under the Ministry of Commerce/ Govt. of India is regularly collecting information on marine product exports from country. However, detailed information on quantity, value realised, product details, species and country of destination are mostly not available for elasmobranch exports from India due to the export of processed products.

Conservation and Management

Due to the development of an international and domestic market for fins and meat, elasmobranch resources become a highly targeted group. Increased fishing effort and capitalisation also brought huge quantity of elasmobranchs as bycatch. Due to these reasons India become a leading elasmobranch fishing nation. As a result of the increasing concern by conservationists of the rapidly declining populations, in an historic movement all elasmobranchs were given protected status in Indian waters with the fisheries exploiting this group of fishes banned in July 2001. Following this, outrage by fishers, merchants and communities affected by the ban and consultations resulted in the ban being lifted with only 10 species retaining from fishing activities, including knifetooth sawfish (*Anoxypristis cuspidata*), the Pondicherry shark (*Carcharhinus hemiodon*), the Ganges shark (*Glyphis gangeticus*), the speartoothed shark (*Glyphis glyphis*), the Ganges stingray (*Himantura fluviatilis*), the freshwater sawfish (*Pristis microdon*), the green sawfish (*Pristis zijsron*), the giant guitarfish (*Rhynchobatus djiddensis*), and the porcupine ray (*Urogymnus asperrimus*) with effect from December 2001. These species now has one of the highest protected status for an animal in India in the Indian Wildlife (Protection) Act, 1972. Whale shark is the most conservation attention derived elasmobranch species in Indian waters and its status were provided by several researchers (Silas, 1986, 1989; Pravin, 2000; Hanfee, 2001; Choudhary *et al.*, 2008; Akhilesh *et al.*, 2013 e)

Since the protected listing in 2001, reports of landings of protected species in commercial fishery, strandings due to human interactions (e.g. vessel collisions, releasing netted and injured sharks), incidental landings (bycatch) and strandings/beaching are still being recorded. However, Whale sharks and saw fishes are getting attention when landed, due to larger sizes and easy identification. Indiscriminate shark fishing and unmanaged trade from India has made Verlecar (2007) to raise the issue of extinction risk and insisting a ban on fishing.

India is the second largest chondrichthyan fishing nation in the world, compiling information on the in depth details of chondrichthyan fishery (species wise catch composition, biogeography, size class, seasonality and biological aspects) will be useful in formulation of management plans.

Table 2.1. List of chondrichthyans described from India and their present status

Species described from India	Type area	Present status/valid as
Aetobatis indica Swainson, 1839	Vizagapatanam, India	Synonym of *Aetobatus ocellatus* Kuhl, 1923
Aetoplatea tentaculata Müller & Henle,1841	?Indian Seas	Valid as *Gymnura tentaculata* (Müller & Henle, 1841)
Bengalichthys impennis Annandale,1909	Balasore Bay, Orissa coast, India	Synonym of *Narke dipterygia* (Bloch & Schneider, 1801)
Benthobatis moresbyi Alcock, 1898	Laccadive Sea, India	Valid as *Benthobatis moresbyi* Alcock, 1898
Carcharias (Hypoprion) hemiodon Muller & Henle,1839	Puduchery, India	Valid as *Carcharhinus hemiodon* (Müller & Henle, 1839)
Carcharias (Physodon) muelleri Müller & Henle, 1839	Bengal	Synonym of *Scoliodon laticaudus* Müller & Henle, 1838
Carcharias (Prionodon) bleekeri Duméril,1865	Puducherry, India	Synonym of *Carcharhinus sorrah* (Müller & Henle, 1839)
Carcharias (Prionodon) dussumieri Muller & Henle,1839	Puduchery, India	Valid as *Carcharhinus dussumieri* (Müller & Henle, 1839)
Carcharias (Prionodon) palasorra Bleeker, 1853	Pala sorrah of Russell (1803)	Possible synonym of *Scoliodon laticaudus* Müller & Henle, 1838
Carcharias (Prionodon) temminckii Muller & Henle,1839	India	Valid as *Lamiopsis temminckii* (Müller & Henle, 1839)
Carcharias malabaricus Day, 1873	Cochin, Calicut, India	Synonym of *Carcharhinus dussumieri* (Müller & Henle, 1839)
Carcharias sorrah kowa Bleeker, 1853	Vizagapatam, India	Synonym of *Rhizoprionodon acutus* (Rüppell, 1837)
Carcharias sorrakowah Cuvier, 1829	on Sorra Kowah of Russell (1803)	Possibly synonym of *Scoliodon laticaudus* Müller & Henle, 1838
Carcharias watu Sarangdhar & Setna, 1946	India	Synonym of *Carcharhinus hemiodon* (Müller & Henle, 1839)
Centrophorus rossi Alcock, 1898	Off Travancore coast, India	Synonym of *Centroscymnus crepidater* (Bocage & Capello, 1864)
Cephaloptera kuhlii Muller & Henle,1841	India	Valid as *Mobula kuhlii* (Müller & Henle, 1841).
Ceratoptera orissa Lloyd, 1908	Puri,Orissa coast, Bay of Bengal,	Possible synonym of *Manta birostris* (Walbaum, 1792)

Species described from India	Type area	Present status/valid as
Cestracion leeuwenii Day, 1865	Malabar coast, India	Synonym of *Sphyrna lewini* (Griffith & Smith, 1834).
Dicerobatis eregoodoo Cantor, 1849	Type locality includes Coromandel, India	Synonym of *Mobula eregoodootenkee* (Bleeker, 1859)
Dicerobatis thurstoni Lloyd, 1908	India	Valid as *Mobula thurstoni* (Lloyd, 1908)
Galeocerdo tigrinus Muller & Henle, 1839	Puduchery, India	Synonym of *Galeocerdo cuvier* (Péron & Lesueur, 1822)
Ginglymostoma muelleri Günther, 1870	India	Synonym of *Nebrius ferrugineus* (Lesson, 1831)
Hemigaleus balfouri Day,1878	Coromandel coast, India	Synonym of *Chaenogaleus macrostoma* (Bleeker, 1852)
Hemipristis pingali Setna, 1946	India, Mumbai	Synonym of *Hemipristis elongata* (Klunzinger, 1871)
Mustelus mangalorensis Cubelio, Remya & Kurup, 2011	Mangalore	Uncertain/holotype couldn't be located
Myliobatis eeltenkee Rüppell, 1837	Type locality includes Vizagapatanam, India	Synonym of *Aetobatus ocellatus* (Kuhl,1823)
Myliobatis nieuhofi var. *cornifera* Annandale, 1909	Balasore, Orissa	Uncertian
Narcine brunnea Annandale, 1909	Bay of Bengal, Hoogli	Valid as *Narcine brunnea* Annandale, 1909
Narcine indica Henle, 1834	Tharangambadi, India	Synonym of *Narcine timlei* (Bloch & Schneider, 1801)
Narcine microphthalma Dumeril, 1852	Malabar coast, India	Synonym of *Narcine timlei* (Bloch & Schneider, 1801)
Pentanchus (Parapristurus) investigatoris Misra, 1962	Andaman Sea	Valid as *Apristurus investigatoris* (Misra, 1962)
Proscyllium alcocki Misra,1950	Andaman Sea	Synonym of *Eridacnis radcliffei* Smith, 1913
Raia fluviatilis Hamilton, 1822	Ganges	Synonym of *Pastinachus sephen* (Forsskål, 1775)
Raja asperrima Bloch & Schneider, 1801	Mumbai, India	Valid as *Urogymnus asperrimus* (Bloch & Schneider, 1801)
Raja bicolor Shaw, 1804	Indian Seas	Uncertain as *Narcine bicolor* (Shaw, 1804)
Raja diabolus marinus Bloch & Schneider, 1801	India	Synonym of *Manta birostris* (Walbaum, 1792)
Raja flagellum Bloch & Schneider, 1801	Coromandel	Valid as *Aetobatus flagellum* (Bloch & Schneider, 1801)
Raja fluviatilis Hamilton, 1822	Ganges, India	Synonym of *Pastinachus sephen* (Forsskål, 1775)
Raja guttata Shaw, 1804	Based on Russell (1803)	Synonym of *Aetobatus ocellatus* (Kuhl, 1823)
Raja imbricata Bloch & Schneider, 1801	Tarangambadi, India	Valid as *Himantura imbricata* (Bloch & Schneider, 1801)

Species described from India	Type area	Present status/valid as
Raja johannisdavisi Alcock, 1899	off Travancore, India	Valid as *Dipturus johannisdavisi* (Alcock, 1899)
Raja poecilura Shaw, 1804	Vizagapatam, India, (on Russell, 1803)	Valid as *Gymnura poecilura* (Shaw, 1804)
Raja sancur Hamilton, 1822	Ganges, India	Synonym of *Pastinachus sephen* (Forsskål, 1775)
Raja timlei Bloch & Schneider, 1801	Tarangambadi, India	Valid as *Narcine timlei* (Bloch & Schneider, 1801)
Raja dipterygia Bloch & Schneider, 1801	Tharangambadi, India	Valid as *Narke dipterygia* (Bloch & Schneider, 1801)
Rhina ancylostomus Bloch & Schneider, 1801	Coromandel coast, India	Valid as *Rhina ancylostoma* Bloch & Schneider, 1801
Rhinobatos variegates Nair & Lal Mohan, 1973	Gulf of Mannaar	Valid as *Rhinobatos variegatus* Nair & Lal Mohan, 1973
Rhinobatus (Rhinobatus) tuberculatus Bleeker, 1853	Suttiwarah of Russell (1803)	Uncertain
Rhinobatus (Rhinobatus) obtusus Müller & Henle, 1841	Pondicherry, Malabar, India	Valid as *Rhinobatos obtusus* Müller & Henle, 1841
Rhinobatus annandalei Norman, 1926	Mouth of the Hooghli, India	Valid as *Rhinobatos annandalei* Norman, 1926
Rhinobatus armatus Gray, 1834	India	Synonym of *Glaucostegus typus* (Anonymous [Bennett], 1830)
Rhinobatus laevis Bloch & Schneider, 1801	India	Valid as *Rhynchobatus laevis* (Bloch & Schneider, 1801)
Rhinobatus lionotus Norman, 1926	Mouth of the Hooghli, India	Valid as *Rhinobatos lionotus* Norman, 1926
Rhinoptera sewelli Misra 1946	Calicut, India	Valid as *Rhinoptera sewelli* Misra, 1946
Rhinoptera adspersa Müller & Henle, 1841	India	Synonym of *Rhinoptera javanica* Müller & Henle, 1841
Rhynchobatus laevis Müller & Henle, 1841	Mumbai and Malabar, India	Synonym of *Rhynchobatus djiddensis* (Forsskål, 1775)
Scoliodon ceylonensis Sarangdhar & Setna, 1946	Mumbai, India	Synonym of *Loxodon macrorhinus* Müller & Henle, 1839
Scoliodon laticaudus Müller & Henle, 1838	India	Valid as *Scoliodon laticaudus* Müller & Henle, 1838
Scyliorhinus (Halealurus) silasi Talwar, 1974	Off Kollam, Arabian Sea	Valid as *Cephaloscyllium silasi* (Talwar, 1974)
Scyllium hispidum Alcock, 1891	Andaman Sea	Valid as *Bythaelurus hispidus* (Alcock, 1891)
Scyllium maculatum Gray, 1830	?India	Synonym of *Atelomycterus marmoratus* (Anonymous [Bennett], 1830)
Scyllium quagga Alcock, 1899	Laccadive Sea, India	Valid as *Halaelurus quagga* (Alcock, 1899)
Squalus caudatus Gronow, 1834	Indian Seas	Synonym of *Chiloscyllium indicum* (Gmelin, 1789)

Species described from India	**Type area**	**Present status/valid as**
Squalus palasorrah Cuvier, 1829	Vizagapatam and Madras, India	Uncertain as *Scoliodon palasorrah* (Cuvier, 1829)
Squalus semisagittatus Shaw, 1804	Based on Russell (1803)	Uncertain
Squalus zebra Shaw, 1804	Indian Seas	Synonym of S*tegostoma fasciatum* (Hermann, 1783)
Stegostoma carinatum Blyth, 1847	India	Synonym of *Stegostoma fasciatum* (Hermann, 1783)
Trygon alcockii Annandale 1909	Puri, Orissa Coast. India	Valid as *Himantura alcockii* (Annandale, 1909)
Trygon atrocissimus Blyth, 1860	India	Uncertain
Trygon bleekeri Blyth, 1860	Calcutta fish market, India	Synonym of *Himantura uarnacoides* (Bleeker, 1852)
Trygon chindrakee Cuvier, 1853	Based on Russell (1803)	Uncertain
Trygon crozieri Blyth, 1860	Arakan coast, India	Synonym of *Dasyatis zugei* (Müller & Henle, 1841)
Trygon ellioti Blyth, 1860	Calcutta fish market, India	Synonym of *Himantura uarnak* (Gmelin, 1789)
Trygon favus Annandale, 1909	off Orissa, Bay of Bengal	Valid as *Himantura fava* (Annandale, 1909)
Trygon gerrardi Gray, 1851	India	Valid as *Himantura gerrardi* (Gray, 1851)
Trygon jenkinsii Annandale,1909	off Ganjam	Valid as *Himantura jenkinsii* (Annandale, 1909)
Trygon marginatus Blyth, 1860	Calcutta fish market, India	Valid as *Himantura marginata* (Blyth, 1860)
Trygon nuda Günther,1870	Indian Seas	Uncertain
Trygon russellii Gray, 1834	India	Questionably the same as (juvenile of) *Himantura leoparda* Manjaji, 2004
Trygon variegatus M'Clelland, 1841	Calcutta, India	Synonym of *Himantura uarnak* (Gmelin, 1789)
Trygon walga Müller & Henle, 1841	Ganges, India	Valid as *Himantura walga* (Müller & Henle, 1841)
Urogymnus asperrimus var. *krusadiensis* Chacko, 1944	Gulf of Mannar	Possible synonym of *Urogymnus asperrimus* (Bloch & Schneider, 1801)
Urogymnus laevior Annandale, 1909	Malpe	Uncertain
Zygaena indica van Hasselt, 1823	Vizagapatam, India	Synonym of *Sphyrna lewini* (Griffith & Smith, 1834)
Zygaena laticeps Cantor, 1837	Bay of Bengal	Synonym of *Eusphyra blochii* (Cuvier, 1816)

Chapter 3

Taxonomy of deep-sea chondrichthyans off the southwest coast of India

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Taxonomy of deep-sea chondrichthyans off the southwest coast of India

Taxonomic studies on chondrichthyans of Indian Ocean are limited compared to Pacific and Atlantic Oceans. Though several fishery expeditions were conducted in the Indian Ocean viz, *Novara* (1865-1867), *Challenger* (1872- 1876), *Valdvia* (1898-1899), *Investigator* (1900s), *Dana* (1928-1930), *Albatross* (1947-1948), *Galathea* (1950-1952), *German Indian Ocean Expedition* (1955), *Anton Bruun* (1963-1964) *Meteor* (1964-1965), *Vityaz* (1988-1989), *Africana* (1994), *Vauban* (1972), *Algoa, La Barbade* (1969), *Royal Indian Ocean Deep slope fishing expedition* (1969), *John Murray* (1939), *Fridtjof Nasen* (1976-1980), *Dm. Stefanov* (1989), *Chulabhorn* (1989), *Zavitinsk* (1981) and *Jurong* (1980), most of them were beyond the Indian EEZ or with limited chondrichthyan collections.

Indian waters support a diverse chondrichthyan fauna consisting of more than 110 known species (Raje *et al.*, 2002). However, the actual number probably will be higher since there are no recent, exclusive studies on this group from the region.

Pioneering deep-sea chondrichthyan research in Indian water was conducted by Alcock (1889-1899), based on the materials collected the survey of *HMS Investigator*. Based on *Investigator* collections Alcock described several new elasmobranchs from Indian seas. After Alcock, for a long time deep-sea chondrichthyan taxonomy was neglected, mostly due to absence of dedicated deep-sea surveys. Most of the recent research work from the region is based on bycatch landings, this is mostly due to the extension of fishing to deeper waters. Deep-sea elasmobranch research from the region has been sporadic, patchy and mostly deals with rare occurrences, new distributional reports etc. and very few new species descriptions (Misra, 1962; Silas *et al.*, 1969; Nair and Lal Mohan, 1971,1972,1973; Talwar, 1974 a; Silas and Selvaraj, 1980; Soundararajan and Roy, 2004; Akhilesh *et al.*, 2010, 2014; Ramachandran *et al.*, 2014).

One of the most recent, work on elasmobrachs from Indian seas by Raje *et al.* (2007) listed 84 species occurring in commercial landings along the Indian coast, but mostly caught in catches made within 200 m depths. Elasmobranchs are known from deeper waters and probably many species, which are not yet recorded, occur in the unexploited/underexploited deep waters of the Indian EEZ. Taxonomy and systematics have a strong connection with sustainable fisheries resource management (Stauffer and Kocovsky, 2007) especially in the case of vulnerable exploited groups like chondrichthyes. So understanding the exploited species accurately is important as much as collection of fishery and biology data.

This chapter deals with the diagnostic and morphometric characters of deep-sea chondrichthyans collected from the deep waters off the southwest coast of India, a least studied marine fauna in Indian waters.

Materials and methods

Study area

The area selected for the research was southwest coast of India, which comprise of 16% of the Indian coastline, extending from about 8ºN to 15º30'N with a coastline length of 994 km, adjoining three maritime states, Kerala, Karnataka and Goa. The continental shelf area off the southwest coast is 75,400 km^2 and 31% of the area is less than 50 m depth. Southwest coast of India is one of the most productive fishing areas in the world oceans due to the coastal upwelling. Southwest coast supports a good fishery, contributing 35.1% (1.39 million tonnes) of total marine production of country in 2012 (CMFRI, 2013)

The ecological and environmental parameters of the southeastern Arabian Sea are peculiar in many aspects viz. the wind pattern (seasonal changes), water circulation (which differ drastically from patterns in similar latitudes), varying thermoclone depths during different seasons, high productivity during upwelling and monsoon periods, presence of archipelago, muddy bottom in the southern coasts, seamounts, narrow continental shelf and deep coral reefs.

Landing centre surveys

During April 2008 to December 2011, field survey observations were made at commercial fish landing centres along the southern coast of India to understand the diversity of deep-sea chondrichthyes in the commercial landings. Materials for taxonomic study were collected either from Cochin fisheries harbour, Kochi, Sakthikulangara Fisheries harbour, Quilon (Kollam), southwest coast of India (Fig. 3.1), or during exploratory surveys.

Exploratory surveys

The multidisciplinary research cruise programme of FORV *Sagar Sampada* (CMLRE/MoES), cruise no 281 (August 2010), covered the latitudes between 8^0 and

21^0 N on the west coast of India. Four deep-sea fishing operations were conducted using HSDT-CV or EXPO in the southwest coast at depths 180-1200 m. Deep-sea chondrichthyans were collected only at stations off Trivandrum and off Kochi.

Identification

Species identification of collected chondrichthyan specimens were based on Alcock (1899); Misra (1952); Compagno (1984 ab); Smith and Heemstra (1986); Shirai and Tachikawa (1993); Didier and Stehman (1996); Compagno (2001); Compagno *et al.* (2005 a); White *et al.* (2006 b); Last *et al.* (2008 ab); Ebert (2013) etc. and other available references of particular genus and species. Morphometric measurements of formalin (5%) preserved specimens were taken using a Mityutyo digital vernier caliper, following methodologies prescribed by Compagno (1984, 2001) for sharks; Last *et al.* (2008) for skates. Didier and Seret (2000) for chimaeras. Morphometric measurements as expressed in percent of total length (% TL) unless otherwise stated.

Results

Taxonomy of deepwater chondrichthyans

Class: **Chondrichthyes**
Order: **Chimaeriformes**
Family: **Rhinochimaeridae**
***Neoharriotta pinnata* (Schnakenbeck, 1931)** Sicklefin chimaera
(Plate 1, Fig. 1)

Schnakenbeck, W.(1931). Über einige Meeresfische aus Südwestafrika. Mitteilungen aus dem Zoologischen Museum in Hamburg, (44): 23-45. [Type locality: Walvis Bay]

Synonyms: *Harriotta pinnata* Schnakenbeck, 1931

Diagnosis: A medium sized chimaera with an elongated body. Tapering tail. Long pointed snout, dorsoventrally flattened and blunt edged. Large head with single gill opening anterior to pectoral base. Oral and preopercular lateral line canals separated by large space. Mouth small and placed ventrally on head. Three ridged tooth plates, two on the upper and one in the lower jaw. Pectoral fins short and broad. Pelvic fins rounded along distal margin. Two dorsal fins, first dorsal fin erect, with a strong spine; second dorsal fin long, low and not falcate, nearly uniform in height. Dorsal fin spine serrated, caudal fin with no tubercles on upper edge but with a short terminal filament. Anal fin present and short. Frontal claspers very large in males. Smooth skin. Colour- Brown or dark brown.

Morphometry: (Expressed in % TL). Pre-caudal length 70.4-87.0; head length 25.5-32.0; head depth (gill slit)10.5-14.9; head width 7.4-9.2; interorbital distance 4.0-5.7; orbit diameter 2.8-3.4; pre-orbital length 16.3-22.7; pre-pectoral length 26.0-35.2; pre-pelvic length 40.5-53.0; pre-anal length 62.0-90.9; pre-first dorsal fin length 28.0-33.0; pre-second dorsal fin length 41.0-67.0; first dorsal fin base length 9.0-12.5; first dorsal fin height 9.3-12.3; second dorsal fin base length 22.1-27.3; second dorsal fin height (middle) 2.3-2.9; second dorsal fin height (posterior end) 1.1-1.3; pectoral fin length 12.0-16.0; pectoral fin base 4.1-4.5; pelvic fin length 8.1-11.4; pelvic fin base length 3.5-4.5; anal fin base length 2.2-2.9; anal fin height 3.8-6.7; caudal fin lower lobe length 20.2-26.6; caudal fin upper lobe length 17.3-21.1; interdorsal distance 7.2-11.4; body height 16.0-27.0; caudal peduncle depth 2.3-2.7.

Distribution and Habitat: Bathydemersal species, occurring in deepwaters, shelves and slopes of Atlantic and Indian Ocean.

Remarks: Silas (1969) and Silas *et al.* (1969) reported *Neoharriotta pinnata* from Indian waters based on the materials collected during the survey of RV *Varuna* in the southeastern Arabian Sea. Silas and Selvaraj (1980) gave a detailed description of *N. pinnata* from west coast. Suresh and Raffi (2012) reported *N. pinnata* from Nagapattinam. *Neoharriotta pinnata* is a common component of bycatch of deep-sea shrimp trawls and deepwater long lines in southern coasts of India (Akhilesh *et al.*, 2011 a) and also reported in the exploratory surveys of FORV *Sagar Sampada* (Jayaprakash *et al.*, 2006).

In Rhinochimaeridae, other species reported from Indian waters are *Rhinochimaera atlantica* Holt and Byrne, 1909 by Chembian (2007) based on egg case, *Harriotta raleighana* Goode and Bean, 1895 by Mathew *et al.* (2008) and *Harriotta? indica* Garman by Misra (1969). However, the validity of these reports needs further confirmation. The IUCN Red List of Threatened Species list the status of *Neoharriotta pinnata* as Data Deficient (Dagit, 2006).

Family: **Chimaeridae**

***Hydrolagus* cf. *africanus* (Gilchrist, 1922)** African chimaera

(Plate 1, Fig. 2)

Gilchrist, J. D. F. (1922). Deep-sea fishes procured by the S.S. "Pickle" (Part I). Report Fisheries and Marine Biological Survey, Union of South Africa Rep. 2 (art. 3): 41-79, Pls. 7-12. [Type locality: Off coast of KwaZulu-Natal]

Synonyms: *Chimaera africanus* Gilchrist, 1922

Diagnosis: A small chimaera without a long pointed snout. Snout short with a bluntly pointed tip. Tail tapering to a filament. Eyes large. Pectoral fin large. First dorsal fin short based, deeply concave in the posterior margin. Dorsal fin spine long, curved; longer than the head from tip of snout to gill opening and usually equal to or sometimes exceeding height of the first dorsal fin. Lateral line canals as grooves and are nearly straight, not dipping markedly below first dorsal. Second dorsal fin with distinct concavity in the middle. Colour-pale brown.

Morphometry: (Expressed in %TL). Pre-first dorsal length 14.6; pre-second dorsal length 24.5; anterior second dorsal fin maximum height 3.1; head length 12.9; pre-orbital length 6.6; first dorsal fin base 7.4; dorsal spine length 13.7; snout-vent length 28.4; trunk length 19.1; first dorsal fin maximum height 7.9; pectoral fin anterior margin length 17.9; pelvic fin anterior margin length 9.6; interdorsal space 3.9; anterior edge of first dorsal fin base to anterior edge of pectoral fin base 7.3; anterior edge of first dorsal fin base to insertion of pectoral fin base 10.4; anterior edge of base of first dorsal fin to anterior edge of pelvic base 20.0; anterior edge of second dorsal fin base to anterior edge of pectoral fin base 12.9; anterior edge of second dorsal fin base to insertion of pectoral fin base 13.5; anterior edge of second dorsal fin base to anterior edge of pelvic fin base 10.9; anterior edge of second dorsal fin base to posterior edge of pelvic fin base 12.3; horizontal eye length 3.9; vertical eye height 2.3; snout tip to nostril 4.5; snout tip to eye 7.0; snout tip to mouth 5.4; snout tip to gill opening 12.9; snout tip to origin of pectoral fin 13.9; gill opening to second dorsal fin origin 11.4; gill opening to pelvic fin origin 17.8; mouth width 3.6; pectoral fin origin to pelvic fin origin 17.4.

The sensory canals were also measured for giving more accurate description of the material collected. Distance between infraorbital and angular canal measured as the straight line distance from junction of the oral and infraorbital canal to the junction of the oral and angular canal (IOA); 16.34 mm; distance between pre-opercular canal and main trunk canal measured from their junction with the infraorbital canal (OTM) 11.3; distance between main trunk canal and supratemporal canal measured from their junctions with the infraorbital and postorbital canals, respectively (OCL) 17.05; distance from anterior oronasal fold to center of nasal canal (ONC) 7.08; length of the nasal canal measured as a straight line distance from right to left side (LNC) 22.34; length of supratemporal canal measured across the head from its junctions with the postorbital canal (STL) 12.85; distance from anterior base of spine to the center of the supratemporal canal (SPS) 9.47; length of the rostral canal (LRC) 3.

Distribution and Habitat: Deepwater species known from off Southern Africa, Kenya and Mozambique and patchily from western Indian Ocean.

Remarks: In Chimaeridae, *Hydrolagus africanus* (Gilchrist, 1922) has been listed in Sreedhar *et al.* (2007) and *Chimaera monstrosa* Linnaeus, 1758 reported in Misra (1969) from Indian waters, latter report need further confirmation. Present *Hydrolagus* cf. *africanus* material was collected during FORV *Sagar Sampada* cruise from 1000 m depths. The IUCN Red List of Threatened Species list the status of *Hydrolagus africanus* as Data Deficient (Compagno and Dagit, 2006).

Order: **Hexanchiformes**

Family: **Hexanchidae**

***Heptranchias perlo* (Bonnaterre, 1788)** Sharpnose sevengill shark

(Plate 1, Fig. 3)

Bonnaterre, J. P. (1788). Tableau encyclopédique et methodique des trois règnes de la nature... Ichthyologie. Panckoucke, Paris. Tableau encyclopédique et méthodique des trois règnes de la nature. Ichthyologie: i-lvi + 1-215, Pls. A-B +1-100. [Type locality: Northwestern Mediterranean Sea]

Synonyms: *Heptranchias dakini* Whitley, 1931

Diagnosis: A slender medium sized shark with seven pair of gill slits; head and snout narrow and pointed. Small mouth, ventrally positioned, teeth wide and lower teeth comb-shaped. Very large eyes. Single, small dorsal fin, originating over inner margins of pelvic fins. Anal fin small. Colour-Brownish grey above, paler below; juveniles with dorsal and caudal fins black tips, which is fading in adults.

Morphometry: (Expressed in % TL). Pre-caudal length 65.7-70.4; pre-dorsal-length 48.0 -51.2; head length 20.2-21.8; pre-branchial length 15.0-16.0; pre-spiracular length 11.3-13.1; pre-orbital length 5.2-5.6; pre-pectoral length 20.4-21.8; pre-pelvic length 40.0-42.9; snout-anterior vent length 44.1-46.3; pre-anal fin length 52.8-56.2; second dorsal-caudal space 11.8-13.3; pectoral-pelvic space 13.3-17.9; pelvic-anal space 5.4-7.0; anal-caudal space 7.9-10.8; pelvic-caudal space 20.5-22.9; anterior vent- caudal tip length 55.6-55.9; pre-narial length 2.6-2.9; pre-oral length 4.7-5.1; eye length 2.6-3.3; eye length 3.1-3.8; eye height 1.8-2.1; inter-gill length 6.3-6.9; first gill slit height 7.7-9.2; fifth gill slit height 5.9-6.8; seventh gill slit height 3.4-4.2; pectoral fin anterior margin length 9.7-12.7; pectoral fin base length 5.4-5.8; pectoral fin inner margin length 3.9-4.9; pectoral fin posterior margin length 7.2-8.5; pectoral fin height 8.1-9.7; pectoral fin length 9-10.6; dorsal caudal margin length 30.8-33.1; pre-ventral caudal margin length 8.2-9.3; upper postventral caudal margin length 15.5-

18.2; lower postventral caudal margin length 3.3-4.1; caudal fork width 6.9-7.2; caudal fork length 8.6-8.7; subterminal caudal margin length 3.9-5.6; subterminal caudal width 2.2-2.6; terminal caudal margin length 4.6-5.6; terminal caudal lobe length 7.1-8.2; first dorsal total length 7.2-8.1; first dorsal anterior margin length 6.8-8.0; first dorsal base length 5.6-6.3; first dorsal vertical height 3.7-4.3; first dorsal inner margin length 1.7-2.0; first dorsal posterior margin length 3.7-4.8; pelvic total length 8.6-9.6; pelvic anterior margin length 3.9-4.6; pelvic base length 6.0-7.9; pelvic height width 2.3-2.9; pelvic inner margin length 1.3-3.9; pelvic posterior margin length 6.0-7.5; anal fin total length 6.8-7.3; anal fin anterior margin length 3.7-4.2; anal fin base length 5.1-5.8; anal fin vertical height 2.0-2.5; anal fin inner margin length 1.3-1.8; anal fin posterior margin length 4.2-4.7; head height at pectoral origin 9.2-12.5; trunk height at pectoral base end 9.4-15.0; abdomen height at first dorsal base end 6.0 -6.9; tail height at pelvic base end 5.5-7.0; caudal peduncle height at caudal origin 3.4-3.9; first dorsal midpoint-pectoral base end 25.5-30.8; mouth length 7.8-9.0; mouth width 6.9-7.5; lower labial furrow length 2.8-3.1; nostril width 1.1-1.3; internarial width 2.7-3.0; eye-spiracle space 3.9-4.2; head width at gill slits 9.4-10.5; trunk width at pectoral base ends 7.8-13.5; abdomen width at first dorsal base end 3.8-5.2; tail width at pelvic base ends 4.5-6.2; caudal peduncle width at caudal origin 2.9-3.3.

Distribution and habitat: Circumglobal distribution in tropical and temperate marine waters. Found in the upper continental slopes and lower shelves at depths 27-720 m (Compagno *et al.,* 2005 a).

Remarks: Compagno and Talwar (1985 a) reported *Heptranchias perlo* from Quilon (Kollam) coast (Arabian Sea) for the first time from Indian waters. *Heptranchias* *perlo* usually occurs as a rare bycatch of deep-sea shrimp trawlers and long liners. No commercial importance in Indian fishery. The IUCN Red List of Threatened Species list the status of *Heptranchias perlo* as Near Threatened (Paul and Fowler, 2003).

Family: **Hexanchidae**

***Hexanchus griseus* (Bonnaterre, 1788)** Bluntnose sixgill shark

(Plate 1, Fig. 4)

Bonnaterre, J. P. (1788). Tableau encyclopédique et methodique des trois règnes de la nature... Ichthyologie. Panckoucke, Paris. Tableau encyclopédique et méthodique des trois règnes de la nature. Ichthyologie: i-lvi + 1-215, Pls. A-B +1-100. [Type locality: Northwestern Mediterranean Sea]

Synonyms: *Squalus griseus* Bonnaterre, 1788

Diagnosis: A large heavy bodied shark with very long six-gill slits and a broad head. Snout very short and blunt. Mouth with six rows of lower, bladelike, comb shaped teeth on each side. Single dorsal fin placed well posterior of body. Dorsal fin base separated from upper caudal fin origin by a distance equal to, or slightly greater than its length. Anal fin smaller than dorsal fin. Origin of anal fin from near to middle of dorsal base. Colour: Brown above, paler below and fins sometimes white edged.

Morphometry: (Expressed in % TL). Fork length 76.4; pre-dorsal length 67.0; dorsal fin base length 6.7; dorsal caudal space 7.9; anal-caudal space 4.9; anal fin base length 5.3; head length 21.6; pre-first gill length 17.1; intergill length 4.7; pre-orbital length 5.2; eye length 3.0; eye height 1.8; pre-narial length 3.2; pre-oral length 5.3; first gill slit height 9.2; sixth gill slit height 5.7; pectoral fin anterior margin length 1.4; pectoral fin base length 7.1; pre-pectoral length 2.1; pectoral pelvic space 1.8; dorsal caudal margin 3.4; dorsal fin anterior margin 6.9; dorsal fin inner margin 2.9; mouth width 14.9; internarial length 5.2; interorbital length 9.8; head width at first gill slit 17.6. Colour-brown or dark brown.

Distribution and habitat: Circumglobal distribution in tropical and temperate marine waters, continental and insular shelves and slopes of Atlantic, Indian and Pacific Oceans (Nelson, 2006) at depths surface and 2500 m (Carey and Clark, 1995). In Indian Ocean *Hexanchus griseus* has been reported from Madagascar, Mozambique, South Africa, India and Maldives.

Remarks: Akhilesh *et al.* (2010) reported *Hexanchus griseus* for the first time from Indian waters. Its rarely occurs as bycatch in commercial fishery operating in deep waters. The IUCN Red List of Threatened Species lists the status of *Hexanchus griseus* as Near Threatened (Cook and Compagno, 2005).

Order: **Squaliformes**

Family: **Echinorhinidae**

***Echinorhinus brucus* (Bonnaterre, 1788)** Bramble shark

(Plate 1, Fig. 5)

Bonnaterre, J. P. (1788). Tableau encyclopédique et methodique des trois règnes de la nature... Ichthyologie. Panckoucke, Paris. Tableau encyclopédique et méthodique des trois règnes de la nature. Ichthyologie: i-lvi + 1-215, Pls. A-B + 1-100. [Type locality: North Atlantic]

Synonyms: *Squalus spinosus* Gmelin, 1789; *Echinorhinus (Rubusqualus) mccoyi* Whitley, 1931; *Echinorhinus obesus* Smith, 1849.

Diagnosis: A robust shark with stout body, sparsely and irregularly distributed dermal denticles on body, which are relatively large and some fused into compound plates. Dermal denticles on juveniles smaller or absent. Head moderately depressed. Snout flat, short and broadly rounded in dorsoventral view. Two small spineless dorsal fins located close together, towards posterior part of body and originating behind pelvic fin origin. Interdorsal distance very short and less than half of first dorsal fin base. No anal fin. Eyes lateral or dorsal lateral. Mouth broadly arched. Teeth on both jaws compressed, saw like cutting edges (1-3 cusps on teeth). No anal fin and sub terminal notch on caudal fin. Caudal deeply compressed. Colour- Light grey to dark brown, sometimes with a green tinge.

Morphometry: (Expressed in % TL). Pre-first dorsal length 54.0-64.0; pre-second dorsal length 59-74; pre-pectoral length 25.7-30.2; pre-pelvic length 50.0-60.0; body depth at pectorals 10.0-14.5; head length 23.0-30.0; eye height 2.0-2.3; eye length 2.4-4.8; interorbital length 8.4-11.8; pre-first gill length 18.0-21.0; pre-orbital length 7.4-8.7; mouth width 11.4-13.2; pre-oral length 7.5-8.7; first gill length 4.0-5.0; fifth gill width 4.5-7.0; first dorsal fin height 4.0-5.1; first dorsal base length 4.3-5.4; first dorsal length 7.0-7.6; interdorsal length 4.6-5.8; internarial distance 4.3-5.6; second dorsal fin base length 3.5-5.0; second dorsal fin height 4.0-5.1; second dorsal fin length 5.8-6.7; pectoral fin base length 7.4-11.0; pectoral fin length 9.2-13.0; pelvic fin length 10.6-15.3.

Distribution and Habitat: Found in the continental and insular slopes and shelves, sea mounts of tropical and temperate seas in the Atlantic, Western Indian Ocean, and Pacific Ocean. Occasionally caught from shallow waters (<200 m) of shrimp abundance. The available distribution records for *Echinorhinus brucus* from the

Arabian Sea coast of India extend from Veraval (Thangavelu *et al.*, 2009) south to Thoothoor and the Laccadive Islands (Ramachandran *et al.*, 2014). In the Indian Exclusive Economic Zone (EEZ) of the Bay of Bengal, *Echinorhinus brucus* is known from deeper waters off Tuticorin, Chennai and Pondicherry (Patel *et al.*, 2005). Sreedhar *et al.* (2007) commented that *Echinorhinus brucus* is possibly the most abundant deep-sea shark in the Bay of Bengal between 11°-18° N and 79°-84° E and at depths of 160-770 m. Records of this species are sparse north of Mangalore in the Arabian Sea and in the northern Bay of Bengal, most likely due to the limited deep-water fishing in these areas.

Remarks: Silas (1969) and Silas *et al.* (1969), based on the exploratory survey of RV *Varuna* in 1968 from West coast, and Nair and Lal Mohan (1971) provided the first reliable records of *Echinorhinus brucus* from east coast. *Echinorhinus brucus* when landed in large quantities utilized for its meat and oil. It forms a major portion of deep-sea shrimp trawl bycatch in the southern coast of India. The IUCN Red List of Threatened Species list the status of *Echinorhinus brucus* as <u>Data Deficient</u> (Paul, 2003).

Family: **Centrophoridae**

***Centrophorus atromarginatus* Garman, 1913** Dwarf gulper shark

(Plate 1, Fig. 6)

Garman, S. (1913).The Plagiostomia (sharks, skates, and rays). Memoirs of the Museum of Comparative Zoology v. 36: i-xiii + 1-515. [Type locality: Suruga Gulf, Japan]

Diagnosis: A medium sized deepwater shark with two dorsal fins with strong spines in front of them. Dorsal fin spines with large grooved spines. Anal fin absent. Denticles block shaped and wide spaced. Long thick snout. Rear tips of pectoral fins narrowly angular and elongated. Second dorsal fin spine base over inner margin of pelvic fins. Colour: Grey above lighter below, prominent black tips in most fins.

Morphometry: (Expressed in % TL). Pre-caudal length 78.4-78.6; pre-second dorsal length 64.5-65.7; pre-first dorsal length 31.0-31.4; pre-vent length 56.1-56.9; pre-pelvic length 55.1-55.7; pre-pectoral length 25.5-26.1; head length 26.5-27.1; pre-branchial length 20.2-22.2; pre-spiracular length 13.4-13.9; pre-orbital length 7.4-7.8; pre-narial length (outer) 4.7-4.8; pre-narial length (inner) 4.3-4.4; pre-oral length 10.3-10.7; mouth width 8.7-8.8; upper labial furrow length 1.5-2.5; lower labial furrow length 3.9-4.5; internarial space 3.7-3.7; interorbital space 8.2-8.6; eye length 4.9-5.2; eye height 1.9-2.2; spiracle length 1.9; first gill-slit height 2.4-3.0; fifth gill-slit height 3.8-4.0; interdorsal space 22.4-24.5; dorsal-caudal space 7.7-8.2; pectoral-pelvic space 26.1-26.5; pelvic-caudal space 14.3-14.7; first dorsal length 16.1-17.0; first dorsal anterior margin 11.0-12.2; first dorsal base length 10.6-11.0; first dorsal height 6.3; first dorsal inner margin 5.7-5.8; first dorsal posterior margin 8.6-9.6; first dorsal spine length 2.5-2.9; first dorsal spine base width 8.0-1.0; second dorsal length 10.2-10.5; second dorsal base length 7.2-8.4; second dorsal height 6.1-6.3; second dorsal posterior margin 4.3-4.7; second dorsal spine length 6.0-6.2; second dorsal spine base width 3.3-4.0; pectoral anterior margin 0.7-0.9; pectoral inner margin 10.9-11.6; pectoral base length 3.8-4.0; pectoral posterior margin 8.6-10.1; pelvic length 10.3-10.5; pelvic height 4.1-4.3; pelvic inner margin 5.0-5.4; dorsal caudal margin 20.4-22.4; pre-ventral caudal margin 12.3-13.6; head width at nostrils 7.1-7.6; head width at mouth 11.3-11.5; head width 12.7-14.3; trunk width 11.0-12.2; tail width 4.6-4.8; caudal peduncle width 2.0-2.1; head height 10.0-11.1; trunk height 11.6-12.7; abdomen height 11.2-11.5; tail height 5.7-6.1; caudal peduncle height 3.4-3.6.

Distribution and habitat: Northwestern Indian Ocean and western Pacific, on the outer continental shelves and slopes.

Remarks: Several *Centrophorus* species have been listed/ reported from India. Silas *et al.* (1969) reported *Atractophorus armatus* from southwest coast. Nair and Lalmohan (1972) reported *Centrophorus armatus* from east coast. *Atractophorus armatus* Gilchrist, 1922 have been synonymised with *Centrophorus moluccensis* Bleeker, 1860 (whose distribution in India needs confirmation). Description of Silas *et al.* (1969), Nair and Lal Mohan (1972) matches well with the *Centrophorus atromarginatus* collected from west coast. *Centrophorus* cf. *moluccensis* listed in Akhilesh *et al.* (2011 a) is also *Centrophorus atromarginatus*. IUCN Red List of Threatened Species list the status of *Centrophorus atromarginatus* as Data deficient (McCormack and White, 2009).

Family: **Centrophoridae**

Centrophorus cf. ***granulosus*** **(Bloch and Schneider, 1801)** Gulper shark

(Plate 1, Fig. 7)

Bloch, M.E. and Schneider, J.G. (1801). M.E. Blochii Systema Ichthyologiae iconibus ex illustratum. Post obitum auctoris opus inchoatum absolvit, correxit, interpolavit. J.G. Schneider, Saxo: 584 p., 110 pl.

Synonyms: *Squalus granulosus* Bloch and Schneider, 1801; *Centrophorus acus* Garman, 1906; *Centrophorus niaukang* Teng, 1959.

Diagnosis: A large species of *Centrophorus* with a robust body, short snout and long head. First dorsal low and long. Second dorsal origin in the inner margins of pelvic fins. Inner margin of pectorals long, free rear tips extend as lobe. Block like denticles. Colour -body uniformly brownish.

Morphometry: (Expressed in % TL): Pectoral fin inner margin length 11.4-12.5; second dorsal origin to upper caudal- length 15.1-15.7; first dorsal fin height 6.5-7.5; second dorsal fin height 5.0-5.3; first dorsal fin insertion to second dorsal fin origin 22.3-22.3; snout to pectoral insertion 26.6-28.0; snout to pectoral origin 23.3-24.4; pre-oral length 9.2-9.6; mouth width 8.6-9.4; interdorsal length 24.0-26.0.

Distribution and Habitat*:* Widespread in Atlantic, Pacific and Indian Ocean in the continental shelves and slopes.

Remarks: Mathew *et al.* (1991) reported *C. granulosus* for the first time from Indian waters. Since there is world over confusion in gulper shark taxonomy, status of this group in India need to be verified. IUCN Red List of Threatened Species lists the status of *Centrophorus granulosus* as Vulnerable (Guallart *et al.*, 2006).

Family: **Centrophoridae**

Centrophorus squamosus (Bonnaterre, 1788) Leafscale gulper shark

(Plate 1, Fig. 8)

Bonnaterre, J. P. (1788).Tableau encyclopédique et methodique des trois règnes de la nature... Ichthyologie. Panckoucke, Paris. Tableau encyclopédique et méthodique des trois règnes de la nature. Ichthyologie: i-lvi + 1-215, Pls. A-B + 1-100. [Type locality: Eastern North Atlantic]

Synonyms: *Centroscymnus fuscus* Gilchrist & Von Bonde, 1924; *Centrophorus foliaceus* Günther (1877)

Diagnosis: A medium sized deepwater shark with two dorsal fins. Strong grooved spines infront of both dorsal fins. Snout short, parabolic in ventral view. Moderately broad and long snout. Teeth blade like and oblique in the lower jaw. Labial furrows not long. Body surface rough. This deepwater shark can be easily identified from its denticle pattern ie, leaf like flattened crowns on elevated pedicels extending above the denticle bases a strong main cusp and three or more side cusps on their posterior edges and ridges running the length of the crown. Dermal denticles of back overlapping with each other. Very rough skin. First dorsal fin very low and long, second shorter and higher. Pectoral fins free rear tips short broadly angular and no extended rear tips. Anal fin absent. Colour- Black brown or black.

Morphometry: (Expressed in % TL). Pre-caudal length 79.5-79.6; pre-second dorsal length 64.4-65.6; Pre-first dorsal length 30.2-33.2; Pre-vent length (anterior) 58.8-61.9; Pre-pelvic length 55.6-58.4; pre-pectoral length 22.6-23.6; head length 24.0-24.5; pre-branchial length 19.3-20.5; pre-spiracular length 13.1-13.4; pre-orbital length 6.8-7.2; pre-narial length (outer) 4.6-5.0; pre-narial length (inner) 4.2-4.5; pre-oral length 9.2-9.5; mouth width 9.2-9.6; upper labial furrow length 2.1-2.5; lower labial furrow length 1.4-2.1; internarial space 2.9-3.2; anterior nasal flap length 0.6-0.8; interorbital space 6.7-7.7; interspiracle length 6.5-6.7; eye length 4.0-4.9; eye height 1.3-1.8; spiracle length 1.9-2.1; first gill-slit height 1.9-2.2; fifth gill-slit height 2.0-2.4; interdorsal space 20.4-21.1; dorsal-caudal space 5.9-6.1; pectoral-pelvic space 31.0-32.4; pelvic-caudal space 13.7-14.3; first dorsal length 19.0-19.9; first dorsal anterior margin 10.7-11.1; first dorsal base length 13.1-13.4; first dorsal height 5.6-

6.1; first dorsal inner margin 6.2-6.7; first dorsal posterior margin 9.9-10.3; first dorsal spine length 1.6-3.0; first dorsal spine base width 1.0-1.4; second dorsal length 13.7-14.5; second dorsal anterior margin 8.5-9.4; second dorsal base length 8.4-10.0; second dorsal height 5.5-5.6; second dorsal inner margin 4.5-4.5; second dorsal posterior margin 8.4-9.2; second dorsal spine length 2.1-2.8; second dorsal spine base width 0.9-1.0; pectoral fin length 11.4-11.9; pectoral fin anterior margin 10.0-11.5; pectoral fin inner margin 6.8-7.3; pectoral fin base length 4.6-4.9; pectoral fin posterior margin 6.4-6.8; pelvic length 10.5-11.9; pelvic fin height 4.9-5.1; pelvic fin inner margin 5.4-6.2; pelvic fin anterior margin 6.4-7.8; dorsal caudal margin 18.6-19.4; pre-ventral caudal margin 10.8-12.7; head width at nostrils 8.0-8.3; head width at mouth 11.4-13.1; head width 12.9-13.4; trunk width 11.0-11.1; abdomen width 8.7-9.0; tail width 2.1-2.6; caudal peduncle width 1.8-2.1; head height 8.7-10.0; trunk height 9.5-10.5; abdomen height 8.6-8.7; tail height 3.5-3.9; caudal peduncle height 3.1-3.5; terminal caudal margin 7.0-8.3; terminal caudal lobe 8.0-8.7.

Distribution and Habitat: Widely distributed in the world oceans, but a patchy distribution in the Eastern Atlantic and Indo-West Pacific. Indian Ocean reports are from South Africa, Aldabra Islands, India and Maldives. Lives at depths between 229 and 2,359 m (Compagno, 1984).

Remarks: Worldwide, the taxonomic status of gulper sharks (Centrophoridae) is often problematic and confusing. According to recent publications related to deep-sea chondrichthyan taxonomy and zoogeography, reports of occurrence of several species of this genus are questionable from Indian waters, which need to be resolved. Occurrence of *C. squamosus* as listed in an earlier work by Titto D'Cruz (2004) is confirmed by Akhilesh *et al.* (2010). According to IUCN Red List of Threatened Species, the status of *C. squamosus* is Vulnerable (White, 2003)

Family: **Centrophoridae**

Deania profundorum **(Smith and Radcliffe, 1912)** Arrowhead dogfish
(Plate 2, Fig. 1)

Smith, H. M. (1912). The squaloid sharks of the Philippine Archipelago, with descriptions of new genera and species. [Scientific results of the Philippine cruise of the Fisheries steamer "Albatross," 1907-10.--No. 15.]. Proceedings of the United States National Museum v. 41 (no. 1877): 677-685, Pls. 50-54 [Type locality: Philippines]

Synonyms: *Nasisqualus profundorum* Smith and Radcliffe, 1912; *Deania profundora* (Smith and Radcliffe, 1912)

Diagnosis: Deepwater shark with a greatly elongated snout and its length greater than distance from centre of mouth to pectoral fin origins. Two dorsal fins with strong spines in front of them anal fin absent, First dorsal fin long, low and keel shaped. Second dorsal fin spine much larger than first. Pectoral fin free rear tip not elongated. Anal fin absent. This species can be easily identified by the presence of a keel on the underside of the caudal peduncle. Teeth of lower jaw broader than that in upper jaw. Dermal denticles on sides of body have stellate bases, high pedicels, tricuspidate erect crowns. Colour- Brownish grey or dark grey.

Morphometry (Expressed in % TL). Pre-caudal length 81.6-82.2; pre-dorsal length 6.4-6.8; head length 26-26.2; pre-branchial length 21-22; pre-spiracular length 15.6-15.7; pre-orbital length 9.8-10; pre-pectoral length 24.7-24.9; pre-pelvic length 6-6.4;

dorsal caudal space 3.3-3.9; interdorsal space 14.9-16.4; pre-narial length 4.8-4.9; pre-oral length 12.7-13.1; inter gill length 5.4-5.6; pectoral fin-anterior margin 10.4-11.2, pectoral base 5-5.1; pectoral fin-inner margin 8.6-9.2; pectoral-posterior margin 7.5-8.2; dorsal caudal margin 18.7-19.5; pre-ventral caudal margin 10-11.8; terminal caudal margin 6-6.6; first dorsal fin length 23.4-24.1; first dorsal anterior margin 11.2-11.9; first dorsal base 17.3-17.4; first dorsal height 4.9-5; first dorsal inner margin 6.3-7.2; second dorsal base 12.5-13.5; second dorsal height 6.4-6.5; second dorsal length 16.6-16.9; second inner margin length 3.9-4.4; pelvic fin length 10.6-10.8; pelvic fin anterior margin 6.7-7.1; pelvic fin base 4.9-5.2; pelvic fin inner margin 5.8; caudal peduncle height 3.3; mouth width 7-7.2; nostril width 2-2.3; internarial length 3.8-3.9; interorbital width 6.4-6.7; head width 12.3-13.3.

Distribution and Habitat*:* Very disjunct distribution in the world oceans. It is distributed on both sides of the Atlantic Ocean and Pacific Ocean (Compagno, 1984). Indian Ocean reports are only from South Africa, Gulf of Aden and India (Compagno, 1998; Bonfil and Abdallah, 2004). Lives at depths between 275 and 1785 m (Compagno, 1984).

Remarks: Akhilesh *et al.* (2010) reported *Deania profundorum* for the first time from Indian waters. Occasionally occurs in the deep-sea shrimp trawl and long line landings. The IUCN Red List of Threatened Species list the status of *Deania profundorum* as Least Concern (Ebert *et al.*, 2009).

Family: **Squalidae**

Squalus cf. ***lalannei*** **Baranes, 2003** Seychelles spurdog

(Plate 2, Fig. 2)

Baranes, A. (2003). Sharks from the Amirantes Islands, Seychelles, with a description of two new species of squaloids from the deepsea. Israel Journal of Zoology, 49, 33-65. [Type locality: Seychelles]

Diagnosis: A medium sized *Squalus* with uniform dark grey (almost charcoal colour) without spots, (lighter ventral parts in juveniles), small but strong dorsal spines. Distance from snout tip to inner margin of nostril shorter than distance from inner edge of nostril to front of upper labial furrow. Short snout, secondary lobe of nasal flap poorly developed. First and second dorsal fins tall and upright dark color (black in juveniles), dark caudal bar (very clear in specimens < 40 cm TL). Pectoral fin tip rounded its posterior margin concave. Denticles tricuspid First dorsal fin with a more oblique anterior margin.

Morphometry: (Expressed in % of TL). Pre-caudal length 78.1-80.8; pre-second dorsal length 61.5-65.4; pre-first dorsal length -30.5-32.8; pre-vent length 49.2-52.6; pre-pelvic length 47.9-51.5; pre-pectoral length 24.2-29.3; head length 23.9-26.0; pre-branchial length 18.7-21.0; pre-spiracular length 11.2-12.8; pre-orbital length 5.6-7.6; pre-oral length 8.5-9.3; mouth width 7.2-8.7; labial furrow length 1.9-2.5; internarial space 4.1-4.7; interorbital space 7.5-8.9; eye length 3.8-4.8; eye height 1.7-2.4; spiracle length 1.6-2.3; first gill-slit height 1.8-2.7; fifth gill-slit height 2.1-2.7; interdorsal space 22.5-26.9; dorsal-caudal space 10.1-11.5; pectoral-pelvic space 14.9-23.1; pectoral-pelvic space 19-22.1; pelvic-caudal space 10.5-26.6; first dorsal length 11.9-13.5; first dorsal anterior margin 9.3-10.6; first dorsal base length 6.7-7.8; first dorsal height 5.5-6.5; first dorsal inner margin 4.9-5.9; first dorsal posterior margin 6.5-7.7; first dorsal spine base width 0.6-0.7; second dorsal length 8.0-11.7; second dorsal anterior margin 5.2-9.2.

Distribution and habitat: Presently known only from deepwaters off Seychelles and southeastern Arabian Sea.

Remarks: Only two *Squalus* species are reported from Indian waters ie, *S. fernandinus* (synonymised with *S. blainville*) from Quilon by Silas and Prasad (1969). Soundararajan and Roy (2004) reported *Squalus megalops* from Andaman waters. The IUCN Red List of Threatened Species list the status of *Squalus lalannei* as Data Deficient (McCormack, 2009).

Family: **Etmopteridae**

***Etmopterus pusillus* (Lowe, 1839)** Lantern shark

(Plate 2, Fig. 3)

Lowe, R. T. (1839). A supplement to a synopsis of the fishes of Madeira. Proceedings of the Zoological Society of London 1839 (pt 7): 76-92. [Type locality: Madeira, eastern Atlantic]

Synonyms: *Acanthidium pusillum* Lowe, 1839; *Centrina nigra* Lowe, 1839; *Etmopterus frontimaculatus* Pietschmann, 1907.

Diagnosis: A small deepwater shark with two dorsal fins with strong spines infront of them. Cylindrical or slightly compressed body. First dorsal fin usually smaller than second dorsal fin, second dorsal spine larger than first. Anal fin absent. Caudal fin with terminal notch. upper and lower teeth different. Denticle truncated. Colour- blackish-brown above, with a broad black mark running above pelvic fins and ending just behind second dorsal.

Morphometry: (Expressed in % of TL). Fork length 87.87-89.03; pre caudal-fin length 80.66-81.72; head length 23.01-25.77; pre-orbital length 5.46-5.48; pre-oral length 8.7- 10.7; eye length 3.3-3.7; inter gill length 5.38-6.76; dorsal caudal-fin margin 16.73-20.65; pre-ventral caudal-fin margin 10.58-10.67; caudal-fin fork length 10.23-10.72; first dorsal-fin anterior margin 5.02-5.44; second dorsal-fin anterior margin 7.48-9.36; inter dorsal space 22.74-26.65; pectoral-fin anterior margin 8.66-9.77; pelvic-fin anterior margin 5.10-5.80; head height 8.24-8.89; trunk height 9.08-10.10; tail height 5.53-5.81; caudal-fin peduncle height 2.20-2.30; head width 10.59-10.65; trunk width 9.15-10.77; tail width 4.13-5.55; caudal-fin peduncle width 1.63-1.81 and intestinal spiral valve count 12-13.

Distribution and Habitat: Circumglobal distribution in the world oceans. In the western Indian Ocean *Etmopterus pusillus* have been reported from South Africa and India, it is found on or near the bottom of continental and insular slopes at depths from 274 to 1000 m and can possibly occur up to 2000 m (Compagno *et al.,* 2005 a).

Remarks: Three *Etmopterus* species are reported/listed from Indian EEZ; *Etmopterus pusillus* (Lowe, 1839); *Etmopterus granulosus* (Günther, 1880) and *Etmopterus lucifer* Jordan and Snyder, 1902 (Jayaprakash *et al.,* 2006; CMFRI, 2007; Sreedhar *et al.,* 2007; Vivekanandan and Sivaraj, 2008). Latter two reports need confirmation. *Etmopterus pusillus* occurs very rarely in commercial landings. Akhilesh *et al.,* (2010); Deepu *et al.,* (2010) provided morphometric details of *E. pusillus* from India. The IUCN Red List of Threatened Species list the status of *E. pusillus* as Least Concern (Coelho *et al.,* 2009).

Family: **Somniosidae**

***Centroselachus crepidater* (Bocage and Capello, 1864).** Longnose velvet dogfish (Plate 2, Fig. 4)

Barbosa du Bocage, J. V. and F. de Brito Capello. (1864). Sur quelque espèces inédites de Squalidae de la tribu Acanthiana, Gray, qui fréquentent les côtes du Portugal. Proceedings of the Zoological Society of London (pt 2): 260-263. [Type locality: Portugal]

Synonyms: *Centroscymnus crepidater* (Bocage and Capello, 1864); *Centrophorus crepidater* Bocage and Capello, 1864; *Centrophorus jonssonii* Saemundsson, 1922; *Centrophorus rossi* Alcock, 1898; *Centroscymnus furvescens* de Buen, 1960

Diagnosis: A deepwater shark with slender body; greatly elongated snout and upper labial furrows (nearly completely encircles mouth); pre-oral length about equal to distance from mouth to pectoral fin origins. Two dorsal fins with very small spines. Dorsal fins almost of same length. Pectoral fins moderately long. Anal fin absent. Small mouth. Lanceolate upper teeth and blade like lower teeth. Dermal denticles round/oval, flat, overlapping and tricuspid. Colour: Black or blackish brown. Posterior fin margins light.

Morphometry: (Expressed in % TL)**.** Pre-caudal length 80.3-82.0; pre-second dorsal-length 65.3-68.0; pre-first dorsal-length 33.4-36.0; head length 25.1-28.0; pre-branchial length 20.9-22.0; pre-spiracular length 14.9-16.0; pre-orbital length 8.0-9.8; pre-pectoral length 23.9-25.4; pre-pelvic length 60.7-62.3; snout-anterior vent length 63.0-65.7; pre-anal fin length 76.0-78.6; interdorsal space 2.2-2.4; dorsal (second dorsal)-caudal space 6.4-7.4; pectoral-pelvic space 3.4-3.6; pelvic-anal space 8.8-9.6;

anal-caudal space 8.5-9.6; pre-oral length 10.4-12.0; eye length 3.7-5.1; eye height 1.6-1.9; inter-gill length 3.6-4.3; first gill slit height 1.7-2.3; fifth gill slit height 2.4-2.7; pectoral anterior margin length 10.4-11.2; pectoral base length 4.3-4.7; pectoral height 8.8-9.3; pectoral length 11.2-11.4; dorsal caudal margin length 17.6-18.1; pre-ventral caudal margin length 10.1-10.9; upper post-ventral caudal margin length 8.4-8.6; lower postventral caudal margin length 3.7-4.0; caudal fork width 7.0-7.4; caudal fork length 10.7-11.4; subterminal caudal margin length 2.7-2.8; sub-terminal caudal width 4.8-4.9; terminal caudal margin length 5.2-5.6; terminal caudal lobe length 5.7-6.1; first dorsal total length 17.3-17.8; first dorsal anterior margin length 12.2-12.5; first dorsal base length 10.7-11.3; first dorsal vertical height 4.5-4.7; first dorsal inner margin length 6.4-6.6; first dorsal posterior margin length 5.1-5.4; second dorsal total length 16.4-16.6; second dorsal anterior margin length 9.7-10.3; second- dorsal base length 10.4-10.8; second - dorsal vertical height 5.2-5.6; second - dorsal inner margin length 4.9-5.1; second dorsal posterior margin length 6.6-6.7; pelvic fin total length 12.2-12.8; pelvic fin anterior margin length 7.5-8.0; pelvic fin base length 7.6-7.9; pelvic fin vertical height 3.7-4.4; pelvic fin inner margin length 4.2-4.6; pelvic fin posterior margin length 7.2-7.7; head height at p origin 11.3-11.8; trunk height at p base end 12.5-12.8; abdomen height at first dorsal base end 12.8-13.1; first dorsal midpoint-pectoral base end 0.7-0.9; nostril width 1.6-1.8; internarial width 4.0-4.2; anterior nasal flap length 0.3-0.4; spiracle length 2.5-2.7; eye-spiracle space 1.6-1.9; head width at middle gill slits 12.2-12.9; trunk width at pectoral base ends 13.6-13.9; abdomen width at first dorsal base end 13.7-13.8; tail width at pelvic base ends 2.7-3.1; caudal peduncle width at caudal origin 1.9-2.1.

Distribution and Habitat: Widely distributed from eastern Atlantic to southwestern Indian Ocean in continental shelves and insular slopes.

Remark: Caught rarely in bottom trawls and longlines in southern coasts of India. The IUCN Red List of Threatened Species list the status as *Centroselachus crepidater* Least Concern (Stevens, 2003).

Family: **Somniosidae**

***Zameus squamulosus* (Günther, 1877**) Smallmouth velvet dogfish

(Plate 2, Fig. 5)

Günther, A. (1877). Preliminary notes on new fishes collected in Japan during the expedition of H. M. S. `Challenger.'. Annals and Magazine of Natural History (Series 4), 20 (119): 433-446. [Type locality: Inoshima, Japan]

Synonyms : *Centrophorus squamulosus* Günther, 1877; *Centroscymnus squamulosus* (Günther, 1877); *Scymnodon squamulosus* (Günther, 1877); *Centroscymnus obscurus* Vaillant, 1888; *Scymnodon obscurus* (Vaillant, 1888); *Scymnodon niger* Chu and Meng, 1982.

Diagnosis: A small deepwater shark with slender body, trunk sub-cylindrical, tapers posteriorly. Head rather low and flat; snout rather narrow. Elevated and dorsolaterally placed gills, very small gill slits. Mouth almost transverse and small. Two dorsal fins with minute dorsal fin spines. First dorsal posterior to pectorals. Second dorsal fin low and keel shaped. Second dorsal fin spine much larger than first. Upper teeth lanceolate shaped. No anal fin. Caudal fin with a strong subterminal notch and a short lower lobe. Dermal denticles leaf like, with three longitudinal ridges. Colour: Uniform black.

Morphometry: (Expressed in % TL). Pre-caudal length 77.9-79.2; pre-second dorsal length 63.2-64.0; pre-first dorsal length 39.6-42.9; pre-vent length 60.4-62.7; pre-pelvic length 56.8-57.8; pre-pectoral length 25.7-26.1; head length 25.2-25.4; pre-branchial length 20.5-21.4; pre-spiracular length 13.2-13.7; pre-orbital length 6.9-7.1; pre-narial length (outer) 3.3-3.5; pre-narial length (inner)3.6-4.0; pre-oral length 9.5-9.6; mouth width 9.0-9.2; labial furrow length 3.6-3.8; internarial space 3.9-4.2; interorbital space 8.8-9.5; eye length 5.4-5.5; eye height 2.0-2.3; spiracle length 1.5-1.7; first gill-slit height 1.6-2.3; fifth gill-slit height 1.8; interdorsal space 15.2-17.3; dorsal-caudal space 8.7-8.9; pectoral-pelvic space 25.4-26.8; pelvic-caudal space 11.9-12.0; first dorsal length 9.8-10.4; first dorsal anterior margin 7.9-8.1; first dorsal base length 5.6-6.0; first dorsal height 2.3-2.9; first dorsal inner margin 4.1-4.4; first dorsal posterior margin 2.8-3.0; first dorsal spine length 0.3; second dorsal length 10.9-11.5; second dorsal anterior margin 7.7-8.4; second dorsal base length 6.7-7.4; second dorsal height 3.1-3.2; second dorsal inner margin 4.3-5.0; second dorsal posterior margin 4.7-5.1; second dorsal spine length 0.3-0.4; pectoral anterior margin 11.5-11.6; pectoral inner margin 5.0-5.7; pectoral base length 6.8-6.9; pectoral posterior margin 4.8-4.9; pelvic length 9.0-9.6; pelvic height 3.4-3.6; pelvic inner margin 3.6; dorsal caudal margin 20.2-21.7; pre-ventral caudal margin 10.6-11.9; upper post-ventral caudal margin 12.8-13.0; lower post-ventral caudal margin 3.5-4.0; caudal fork width 6.3-7.0; caudal fork length 11.2-12.0; head width at nostrils 6.4-6.5; head width at mouth 10.9-11.8; head width 11.9-13.0; trunk width 11.5-12.5; abdomen width 8.1-8.8; tail width 2.8-3.2; caudal peduncle width 1.7-2.4; head height 8.4-9.8; trunk height 8.8-10.7; abdomen height 7.5-10.3; tail height 4.0-4.5; caudal peduncle height 3.1-3.4.

Distribution and Habitat: A cosmopolitan deepwater shark. Found in the continental or insular slopes, on or near bottom depths of 550 to 1,450 m (Compagno *et al.,* 2005 a). Indian Ocean reports are only from South Africa, India, Madagascar, Mauritius and Indonesia (White *et al.*, 2006; Ebert, 2013).

Remarks: Report of *Zameus squamulosus* by Akhilesh *et al.* (2013 a) from southeastern Arabian Sea extended the known distribution range to northern Indian Ocean and filled the gap in the distribution range. The IUCN Red List of Threatened Species list the status of *Zameus squamulosus* as Data Deficient (Burgess and Chin, 2006)

Order: **Lamniformes**

Family: **Odontaspididae**

Odontaspis noronhai **(Maul, 1955)** Bigeye Sand Tiger

(Plate 2, Fig. 6)

Maul, G. E. (1955). Five species of rare sharks new for Madeira including two new to science. Notulae Naturae (Philadelphia) No. 279: 1-13. [Type locality: Madeira, eastern Atlantic]

Synonym: *Carcharias noronhai* Maul, 1955

Diagnosis: A large stout shark. Head depressed, with a long, bulbous snout. Eyes very large, without nictitating eyelids. Mouth long and extending behind eyes; teeth moderately large, with prominent narrow cusps. Single pair of lateral upper anterior teeth separated from lateral teeth by one row of small intermediate teeth. First dorsal fin on back and closer to pectoral fins than pelvic fin. First dorsal fin with its posterior margin extending vertically from its apex. Origin of second dorsal fin about over first thirds of pelvic bases. Anal fin low and rounded, height much less than base length. Caudal peduncle with pre-caudal pit. Lateral keels absent from caudal peduncle. Caudal fin asymmetrical but with a strong ventral lobe; anal fin and second dorsal fin smaller than first dorsal. Colour-uniform dark chocolate brown, without spots.

Morphometry: (Expressed in % TL). Pre-dorsal length 35.67; eye diameter 2.34; first gill slit height 7.60; second gill slit height 8.19; third gill slit height 7.02; fifth gill slit height 7.02; pectoral fin anterior margin 13.45; pectoral fin posterior margin 8.77; pectoral fin inner margin 5.26; first dorsal anterior margin 10.53; first dorsal posterior margin 6.43; first dorsal inner margin 2.63; interdorsal space 17.54; second dorsal anterior margin 6.73; second dorsal posterior margin 4.68; second dorsal inner margin 2.63; pelvic pectoral space 22.81; pelvic anterior margin 7.89; pelvic posterior margin 8.48; pelvic fin inner margin 3.22; anal fin anterior margin 3.80; anal fin posterior margin 3.51; anal fin inner margin 2.05; upper caudal lobe length 30.99; lower caudal lobe width 9.94; lower w 25.44; dorsal fin height 6.14; second dorsal caudal space 6.14.

Distribution and Habitat: A rare pelagic deepwater shark inhabiting the continental and insular slopes in tropical and warm-temperate waters.

Remarks: It is the first report of *Odontaspis noronhai* from India. Indian Ocean distribution, India and Sri Lanka (Moron *et al.*, 1998). The IUCN Red List of Threatened Species list the status of *Odontaspis noronhai* as Data Deficient (Amorim *et al.*, 2005).

Family: **Pseudocarchariidae**

***Pseudocarcharias kamoharai* (Matsubara, 1936)** Crocodile shark

(Plate 2, Fig. 7)

Matsubara, K. (1936). A new carcharoid shark found in Japan. Dobutsugaku Zasshi, 48 (7): 380-382. [Type locality: Koti, Japan]

Synonyms: *Carcharias kamoharai* Matsubara, 1936

Diagnosis: A small slender-bodied shark with a cylindrical trunk and large eyes without nictitating membrane. Head short with moderately long bluntly pointed snout, long gill slits. Long cusped teeth without lateral cusps. Highly protrusible jaws. Small pectoral fins. Gill slits long, extending onto dorsal surface of head. Dorsal and anal fins small without spines; second dorsal fin smaller than first but larger than second. Pectorals small. Caudal fin asymmetrical. Pre-caudal pits present; lateral keels on caudal peduncle not well developed. Colour- Dark grey-brown dorsally, lighter ventral portion. Light-edged fins.

Morphometry: (Expressed in % TL). Pre-caudal length 76.2; pre-second dorsallength 64.6; pre-first dorsal-length 37.0; head length 24.3; pre-branchial length 16.9; pre-orbital length 6.2; interorbital length 5.2; pre-pectoral length 23.3; pre-pelvic length 57.7; snout-anterior vent length 60.3; pre-anal fin length 68.8; interdorsal space 18.8; second dorsal-caudal space 8.0; pectoral-pelvic space 30.5; pelvic-anal space 5.3; anal-caudal space 5.7; pelvic-caudal space 13.5; anterior vent-caudal tip length 15.3; pre-narial length 4.9, pre-oral length 6.9; eye length 2.6; eye height 3.0; intergill length 7.3; first gill slit height 6.7; fifth gill slit height 6.5; pectoral fin anterior margin length 9.5; pectoral fin base length 4.8; pectoral fin inner margin length 4.0;

pectoral fin posterior margin length 6.0; pectoral fin height 7.0; pectoral fin length 8.1; dorsal caudal margin length 24.9; pre-ventral caudal margin length 10.6; upper post-ventral caudal margin length 12.7; lower post-ventral caudal margin length 6.9; caudal fork width 7.2; caudal fork length 9.1; subterminal caudal margin length 4.2; subterminal caudal width 3.0; terminal caudal margin length 4.8; terminal caudal lobe length 6.3; first dorsal total length 11.6; first dorsal anterior margin length 7.6; first dorsal base length 9.0; first dorsal vertical height 3.5; first dorsal inner margin length 2.4; first dorsal posterior margin length 6.4; second dorsal total length 7.5; second dorsal anterior margin length 4.0; second drosal base length 4.5; second dorsal vertical height 2.0; second dorsal inner margin length 2.9; second dorsal posterior margin length 4.4; pelvic total length 8.6; pelvic anterior margin length 5.2; pelvic base length 6.6; pelvic height 3.5; pelvic inner margin length 2.0; pelvic posterior margin length 6.2; anal fin total length 4.7; anal fin anterior margin length 2.6; anal fin base length 2.4; anal fin vertical height 1.7; anal fin inner margin length 2.6; anal fin posterior margin length 3.2; head height at pectoral origin 14.6; trunk height at pectoral base end 14.8; abdomen height at first dorsal base end 14.3; mouth length 3.9; mouth width 6.3; upper labial furrow length 2.3; nostril width 1.2; internarial width 2.3; interior nasal flap length 0.1; head width at middle gill slits 11.3; trunk width at pectoral base ends 10.8; abdomen width at first dorsal base end 2.7.

Distribution and Habitat: Circumtropical distribution, usually found offshore and far from land but sometimes occurring inshore and near to the bottom, having a depth preference of surface to 590 m. Indian Ocean reports of *P. kamoharai* are few and patchy (Compagno *et al.,* 2005 a).

Remarks: *Pseudocarcharias kamoharai* distribution in the Bay of Bengal has been reported as erroneous by Compagno (1984); Compagno and Musick (2005), however Kizhakudan and Rajapackiam (2013) confirmed its occurrence in Chennai, Bay of Bengal. The IUCN Red List of Threatened Animals list the status of *P. kamoharai* as Near Threatened (Compagno and Musick, 2005).

Order: **Carcharhiniformes.**

Family: **Scyliorhinidae**

***Bythaelurus hispidus* (Alcock, 1891).** Bristly catshark

(Plate 2, Fig. 8)

Alcock, A. W. (1891). Class Pisces. In: II.--Natural history notes from H. M. Indian marine survey steamer `Investigator,' Commander R. F. Hoskyn, R. N., commanding.--Series II., No. 1. On the results of deep-sea dredging during the season 1890-91. Annals and Magazine of Natural History (Series 6) v. 8 (no. 43/44): 16-34,119-138: Pls. 7-8. [Type locality: Andaman Sea]

Synonyms: *Scyllium hispidum* Alcock, 1891; *Halaelurus hispidus* (Alcock, 1891)

Diagnosis: A very small slender elongated shark. Anterior nasal flaps subtriangular. anal fin base shorter than interdorsal space. The roof of mouth with numerous small papillae. Eye length less than fourteen times in pre-dorsal distance in adults. Short rounded snout. Origin of dorsal fin over the base of pelvic and anal fins. Colour-Pale brown sometimes with pale brown cross bands at dorsal base.

Morphometry: (Expressed in % TL). Pre-caudal length 76.4-76.5; pre-second dorsal length 66.2-67.2; pre-first dorsal length 46.4-48.9; head length 19.7-21.9; pre-branchial length 15.7-17.2; pre-spiracular length 9.4-10.1; 4.7-5.4 ; pre-orbital length 6.1-5.5; pre-oral length 4.3-4.9; pre-narial length (outer) 4.3-4.6; pre-narial length (inner) 4.1-4.0; pre-pectoral length 19.1-20.8; pre-pelvic length 43.7-43.9; snout-vent distance 45.0-45.7; pre-anal length 62.9-61.9; interdorsal distance 12.7-13.2; dorsal-caudal distance 5.0-7.6; pectoral-pelvic distance 17.9-19.5; pelvic-anal distance 11.6-12.4; anal-caudal distance 2-2; eye length 3.3-3.6; eye height 0.9-1.0; interorbital width 6.0-6.0; nostril width 2.7-2.7; internarial space 2.5-2.6; spiracle length 0.9; mouth length (point) 3.7-3.7; mouth width 8.5-9.0; upper labial furrow length 1; lower labial furrow length 1.4-1.5; first gill slit height 2.0; fifth gill slit height 1.8-1.9; head height 7.9-9.1; trunk height 9.5-9.6; caudal peduncle height 2.9-3.1; head width at fifth gill 7.9-11.4; trunk width pectoral insertion 9.7-10.1; caudal peduncle width 1.6-1.9; pectoral fin -length 11.8-12.4; Pectoral fin-anterior margin length 12.3-13.1; Pectoral fin -base length 5.2-5.3; pectoral fin-height 10.0-11.3; pectoral fin-inner margin length 6.5-7.1; pectoral fin-posterior margin length 8.8-10.9; Pelvic fin-length 10.5-10.7; pelvic fin-anterior margin length 5.9-6.3; pelvic fin-base length 3.0-3.5; pelvic fin-height 3.1-3.3; pelvic fin-inner margin length 4.0-4.8; pelvic fin-posterior margin length 6.2-6.5; first dorsal fin-length 5.7-8.8; first dorsal fin-anterior margin 9.1; first dorsal fin-base length 5.8-6.5; first dorsal fin-height 4.5-5.2; first dorsal fin-inner margin 2.5-2.6; first dorsal fin-posterior margin 3.5-4.9; second dorsal fin-length 7.4-7.8; second dorsal fin-anterior margin 7.3-8.0; second dorsal fin-base length 5.4-6.1; second dorsal fin-height 3.2-4.0; second dorsal fin-inner margin 2.4-2.4; second dorsal fin-posterior margin 2.6-2.9; anal fin-length 11.0-11.6; anal fin-anterior margin length 7.3-7.5; anal fin-base length 9.1-9.5; anal fin-height 3.6-3.7; anal fin-inner margin length 1.8-2.1; anal fin-posterior margin length 5.7-5.9; caudal fin-dorsal margin length 22.4-24.2; caudal fin-preventral margin length 9.7-11.6; caudal fin-upper postventral margin 11.3-11.5; caudal fin-subterminal margin length 5.2-5.8; caudal fin-terminal margin length 4.1-4.3; caudal fin-terminal lobe length 4.3-4.5; second dorsal origin-anal fin origin 6.1-6.4.

Distribution and Habitat: Known only from Andaman Seas, Gulf of Mannar, Kerala coast and Oman.

Remarks: Occurs only as bycatch in deep-sea shrimp trawls and no commercial importance. The IUCN Red List of Threatened Species list the status *Bythaelurus hispidus* as Data Deficient (White, 2004)

Family: **Scyliorhinidae**

***Halaelurus quagga* (Alcock, 1899)** Quagga catshark

(Plate 2, Fig. 9)

Alcock, A. W. (1899). A descriptive catalogue of the Indian deep-sea fishes in the Indian Museum. Being a revised account of the deep-sea fishes collected by the Royal Indian marine survey ship Investigator. Calcutta. A descriptive catalogue of the Indian deep-sea fishes in the Indian Museum: i-iii + 1-211. [Type locality: Laccadive Sea, India]

Synonyms: *Scyllium quagga* Alcock, 1899

Diagnosis: A small shark with numerous (>20) vertical stripes on the body without dark spots. Snout tip knoblike but not prominently upturned. Eyes in adults 12-13 times in distance from snout to first dorsal origin. Anterior nasal flaps sub triangular. Gills dorsolaterally placed and elevated above the mouth level. First dorsal-fin origin about opposite pelvic-fin insertion. Light brown above with pale ventral side, dark brown cross bands on the body. Lower caudal fin lobe poorly developed but distinct. Colour -Dorsal surface light brown with numerous very dark brown bands, with six bands from the pectoral insertion to first dorsal origin. No dark spots on the body. Posterior margin of pectoral, pelvic and anal fins whitish. Inter-dorsal space with three bands, middle one largest with a paler area in the centre. First and second dorsal fins with bands continued from the body, a lighter area in the centre of dorsal fins. Ventral surfaces whitish.

Morphometry: (Expressed in % TL). Pre-caudal length 79.3-80.6; pre-second dorsal length 65.0-66.7; pre-first dorsal length 43.7-45.7; trunk length 20.1-23.4; head length 20.5-21.7; pre-branchial length 14.9-16.4; pre-spiracular length 9.9-10.3; pre-orbital length 5.7-6.5; pre-oral length 4.4- 5.0; pre-narial length 4.2-4.7; pre-pectoral length 18.9-21.0; pre-pelvic length 37.7-40.2; snout-vent distance 40.5-42.2; pre-anal length 56.3-58.5; interdorsal distance 13.2-15.7; dorsal-caudal distance 8.0-8.7; pectoral-pelvic distance 12.6-17.2; pelvic-anal distance 10.2-13.9; anal-caudal distance 10.9-12.4; eye length 3.3-3.7; eye height 0.9-1.4; interorbital width 5.9-6.6; nostril width 2.5-2.9; internarial space 1.8-1.9; anterior nasal flap length 0.9-1.1; spiracle length 1.0-1.1; eye-spiracle distance 0.5-0.7; mouth length 4.9-5.1; mouth width 8.0-9.1; upper labial furrow length 0.3-0.4; lower labial furrow length 1.5-1.7; intergill length 5.8-6.1; first gill slit height 2.0-2.1; fifth gill slit height 1.1-1.3; head height 6.1-7.5; trunk height 6.4-7.8; abdomen height 5.1-5.5; caudal peduncle height 2.7-2.9; head width 13.8-14.8; trunk width 11.1-12.6; abdomen width 4.7-5.6; caudal peduncle width 2.1-2.6; pectoral fin-length 9.7-10.5; pectoral fin-anterior margin length 9.8-10.9; pectoral fin -base length 5.2-5.7; pectoral fin-height 8.1-10.0; pectoral fin-inner margin length 4.0-5.9; pectoral fin-posterior margin length 6.9-8.4; pelvic fin-length 11.2-12.2; pelvic fin-anterior margin length 5.6-6.2; pelvic fin-base length 7.7-8.2; pelvic fin-height 2.9-4.4; pelvic fin-inner margin length 3.4-4.3; pelvic fin-posterior margin length 6.1-6.9; first dorsal fin-length 8.2-8.6; first dorsal fin-anterior margin 7.6-7.9; first dorsal fin-base length 6.1-6.5; first dorsal fin-height 4.2-4.6; first dorsal fin-inner margin 1.8-2.3; first dorsal fin-posterior margin 4.0-5.4; second dorsal fin-length 8.2-8.8; second dorsal fin-anterior margin 7.0-7.5; second dorsal fin-base length 6.1-7.1; second dorsal fin-height 3.4-4.0; second dorsal fin-inner margin 1.4-2.4; second dorsal fin-posterior margin 3.0-4.1; anal fin-length 9.6-10.6; anal fin-anterior margin length 6.1-6.9; anal fin-base length 7.1-8.3; Anal fin-height 2.8-3.1; Anal fin-inner margin length 2.4-2.6; anal fin-posterior margin length 4.8-5.4; caudal fin-dorsal margin length 18.4-20.1; caudal fin-preventral margin length 10.1-11.0; Caudal fin-upper postventral margin 7.7-9.1; caudal fin-subterminal margin length 4.0-4.5; caudal fin-terminal margin length 4.2-4.8; caudal fin-terminal lobe length 5.2-6.1; second dorsal origin-anal fin origin 8.2-8.8; second dorsal insertion-anal fin insertion 6.1-7.6.

Distribution and habitats: Known only from western Indian Ocean: India (Arabian Sea) and Somalia (Indian Ocean coast), offshore on continental slope, 54-186 m (Springer and D'Aubrey, 1972; Compagno *et al.*, 2005 a). Collection of *H. quagga* from deep-sea shrimp trawlers indicate that the species could have a wider depth distribution, possibly down to 280 m.

Remarks: Two *Halaelurus* species reported to occur in Indian waters, i.e. *H. quagga* and *H. boesemani*. Misra (1952; 1969) possibly misidentified *H. boesemani* for *H. buergeri*; however, the later species does not occur in Indian waters, and may not occur in the Indian Ocean (Springer and D'Aubrey, 1972; Compagno *et al.*, 2005 a). After the original description of *H. quagga* from the Arabian Sea coast of India (off Malabar), the only other reports of *H. quagga* came from off Somalia (Springer and D'Aubrey, 1972; Springer, 1979). The holotype is the only previously known specimen from India until Akhilesh *et al.* (2011 b) rediscovered *H. quagga* over 100 years after its original description. The IUCN Red List of Threatened species list the status of *H. quagga* as Data Deficient (Cronin, 2009)

Family: **Scyliorhinidae**

***Cephaloscyllium silasi* (Talwar, 1972)** Indian Swell shark

(Plate 3, Fig. 1)

Talwar, P.K. (1974). On a new bathypelagic shark, *Scyliorhinus (Halaelurus) silasi* (Fam. Scyliorhinidae) from the Arabian Sea. *Journal of the Marine Biological Association of India*, 14 (2): 779-78. [Type locality: off Kollam, India]

Synonyms: *Scyliorhinus silasi* Talwar, 1974

Diagnosis: A small species of swell shark, with a stout body and seven dark bands on the body surface. Second dorsal fin smaller than the first. Head depressed flattened and broad, rounded in dorsal and ventrally. Mouth large and arched. Labial furrows absent, inter narial distance shorter than pre-narial length and nostril width. Anterior nasal flaps broadly triangular. Last two gill slits over pectorals. First to third gill slits sub equal in length, fifth gill slit smallest. Eyes dorsolateral and slit like. Head width widest at just in front of first gill slit. Gill slits dorsolaterally placed and last two gill slits over pectorals. Eyes dorsolaterally placed and slit like small spiracle anal fin larger than second dorsal fin. Belly expanded. Teeth small and pointed. Pelvic-anal space greater than anal-fin length. Colour: Brown colour with seven dark bands, ventral side pale.

Morphometry: (Expressed in % TL). Pre-caudal length 79.00-81.3; pre-second dorsal length 66.00-70.00; pre-first dorsal length 51.25-55.56; head length 26.25-27.78; pre-branchial length 19.56-20.13; pre-spiracular length 10.70-11.20; pre-orbital length 6.33-7.07; pre-oral length 3.59-4.15; pre-narial length 3.89-4.21; pre-pectoral length 25.04-27.78; pre-pelvic length 47.50-51.56; snout-vent distance 50.25-55.56; pre-anal length 65.25-67.11; interdorsal distance 6.73-7.71; dorsal-caudal distance 6.71-7.25; pectoral-pelvic distance 16.54-20.13; anal-caudal distance 5.46-6.04; eye length 2.55-2.82; eye height 0.70-0.85; interorbital width 8.37-9.60; nostril width 3.39-3.65; internarial space 1.57-1.92; anterior nasal flap length 1.12-1.60; spiracle length 0.59-0.61; eye-spiracle distance 1.00-1.33; mouth length 4.25-4.80; mouth width 14.50-15.69; first gill slit height 2.88-3.64; second gill slit height 3.35-3.78; third gill slit height 3.12-3.44; fourth gill slit height 3.21-3.38; fifth gill slit height 1.90-2.48; head height 10.08-12.04; trunk height 11.76-15.00; caudal peduncle height 2.63-2.76; head width 20.93-23.04; trunk width 18.25-21.11; caudal peduncle width 2.00-2.14; pectoral fin-length 13.51-14.07; pectoral fin-anterior margin length 14.16-15.72; pectoral fin-base length 8.07-8.67; pectoral fin -height 12.30-13.00; pectoral fin-inner margin length 5.34-6.11; pectoral fin-posterior margin length 11.63-12.37; pelvic fin-length 11.57-12.28; pelvic fin-anterior margin length 5.42-6.86; Pelvic fin-base length 8.94-9.04; pelvic fin-height 5.07-5.91; pelvic fin-inner margin length 3.10-3.22; pelvic fin-posterior margin length 7.07-7.45; first dorsal fin-length 9.23-9.87; first dorsal fin-anterior margin 10.09-10.62; first dorsal fin-base length 6.57-7.18; first dorsal fin-height 5.85 6.09; first dorsal fin-inner margin 2.50-3.18; first dorsal fin-posterior margin 4.23-5.23; second dorsal fin-length 6.92-7.89; second dorsal fin-anterior margin 6.26- 7.34; second dorsal fin-base length 4.61-5.08; second dorsal fin-height 3.37-3.42; second dorsal fin-inner margin 2.49-2.91; second dorsal fin-posterior margin 3.20-3.51; anal fin-length 8.51-9.34; anal fin-anterior margin length 7.25-7.79; anal fin-base length 5.74-5.96; anal fin-height 3.77-3.88; anal fin-inner margin length 2.84- 3.22; anal fin-posterior margin length 3.80-4.22; caudal fin-dorsal margin length 18.68-21.63; caudal fin-preventral margin length 8.95-11.01; caudal fin-upper postventral margin 9.07-10.68; caudal fin-subterminal margin length 3.62-4.15; caudal fin-subterminal margin width 3.81-4.03; caudal fin-terminal margin length 5.37-5.93; caudal fin-terminal lobe length 6.33-6.85.

Distribution: Endemic to southwest coast of India. A similar small swell shark occurs in Andaman Sea, but that needs to be compared with this species (Compagno *et al.*, 2005 a). Manilo (1993) reported *C. silasi* from Gulf of Aden, which needs confirmation.

Remarks: Though reported as a relatively common species in the holotype collection area (See Compagno, 1984) couldn't find additional references on species from India other than quoting Talwar (1974) and Compagno (1984) in the latest works related to chondrichthyans from India. Though some authors listed *C. sufflans* from India only *C. silasi* is valid (Talwar, 1974; Venkataraman *et al.*, 2003; Raje *et al.*, 2007). Till date no other details *Cephaloscyllium silasi* is is published and it is listed as <u>Data Deficient</u> in the IUCN Red List of Threatened Species (Mc'Cormack, 2009).

Family: **Proscylliidae**

***Eridacnis radcliffei* Smith, 1913.** Pygmy ribbontail catshark

(Plate 3, Fig. 2)

Smith, H.M. (1913). Description of a new carcharioid shark from the Sulu Archipelago. [Scientific results of the Philippine cruise of the Fisheries steamer "Albatross," 1907-1910.--No. 29.]. Proceedings of the United States National Museum, 45: 599-601. [Type locality: Sulu Islands, Philippines]

Synonyms: *Proscyllium alcocki* Misra, 1950

Diagnosis: A small deepwater shark. Head and snout narrowly rounded in dorsoventral view, oral papillae and gill rakers present in mouth and narrow and ribbon like caudal fin are the common characters of this genus. The pre-oral snout less than 1.5 times mouth length and lateral dermal denticles narrow and with narrow, long cusps. Colour- pale dark with two caudal fin bands.

Morphometry: (Expressed in % TL). Pre-caudal length 71.9-74.8; pre-second dorsal length 56.3-56.5; pre-first dorsal length 31.3-33.1; pre-vent length 42.7-44.9; pre-pelvic length 40.3-42.9; pre-pectoral length 17.3-20.6; head length 20.2-21.6; pre-branchial length 15.3-6.5; pre-spiracular length 10.1-10.3; pre-orbital length 5.5-5.6; pre-narial length (outer) 4.1-4.3; pre-narial length (inner) 3.7-4.5; mouth width 8.4-8.5; mouth length 2.7-3.6; inter-narial space 2.4-2.6; inter-orbital space 5.4-5.8; eye length 3.9-4.0; eye height 1.8-1.9; spiracle length 0.9-1.1; first gill-slit height 2.1-2.7; fifth gill-slit height 1.5-2.4; interdorsal space 17.1-17.7; dorsal-caudal space 10.7-12.3; pectoral-pelvic space 15.3-21.0; first dorsal length 10.8-14.5; second dorsal length 11.4-12.6; head width at nostrils 7.2-7.3; head width at mouth 11.4-11.9; head width 10.4-13.5; caudal peduncle width 2.3-2.4; head height 5.4-7.3; tail height 2.9-3.0.

Distribution and Habitat: Patchy distribution in the Indo-west Pacific, on muddy bottom of continental shelves and slopes.

Remarks: The IUCN Red List of Threatened Species list the status of *Eridacnis radcliffei* as Least Concern (McCormack *et al.*, 2009)

Order: **Rajiformes** (Batoids)

Family: **Rhinobatidae**

***Rhinobatos variegatus* Nair and Lal Mohan, 1973** Stripenose guitarfish.

(Plate 3, Fig. 3)

Nair, R.V. and Lal Mohan, R. S. (1973). On a new deep sea skate, *Rhinobatos variegatus*, with notes on the deep sea sharks *Halaelurus hispidus*, *Eridacnis radcliffei* and *Eugaleus omanensis* from the Gulf of Mannar. *Senckenbergiana Biologica* 54: 71-80. [Type locality: Gulf of Mannar, India]

Diagnosis: A medium sized *Rhinobatos* with following combination of characters; disc wedge shaped and generally smooth, except small/rudimentary tubercle on dorsal median line and anterior to orbit and near spiracle in larger specimens, but not prominent. Shorter snout, snout length 2.7-3 times interspiracular distance. Orbit medium sized, orbit diameter 1.1-1.2 time's internarial distance. Distance between first gill slit 1.3-1.4 times distance between fifth gill slit. Distance between fifth gill slit 2.8-3.1 in ventral head length. Anterior nasal flaps well developed. Interdorsal 2.7-3 in first dorsal base. Two cutaneous folds in spiracle, outer one larger than inner. Colour- Body bright yellowish brown dorsally, dense cover of faint/paler blotches along the body. Dorsal side, pectoral margins snout tip plain with three brownish red broad lateral bands and one medially. Pectoral and pelvic fins with light purple blue variegated markings. Ventral surface uniformly pale, ventral snout tip of juveniles/pups, with a prominent black spot, which is absent or present in larger specimens.

Morphometry: (Expressed in % TL). Disc width (maximum) 28.9-30.3; disc length 37.7-39.8; head length (dorsal) 24.0-24.4; head length (ventral) 24.2-24.5; snout length 12.6-13.4; Snout length (horizontal) 12.2-13.1; orbit diameter 2.3-2.4; spiracle width 1.8-2.0; spiracle length 1.0-1.3; small fold length 0.3-0.4; large fold length 0.5-0.6; distance between bases of folds 0.2-0.4; orbit and spiracle length 4.3-4.4; inter-orbital width 2.9-3.2; inter-spiracular width 4.5-4.7; snout to max width 31.2-33.3; pre-oral length 14.5-15.4; mouth width 5.3-5.5; pre-narial distance 11.9-12.4; nostril length 2.9-3.2; anterior aperture-width 1.0-1.1; anterior nasal flap-base length 2.5-2.6; anterior nasal flap base-width 1.5-1.5; posterior-lateral nasal flap- total length 2.3-2.4; posterior-lateral nasal flap- width 0.5- 0.6; posterior nasal flap- base length 1.3-1.5; posterior nasal flap-width 0.9-0.9; distance across anterior nasal apertures 8.0-8.4; inter-narial distance-minimum 2.5-2.6; distance between anterior nasal flaps 1.1-1.3; distance from nostril to disc margin 3.4-3.9; first gill opening 1.2; third gill opening 1.3-1.5; fifth gill opening 1.0-1.2 distance between first gill openings 11.0-12.0; distance between third gill openings 8.0-8.4; distance between fifth gill openings 8.0-8.6; pelvic fin- length 15.6-17.7; pelvic fin- anterior margin length 8.7-9.2; pelvic fin-width 3.9-4.8; pelvic fin-base length 7.5-10.1; pelvic fin- inner margin length 7.0-8.9; first dorsal fin- length 6.2-6.4; first dorsal fin- anterior margin length 9.0-9.3; first dorsal fin- height 6.9-7.2; first dorsal fin- base length 4.4-4.5; first dorsal fin- inner margin length 1.9-2.0; first dorsal posterior margin 6.3-7.2; second dorsal fin- length 6.3-6.9; second dorsal fin- anterior margin length 9.1-9.3; second dorsal fin- height

5.8-6.9; second dorsal fin- base length 4.7-5.0; second dorsal fin- inner margin length 1.7-1.9; second dorsal posterior margin 5.8-6.9; caudal fin- dorsal margin 12.2-13.1; caudal fin- pre-ventral margin 6.7-7.5; snout to first dorsal fin origin 56.7-59.4; snout to second dorsal fin origin 74.4-76.1; snout to upper caudal fin origin 87.1-87.7; snout to lower caudal fin origin 88.3-88.7; snout to pelvic fin origin 34.4-35.8; snout to anterior vent 37.0-39.6; pelvic fin insertion to dorsal fin origin 14.0-15.5; interdorsal distance 12.1-12.9; caudal peduncle length-dorsal 6.2-7.7; body width- pectoral fin insertion 11.9-13.9; body width- pelvic insertion 10.0-10.5; disc width- anterior orbit 16.5-17.3; disc width- anterior orbit 16.3-16.6; body width- first dorsal fin origin 10.3-10.8; body width- second dorsal fin origin 5.4-5.8; clasper length inner 0.0-11.9; clasper length outer 5-6.4; clasper width at insertion 1.1-1.3.

Distribution and habitat: Western Indian Ocean: Possibly endemic to the southern coasts of India. *Rhinobatos variegatus* so far known only from Gulf of Mannar. Present study extends its distribution range to west coast of India, which is common in landings as bycatch in demersal trawlers operating at very shallow waters, where the operation depth is 30 to 150 m.

Remarks: Nair and Lal Mohan (1973) described *R. variegatus* based on a single specimen collected from Gulf of Mannar. After the original description, no other information was available on the species and holotype is the only previous known specimen. This is the first report of *R. variegatus* from the west coast of India and second report after the original description. The IUCN Red List of Threatened Species lists the status of *R. variegatus* as Data Deficient (McCormack, 2009)

Family: **Narcinidae**

***Benthobatis moresbyi* Alcock, 1898** Dark blindray

(Plate 3, Fig. 4)

Alcock, A. W. (1898). Natural history notes from H. M. Indian marine survey ship `Investigator,' Commander T. H. Heming, R. N., commanding. Series II., No. 25. A note on the deep-sea fishes, with descriptions of some new genera and species, including another probably viviparous ophidioid. *Annals and Magazine of Natural History* (Series 7) 2 (8): 136-156. [Type locality: Laccadive Sea, India]

Diagnosis: A small black coloured deepwater electric ray with oval/ rounded pectoral disc. Origin of first dorsal well anterior. Snout elongated. Dorsal fins close together; interdorsal space less than length of dorsal bases. Very small fleshy dorsal fins. Distance between second dorsal and caudal fins much smaller than length of base of second dorsal fin. Caudal fin extremely elongate. Gill opening are large and well spaced. The posterior one is nearer to the cloacal opening than to the mouth. Eyes very small. Colour- Dorsal and ventral surfaces dark brown; ventral entirely dark.

Morphometry: (Expressed in % TL). Disc width 31.0-38.0; disc length 42.0-47.0; pre-orbital length 18.0-23.0; pre-oral length 18.0-22.0; first dorsal height 6.0-11.3; first dorsal base length 5.0-10.4; second dorsal height 4.8-12.1; second dorsal base length 6.7-12.0; inter dorsal space 3.3-4.2; first gill slit length 2.4-3.0; third gill slit length 2.5-3.2; fifth gill slit length 2.1-2.4; pre first dorsal length 55.4-60.0; pre-second dorsal length 68.2-84.0.

Distribution and Habitat: Western Indian Ocean. Presently known only from deepwaters off southwestern India, Yemen and Somalia

Remarks: The IUCN Red List of Threatened Species lists the status of *Benthobatis moresbyi* as Data Deficient (Carvalho and McCord, 2009)

Family: **Plesiobatidae**

***Plesiobatis daviesi* (Wallace, 1967)** Deep-sea stingray

(Plate 3, Fig. 5)

Wallace, J.H. (1967). The batoid fishes of the east coast of southern Africa. Part 2: manta, eagle, duckbill, cownose, butterfly and stingrays. Investigational Report. Oceanographic Research Institute Durban 16: 1-56. [Type locality: Mozambique Channel, South Africa]

Synonyms: *Urotrygon daviesi* Wallace, 1967; *Urolophus marmoratus* Chu, Meng, Hu. & Li (1981);

Diagnosis: A big broadly rounded deepwater stingray with pointed snout, small eyes and a round disc. Snout length > 6 times orbit diameter. Tail short with a long lobe-like caudal fin and a narrow sting. No dorsal fin or skin folds on side or undersurface of tail. Skin soft, thin and translucent. The entire dorsal surface of the disc covered with small evenly scattered prickles. Tail covered with prickles except on the ventral side of the base of the tail. Ventral side and both sides of the pelvic fin devoid of prickles. Grey-black to brownish in colour.

Morphometry: (Expressed in % TL). Disc length 46-50.2; disc width 50-53.4; pre-orbital length 17.3-19.7; interorbital width 6.8-7.2; interspiracle width 8.2-8.8; mouth width 6-6.6; internarial width 7.2-7.8; distance between first pair of gill slits 12.4-13.2; distance between fifth pair of gill slits 7.8-8.5; pre-gill length 23.8-25.3; eye length 1.4-1.6; eye height 0.51-0.68; spiracle length 3.4-3.8; pre-oral length 18-19.5;

pre-narial length 15.3-15.8; snout to origin of spine 72-74.4; pre-spiracle length 19-20; head length (ventral) 29-32; nostril width 1.7-1.9; interorbital width 7-7.4; first gill slit length 1.8-2; second gill slit length 1.7-2.2; fifth gill slit length 1.4-1.6.

Distribution and habitat: *Plesiobatis daviesi* is well distributed in the Indo-West and Central Pacific Ocean from South Africa to Hawaii. Nair and Soundararajan (1973) reported *P. daviesi* for the first time from Indian waters off Mandapam. Jayaprakash *et al.* (2006) listed it from southwest coast. Akhilesh *et al*. (2009) reported *P. daviesi* from Andaman waters. *Plesiobatis daviesi* occurs in deepwaters on continental shelves and slopes.

Remarks: *Plesiobatis daviesi* is a rare bycatch in deep-sea fishery. The IUCN Red List of Threatened Species list the status of *P. daviesi* as Least Concern (White *et al.*, 2006 c).

Family: **Rajidae**

***Okamejei powelli* (Alcock, 1898)** Indian Ringed Skate

(Plate 3, Fig. 6)

Alcock, A.W. (1898). Natural history notes from H. M. Indian marine survey ship `Investigator,' Commander T. H. Heming, R. N., commanding.--Series II., No. 25. A note on the deep-sea fishes, with descriptions of some new genera and species, including another probably viviparous ophidioid. *Annals and Magazine of Natural History* (Series 7) 2 (8): 136-156. [Type locality: Gulf of Martaban, Myanmar]

Synonyms: *Raja powelli* Alcock, 1898

Diagnosis: A medium sized skate with rhomboid shaped disc, long pointed snout. Single ocellus in the base of each pectoral fin. Interdorsal space more than dorsal base length. Five or six interdorsal thorns. Eye diameter less than interorbital distance. Mouth width morethan 8% TL. Colour- Dorsal surface yellowish brown with white spots all over the body. Ventral surface pale.

Morphometry: (Expressed in % TL). Disc width 59.5-62.3; disc length 54.5-54.7; snout to maximum width 30.9-33.5; snout length 15.7-16.4; snout to spiracle 16.6-22.0; orbit diameter 2.4-3.4; orbit and spiracle length 5.6-6.2; spiracle length 2.7-3.5; distance between orbits 4.3-4.6; distance between spiracles 5.5-6.2; snout to cloaca (1^{st} hemal spine) 50.6-52.4; distance-cloaca to caudal-fin tip 47.6-49.6; pre upper jaw 16.3-16.9; pre-nasal length 13.4-14.5; ventral head length 31.8-33.5; mouth width 3.9-4.4; distance between nostrils 7.7-8.5; nasal curtain length 4.6-5.3; nasal curtain (total width) 9.6-11.0; nasal curtain (lobe width) 2.7-2.9; width of first gill opening 1.3-2.2; width of fifth gill opening 1.3-1.6; distance between first gill openings 16.1-19.3; distance between fifth gill openings 7.0-9.3; length of anterior pelvic lobe 12.4-13.5; length of posterior pelvic lobe 14.7-19.5; pelvic base width 7.2-10.5; tail at axil of pelvic fins (width) 3.7-4.7; tail at axil of pelvic fins (height) 1.9-2.8; tail at mid-length (width) 1.4-2.4; tail at midlength (height) 1.2-2.3; tail at first dorsal origin (width) 1.0-2.0; tail at tail at first dorsal origin height 1.0-2.4; tail at first dorsal base length 4.3-5.0; first dorsal height 1.8-3.6; tail at first dorsal origin to caudal-fin tip 18.0-18.4; second dorsal origin to caudal-fin tip 10.0-11.7; caudal-fin length 4.5-7.4; snout to origin of first dorsal 81.9-82.9; snout to origin of second dorsal 89.9-90.3; interdorsal length 2.9-5.7; second dorsal base length 4.3-6.2.

Distribution and Habitat: Indian ringed skate, *O. powelli* is one of the common skates occurring along the southwest and southeast coasts of India.

Remarks: *Okamejei powelli* was described by Alcock (1898) as *Raja powelli* based on collections of RIMS *Investigator* at 121 m off Myanmar. Annandale (1909) collected a single specimen of *O. powelli* in shallow water off Trivandrum on the south-west coast of India. Samuel (1963) reported *Raja ocellifera* based on a specimen collected during an offshore cruise of *RV Conch* at 229 m off Cochin (southeastern Arabian Sea). Jayaprakash *et al.* (2006) listed *R. miraletus* from the offshore waters off south west coast of India was later identified as *O. powelli.* Nair (2007) provided the taxonomic status of *R. miraletus* based on a 39 cm TL specimen collected off south west coast of India. Raju *et al.* (2008) reported *R. texana* from Gulf of Mannar at a depth of 70 m. All this reports are clearly a misidentification of *O. powelli.* The IUCN Red List of Threatened Species lists the status of *O. powelli* as Data Deficient (Cronin, 2009).

Family: **Rajidae**

Dipturus cf. ***johannisdavisi*** **(Alcock, 1899)** Travancore Skate

(Plate 3, Fig. 7)

Alcock, A. W. (1899). A descriptive catalogue of the Indian deep-sea fishes in the Indian Museum. Being a revised account of the deep-sea fishes collected by the Royal Indian marine survey ship Investigator. Calcutta. A descriptive catalogue of the Indian deep-sea fishes in the Indian Museum: i-iii + 1-211 + i-viii. [Type locality: Laccadive Sea, India]

Synonyms: *Raja johannisdavisi* Alcock, 1899

Diagnosis: A small deep-sea *Dipturus* skate with rhomboid disc, single nuchal thorn, long and slender tail; no median dorsal spines and a single tail thorn row.

Morphometry: (Expressed in % TL). Disc width 68.1; disc length (direct) 53.7; snout to maximum width 34.2; snout length 16.1; snout to spiracle 21.4; head length (dorsal length) 22.7; orbit diameter 3.9; orbit and spiracle length 5.4; spiracle length 2.2; distance between orbits 4.7; distance between spiracles 6.7; snout to cloaca length (up to 1st hemal spine) 48.9; distance-cloaca to caudal-fin tip 50.8; ventral snout length 17.1; prenasal length 14.2; ventral head length 30.7; mouth width 7.9; distance between nostrils 8.4; nasal curtain length 9.8; distance between first gill openings 16.7; distance between fifth gill openings 10.2; snout to origin of first dorsal fin 76.5.

Distribution and Habitat: known only from deepwaters off southern coast of India and Madagascar.

Remarks: *Dipturus johannisdavisi* is the only valid deepwater skate species known from Indian waters described Alcock (1899) based on a single specimen of 230 mm disc width. Characters provided by Alcock (1899) fits to the characters of many deepwater skate juveniles. Moreover, Alcock (1899) had suggested the possibility of a large undescribed rajid species off the Kerala coast at a depth of 1483 m. From Sri Lankan waters, also a similar large skate has been reported (Moron *et al.,* 1998). However, at least three deep-sea skate species were collected during the study (Bineesh *et al.,* 2013) warranting further studies on the group. The IUCN Red List of Threatened Species lists the status of *Dipturus johannisdavisi* as Data Deficient (McCormack, 2009).

Conclusion

Fisheries management and sustainable exploitation of fisheries resources depend upon understanding the identity of exploited resources. One of the major issues in the elasmobranch fishery management is the non availability of species specific data, which is often reported in group names such as sharks, rays and skates. Misidentification in the fishery data, used for the formulation of policies can lead to management conflicts.

The diversity of deep-sea chondrichthyan fauna of Indian EEZ still remains largely unexplored, this is due to the lack of exclusive chondrichthyan surveys. Recent development of multiday deep-sea fishing is resulting in landings of rare deep-sea species, which were not reported earlier from Indian waters.

In the present study several elasmobranchs like *Hexanchus griseus, Deania profundorum, Zameus squamulosus, Odontaspis noronhai* are reported for the first time from Indian waters (Akhilesh *et al.,* 2010, 2013 a); some rare species like *Halaelurus quagga* and *Cephaloscyllium silasi* are rediscovered after a long time (Akhilesh *et al.,* 2011 b, 2014). Occurrence of deep-sea skate *Rhinobatos variegatus* and crocodile shark *Pseudocarcharias kamoharai* were confirmed in the Arabian Sea (Akhilesh *et al.*, 2013 b).

Chondrichthyan species having wider or circumglobal distribution in the oceans should be carefully identified with the support advanced biotechnological tools, since the recent studies have shown the occurrence of wide-ranging species as distinct species with similar morphology and external appearance (Ebert *et al.,* 2010). Certain species from Indian waters belonging to families Scyliorhinidae, Centrophoridae, Rajidae, Squalidae, Echinorhinidae needs to be critically compared with the type materials and specimens collected across its distribution range with genetic data to confirm it is not a species complex. The occurrence of several deep-sea elasmobranchs in Indian waters indicates the rich diversity of chondrichthyans in the Indian EEZ, and further emphasizes the need to conduct more exploratory surveys and studies to increase the knowledge on deep-sea chondrichthyans.

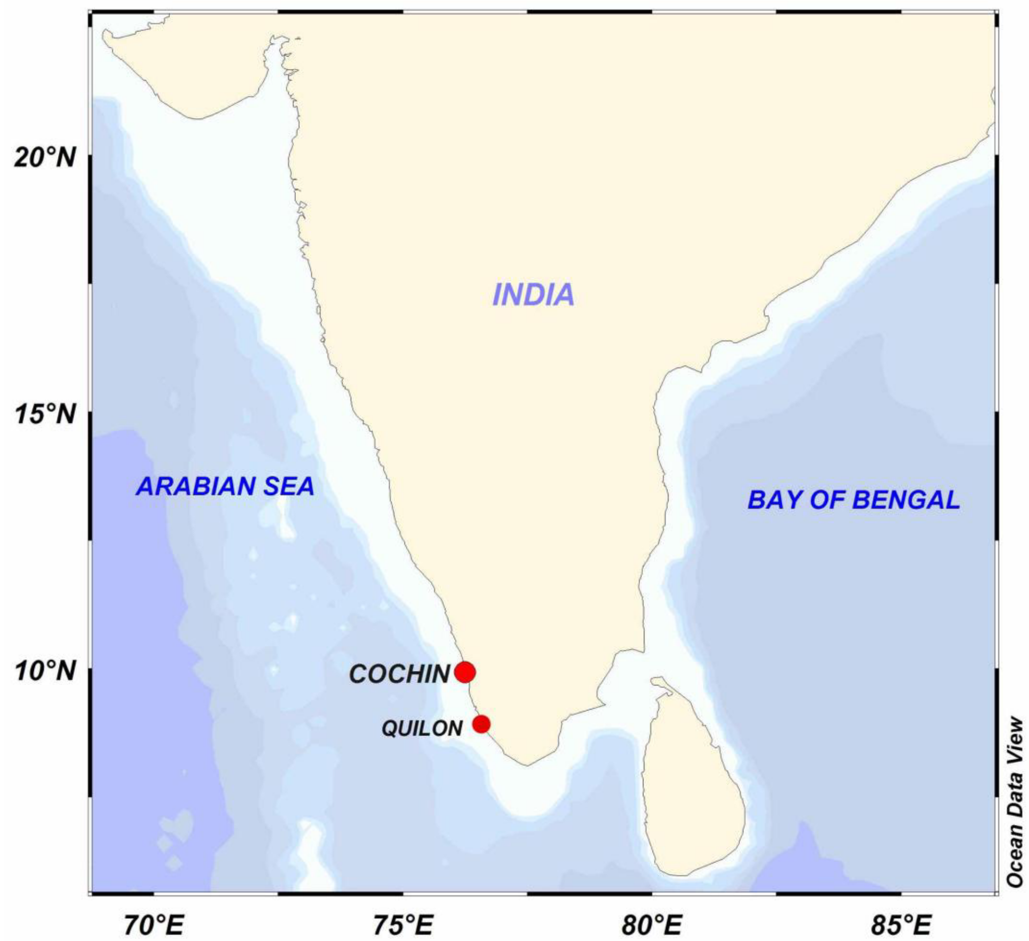


Figure 3. 1. Collection locations (fisheries harbours/landing centres) of study materials

Figure 1.

Neoharriotta pinnata

Family: Rhinochimaeridae

Figure 2.

Hydrolagus* cf. *africanus

Family: Chimaeridae

Figure 3.

Heptranchias perlo

Family: Hexanchidae

Figure 4.

Hexanchus griseus

Family: Hexanchidae

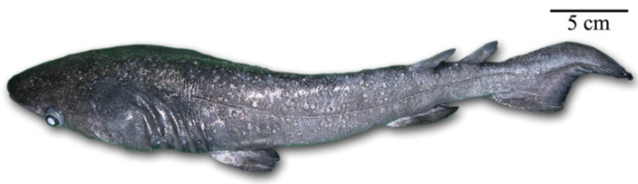


Figure 5.

Echinorhinus brucus

Family: Echinorhinidae

Figure 6.

Centrophorus atromarginatus

Family: Centrophoridae

Figure 7.

Centrophorus* cf. *granulosus

Family: Centrophoridae

Figure 8.

Centrophorus squamosus

Family: Centrophoridae

PLATE 1: Deep-sea chondrichthyans off the southwest coast of India

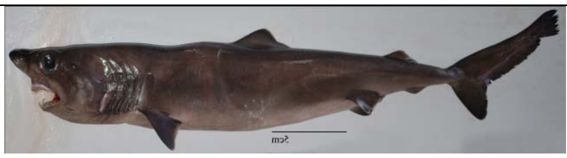
	**Figure 1.** ***Deania profundorum*** Family: Centrophoridae
	**Figure 2.** ***Squalus*** cf. ***lalannei*** Family: Squalidae
	**Figure 3.** ***Etmopterus pusillus*** Family: Etmopteridae
	**Figure 4.** ***Centroselachus crepidater*** Family: Somniosidae
	**Figure 5.** ***Zameus squamulosus*** Family: Somniosidae
	**Figure 6.** ***Odontaspis noronhai*** Family : Odontaspididae
	**Figure 7.** ***Pseudocarcharias kamoharai*** Family: Pseudocarchariidae
	**Figure 8.** ***Bythaelurus hispidus*** Family: Scyliorhinidae
	**Figure 9.** ***Halaelurus quagga*** Family: Scyliorhinidae

PLATE 2: Deep-sea chondrichthyans off the southwest coast of India

	**Figure 1.** ***Cephaloscyllium silasi*** Family: Scyliorhinidae
	**Figure 2.** ***Eridacnis radcliffei*** Family: Proscylliidae
	**Figure 3.** ***Rhinobatos variegatus*** Family: Rhinobatidae
	**Figure 4.** ***Benthobatis moresbyi*** Family: Narcinidae
	**Figure 5.** ***Plesiobatis daviesi*** Family: Plesiobatidae
	**Figure 6.** ***Okamejei powelli*** Family: Rajidae
	**Figure 7.** ***Dipturus* cf. *johannisdavisi*** Family: Rajidae

PLATE 3: Deep-sea chondrichthyans off the southwest coast of India

Chapter 4

Deep-sea chondrichthyan fishery off the southwest coast of India

Chapter 4

Deep-sea chondrichthyan fishery off the southwest coast of India

Chondrichthyan fishery of India is one of the largest in the world. Despite having a substantial fishery and landings, studies on fishery, its species and catch composition, size contribution were few and that on deep-sea chondrichthyans were meagre. Limited studies on deep-sea elasmobranchs were due to the absence of a full-fledged targeted deep-sea chondrichthyan fishery prior to 1980. However, there are instances of reports of deep-sea chondrichthyans in surveys and commercial fishery landings (Silas, 1969; Silas *et al.*, 1969; Nair and Lal Mohan, 1971). Up to 2000–2002, there was only incidental catch of deep-sea chondrichthyans in fisheries at some locations, e.g. Thoothoor, Tuticorin and Cochin (Fig. 4.1) (Nair and Thulasidas, 1984; Balasubramanian *et al.,* 1993; Devadoss, 1996; Joshi *et al.,* 2008) and rarely non targeted heavy landings of deep-sea chondrichthyans also been reported (Hamsa *et al.,* 1991).

Targeted deep-sea shark fishery was reported from Andaman waters during 1984 (Mustaffa, 1985; Soundararajan and Roy, 2004) and Thoothoor during 1995-98. However, targeted fishery for deep-sea sharks is of recent origin in the west coast of India, which commenced after 2002, and lead to significant increase in deep-water elasmobranch landings especially, gulper sharks *Centrophorus* spp., bramble shark *Echinorhinus brucus,* and sicklefin chimaera *Neoharriotta pinnata.* Heavy bycatch in deepwater shrimp trawl fishery, which started in 1999 also contributed to increased landings of chondrichthyans especially at the Cochin Fisheries Harbour, Kochi and Kollam (Kerala) (Akhilesh *et al.*, 2011 a)

Deepwater chondrichthyans are highly vulnerable to over-exploitation. Globally, lack of accurate catch and effort data (due to under-reporting catch, lack of by-catch recording, poor species identification and illegal fishing etc.) makes assessment and management of chondrichthyan fishery a difficult task.

Present chapter deals with characteristics of deepwater chondrichthyan fishery, species and catch composition, gear-wise contribution, their utilization, marketing and trade in the southwest coast of India, observed during 2008-2012.

General description of deep-sea chondrichthyan fishery at Cochin

The targeted fishery for deep-sea sharks, gulper sharks (Centrophoridae) are of recent origin in the south west coast of India, and are mostly landed at Cochin Fisheries Harbour (Akhilesh *et al.,* 2011). However, occasional landings of certain deep-sea sharks like *Centrophorus molluccensis, C. granulosus, C. squamosus* and *E. brucus* has been reported in the landing centres along the west coast of India (Nair and Thulasidas, 1984; Mathew *et al.,* 1991; Titto D'Cruz, 2004). During the 1980s and early 2000 the entire elasmobranch landings in the Cochin Fisheries Harbour occurred as by-catch in single day drift gill net/hooks and line fleet operated in shallow waters at about 50 m depths (Silas *et al.,* 1984; Nizar *et al.,* 1988; Jayaprakash *et al.,* 2002). By late 2000, this fleet had expanded operations to more offshore waters (>200 m depths) and conducted multiday distant water fishing, resulting in landings of several large oceanic species and rarely deep-sea chondrichthyans (Joshi *et al.,* 2008). The expansion of fishing to deeper waters and development of deep-sea shrimp trawl fishery brought deep-sea fishes and elasmobranchs as bycatch or sometimes included as major share of their catch.

During 2000-2002 the contribution of deep-sea chondrichthyans at Cochin was negligible to the total landings (Joshi *et al.*, 2008). However, after 2002 the contribution of deep sea chondrichthyans to the fishery at Cochin increased significantly by the targeted fishery for gulper sharks (*Centrophorus* spp.) [locally called *mullan sravu* (vernacular for shark having spines) or *enna sravu* (oil shark)] due to the heavy demand for deep-sea shark liver oil from pharmaceutical companies and foreign countries. Bycatch in commercial fishing operations in deeper/oceanic waters also brought huge quantity of deep-sea chondrichthyans (Fig. 4.2).

Development of a targeted deep-sea shark fishery is very evident at Cochin after 2002. During 2006 and 2007, there was significant increase in the deep-sea shark landings with *Alopias superciliosus* (24%), *Echinorhinus brucus* (17%) and gulper shark, Centrophoridae (12.3%) of total shark landings at Cochin (Vivekanandan and Sivaraj, 2008). The landings at Cochin almost represented composition of entire west coast with effort from more than 360 multiday fishing units and of which around 60 deep-sea shark specific vessels based at Cochin and the crew mainly from Thoothoor and nearby villages.

Though there was heavy mechanization and modernization in the Indian marine fishing industry, there is not much change in the craft and gear for deep-sea shark fishing, which is dominated by gillnets, handlines and longlines. Deep-sea gulper sharks mostly caught using bottom set gillnets (locally called *thathu vala*), hand lines and bottom set vertical longlines (locally called *vepu vala*). Gillnets were made of monofilament/poly ethylene and lead sinkers. The deepwater shark long lining boats are usually medium sized boats of 45-55 feet (Fig. 4.3), crew of 7- 12 people (7-9 normally) which conduct multiday fishing at a depth of about 200-1200 m. These boats are normally smaller and older compared to multiday gillnetters or longliners. Each fishing trips commonly extends for 8-12 days with a vessel speed of 6-8 knots and Global Positioning System (GPS) is used for navigation. For a single trip 300-350 ice blocks and 1500 L diesel are used. For targeted deep-sea gulper shark fishing round, bent fishing hooks (numbers. 7 and 8) (Fig. 4.4) attached to 40-50 cm wire leaders to mainline are used. Depending on the size of vessel and crew members these units employ hooks ranging from 1000-3500 (normally 1500) numbers and fishes such as scads (*Decapterus russelli, Megalaspis cordyla*), tuna, sardines, flying fish, sail fish meat and squids are used as bait purchased from other boats or caught while sailing to the fishing area. Fishing area in the southwest coast of India is normally between 08°30′N, and 10°30′ N - 75°20′E and 78°10′E, 12° 05′ N -75°20′E, 09°15′N- 75°40′E at a depth of about 200-1200 m. From the experience of earlier fishing operations, fishermen knows about certain areas where there will be high catch and catch rates. Mostly fishing gears are operated during night. Line winches are not used. Lines are released by hand supported by rough materials (sack) and catch is hauled by hand. During fishing season 100-150 boats operate for deep-sea sharks in the Indian Exclusive Economic Zone (EEZ). Deep-sea shark fishermen accidently /occasionally enters in to Sri Lankan waters, where good deep-sea resources remain unexploited. Besides the targeted fishery (Fig. 4.5), many other deep-sea chondrichthyan species occur in large quantity as bycatch of targeted fishing and deep-sea shrimp trawlers operating at depth 200–500 m depth along the southern coasts of India (Fig. 4.6-4.7). In the targeted deep-sea shark fishery at Cochin, the most valued shark is *Centrophorus* cf. *granulosus* followed by *C. squamosus*, *C. atromarginatus* and *E. brucus.* Price difference is due to larger size as well as higher quality and quantity of liver oil.

Targeted shark/ray fishing boats [gillnetter or longliners, larger than deep-sea shark boats (Fig. 4.8-4.10)] migrate all along Indian coasts and even to oceanic waters beyond EEZ. They use large gill nets (length 1000 and 2500 m, height of 15 m and a mesh size of 50-200 mm) or longlines (5-10 km, 500-1500 hooks, number 0-4) (Fig. 4.4), These vessels carry 350-600 ice blocks, more than 1500 L diesel and mostly have a crew of 8-14 (8-10) and conduct multiday fishing for 8-30 days (15-25 average). Fishing carried out both day and night. GPS is used for navigation and echo-sounder for depth profiling. Fishes such as scads (*Decapterus russelli*, *D. macarellus* and *Selar crumenophthalmus*), tuna, sardines, flying fishes, groupers, snappers, pigfacebreams and squids are used as bait. Few shark fishermen conduct fishing operations in and around the seamounts/knolls and in the oceanic waters. There are several identified potential fishing areas for elasmobranchs in the Indian waters locally called as mada, paaru, parappu, thitta etc. Few well known similar fishing areas according to fishermen are Manchappara, Beypore thitta, Ratnagiri bank, Periyapani, Chinnapani, Ezhukalpanathitta which are intensively fished throughout the year. Due to the abundance of elasmobranchs in northern part of Arabian Sea and beyond, most multiday fishers venture into northern Arabian Sea (off Gujarat and Veraval) and brings catch to the landing centres where they fetch good price and berthing facility (mostly Cochin).

Most of the multiday, distant water elasmobranch fishermen are from Thoothoor and nearby areas of Kanyakumari district (Tamilnadu) and can be considered as the most skilled fishermen of the country due to working in hardy environment and fishing without advanced technologies. Normally elasmobranch fishing is conducted throughout the year, but gulper shark (deep-sea shark) fishermen stop fishing, when the demand and availability of food fishes increase, decrease in availability and size of gulper sharks, rough weather during the monsoon (June-August) periods. Elasmobranch fishing in India is carried out all along the coast, but deep-water shark fishery is limited to southern coasts and Andaman waters at depths 200-1200 m.

During 2002- 2008, the market value for gulper sharks (*Centrophorus* spp.) increased steadily due to international demand which lead to boom in the deep-sea shark fishery at Cochin. However, the targeted fishery for deep-sea sharks at Cochin declined considerably by early months of 2009, when the fishermen refrained from deep-sea fishing as a result of a price fall by more than 50% probably due to the global economic recession causing a fall in exports as well as declining catch and catch rates. Since late 2009 targeted fishery commenced again with occasional landings of 1-3 boats/ month and not in full swing as occurred in 2008 or before.

Along the west coast, multiday gillnetters/longliners have an affinity towards Cochin Fisheries Harbour due to competitive price, transport and berthing facilities. The trend is similar for deep-sea chondrichthyans. Deep-sea shark landings of nearby small landing centres in and around Cochin (within 50 km), distant landing centers (>100 km) like Sakthikulangara were also occasionally brought to Cochin.

Methods

Surveys at fish landing centre and interviews with fishermen, buyer agents and merchants/vendors were conducted between 2008 and December 2011 along southern coasts of India at Mangalore, Calicut, Cochin, Sakthikulangara (Kollam), Thoothoor, Tuticorin and Chennai (Fig. 4.1), to understand the species diversity, distribution and abundance of deepwater chondrichthyans in the commercial landings.

Compared to any other fish landing centres or harbours in southern India, Cochin Fisheries Harbour, Kochi, Kerala had a history of deepwater elasmobranch landings and continued with a good fishery in survey period. Due to these reasons, Cochin was selected as a base centre for fishery and biological studies. Weekly surveys at the Cochin Fisheries Harbour (CFH), Kerala in southwest India were conducted between 2008 and 2011 to determine the species and size composition of the chondrichthyan landings. Weekly catch data (in kg) were collected from the landing centre exploited by different gears like deep-sea shrimp trawl fishery (operating at 200–500 m depth), and bottom set gillnet and longline fisheries (operating in 200–1200 m depth). Catch details were also obtained from logbook maintained by the buyer agents/merchants as it was not possible to obtain individual weights from all the individuals. This information was supplemented by interviews of fishermen, merchants and agents who provided catch data (total weights only) on the days not surveyed. Since the common and economically important deepwater chondrichthyans are with very distinctive characters (*Echinorhinus brucus* with thorns on body, *Alopias superciliosus* with long tail and notch on head, *Centrophorus atromarginatus* two spines infront of dorsal fins and grey colour, *C.* cf.*garanulosus* brown colour, *Centrophorus squamosus* -black colour, two strong spines and rough skin), the catch data collected by the interviews and logbooks were considered to be directly comparable to data collected during the landing site surveys. It should be noted that the deep-sea shark landings of nearby small landing centres in and around Cochin (within 50 km), distant landing centers (>100 km) like Sakthikulangara were also occasionally brought to Cochin and thus included in the total landings for this landing centre. The annual landings (in tonnes) were estimated based on survey data and information from the fishers. The total length (TL) to the nearest cm and sex of each individual was recorded. Fishery status during end of study period calculated based on percentage difference from the initial year of study.

Results

1. **Deep-sea chondrichthyan diversity in commercial landings along the southern coasts of India**

Surveys along the landing centres of southern coast of India (Fig. 4.1) for understanding diversity of deep-sea chondrichthyes, revealed the diverse and rich fauna. This can be attributed to bottom profile; different types of crafts and gears operated in the region and increased fishing effort in the deep-waters off southern coasts

Deep-sea chondrichthyans belonging to the 18 familes viz; Alopiidae, Hexanchidae, Echinorhinidae, Centrophoridae, Squalidae, Carcharhinidae, Pseudotriakidae, Triakidae, Scyliorhinidae and Somniosidae etc. were recorded, (Table. 4.1). In the deep-sea chondrichthyan landings, Squaliformes dominated in diversity, with species observed *Centrophorus squamosus, C. atromarginatus, Centrophorus* cf. *granulosus*, *Deania profundorum*, *Squalus* cf. *mitskurii*, *Squalus* cf.

lalannei, *Etmopterus pusillus*, *Etmopterus* cf. *lucifer*, *Zameus squamulosus, Echinorhinus brucus* and *Centroselachus crepidator* landed. Alopiidae supported by *Alopias superciliosus* was the dominant species in biomass. *Neoharriotta pinnata* and *E. brucus* was the most common species in fishery. Deepwater shark species such *Hexanchus griseus, Etmopterus pusillus, Deania profundorum, Zameus squamulosus* and *Odontaspis noronhai* recorded during the study period were new distributional records for Indian waters (Akhilesh *et al.*, 2010, 2013 a) and *Pseudocarcharias kamoharai* and *Rhinobatos variegatus* were new distribution records to west coast of India. Several species were identified only up to generic level due to taxonomic issues and non availability of additional comparative materials, of which a few could be possible new species.

The results of diversity survey are given in Table 4.1, which shows that Cochin Fisheries Harbour, Kochi (Kerala) has diverse deep-sea chondrichthyan followed by Kollam (Kerala) and Tuticorin (Tamilnadu).

2. Deep-sea chondrichthyan landings at Cochin Fisheries Harbour, Kerala

Deep-sea chondrichthyan landings of Cochin Fisheries Harbour, Kerala was monitored during 2008-11. The highest landing was observed in 2008 with 629 tonnes which decreased considerably to 228 tonnes in 2011, showing a 64% decline in catch from 2008 (Fig. 4.11). Yearly catch trends from all gears during 2008 -2011 showed that fishery was dominated by species belonging to families, Alopiidae, Echinorhinidae, Centrophoridae and Rhinochimaeridae (Fig. 4.12). Though, deepwater shark fishery is targeting gulper sharks (Centrophoridae), several other commercially important sharks and chimaeroids also occur in this fishery as bycatch.

There were occasional landings of deep-sea elasmobranchs belonging to families Hexanchidae, Triakidae, Proscyllidae, Scyliorhinidae, Squalidae, Rajidae and Plesiobatidae etc. but their catch was very low, less than 2 tonnes/year (Fig. 4.13). Sharks belonging to families, Proscyllidae (*Eridacnis*) and Scyliorhinidae (*Apristurus, Cephaloscyllium, Halaelurus* and *Bythaelurus*), were caught only by deep-sea trawlers and did not account for commercial fishery.

Table 4.1. Diversity of deep-sea chondrichthyans in the landings along the southern coast of India

Family	Species	Mangalore	Calicut	Cochin	Kollam	Thoothoor	Tuticorin	Chennai
Rhinochimaeridae	*Neoharriotta pinnata*	*	*	*	*	*	*	*
	Neoharriotta cf. *pinnata*				*	*		
	Rhinochimaera sp.			*	*			
Hexanchidae	*Hexanchus griseus*			*	*			
	Heptranchias perlo			*	*		*	
Echinorhinidae	*Echinorhinus brucus*	*	*	*	*	*	*	*
Alopiidae	*A. superciliosus*	*						
Squalidae	*Squalus* cf. *mitskurii*			*	*	*		
	Squalus cf. *lalannei*			*	*			
Centrophoridae	*Centrophorus squamosus*			*				
	C. atromarginatus	*	*	*	*	*	*	
	*C.*cf. *granulosus*			*	*	*		
	*C.*cf. *isodon*			*	*	*		
	Centrophorus sp.			*	*	*		
	Deania profundorum			*				
Etmopteridae	*Etmopterus pusillus*			*	*			
	E.cf. lucifer			*				
Somniosidae	*Centroselachus crepidator*			*	*			
	Zameus squamulosus			*				
Odontaspidae	*Odontaspis noronhai*			*				
Pseudocarchariidae	*Pseudocarcharias kamoharai*			*			*	*
Alopiidae	*A. superciliosus*	*	*	*	*	*	*	*

Family	Species	Mangalore	Calicut	Cochin	Kollam	Thoothoor	Tuticorin	Chennai
Scyliorhinidae	*Apristurus* cf. *indicus*			*				
	Apristurus sp.1			*	*			
	Cephaloscyllium silasi			*	*			
	Bythaelurus hispidus			*	*		*	
	Halaelurus quagga			*	*			
Proscyllidae	*Eridacnis radcliffei*			*	*		*	
Pseudotriakidae	*Planonasus* sp.1			*				
Triakidae	*Iago* cf. *omanensis*	*	*	*	*	*	*	*
	Iago sp. 1	*	*	*	*	*	*	*
	Mustelus sp.1	*	*	*	*			
Rajidae	*Okamejei powelli*			*	*		*	
	Dipturus cf. *johannisdavisi*				*			
	Dipturus sp. 1			*	*		*	
	Dipturus sp. 2			*				
Plesiobatidae	*Plesiobatis daviesi*			*	*		*	
Rhinobatidae	*Rhinobatos variegatus*			*	*		*	

(* observation)

Among gears, the largest gear contributor to deep-sea chondrichthyan fishery was longline/drift gillnets, with an average 55.5% during the study period and supported by a single species *Alopias superciliosus* (Fig. 4.14). Though *A. superciliosus* is considered as a deep-water species, it is occasionally caught in longliners and gillnets operating at shallower depths. Average contribution of targeted longlines, gillnet and trawls were 25.5%, 16.6% and 2.4% respectively. Monthly catch data clearly shows considerable variation in landings, but one consistent peak in a year, in April (Fig. 4.15). Deep-sea shrimp trawl fishery brings a large quantity of elasmobranchs as bycatch, many species like skates, rays and sharks (Scyliorhinids and Proscyllids) are often discarded as trash in landing centres due to poor market demand.

Family Alopiidae was the most abundant deep-sea shark family and the fishery supported by single species *Alopias superciliosus,* which contributed > 50 % of the deep-sea chondrichthyan landings at Cochin during 2008-2011. Though the catch declined in the subsequent years *A. superciliosus* continuously contributed more than half of deep-sea chondrichthyan landings at Cochin. Bramble shark, *Echinorhinus brucus* was the second largest contributor to fishery with 21 %, 26 %, 24% and 22 % in 2008, 2009, 2010 and 2011 respectively. Deep-sea shark family Centrophoridae was the third largest contributor to fishery dominated by *C. atromarginatus,* with 16 %, 5 %, 11 % and 12 % in 2008, 2009, 2010 and 2011 respectively (Fig. 4.16-4.19), though many other deep-sea elasmobranch families are observed in landings which doesn't account to more than 1%.

The overall status of deep-sea chondrichthyan fishery at Cochin during the period was assessed, comparing the catch of initial year of study shows species wise catch has declined to an average 70%. However, it cannot be related to stock collapse since there was an overall reduction in deep-sea fishing.

Table 4. 2. Status of deep-sea chondrichthyan fishery at Cochin (2008-2011).

Species	Catch (t)		Decline in catch (%)
	First year (2008)	Last year (2011)	
C. atromarginatus	98.2	28.5	71
C. cf. *granulosus*	14.6	10.3	30
C. squamosus	1.1	0.04	97
N. pinnata	57.9	5.8	90
A. superciliosus	324.0	131.7	59
E. brucus	132.6	49.5	63
Iago spp.	0.8	0.2	81

Landings of Bramble shark, Echinorhinidae

Echinorhinidae was constituted by a single species *Echinorhinus brucus* in the fishery landings**.** The estimated annual landings of *E. brucus* at Cochin was highest in 2008 (132.6 tonnes) and 2009 (119.6 tonnes) and declined in the subsequent two years, i.e. 88.85 tonnes in 2010 and 49.5 tonnes in 2011. Thus, landings in 2011 were only 37% of the 2008 recorded landings (Fig. 4. 20).

Landings of *E. brucus* at Cochin varied considerably between months with the highest landings recorded in October 2008 (49 tonnes, due to large longline bycatch) followed by April 2009 (30 tonnes) and May 2010 (23 tonnes) (Fig. 4.21).

Gearwise contribution to the fishery landings shows that the bycatch from the longline fishery was the highest contributor to the *E. brucus* landings (55.5% average). Bycatch of the deep-sea shrimp trawl fishery accounted for an average of 36% of the *E. brucus* landings between 2008 and 2011, with the highest contribution in 2011 (48%) (Fig. 4. 22).

Landings of Gulper sharks, Centrphoridae

Gulper shark fishery at Cochin was supported by *Centrophorus atromarginatus*, *C. squamosus, C.* cf. *granulosus, C.* cf. *isodon* and *Deania profundorum*. Contribution of *D. profundorum* and *C.* cf. *isodon* to fishery was insignificant. The estimated annual landings of gulper sharks at Cochin was highest in 2008 (114 tonnes) which drastically reduced in subsequent years i.e. 21.8 tonnes in 2009 and 50.65 tonnes in 2010 and 38.8 tonnes in 2011 (Fig. 4.12). Though high level targeted fishery discontinued in early 2009 due to non profitable markets and catch decline. However, landings continued as bycatch of gillnetters and longliners operating in deeper waters, deep-sea shrimp trawls bycatch as well as occasional landings of targeted deep-sea shark fishing boats which all contributed to fishery. Thus, landings in 2009 were only 37% of the 2008 landings (Fig. 4.12). *Centrophorus atromarginatus* was the largest contributor in gulper shark fishery contributing average 84 % of study period, followed by *C.* cf. *granulosus* with 16.5 % and *C. squamosus* with 0.9 % (Fig. 4.23).

Gearwise contribution shows that longline fishery was the highest contributor to the Centrophoridae landings (72% average). Bycatch of the deep-sea shrimp trawl fishery accounted for an average of 25% of the landings between 2008 and 2011, with the highest contribution in 2009 (44%). Gillnets contributed only very little to the fishery forming 2.4% for the study period (Fig. 4.24)

Landings of gulper shark, *Centrophorus atromarginatus*

The estimated annual landings of *Centrophorus atromarginatus* at Cochin was highest in 2008 (98.2 tonnes) and 2010 (38.7 tonnes) and declined in the subsequent two years, i.e. 20.5 tonnes in 2009 and 28.5 tonnes in 2011 (Fig. 4.25). Landings of *Centrophorus atromarginatus* at Cochin varied considerably between months with the highest landings recorded in April 2008 (37 tonnes), followed by March 2010 (24 tonnes) September 2008 (17 tonnes) (Fig. 4.26). Catch from the longline fishery was the highest contributor to the landings (71%). Bycatch of the deep-sea shrimp trawl fishery accounted for an average of 28% of the *C. atromarginatus* landings between 2008 and 2011, with the highest contribution in 2009 (46%) (Fig. 4.27)

Landings of gulper shark, *Centrophorus* cf. *granulosus*

The estimated annual landings of *Centrophorus* cf. *granulosus* at Cochin was highest in 2008 (15 tonnes) and 2010 (12 tonnes) and showed declining trends in the other two years of study, i.e. one tonne in 2009 and 11 tonnes in 2011(Fig. 4.28). Though the landing of *C. cf. granulosus* was very less, this species fetched higher price compared to other species. Landings of *C.* cf. *granulosus* at Cochin varied considerably between months with the highest landings recorded in September 2010 (9 tonnes), which accounted for 24 % landings during study period, followed by March 2011 (6 tonnes) (Fig. 4.29). Landings of *C.* cf. *granulosus* were generally higher in March and September (Fig. 4.29). The catch from the longline fishery was the highest contributor to the landings (88%) followed by bycatch of the deep-sea shrimp trawl fishery (8%) accounted for an average of the *C.* cf. *granulosus* landings between 2008 and 2011, with the deep-sea shrimp trawl fishery contribution to *C.* cf. *granulosus* highest in 2010 (18%) (Fig. 4.30).

Landings of gulper shark, *Centrophorus squamosus*

The estimated annual landings of *C. squamosus* at Cochin was highest in 2008 (1.1 tonnes) and 2009 (0.5 tonnes) and declined in the two subsequent years, i.e. 0. 3 tonnes in 2010 and 0.04 tonnes in 2011 (Fig. 4.31). Landings *of C. squamosus* at Cochin varied considerably between months with the highest landings recorded in December 2009 (0.5 tonnes), due to longline bycatch followed by October 2008 (0.32 tonnes) and April 2008 (0.25 tonnes) (Fig. 4. 32). In the study period (2008–2011), landings of *C. squamosus* were generally higher in 2008, than subsequent years (Fig. 4. 31). There was no substantial gillnet landings of *C. squamosus*. Smaller ones contributed most of the landings. Bycatch of the deep-sea shrimp trawl fishery accounted for an average of 56% of the *C. squamosus* landings between 2008 and 2011, with the highest contribution in 2011 (100%) (Fig. 4.33).

Landings of long nose chimaera, *Neoharriotta pinnata*

The estimated annual landings of *Neoharriotta pinnata* at Cochin was highest in 2008 (58 tonnes) and followed by 2009 (40 tonnes) but declined in the two subsequent years, i.e. 33 tonnes in 2010 and 6 tonnes in 2011. There was 90 % reduction in 2011 compared to 2008 (6 tonnes) (Fig. 4.12). Landings of *Neoharriotta pinnata* at Cochin varied considerably between months with the highest landings recorded in October 2008 (32 tonnes, due to large longline bycatch), followed by August 2010 (18 tonnes) (Fig. 4.34). There were no gillnet landings of *Neoharriotta pinnata*. Bycatch of the deep-sea shrimp trawl fishery accounted for 76% of the *Neoharriotta pinnata* landings between 2008 and 2011. During 2011, *Neoharriotta pinnata* landing was solely contributed by bycatch of deep-sea shrimp trawl fishery (Fig. 4. 35).

3. **Utilization** (Plates 4-7)

Elasmobranchs and its meat products have an acceptance in all Indian coastal states; however, Indian elasmobranch fishery is mainly driven by international demand. Several elasmobranch products other than of direct usage (meat, fins) like liver oil, skin, cartilage and jaws also have high market value. All elasmobranch body parts are used in one or another form; however, the most valued product from shark is its fins, whose international demand determines the trends in fishery.

Targeted fishery for deep-sea sharks commenced due to demand for high value Squalene rich liver oil and meat. When landed in large quantities (Fig. 4.3), they are taken to nearby processing centres, and processed for its meat, by filleting, salting and sold in local markets. The large livers are removed and the oil extracted, while other deepwater sharks are far less valuable than gulper sharks. The crude liver oil is stored in large barrels and either distributed to pharmaceutical companies or sold to exporters and local merchants.

Liver oil: Deep-sea shark livers have more Squalene, than coastal elasmobranchs. The targeted deep-sea shark fishery is driven by soaring market demand of Squalene (a highly unsaturated aliphatic hydrocarbon) rich liver oil from gulper sharks (*Centrophorus* spp.). It is used in health products, skin creams and in moisturizers. Fisher families often use crude liver oil for winter diseases and skin problems. Even though targeted deep-sea shark fishing boats and deep-sea trawlers bring many other chondrichthyan species (Table 4.1), most of them are not used for liver oil preparation because of their low oil content and poor quality. Deep-sea sharks like *Echinorhinus brucus* and *Hexanchus griseus* used to sell at a comparatively higher price because of large liver and meat quantity. Earlier coastal shark liver oil was used for preparation of lubricants and used for painting the boats (waterproofing and antifouling), but nowadays the use of liver oil for the same purpose has been reduced. According to merchants deep-sea shark liver oil is mostly exported to Japan.

Fins: Elasmobranch fishery is driven by market value of fins, which fetches good price in the export markets of south East Asian countries like Singapore, Thailand, Taiwan, Malaysia, China and Hongkong etc. Value of fins varies between size, species and condition of fins. The demand and price for deep-sea shark fin is lower compared to coastal species. After removing fins, the body of sharks as a whole is sold to merchants for salting.

Meat: Elasmobranch meat has been used in coastal states for a long time. Usually immediately upon landing, they are moved to processing centres where the head, fins, gills and viscera are removed. Processing includes the cut/deep scores in several parts of the body, without touching skin, for penetration of salt and urea removal. For reducing the ammonia smell, meat is washed thoroughly in freshwater. Semi crystal salt is filled in deep cuts. Then it is kept in curing tanks with alternate layers of salt and salted meat. Filleted, salted, dried meat and fresh meat has wider domestic demand in all coastal states, Fillets of smaller sharks are sold as fresh in domestic market.

Along the coastal belts, smaller sharks (*Rhizoprionodon* and *Scoliodon*) or young sharks and rays have wider acceptance due to less odor and urea content. In certain parts of Kerala, food items prepared from rays are used for ceremonial functions, festivals and gatherings. Shark pickle has wide acceptance in Malabar region (Northern Kerala). Deep-sea sharks like *Echinorhinus brucus, Hexanchus griseus, Alopias supercilious, Centrophorus* spp. *Squalus* spp. are used for dried salt meat preparation and the latter two used in fresh condition and is gaining consumer preference.

Shark jaws are also sold or exported to souvenir collectors abroad. Price changes with international demand. Certain online stores (http://www.tellmewhereonearth.com) shows a rate of US $ 10-125/per jaw for deep-sea sharks like *E. brucus* and *Centrophorus* sp. Jaws are removed from head without damage, keeping the intact shape.

Cartilage: In several parts of world especially China and Japan, elasmobranch cartilage is used as food. Dried shark cartilage is used by pharmaceutical companies. Cartilage in general is a good source of Chonrdroitin and Glucosomine sulfate. Deep-sea shark cartilages are very soft and are normally cut with meat and not used for preparation of dry cartilages.

Discussion

Deepwater chondrichthyans have a high *K* selected life history traits as they are relatively slow growing, have long life span, late age at maturity and low reproductive output. Due to these characters their productivity (ability to sustain fishing pressure / recover from overfishing) has been estimated as very low, which is a matter of high concern.

Targeted fishery for gulper sharks/oil sharks from southwest coast of India have emerged recently after 2002, and landings peaked during 2002-2008 due to an increase in the market value of gulper sharks. Cochin Fisheries Harbour has diverse deep-sea chondrichthyan landings followed by Kollam and Tuticorin. This is possibly due to the multigear, multiday fishing practices including deepwater trawl and the bycatch of targeted deep-sea shark fishery. Higher diversity at Kollam and Tuticorin are due to the heavy deep-sea shrimp trawl fishery, which brings marketable size deep-sea fishes and chondrichthyans. There could be possible bias in the diversity study due to limited surveys at certain centers Chennai (4), Tuticorin (6), Mangalore (4) and Thoothoor (2).

The magnitude of deepwater chondrichthyan landings in Indian waters is far greater than what would be expected of many patchily distributed deep-water species, which has only been recorded in low numbers throughout most of its known range. The huge scale deepwater chondrichthyan landings at Cochin is clearly evident in earlier studies also, during 2006 and 2007, the deep-sea chondrichthyan landings increased significantly with *E. brucus* comprising 17% of total shark landings at Cochin *A. superciliosus* 24%, and Centrophoridae contributing 12.3 % (Vivekanandan and Sivaraj, 2008). High level mechanization of craft and modernization of gear, extension of fishing grounds to more deeper waters, targeted fishing for elasmobranchs and deep-sea shark landings of nearby landing centres in and around Cochin (within 50 km) and distant landing centers (>100 km) like Sakthikulangara also being occasionally brought to Cochin and thus included in the total landings for this centre, could be the reasons for heavy chondrichthyan landings at Cochin. Deepwater chondrichthyans also form a major portion of bycatch component of the deep-sea shrimp trawl fishery which targets the shrimp species *Heterocarpus* spp., *Plesionika* sp. and Arabian red shrimp *Aristeus alcocki* at depths 200-500 in the southern coasts.

The landings between 2008 and 2011 from Cochin appeared to show a marked decline from 629 and 228 tonnes, but only limited information on catch per unit effort (CPUE) was collected, though there was an overall reduction in fishing effort. However, during this period, there was a large shift in the longline fishery targeting gulper sharks in which bramble shark and chimaeras were a major bycatch component. The decline in landings recorded in this study at Cochin is possibly due to a shift in fisheries from targeted deepwater shark fishery due to non profitability, decreasing market demand also and a shift in operational area etc., As a result, no conclusions can be made as to whether landings of this species are declining due to over-exploitation and stock decline or due to shift in fishing practices.

The constantly changing deep-water fisheries along the southern coasts of India are currently not well monitored. Globally there has been a continued expansion of fishing activities into deeper waters and along with this, great concern about the ability of many deep-water species to sustain such exploitation (Morato *et al.*, 2006). Kyne and Simpfendorfer (2010) highlighted the extremely unproductive nature of many deep-water chondrichthyan species. Although there is little published information on most deep-water chondrichthyan species, there are several well documented cases of collapses in deep-water shark stocks due to overfishing. For example, off southeastern Australia, populations of several dogfish species declined rapidly between 1976–77 and 1996–97 due to the Southern and Eastern Scalefish and Shark Fishery (SESSF) (Graham *et al.,* 2001). Quero and Cendrero (1996) and Quero (1998) reported the virtual disappearance of *E. brucus* species in the Bay of Biscay area of the North East Atlantic due to fishing activities. Bycatch is a major issue with regard to deepwater stocks in southern coast of India. Since there are examples of significant decline due to bycatch in fishery like skates *Dipturus batis* and *D.laevis* from Mediterranean (Brander, 1981; Casey and Myers, 1998), Indian deep-sea fishery should be monitored promptly.

A large proportion of deep-water chondrichthyans are assessed as Data Deficient by the IUCN and species specific biological data is critical for future management of such species (Kyne and Simpfendorfer, 2010). Though this issue was addressed by Convention on International Trade in Endangered Species (CITES) in 1994 which requested contracting parties to collect biological and trade information on sharks taken in their fisheries and reiterated by FAO in 1999 when it adopted the International Plan of Action (IPOA) for Conservation and Management of sharks reliable data on biological characters is still lacking for most of deep-sea sharks. At present, only a few countries have chondrichthyan fishery management policies for sustainable exploitation and India is still in a preparatory stage of IPOA.

In view of the open access, multigear-multispecies, capture fisheries of India and with reference to targeted exploitation of elasmobranchs, more detailed studies and continuous monitoring of catch, catch composition and effort is required for the formulation of deep-sea chondrichthyan fishery management plans.

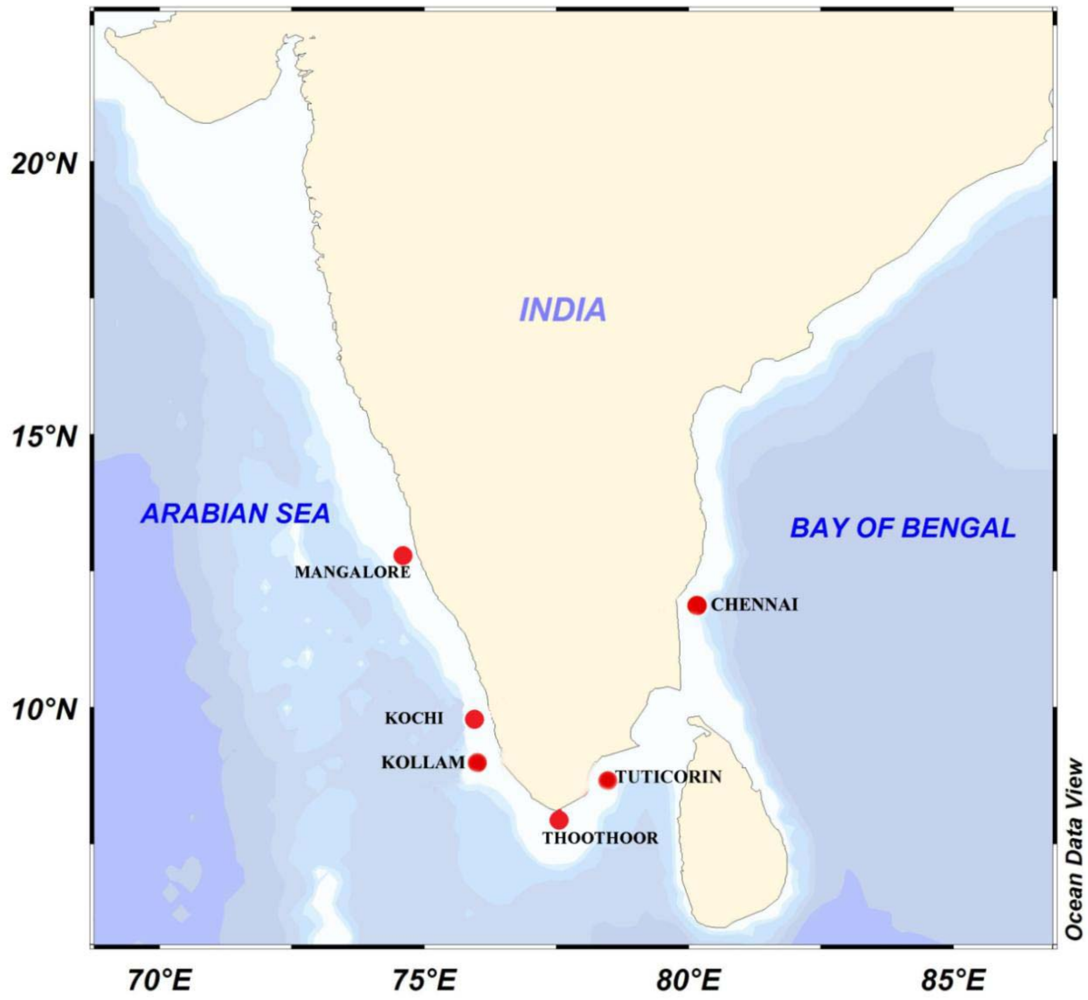


Figure 4. 1. Map showing locations (fisheries harbours/landing centres) of deep-sea chondrichthyan fishery and diversity survey

	
Figure 4.2.1. *Alopias supercilious*	**Figure 4.2.2.** *Echinorhinus brucus*
	
Figure 4.2.3. *Centrophorus* spp.	**Figure 4.2.4.** *Neoharriotta pinnata*

Figure 4.2. Landings of deep-sea chondrichthyans at Cochin Fisheries Harbour

Figure 4. 3. Targeted deep-sea shark fishing fleet at Cochin Fisheries Harbour

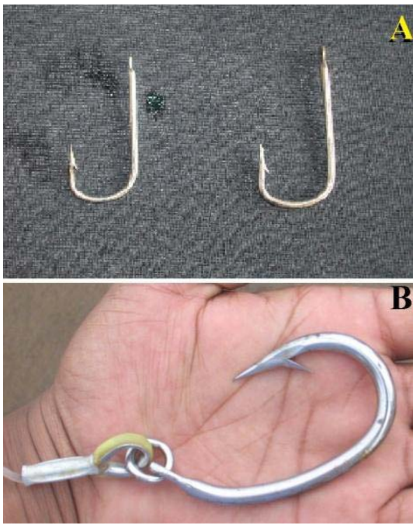


Figure 4. 4. Hooks (a) for deep-sea shark (b) for large elasmobranchs

Figure 4. 5. Targeted deep-sea shark (gulper shark) landings at Cochin Fisheries Harbour

Figure 4.6. Bycatch landing of deep-sea skates, *Dipturus* spp.

Figure 4.7. Bycatch landing of *Squalus* spp. from deep-sea shrimp trawler

Figure 4. 8. Multiday elasmobranch longliner/gillnetter

Figure 4. 9. Landings of shark catch by multiday longliners/gillnetters

Figure 4.10. Landings of devil ray catch by multiday longliners/gillnetters

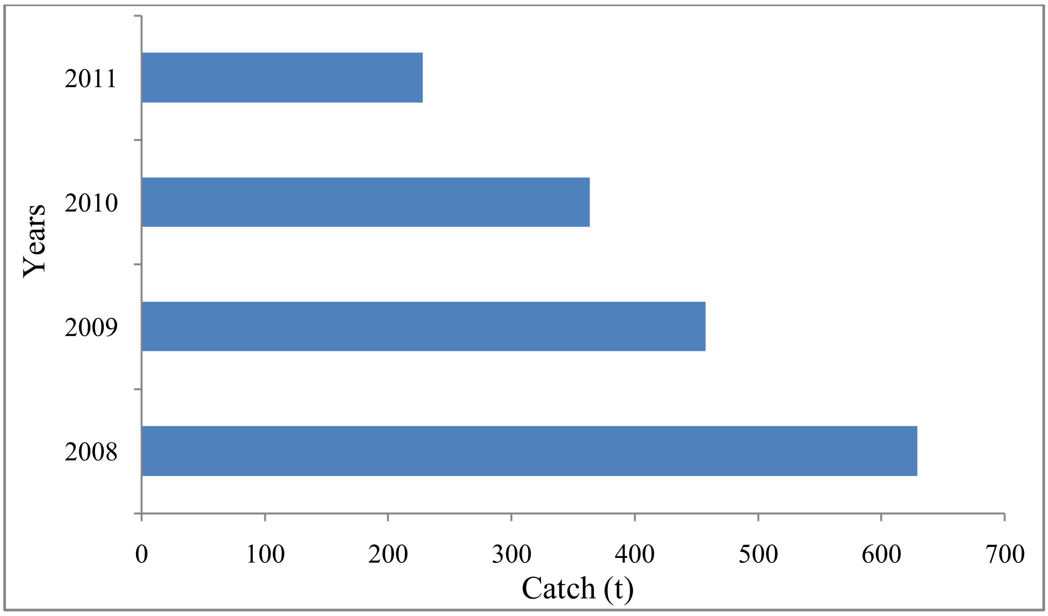


Figure 4.11 Estimated landings of deep-sea chondrichthyans at Cochin Fisheries Harbour, Kochi

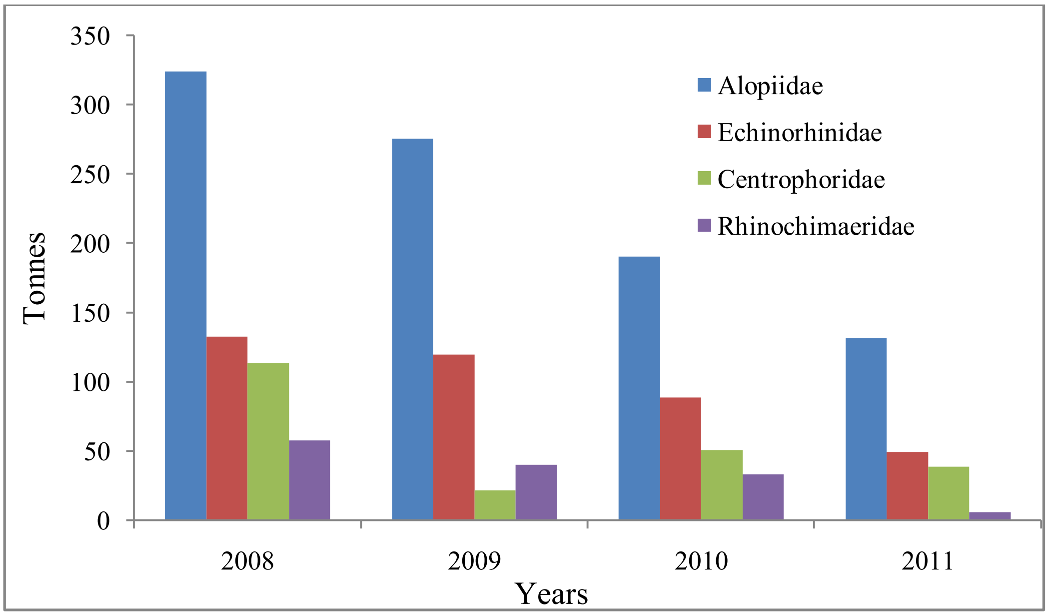


Figure 4.12. Estimated landings of deep-sea chondrichthyan families at Cochin Fisheries Harbour, Kochi (>2 tonnes/year).

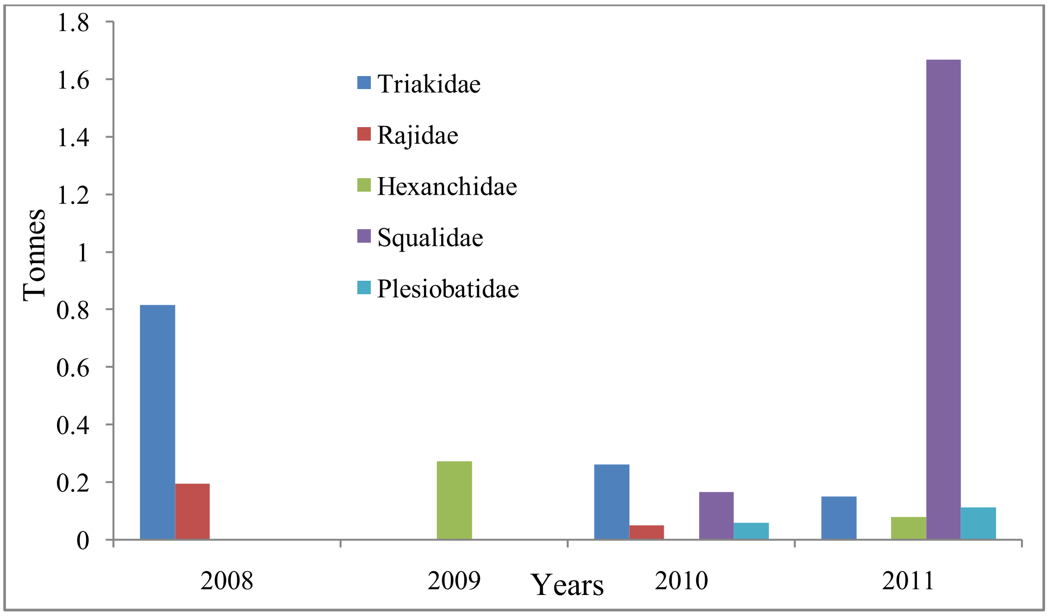


Figure 4.13. Estimated landings of deep-sea chondrichthyan families at Cochin Fisheries Harbour, Kochi (<2 tonnes/year).

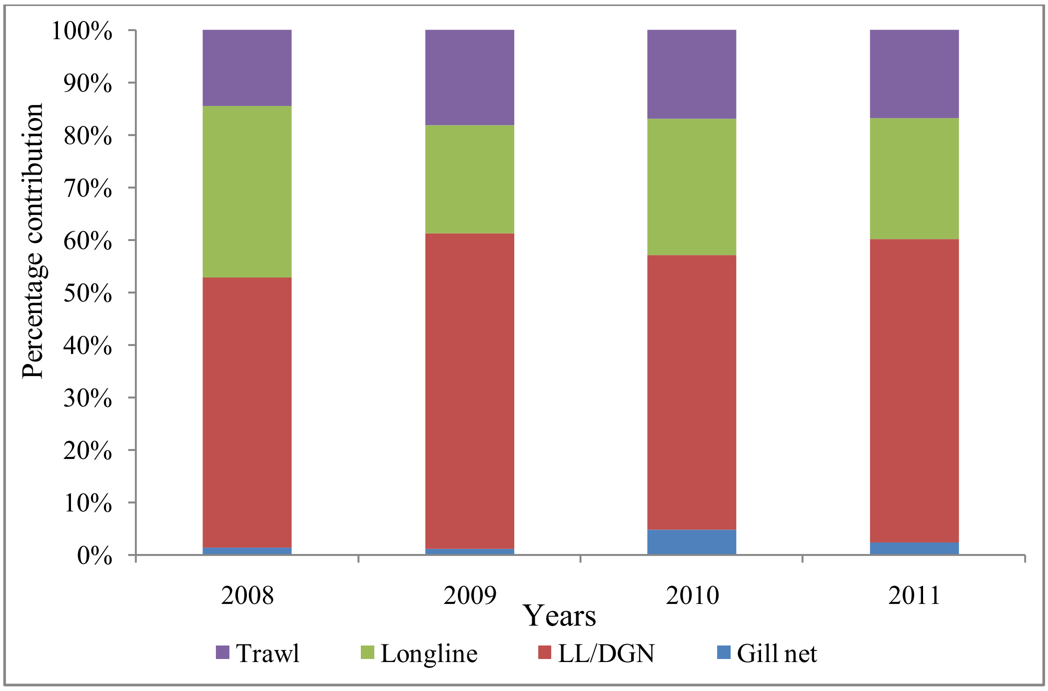


Figure 4.14. Percentage contributions of different gears to deep-sea chondrichthyan landings at Cochin Fisheries Harbour, Kochi

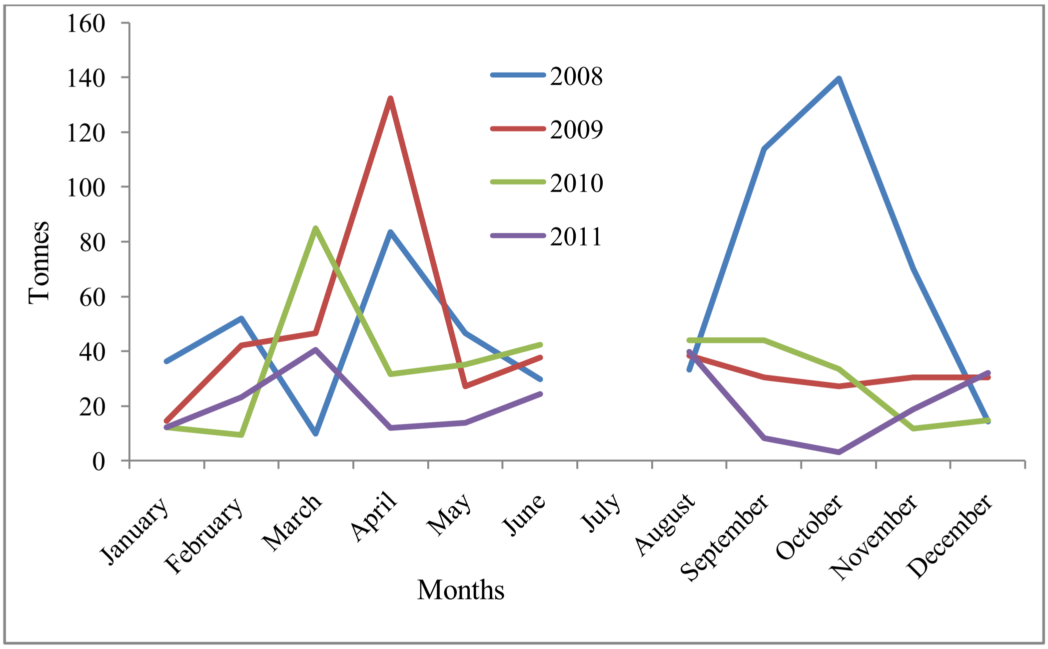


Figure 4.15. Monthly estimated landings of deep-sea chondrichthyans at Cochin Fisheries Harbour, Kochi

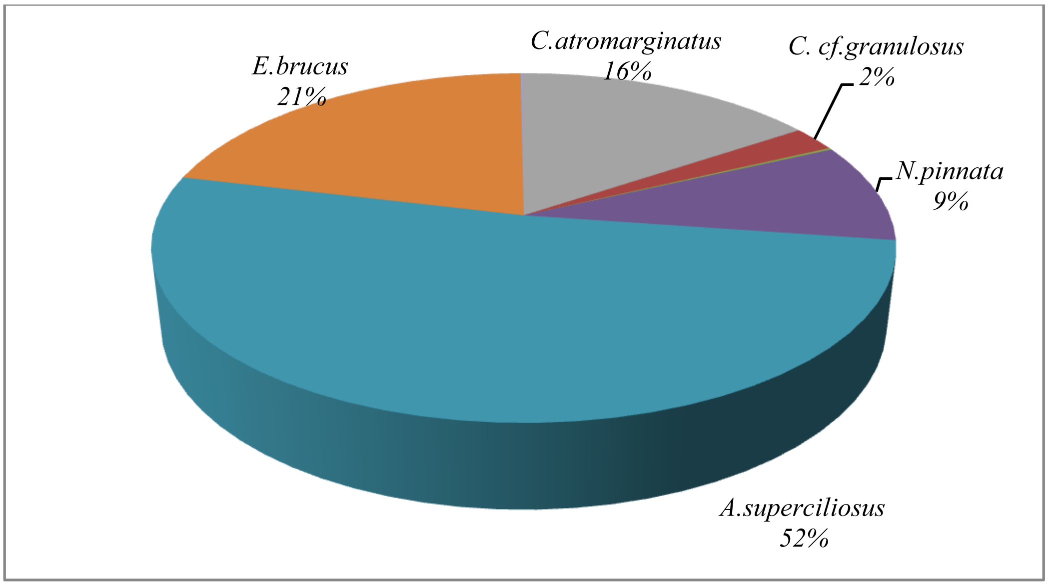


Figure 4.16. Percentage contribution of deep-sea chondrichthyan landings (by weight) at Cochin Fisheries Harbour, Kochi during 2008.

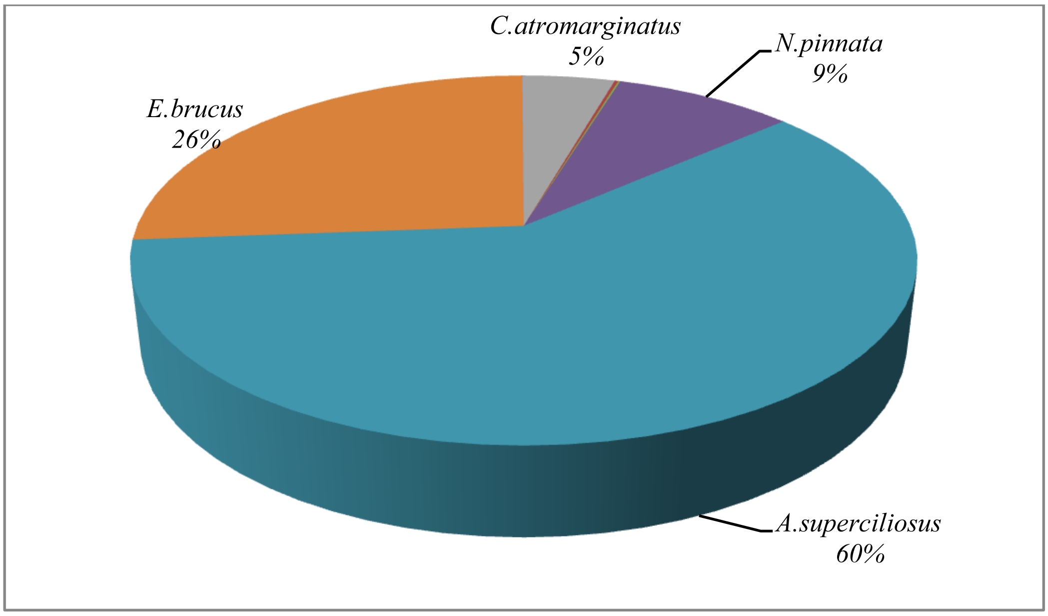


Figure 4.17. Percentage contribution of deep-sea chondrichthyan landings (by weight) at Cochin Fisheries Harbour, Kochi during 2009.

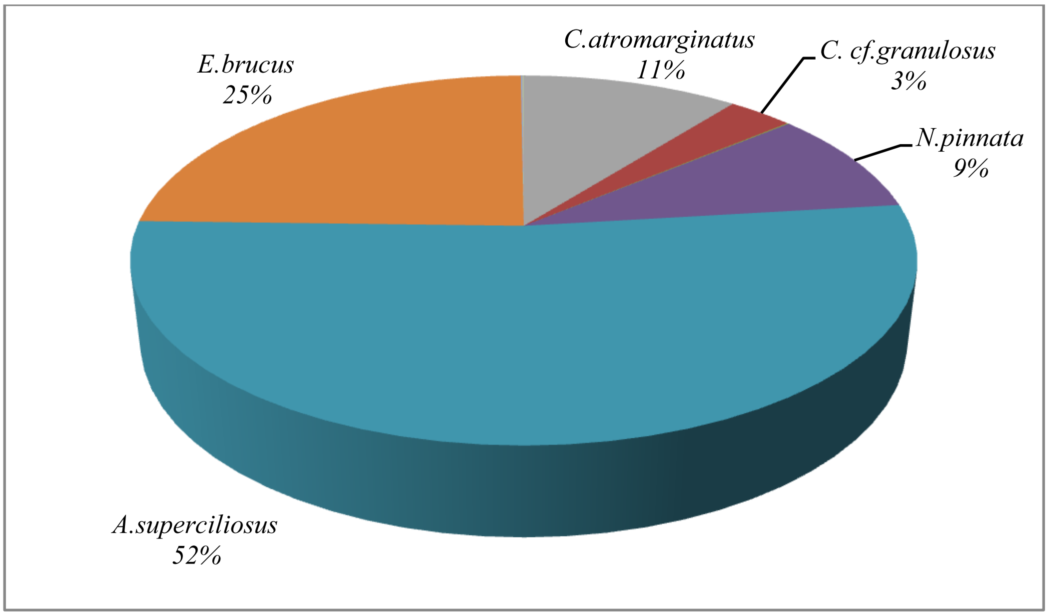


Figure 4.18. Percentage contribution of deep-sea chondrichthyan landings (by weight) at Cochin Fisheries Harbour, Kochi during 2010.

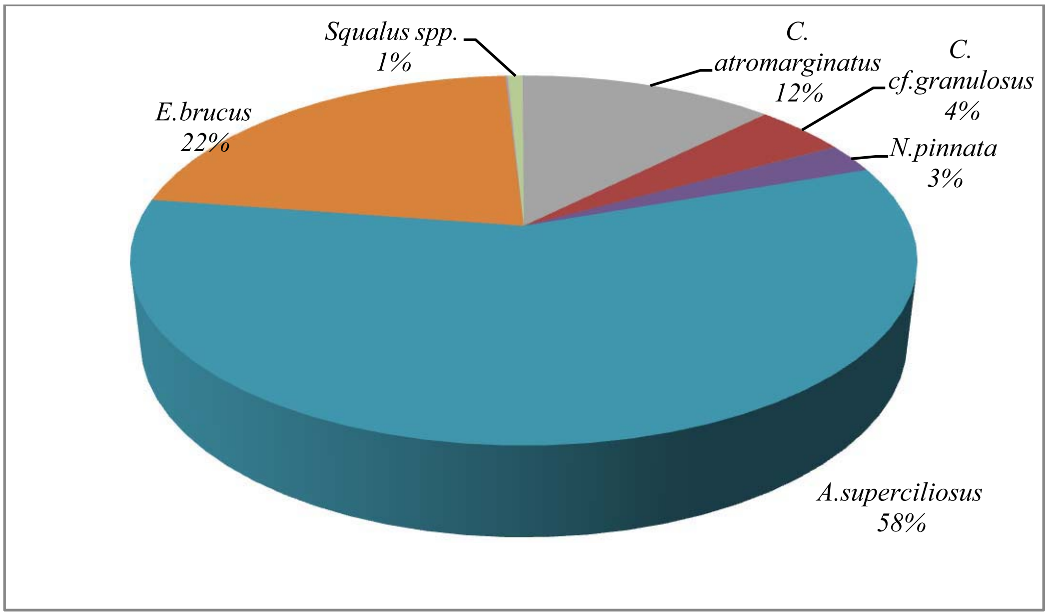


Figure 4.19. Percentage contribution of deep-sea chondrichthyan landings (by weight) at Cochin Fisheries Harbour, Kochi during 2011.

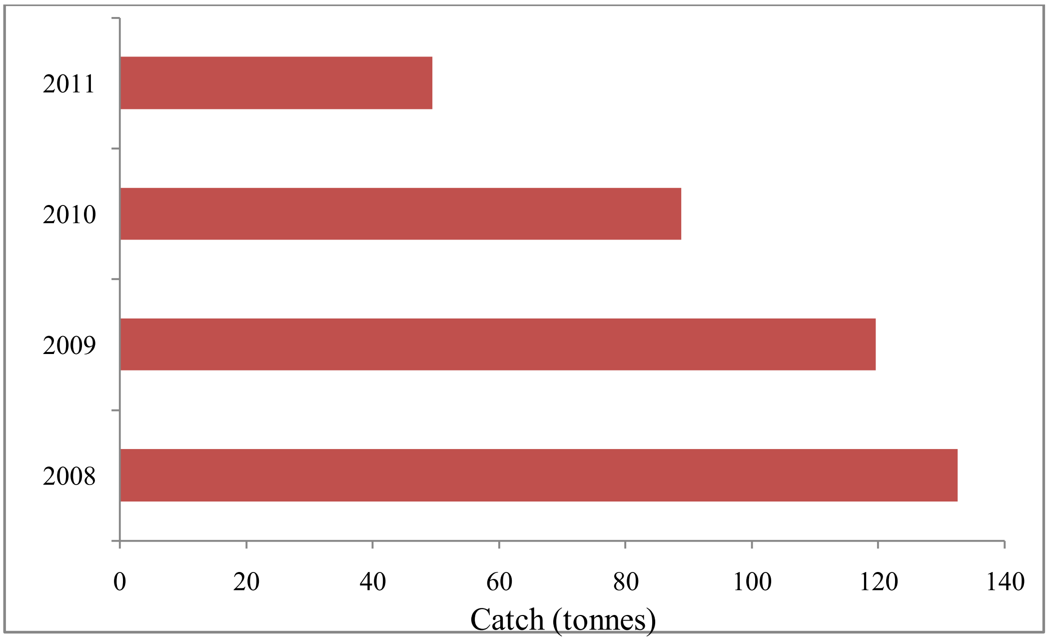


Figure 4.20. Landings of *Echinorhinus brucus* at Cochin Fisheries Harbour, Kochi from 2008 -2011

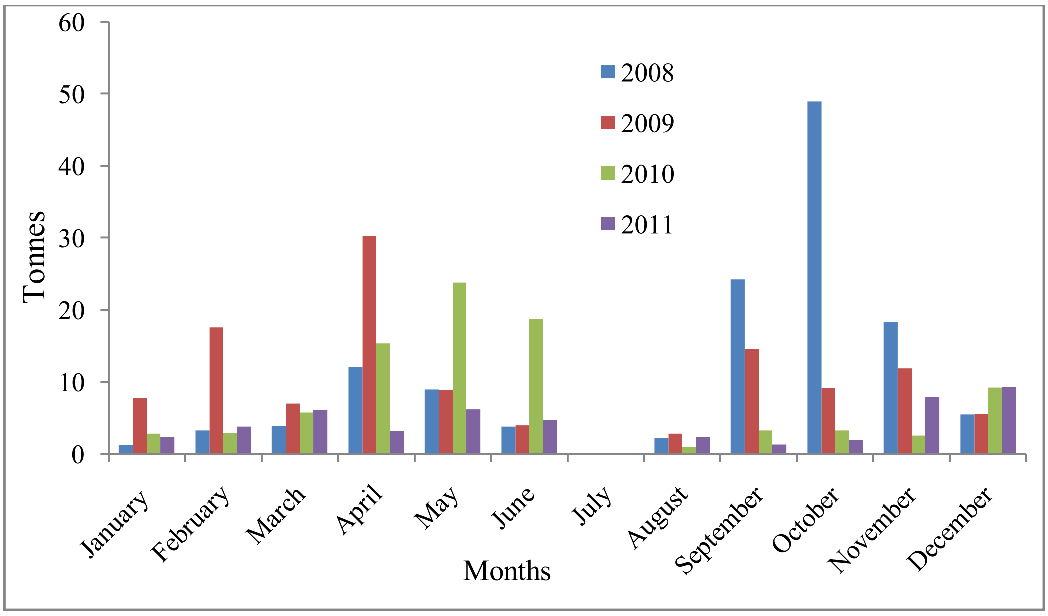


Figure 4. 21. Comparative monthly landings of *Echinorhinus brucus* at Cochin Fisheries Harbour, Kochi

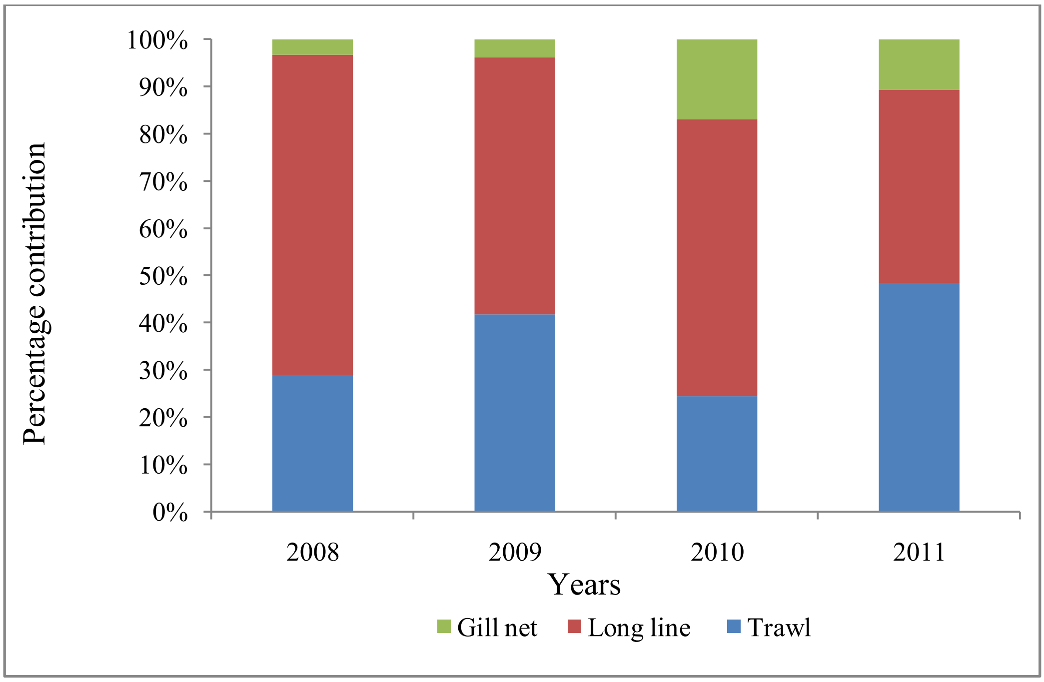


Figure 4.22. Gear-wise percentage contribution of *Echinorhinus brucus* landings at Cochin Fisheries Harbour, Kochi

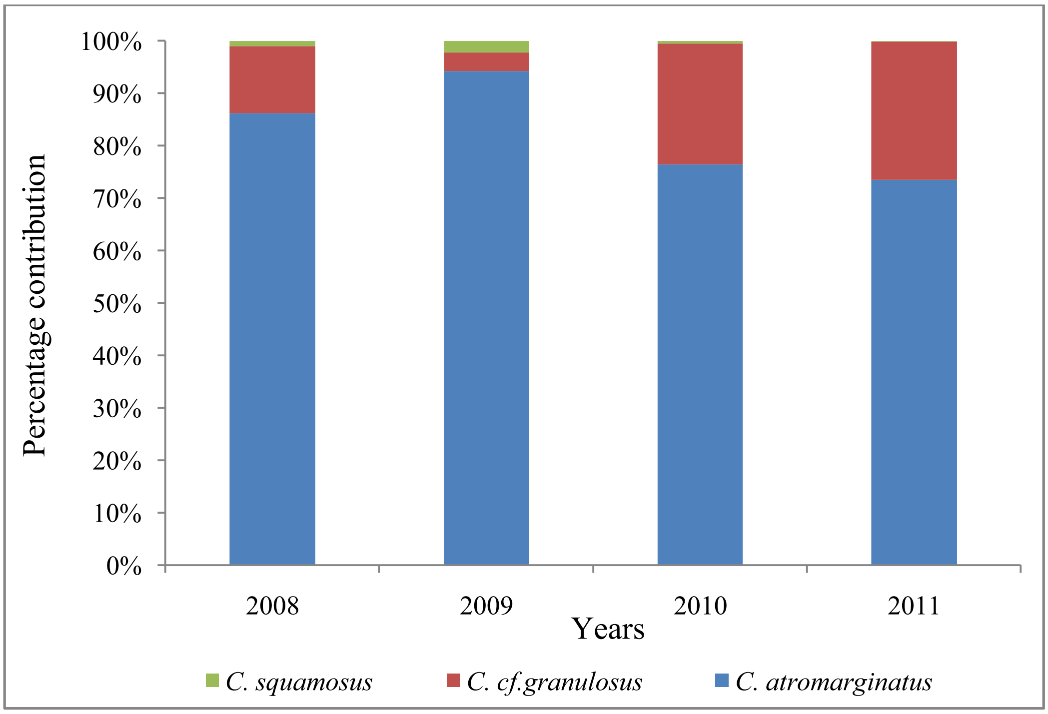


Figure 4.23. Percentage contribution of *Centrophorus* spp. to gulper shark fishery at Cochin Fisheries Harbour, Kochi

Figure 4.24. Gear-wise percentage contribution of Centrophoridae landings at Cochin Fisheries Harbour, Kochi

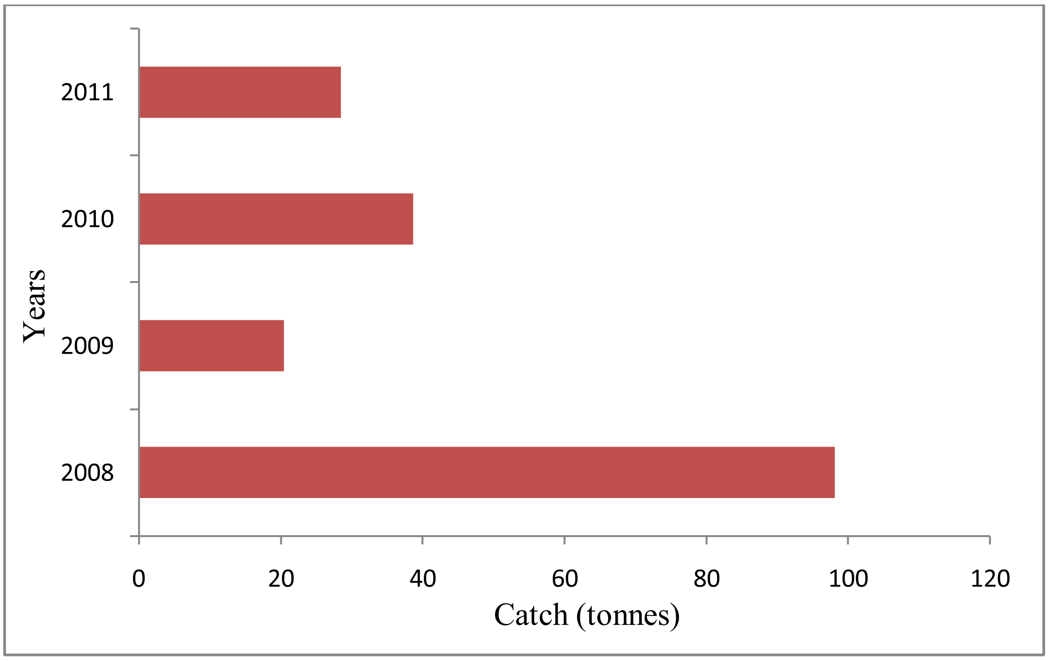


Figure 4.25. Landings of *Centrophorus atromarginatus* at Cochin Fisheries Harbour, Kochi from 2008- 2011

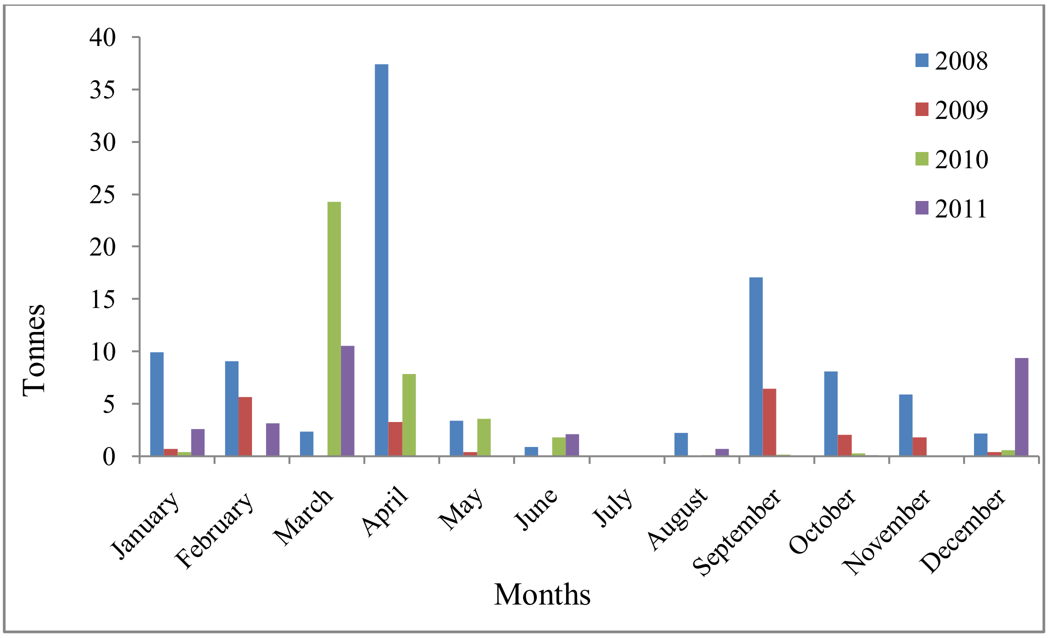


Figure 4. 26. Monthly landings of *Centrophorus atromarginatus* at Cochin Fisheries Harbour, Kochi

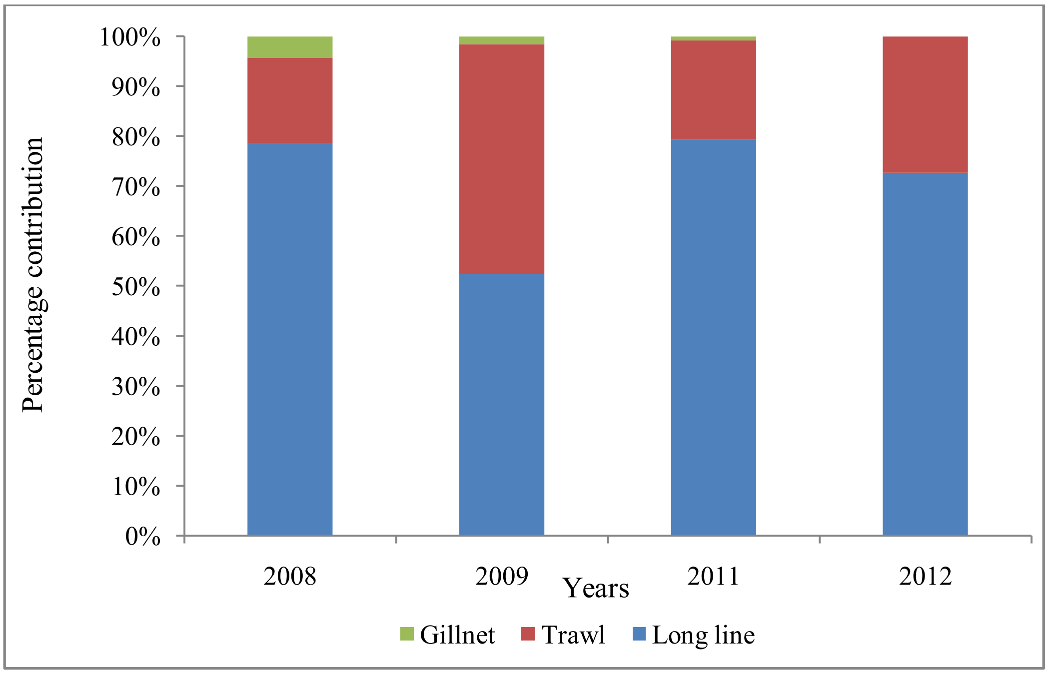


Figure 4.27. Gear-wise percentage contribution of *Centrophorus atromarginatus* landings at Cochin Fisheries Harbour, Kochi

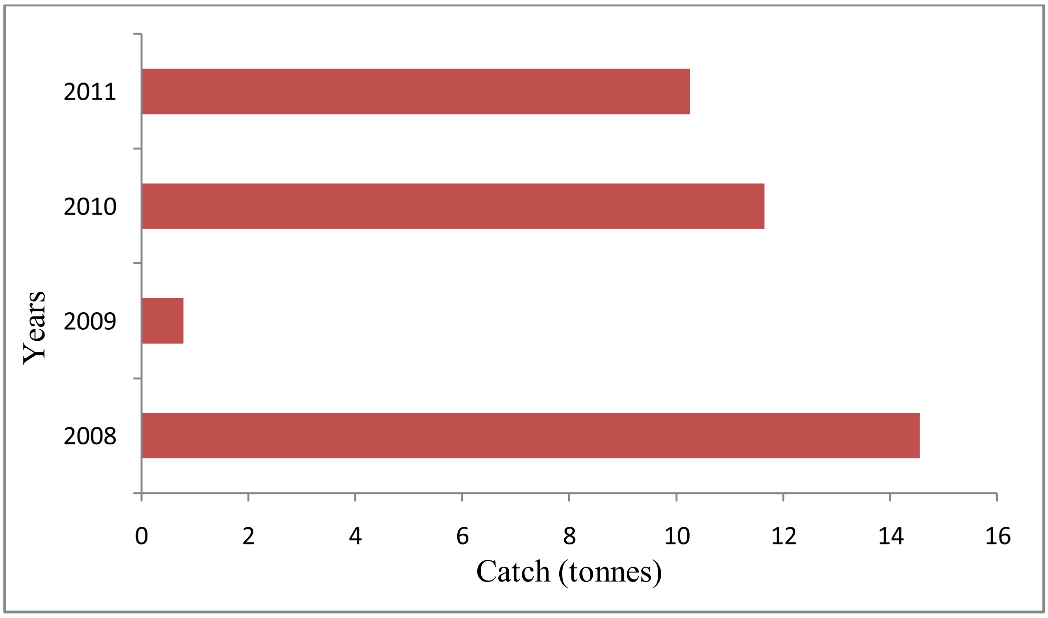


Figure 4. 28. Landings of *Centrophorus* cf. *granulosus* at Cochin Fisheries Harbour, Kochi from 2008- 2011

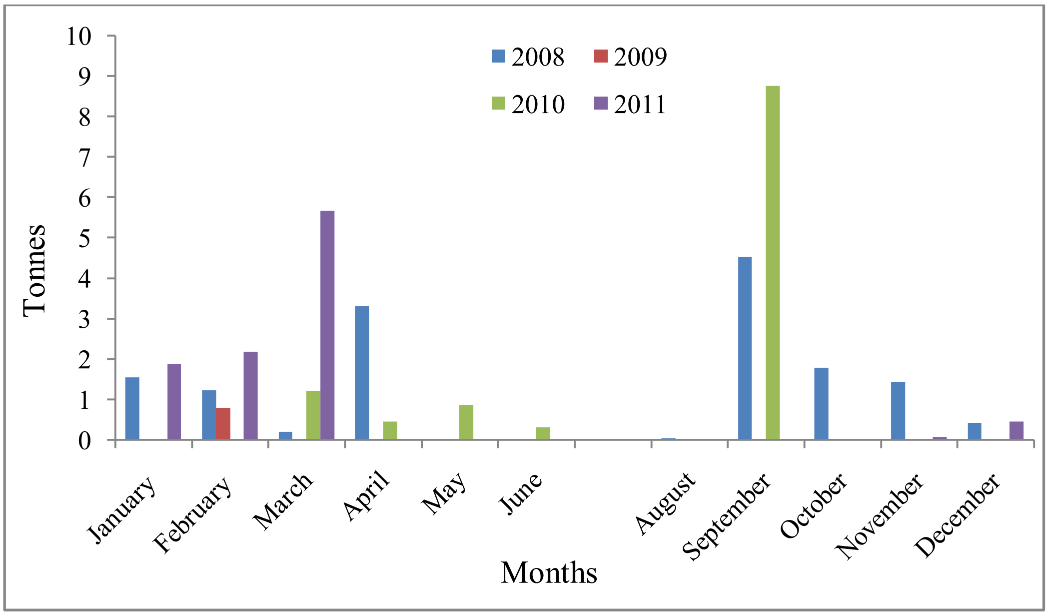


Figure 4. 29. Monthly landings of *Centrophorus* cf. *granulosus* at Cochin Fisheries Harbour, Kochi

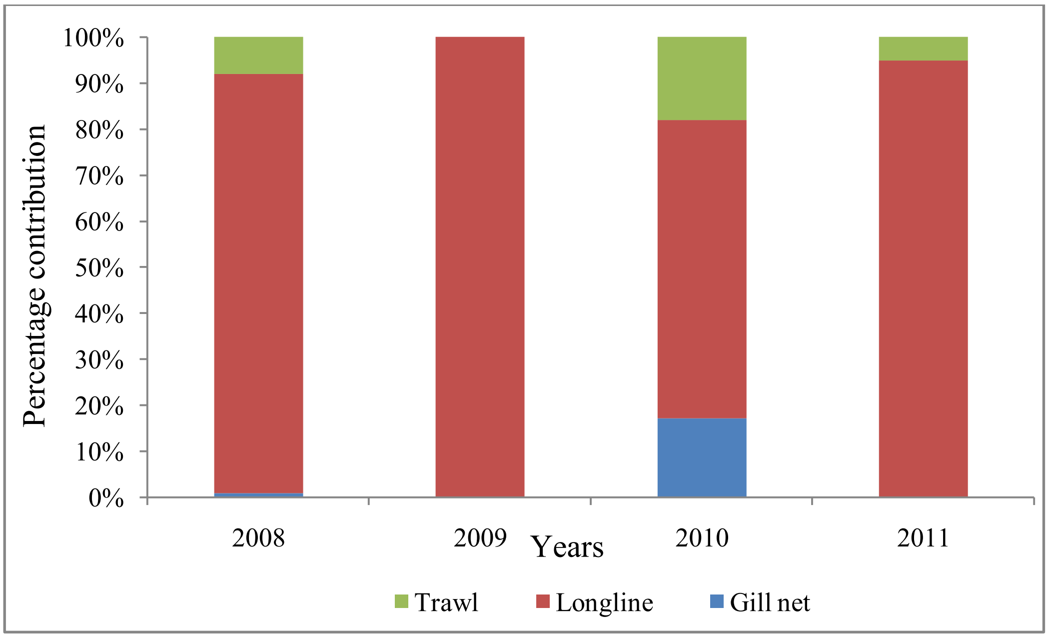


Figure 4. 30. Gear-wise percentage contribution of *Centrophorus* cf. *granulosus* landings at Cochin Fisheries Harbour, Kochi

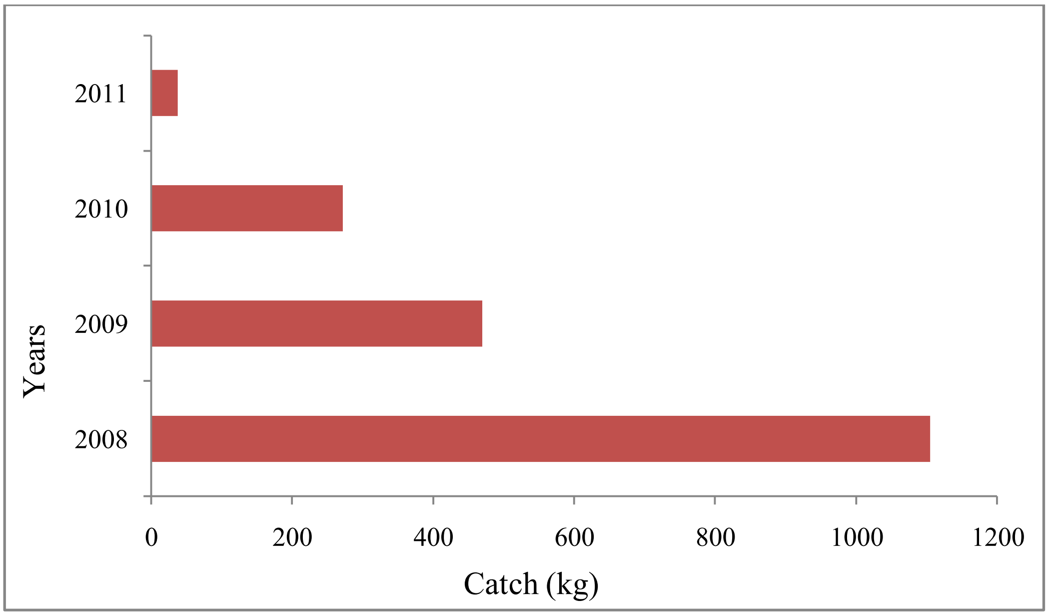


Figure 4.31. Landings of *Centrophorus squamosus* at Cochin Fisheries Harbour, Kochi from 2008 -2011

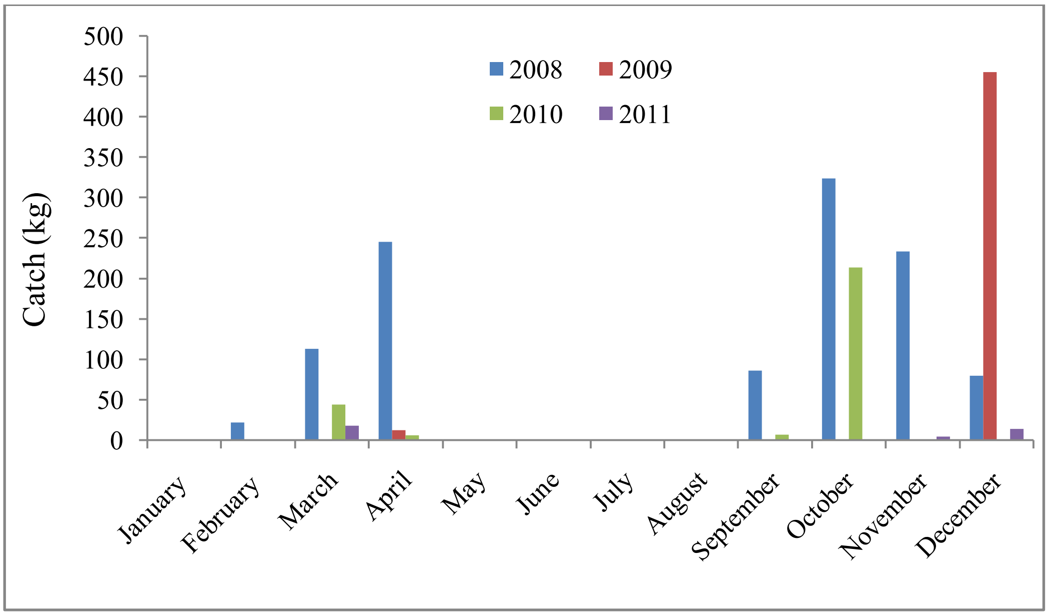


Figure 4. 32. Monthly landings of *Centrophorus squamosus* at Cochin Fisheries Harbour, Kochi

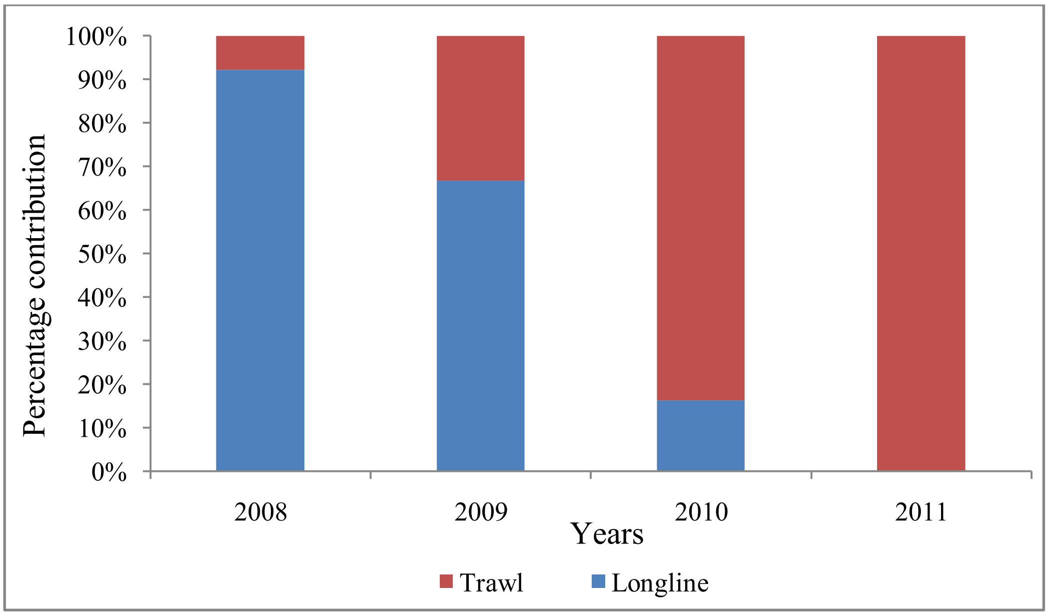


Figure 4.33. Gear-wise percentage contribution of *Centrophorus squamosus* landings at Cochin Fisheries Harbour, Kochi

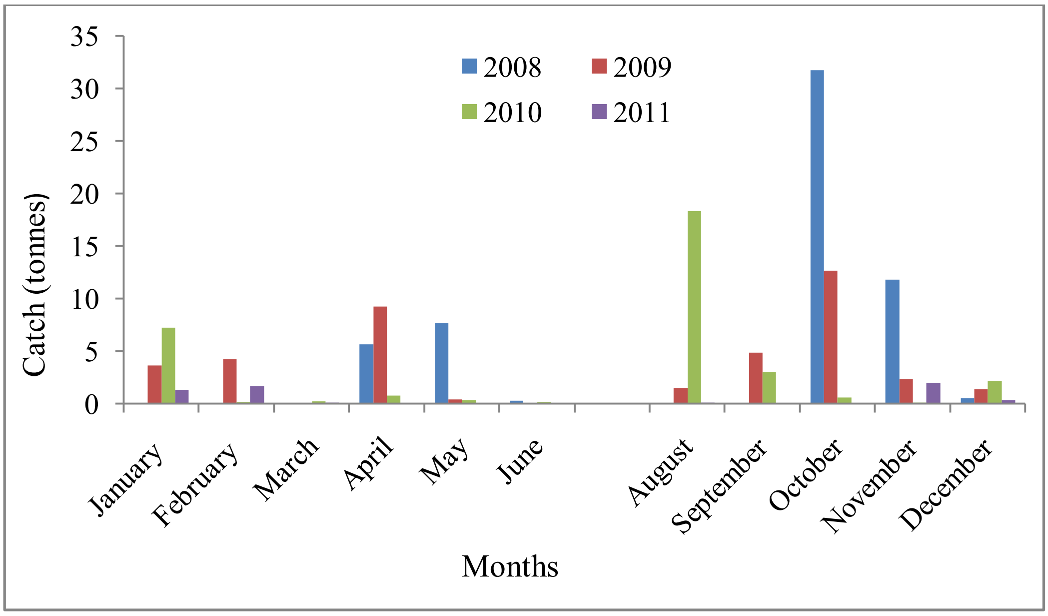


Figure 4. 34. Monthly landings of *Neoharriotta pinnata* at Cochin Fisheries Harbour, Kochi

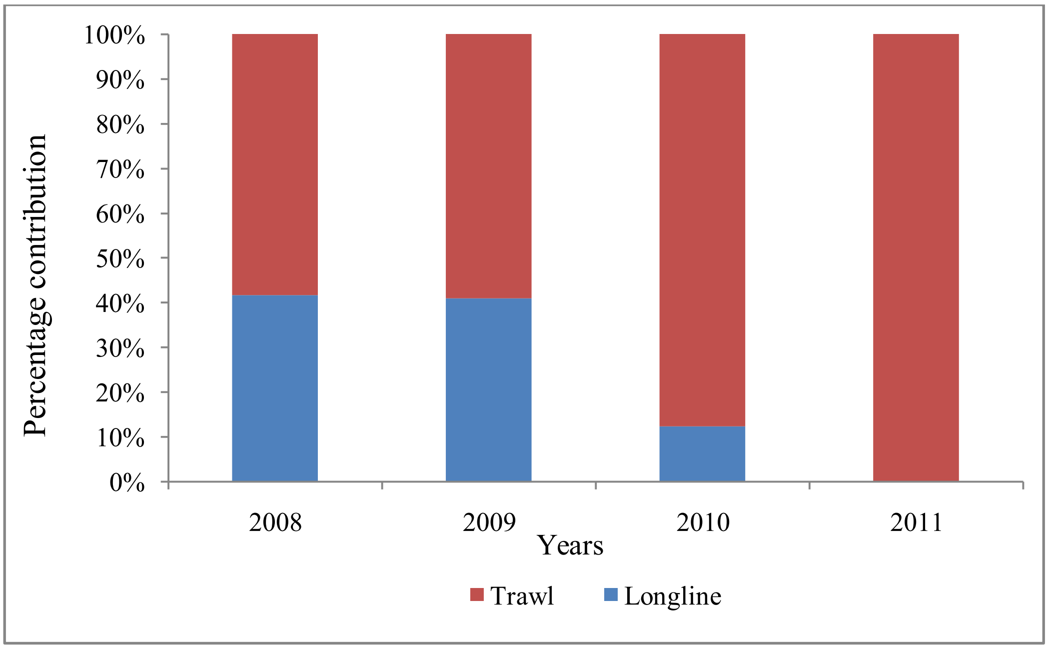


Figure 4.35. Gear-wise percentage contribution of *Neoharriotta pinnata* landings at Cochin Fisheries Harbour, Kochi

Transportation of deep-sea sharks to the processing centres

Deep-sea sharks in the processing centres

Processing of Gulper sharks (Liver removal and meat cutting)

Processing of Bramble sharks

Bramble shark cutting and meat slicing

Washing of shark meat in freshwater

PLATE 4: Processing of shark meat

Curing process of shark meat

Salted shark meat

Salted shark meat in the salting tank (first day)

Salted shark meat after 18 days

Dry-salted shark meat in market

PLATE 5: Processing of shark meat

	
Liver removal	Chopping of liver into small pieces
	
Crude liver oil extraction machine	Crude liver oil kept for settling
	
Collecting clear crude liver oil avoiding debris and impurities	Crude liver oil in barrels ready for sales to agents, exporters, processing firms

PLATE 6: Processing of deep-sea shark liver

	
Drying of shark fins- *Centrophorus* spp.	Drying of shark fins- *Alopias* spp.
	
Drying of shark fins- *Echinorhinus brucus*	Removal of jaw from head
	
Shark jaws kept for cleaning and whitening	Processed jaw of *Echinorhinus brucus*

PLATE 7: Processing of shark fins and jaws

Chapter 5

Biology of deep-sea sharks off the southwest coast of India

Chapter 5

Biology of deep-sea sharks off the southwest coast of India

Chondrichthyans are highly vulnerable to any high fishing effort directed at them due to their life history characters, called as *K* selected, having slow growth rate, late maturity, low fecundity and low natural mortality (Hoenig and Gruber, 1990: Musick, 1999; Stevens *et al.,* 2000). These particular *K* selected characteristics makes chondrichthyans very poor resilient to fishing mortality (Hoenig and Gruber, 1990; Smith *et al.,* 1998). Population decline of elasmobranch species can occurs quickly when they are over exploited and are difficult to re-establish like most of the finfish population reductions (Sminkey and Musick, 1995; 1996).

Historically, more attention has been concentrated on the understanding the biological aspects of pelagic/coastal elasmobranchs, which are heavily exploited whereas information on biological aspects of deepwater chondrichthyans are poorly known. Most of the studies on deep-sea chondrichthyans are limited to commercially important groups like; Centrophoridae and Squalidae (Kyne and Simpfendorfer, 2007). Sustainable fisheries management requires information on biological characters viz: age, growth and reproduction of all exploited species for understanding and assessing the status and for formulating suitable management plans.

Due to the declining coastal fish stocks, commercial fisheries is now moving to more deeper waters and targeting deepwater fishes (Morato *et al.,* 2006), which is having a impact of chondrichthyan populations. In India also, fishing has extended to deeper waters and many deepwater chondrichthyans are being brought to landing centres as bycatch and also in targeted fishery.

There is a worldwide concern over the sustainability of deepwater chondrichthyans to overfishing. However, there is a general lack of basic information on the biology and ecology of many deepwater chondrichthyans, which is mostly due to their peculiar habitat and sampling difficulties. There are only very few records of biological observations on deep-sea sharks from India. This chapter presents information on the biological aspects of deepwater sharks such as, *Eridacnis radcliffei, Bythaelurus hispidus* and *Echinorhinus brucus* from southwest coast of India

Materials and methods

Regular surveys of fish landing sites at selected location along the southwest coast of India were conducted weekly between 2008 to 2011. Samples for biological studies were collected either from Cochin Fisheries Harbour, Kochi or Sakthikulangara Fisheries Harbour, Kollam. Samples were brought to laboratory, except for large shark, *Echinorhinus brucus*. Specimens were identified based on Compagno *et al.* (2005). Total lengths (TL), from snout to caudal tip, were recorded in centimeter (cm) and weight in kilogram (kg) for *Echinorhinus brucus* and millimeter (mm) and gram (g) for *Eridacnis radcliffei* and *Bythaelurus hispidus.*

Studies on length-weight relationship of fishes are important in fisheries biology. Its application includes: (i) estimation of average weight of fish of given length group ; (ii) conversion of length - growth equations to weight – growth equivalents (i.e. length - at - age to weight-at-age) in Yield per Recruit and related models; (iii) interspecific and interpopulational morphometric comparison of fish species; and (iv) assessing the relative well-being of fish populations. Indices of well-being or condition factor are another way of expressing the relationship between length and weight of a particular fish. There are three basic variations of indices of well-being for whole fish, Fulton-type (1904), relative condition factor of Le Cren (1951) and Relative Weight (Wege and Anderson, 1978). In the present study the Length-weight relationship was calculated as $W = a L^b$ (Lecren, 1951), where W is the weight of the fish in gram and L is its total length in cm with (a regression intercept and b slope). The case where b =3 represents fish that become less round as length increases, whereas when b>3 fish become more round as length increases.

For males, outer clasper length and level of calcification of the claspers was recorded. Clasper length (CL) was measured from outer pelvic insertion to clasper apex. The maturity status was also recorded for each individual following the maturity scale reported by Stehmann (2002), based on ovarian and uterine condition for females and clasper calcification for males. For calculation of Length at-maturity (L_m) for females and males, individuals were classed as either immature (uncalcified or partially calcified claspers for males; ovaries not developed or with maturing oocytes but uteri thin and ribbon-like for females) or mature (claspers fully calcified; ovaries and uteri both fully developed). The length at which females and males attain maturity (L_m) was calculated using cumulative frequency, percentage of cumulative frequency were graphically plotted against the length groups and the length at which 50% of the sample were found to be matured, was taken as the length at first maturity (L_m) (White *et al.*, 2007).

To describe the diet, percentage frequency of occurrence (%O), percentage composition by number (%N), percentage composition of weight (%W) and Index of Relative Importance (IRI) were used following IRI= (%N+% W)* %O (Pinkas *et al.*, 1971). The IRI was expressed as a percentage (% IRI) following % IRI = (IRI/ Σ IRI) X 100 to allow for a comparison of values between prey groups (Cortés, 1997).

5.1. Biology of pygmy ribbontail catshark, *Eridacnis radcliffei* Smith,1913

The pygmy ribbontail catshark *Eridacnis radcliffei* Smith, 1913 (Proscyllidae: Carcharhiniformes) is one of the smallest living shark species and the smallest carcharhinoid shark, reaching only 257 mm total length (TL). *Eridacnis radcliffei* was described from the Philippines and has a scattered distribution in the Indo–West Pacific, from East Africa to the Philippines. It occurs on or near muddy bottom on the continental shelf and slope at depths of 71–766 m, and is reported to be very abundant at several locations, such as off southern India and the Philippines (Compagno *et al.*, 2005 a). The IUCN Red List of Threatened Species list the status of *E. radcliffei* as „Least Concern' as it is a small species that is not targeted by fisheries and inhabits a wide range of water depths including depths beyond the commercial fisheries (McCormack *et al.*, 2009). Of the three species in the *Eridacnis* genus, *E. radcliffei* is by far the most widely distributed species with a geographical range extending from waters of Tanzania to Philippines (Compagno *et al.*, 2005 a). Compagno *et al.* (2005 b) suggested that specimens of *E. radcliffei* from across its wide range need to be critically compared to determine if they are all conspecific.

Despite wide geographical distribution and prominence in trawl bycatch, there is little information on the biology or behavior of *E. radcliffei*. Published information on this species is sparse and usually based on inadequate sample sizes. Misra (1950) described *Proscyllium alcocki* based on two specimens from the Andaman Islands in the Bay of Bengal, which was later synonymised with *E. radcliffei* (Nair and Lal Mohan, 1973; Compagno, 1984 a). The available distribution records for *E. radcliffei* from Indian waters are by Misra (1950) and Rajan *et al.* (2012) from the Andaman Islands, Nair and Lal Mohan (1973) and Nair and Appukkutan (1973) from the Gulf of Mannar and Jayaprakash *et al.* (2006) from the southwest coast. Nair and Appukkutan (1973) provided information on the food and feeding habits of *E. radcliffei*. Nair and Appukkutan (1974) reported on embryonic development of *E. radcliffei* based on a small sample size of embryos from 15 pregnant females. The present study provides detailed biological information on *E. radcliffei*.

Materials

Specimens of *E. radcliffei* were collected from the bycatch landings of the deep-sea shrimp trawl fishery, which operates on the southwest coast of India at depths of 200–500 m, from during September 2010 to March 2011 and during January 2012 operating at depths 200-500 m off Kollam and landed at the Sakthikulangara fisheries harbour (Kollam), Kerala in the southwest coast of India (Fig. 4.1).

Deep-sea shrimp trawl catch composition

Eridacnis radcliffei was a regular bycatch component of the deep-sea shrimp trawls, which mainly target the shrimp species *Plesionika* spp., *Solenocera* spp., *Heterocarpus* spp., *Metapenaeopsis* spp. and *Aristeus alcocki.* The bycatch of this fishery includes the sharks *Echinorhinus brucus, Cephaloscyllium silasi, Iago* spp., *Squalus* spp., *Centrophorus* spp., the chimaera *Neoharriotta pinnata* and the dominant teleosts were *Neoepinnula orientalis*, *Chlorophthalmus corniger, Chlorophthalmus acutifrons, Chascanopsetta lugubris*, *Cubiceps* spp., *Chelidoperca investigatoris, Neoscopelus microchir, Bembrops caudimacula*, *Diaphus watasei, Bathyclupea honskyi, Polymixia* sp., *Synagrops philippinensis* etc. Detailed list of deep-sea trawl bycatch species along the southwest coast of India is provided (Table. 5.1.1). It should be noted that other than shrimps only large sized fishes and sharks which have some commercial value or the final haul with unsorted catch are landed unless all the bycatch are discarded at sea during onboard sorting. In the Quilon Bank area/Wadge Bank area, deep-sea shrimp trawls are operated mostly at depths ranging from 200–500 m. Nair and Appukkutan (1973) reported *E. radcliffei* was caught along with *Puerelus sewelli, Solencera hextii* and *Heterocarpus gibbosus*, where lobsters and shrimps formed major catch from off Gulf of Mannar at 183–275 m depths.

Biology

For the biological studies, a total of 549 individuals of *E. radcliffei* were collected, comprising of 284 females, 218 males and 47 indeterminate individuals. The overall sex ratio of females to males was 1.3:1, which vary considerably in months being 0.4:1 in January 2011 and 8.8: 1 in 2012 January (Fig. 5.1.1).

Females and males ranged in length from 106–257 and 107–235 mm TL respectively, with most individuals between 160 and 240 mm TL. Females are attaining a larger size than males. The 100–150 mm TL length classes were dominated by females, while the 150–200 mm TL length class was dominated by males (Fig. 5.1.2).

Length weight relationship

A total of 297 individuals, consisting of 169 females (107–257 mm TL) and 128 males (106–235 mm TL) were used to generate length-weight relationship for this species. The relationship between W (g) and TL (mm) for combined sexes, females and males is expressed by the following equations and scatter diagram for the same has been plotted (Fig. 5.1.3-5.1.5)

Length-weight relation (Males) : $W = 1.1 \times 10^{-3} \times TL^{3.28}$ ($r^2 = 0.90$)

Length-weight relation (Females) : $W = 5.4 \times 10^{-4} \times TL^{3.55}$ ($r^2 = 0.97$)

Length-weight relation (pooled sexes) : $W = 5{\cdot}8 \times 10^{-4} \times TL^{3{\cdot}52}$ ($r^2 = 0{\cdot}95$)

Reproductive biology

Eridacnis radcliffei is an aplacental viviparous (previously termed ovoviviparous) species whereby females give birth to live young and there is no direct connection between embryo and the mother via a uterine connection. The developing embryo obtains all of its nutrients from an external yolk sac with birth occurring soon after the yolk is completely absorbed. Females have one functional ovary (right) and both uteri are functional. Of the 136 gravid females observed in the present study, 63% of pregnant females had an embryo or fertilised egg in only the right uterus, 24% in both uteri and 13% in only the left uterus. Mature females with developing oocytes (0.6–28 mm diameter) were observed in females with lengths between 144 and 230 mm TL (Plate 8). The smallest female with mature oocytes was 153 mm TL. Length at maturity (Lm) for females was estimated at 183 mm TL (Fig. 5.1.6). Compagno *et al.* (2005) suggested that females probably mature at 150–160 mm TL.

During the present study, gravid females with developing and mature oocytes, and embryos were observed in all sampling months with peaks in December and January where 76–87% of observed females were gravid. This could indicate a continuous recruitment and protracted breeding season, but present sample size is not enough to ascertain any seasonality to the breeding cycle. Nair and Appukkutan (1974) suggested a possible breeding period in February, off Gulf of Mannar for *E. radcliffei*, due to dominance of pregnant females in the collection at this time (n=15) and stated the need for more studies on geographical basis.

Ovarian fecundity for females was 3 or 4, but uterine fecundity was only 1 or 2. The embryos recorded ranged in size from 80–128 mm TL. The late-term embryos (>90 mm TL) had fully absorbed all yolk in the yolk sac with either the yolk-sac stalk still attached or with a scar where yolk sac was located (Plate 8). Since the smallest free-swimming individual was 106 mm TL, size at birth in this species is likely between 105 and 128 mm TL. The largest free-swimming individual possessing an umbilical scar was 136 mm TL.

In the case of males, all maturity stages of *Eridacnis radcliffei* were represented and the vast majority (85%) were <174 mm TL (Fig. 5.1.2). The smallest mature male recorded was 164 mm TL, while the largest immature male was 186 mm TL. The vast majority of males >180 mm TL possessed fully calcified claspers, while most between 150–170 mm TL possessed partially calcified claspers. The relationship between CL (clasper length) showed a direct relation where it was observed that CL increased with size and maturity. Length at maturity (L_m) in *E. radcliffei* males estimated as 170 mm TL (Fig. 5.1.7). Compagno *et al*. (2005 a) reported that males of *E. radcliffei* were first mature between 180 and 190 mm TL.

Food and feeding

The dietary composition of *E. radcliffei* was determined to understand its food and prey preferences. Stomachs of 484 individuals were examined, of which 37% were empty, 23% with trace contents only, 10% half full, 12% three quarters full and 18% full (Fig. 5.1.8).

The analysis of stomach contents revealed *Eridacnis radcliffei* feeds primarily on crustaceans (74.2%) (Fig. 5.1.9). The most common dietary item was shrimps (mostly *Aristeus* spp, *Ophlophorus* spp, *Plesionika quasigrandis, Heterocarpus* spp, etc) which comprised 63% of the dietary items, followed by fish remains (23.4%) (Table. 5.1.2)

The vast majority of the pregnant females contained food items, providing some evidence of active feeding during gestation. These results differ from that of Nair and Appukuttan (1973) who reported that 55% of *E. radcliffei* diet was composed of bony fishes followed by crustaceans (28%) and squid (14%). In that study, a variety of prey items were recorded, including the teleosts *Myctophum* sp, *Gonostoma* sp., and various eels; and the invertebrates *Solenocera hextii*, stomatopod larvae and bivalves. Furthermore, Appukuttan and Nair (1988) reported deep-sea fishes, crustaceans and squids as prey items of *E. radcliffei*. The present study provides new biological information on *E. radcliffei* based on a large number of specimens collected from the bycatch of deep-sea shrimp trawl fisheries off southwest coast of India.

Table 5.1.1. List of fish species in deep-sea shrimp trawl bycatch landings

Family	Species
Rhinochimaeridae	*Neoharriotta pinnata* (Schnakenbeck, 1931)
Echinorhinidae	*Echinorhinus brucus* (Bonnaterre, 1788)
Centrophoridae	*Centrophorus* cf. *granulosus* (Bloch & Schneider, 1801)
	Centrophorus squamosus (Bonnaterre, 1788)
Squalidae	*Squalus* spp.
Etmopteridae	*Etmopterus pusillus* (Lowe, 1839)
Proscyllidae	*Eridacnis radcliffei* Smith, 1913
Scyliorhinidae	*Halaelurus quagaa* (Alcock, 1899)
	Bythaelurus hispidus (Alcock, 1891)
Rajidae	*Dipturus* spp.
Synodontidae	*Saurida tumbil* (Bloch, 1795)
Congridae	*Gavialiceps taeniola* Alcock, 1889
Nemichthyidae	*Nemichthys scolopaceus* Richardson, 1848
Alepocephalidae	*Alepocephalus bicolor* Alcock, 1891
Stomiidae	*Astronesthes indicus* Brauer, 1902
	Astronesthes lucifer Gilbert, 1905
	Chauliodus sloani Bloch & Schneider 1801
Sternoptychidae	*Argyropelecus hemigymnus* Cocco, 1829
	Polyipnus indicus Schultz, 1961
Gonostomatidae	*Vinciguerria* sp.
Ateleopodidae	*Ateleopus indicus* Alcock, 1891
Chlorophthalmidae	*Chlorophthalmus corniger* Alcock, 1894
	Chlorophthalmus acutifrons Hiyama, 1940
Ipnopidae	*Bathypterois atricolor* Alcock, 1896
Evermannellidae	*Evermannella indica* Brauer,1906
Neoscopelidae	*Neoscopelus microchir* Matsubara 1943
	Scopelengys tristis Alcock, 1890
Myctophidae	*Benthosema fibulatum* (Gilbert & Cramer, 1897)
	Diaphus watasei (Jordan & Starks, 1904)
	Diaphus thiollierei (Fowler, 1934)
	Diaphus sp.
	Diaphus garmani Gilbert, 1906
	Diaphus splendidus (Brauer, 1904) *Myctophum obtusirostre* (Taning, 1928) *Myctophum fissunovi* Becker & Borodulina, 1971
	Symbolophorus evermanni (Gilbert, 1905)

Family	Species
Macrouridae	*Coelorinchus sp.*
	Malacocephalus laevis (Lowe, 1843)
	Coryphaenoides macrolophus (Alcock, 1889)
	Macrurus sp.
	Gadomus spp.
Moridae	*Physiculus roseus* Alcock, 1891
Ophidiidae	*Dicrolene nigricaudis* (Alcock, 1891)
	Luciobrotula sp.
	Neobythites analis Barnard, 1927
	Glyptophidium argenteum Alcock, 1889
	Glyptophidium sp.
Acropomatidae	*Synagrops* sp.
Lophiidae	*Lophiomus setigerus* (Vahl, 1797)
Chaunacidae	*Chaunax pictus* Lowe, 1846
Ogcocephalidae	*Halieutaea* sp.
Trachichthyidae	*Gephyroberyx darwinii* (Johnson, 1866)
Berycidae	*Beryx splendens* Lowe, 1834
	Berynx sp.
Zeidae	*Zenopsis conchifer* (Lowe, 1852)
Scorpaenidae	*Setarches guentheri* Johnson, 1862
	Pontinus nigerimum Eschmeyer, 1983
Triglidae	*Pterygotrigla hemisticta* (Temminck & Schlegel, 1843)
	Lepidotrigla sp.
	Pterygotrigla sp.
Priacanthidae	*Priacanthus hamrur* (Forsskål, 1775)
	Pristigenys refulgens Valenciennes, 1862
	Heteropriacanthus sp.
Serranidae	*Chelidoperca investigatoris* (Alcock, 1890)
	Chelidoperca occipitalis
Centrolophidae	*Psenopsis cyanea* (Alcock, 1890)
Trichiuridae	*Trichiurus auriga* Klunzinger, 1884
	Trichiurus lepturus Linnaeus, 1758
Bathyclupeidae	*Bathyclupea elongata* Trunov 1975
Champsodontidae	*Champsodon* spp.
Gempylidae	*Gempylus serpens* Cuvier, 1829
	Neoepinnula orientalis (Gilchrist & von Bonde, 1924)
	Rexea prometheoides (Bleeker, 1856)
	Ruvettus pretiosus Cocco, 1833
	Promethichthys prometheus (Cuvier, 1832).
	Thyrsitoides marleyi Fowler ,1929

Family	Species
Polymixiidae	*Polymixia cf. berndti* Gilbert ,1905
Epigonidae	*Epigonus sp.*
Ariommatidae	*Ariomma indicum* (Day, 1871)
Gobiidae	*Bathygobius* sp.
Uranoscopidae	*Uranoscopus archionema* Regan, 1921
	Xenocephalus elongatus
Cepolidae	*Owstonia sp*
	Sphenamthias whiteheadi Talwar, 1973
Nomeidae	*Cubiceps baxteri* McCulloch, 1923
Nomeidae	*Cubiceps* sp.
Percophidae	*Bembrops caudimacula* Steindachner, 1876
Triacanthodidae	*Macrorhamphosodes uradoi* (Kamohara, 1933)
Peristediidae	*Peristedion miniatum* Goode ,1880
Bothidae	*Laeops nigromaculatus* von Bonde,1922
	Chascanopsetta lugubris Alcock,1894
Cynoglossidae	*Cynoglossus arel* (Bloch & Schneider,1801)
	Cynoglossus carpenteri Alcock ,1889

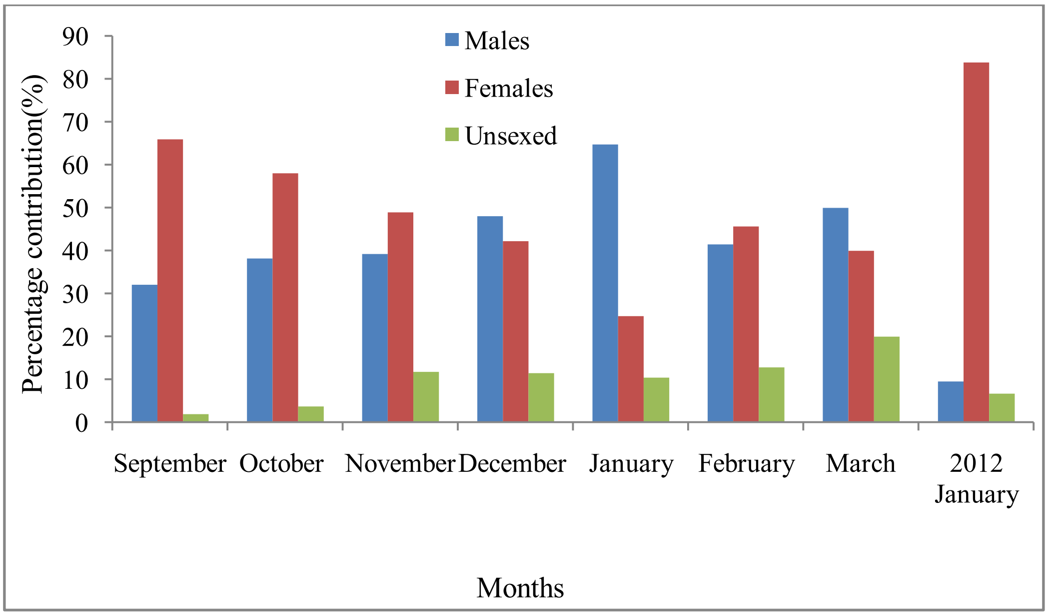


Figure 5.1.1. Percentage contribution of males and females in sampling months for *Eridacnis radcliffei*

Table 5. 1.2. Percentage contribution by number (% N), mass (% M), occurrence (% O) as well as the Index of Relative Importance (% IRI) of prey items in the stomach contents of *Eridacnis radcliffei* from southwest coast of India

	Prey items	%N	%W	%O	%IRI
Crustacea					
Portunidae					
	Charybdis sp.	3.0	4.5	1.7	1.3
Aristeidae					
	Aristeus sp.	6.0	3.0	2.7	2.5
Pandalidae					
	Heterocarpus sp.	3.0	7.1	1.2	1.3
	Plesionika quasigrandis	2.2	4.0	0.8	0.5
	Plesionika sp.	1.5	3.0	0.6	0.3
Penaeidae					
	Metapenaeus sp.	1.9	4.0	0.8	0.5
Oplophoridae					
	Oplophorus sp .	4.1	1.5	1.7	1.0
Squillidae					
	Squilla sp.	2.2	1.5	0.8	0.3
Sergestidae					
	Acetes sp.	11.9	3.0	3.3	5.1
Other					
	Unidentified shrimp	28.4	19.2	11.6	56.9
	Unidentified crab	4.9	11.1	2.7	4.4
Teleostei					
Callyonomidae					
	Callyonomid sp.	7.8	16.2	3.3	8.2
Champsodontidae					
	Champsodon sp.	4.5	7.1	2.1	2.5
Other					
	Unidentified telesotei	14.2	9.6	5.2	12.7
Other					
	Fish scales, completely digested, unidentified)	4.5	5.1	2.5	2.4

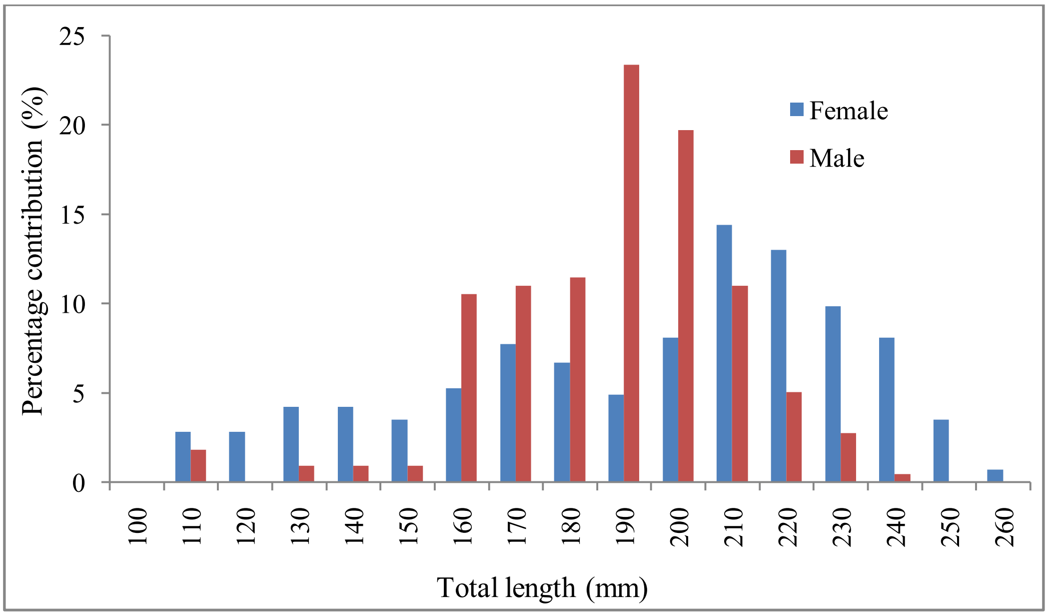


Figure 5.1.2. Percentage contribution of males and females in 10 mm size class for *Eridacnis radcliffei*

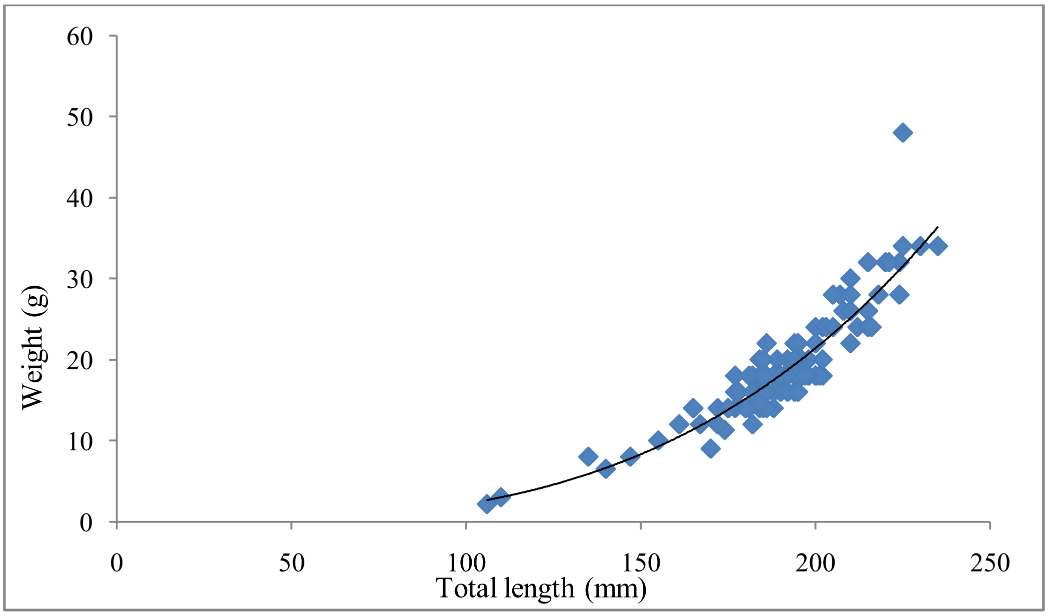


Figure 5.1.3. Length weight relation for males of *Eridacnis radcliffei* ($W = 1.1 \times 10^{-3} \times TL^{3.28}$)

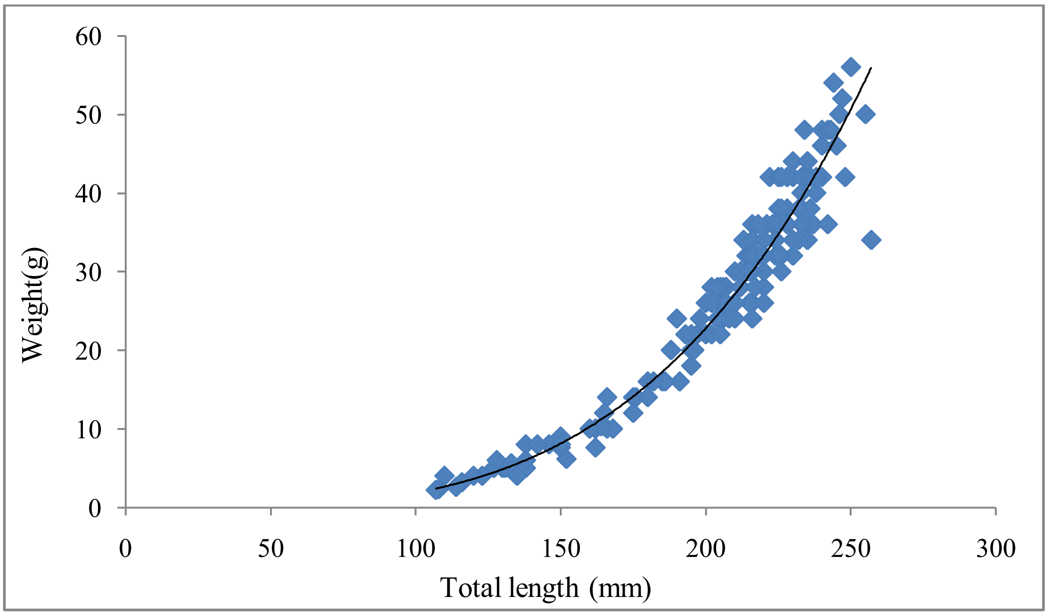


Figure 5.1.4. Length weight relation for femalesof *Eridacnis radcliffei*

(W= 5.4 x 10^{-4} x $TL^{3.55}$)

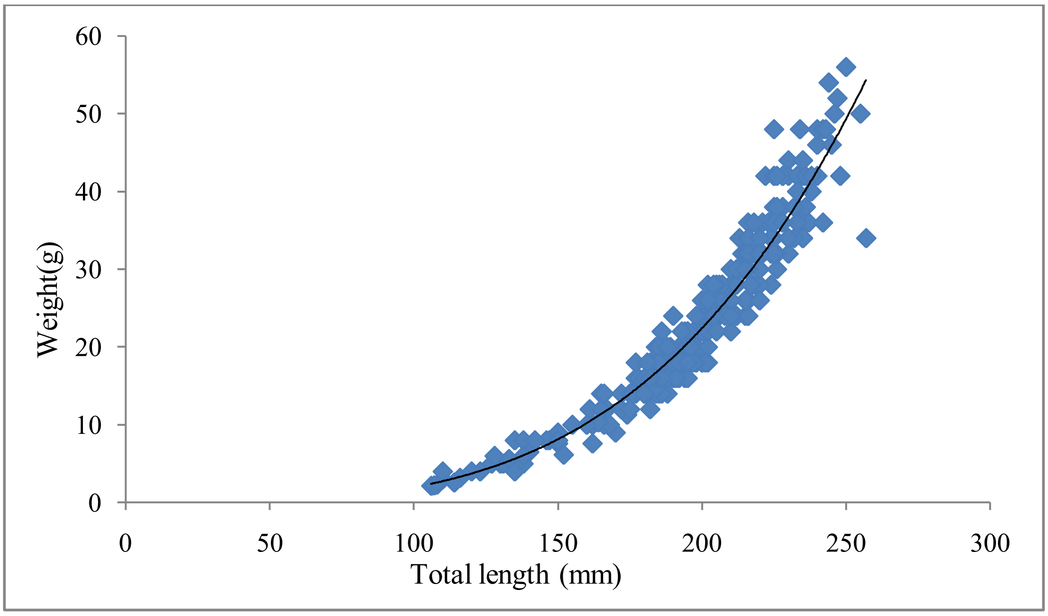


Figure 5.1.5. Length weight relation for combined sexes of *Eridacnis radcliffei*

(W= 5.8 x 10^{-4}x $TL^{3.52}$)

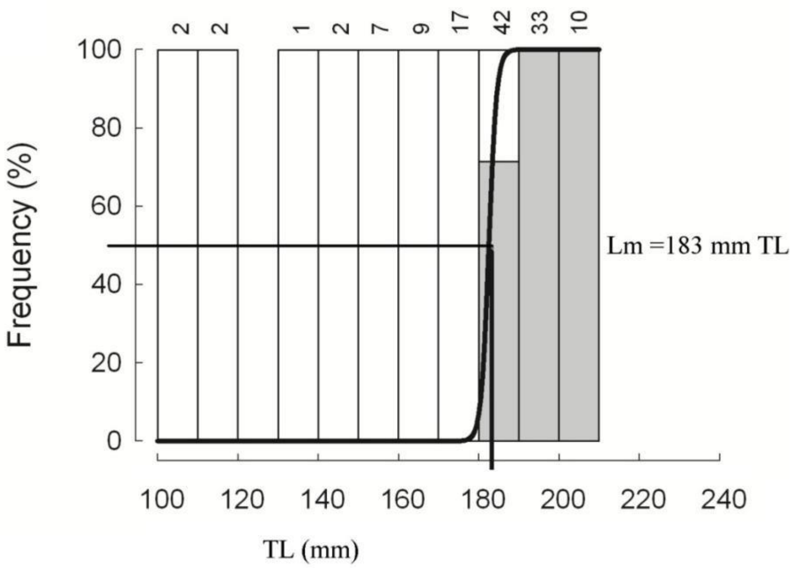


Figure 5.1.6. Length at first maturity for *Eridacnis radcliffei* females (Lm=183 mm TL)

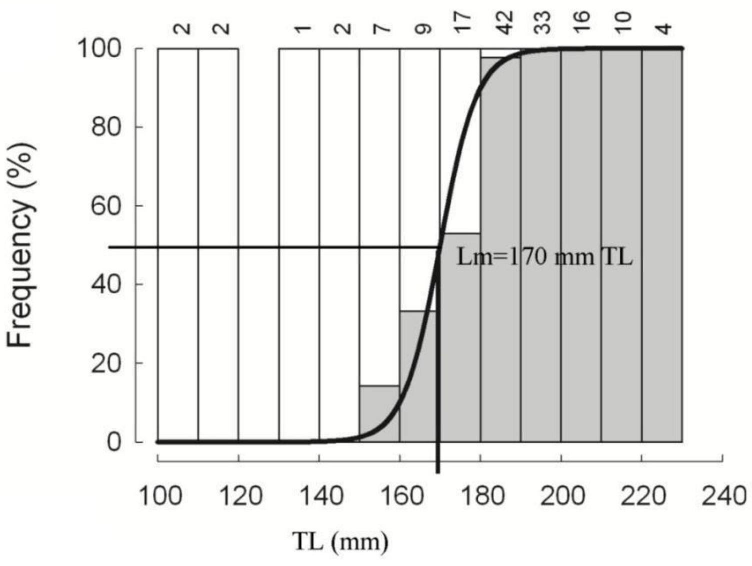


Figure 5.1.7. Length at first maturity for*Eridacnis radcliffei* males (Lm= 170 mm TL)

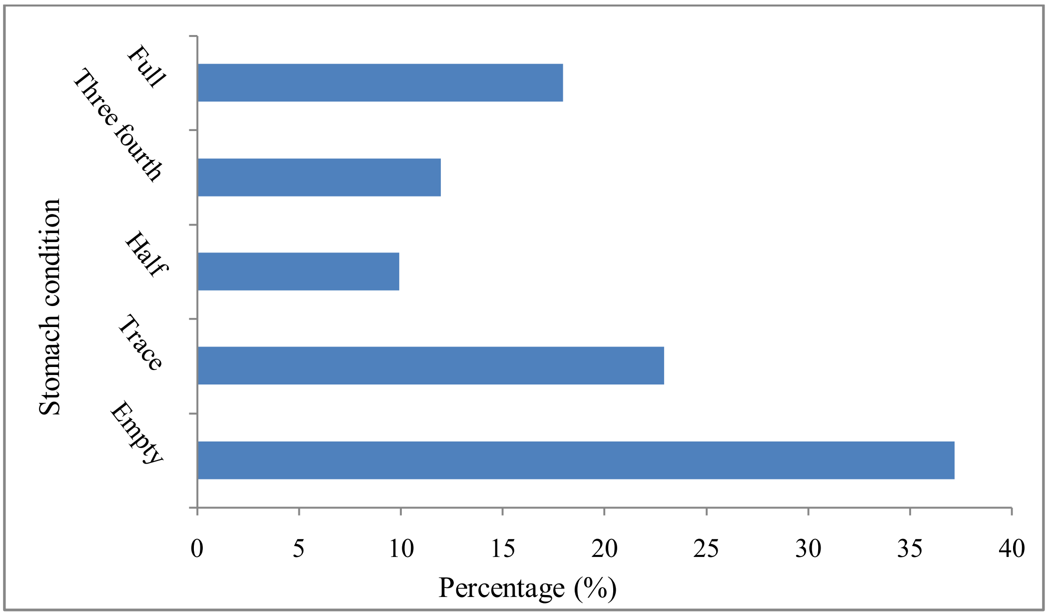


Figure 5.1.8. Percentage stomach condition of *Eridacnis radcliffei*

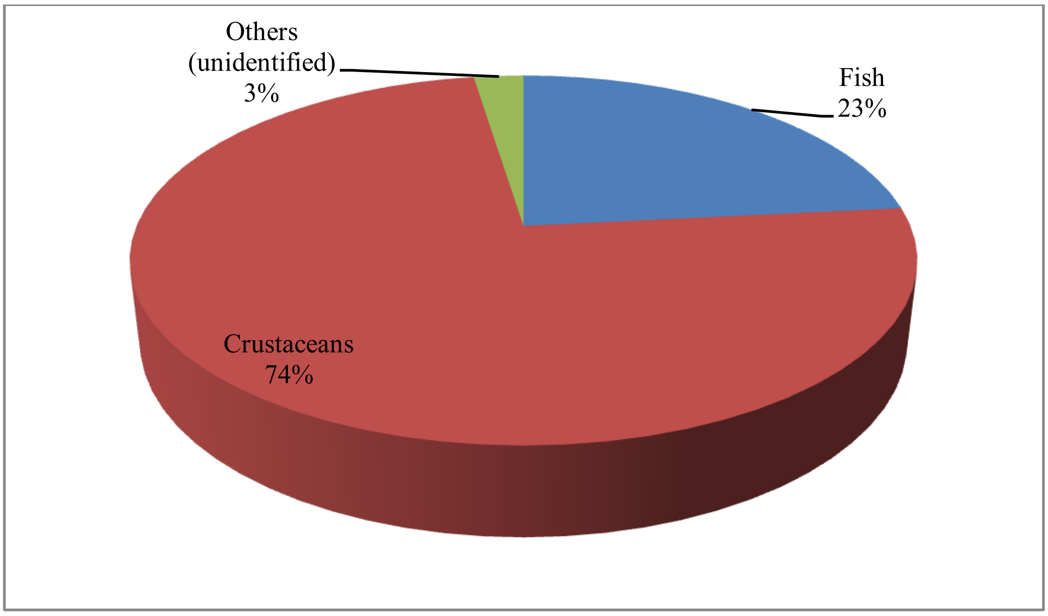


Figure 5.1.9. Index of Relative Importance (%IRI) of prey items in the stomach contents of *Eridacnis radcliffei*

5.2. Biology of bristly catshark, *Bythaelurus hispidus* (Alcock, 1891)

The bristly catshark *Bythaelurus hispidus* (Alcock, 1891) was described from the Andaman Sea and is restricted to Indian, Sri Lanka, the Andaman Islands and Thailand on the upper continental slopes at depths of 293 to 766 m (Compagno *et al.*, 2005 a). The IUCN Red List of Threatened Animals list the status of *B. hispidus* as “Data Deficient” due to the paucity of information on population sizes or trends and biological data (White, 2004).

Distributional records and/or basic taxonomic accounts of *B. hispidus* have been provided previously by Silas (1969) and Akhilesh *et al.* (2011 a) from the Kerala coast; Nair and Lal Mohan (1973) from the Gulf of Mannar; Talwar (1981) and Rajan *et al.* (2012) from the Andaman Sea. Nair and Appukuttan (1973) provided some basic information on the food and feeding of *B. hispidus* from the Gulf of Mannar. The present study provides new biological information on *B. hispidus* based on specimens collected from the bycatch of deep-sea shrimp trawl fisheries operating off south-west coast of India.

Materials

Specimens of *B. hispidus* were collected from the bycatch landings of the deep-sea shrimp trawl fishery, which operates on the Quilon bank area /Wadge bank area of the southern Indian EEZ at depths of 200–500 m, from September 2010 to February 2011 and additional data of January 2012 was also included to supplement sample size. *Bythaelurus hispidus* is a relatively rare component of this fishery which targets the deep-sea shrimp species *Plesionika quasigrandis* Chase 1985, Arabian red shrimp *Aristeus alcocki* Ramadan, 1938, rice velvet shrimp *Metapenaeopsis andamanensis* (Wood-Mason, 1891) and *Heterocarpus* spp. The major chondrichthyan bycatch of this fishery includes; bramble shark *Echinorhinus brucus* (Bonnaterre, 1788), *Iago* spp, *Squalus* spp, *Centrophorus* spp, pygmy ribbontail catshark *Eridacnis radcliffei* Smith, 1913 and sicklefin chimaera *Neoharriotta pinnata* (Schnakenbeck, 1931). Other bycatch species in the deep-sea shrimp fishery is provided in Table. 5. 1.1

Results

Bythaelurus hispidus is a relatively rare component of the deep-sea shrimp trawl fishery. A total of 162 individuals of *B. hispidus* were collected, comprising 99 females and 63 males, with 92 of these (63 females, 29 males) recorded in January 2011. Females were more abundant in landings than males with the overall sex ratio of females to males being 1.6:1 (Table.5.2.1).

Table 5.2.1. Sex ratio of *Bythaelurus hispidus*

	September	October	November	December	January	February
Female	4	8	10	8	63	6
Male	12	5	4	4	29	9
F/M ratio	0.33	1.60	2.50	2.00	2.17	0.67

Interestingly, Nair and Appukuttan (1973) reported a sex ratio of 0.5:1 females to males from the Gulf of Mannar based on 241 specimens. Further information on sex ratios of various populations of this species throughout its range would be required to determine any real trends in sexual segregation.

Females and males ranged from 120–366 and 135–311 mm TL, respectively, with the majority in the 280–300 mm and 310–340 mm TL length classes, respectively (Fig. 5.2.1). The number of small individuals (<230 mm TL) was low which probably reflects trawl selectivity due to mesh size. A similar situation was found for the pygmy ribbontail catshark *Eridacnis radcliffei* samples from the same fishery (Akhilesh *et al.*, 2012). The maximum size for females and males recorded in the present study, i.e. 366 and 311 mm TL respectively, are larger than previously reported for this species, i.e. 290 mm TL (Compagno *et al.*, 2005 a).

Length weight relation

A total of 134 individuals, consisting of 81 females (120–366 mm TL) and 53 males (135–311 mm TL) was used to generate accurate length-weight relationships for this species. The relationship between W and TL for combined sexes, females and males is expressed by the following equations and its scatterdiagram is provided (Fig. 5.2.2-5.2.4).

Length weight relation (pooled sexes): $W = 5.99 \times 10^{-7} \times TL^{3.25}$ ($r^2 = 0.98$)

Length weight relation (Females) : $W = 4.76 \times 10^{-7} \times TL^{3.30}$ ($r^2 = 0.98$)

Length weight relation (Males) : $W = 1.60 \times 10^{-6} \times TL^{3.07}$ ($r^2 = 0.98$)

Reproductive biology

In this study *Bythaelurus hispidus* was shown to be an aplacental viviparous (previously termed ovoviviparous) species whereby females give birth to live young from a thin egg case in uterus and there is no direct link between embryo and the mother via a uterine connection. This reproductive mode is similar to that of its congeners broadhead catshark *Bythaelurus clevai* Séret 1987 and mud catshark *Bythaelurus lutarius* (Springer and D'Aubrey, 1972) in having developing embryos enclosed in a very thin, fragile, membranous egg case *in utero* (Compagno *et al.*, 2005; Francis, 2006) (Plate 9).

Scyliorhinid catsharks are a large and diverse family with three reproductive modes displayed (Francis, 2006). The vast majority of scyliorhinids are oviparous with fertilised eggs inside a tough, leathery egg case which is deposited onto a suitable substratum and the embryo develops and then hatches directly into the external environment (Compagno, 1988, 1990). There are two different modes of oviparity within scyliorhinid catsharks, single oviparity and multiple (retained) oviparity, with the majority of species displaying single oviparity (Compagno, 1988; Francis, 2006). For example, the draughtboard shark *Cephaloscyllium laticeps* off southeastern Australia deposits eggs in pairs throughout the year immediately following fertilisation and encapsulation with embryos hatching 11–12 months later (Awruch *et al.*, 2009). In contrast, the Indonesian speckled catshark *Halaelurus maculosus* from southern Indonesia displays multiple (retained) oviparity with females found to retain egg cases *in utero* (3 or 6 per uterus) for at least the early to mid stages of embryo development (White, 2007).

The third reproductive mode, aplacental viviparity, is displayed by only a small number of scyliorhinid catsharks. *Bythaelurus hispidus*, *B. clevai* and *B. lutarius* share this mode by possessing membranous egg cases only (Compagno *et al.*, 2005 a). While Compagno *et al*. (2005 a) states that the New Zealand catshark *Bythaelurus dawsoni* (Springer 1971) displays aplacental viviparity, Francis (2006) found that the reproductive mode of this species (as *Halaelurus dawsoni*) was actually oviparous, as with dusky catshark *Bythaelurus canescens*. While no multiple oviparous species of *Bythaelurus* have been recorded, the reproductive mode of several species is still not known. A review of known reproductive modes in scyliorhinids were provided by Akhilesh *et al.* (2013 c)

All 38 pregnant females, observed in January 2011, contained either one embryo or one fertilised egg in each uterus. Mature females with developing oocytes (0.6–30 mm diameter) were observed in the functional ovary of females greater than

241 mm TL and the smallest female containing maturing oocytes was 232 mm TL. The L_{50} (95% CI) of females at maturity was estimated at 252 (236–259) mm TL (Fig. 5.2.5), larger than that previously suggested by Compagno *et al.* (2005), i.e. 220–240 mm TL. In the present study it was not possible to ascertain any seasonality in the reproductive cycle for this species. Ovarian fecundity for females was 2–4, but uterine fecundity was always 2 (1 per uterus). The embryos recorded ranged in size from 40–122 mm TL. Late-term embryos (>100 mm TL) had fully absorbed all yolk in the yolk sac and either had a small yolk-sac stalk still attached or a scar where it was located. Since the smallest free-swimming individual was 120 mm TL, size at birth in this species is at approximately 120 mm TL. The largest free-swimming individual possessing an umbilical scar was 132 mm TL. The smallest individuals reported by Nair and Lal Mohan (1973) were of 121 mm TL.

In the case of males, all maturity stages of *B. hispidus* were represented and the majority of the total number collected (76%, n = 48) were <240 mm TL. The smallest mature male recorded was 228 mm TL, while the largest immature male was 265 mm TL. The vast majority of males >225 mm TL possessed fully calcified claspers, while most between 200–230 mm TL possessed partially calcified claspers. Although the length at maturity in males of this species is thus most likely between 240 and 250 mm TL, the number of specimens in the critical size classes between maturing and mature stages were low. The Lm of males at maturity was 235 (223–245) mm TL (Fig. 5.2.6). Springer and D’Aubrey (1972) reported that three males of *B. hispidus* between 240 and 260 mm TL were mature.

Food and feeding

Stomachs of 121 individuals were examined, with 24% being empty, 18% with trace contents only, 15% half full, 21% three quarters full and 22% full (Fig. 5.2.7). The analysis of stomach contents (% IRI) revealed *B. hispidus* feeds primarily on fishes (52%). The majority of fish prey could not be identified to a narrower taxonomic unit than unidentified teleost (40%), followed by *Bregmaceros* sp. (10.28%) and Myctophidae (1.24%) (Table 5.2.2, Fig.5.2.8).

The next most abundant prey group was crustaceans (37%) comprising mostly *Aristeus* spp, *Plesionika* spp; and gastropods (1%). Muddy sediments were observed in 18 of the stomachs examined. Acuna and Villarroel (2010) reported a variety of items as prey of *B. canescens* and observed mud in the stomach contents.

Present results are similar to Nair and Appukuttan (1973) who reported that 60.5% of *B. hispidus* diet (%V) was composed of bony fishes followed by crustaceans (16.1%), squid (17.5%) and mud (5.6%) from specimens studied off the Gulf of Mannar. In that study, a variety of prey items were recorded, including the teleosts *Myctophum* sp, *Gonostoma* sp., and various eels; and the invertebrates deep-sea mud shrimp *Solenocera hextii*, stomatopod larvae, gastropods and algae. Furthermore, Appukuttan and Nair (1988) reported fishes, crustaceans and squids as prey items of *B. hispidus*, with juveniles preferring crustaceans. The present study provides new and detailed biological information on a poorly known deep-sea shark from southwest coast of India.

Table 5. 2.2. Percentage contribution by number (% N), mass (% M), occurrence (% O) as well as the Index of Relative Importance (% IRI) of prey items in the stomach contents of *Bythaelurus hispidus* from southwest coast of India

	Prey item	%N	%W	%O	%IRI
Crustacea					
Aristeidae					
	Aristeus sp.	14.3	4.3	14.1	11.1
Pandalidae					
	Plesionika sp.	7.1	4.3	3.3	1.6
Sergestidae					
	Acetes sp.	10.7	5.0	2.2	1.4
Others					
	Unidentified shrimps	9.8	11.5	7.6	6.9
	Unidentified crabs	11.6	15.8	14.1	16.4
Teleostei					
Myctophidae					
	Diaphus sp.	2.7	10.8	2.2	1.2
Bregmaceratidae					
	Bregmaceros sp.	10.7	17.3	8.7	10.3
Others					
	Unidentified telesotei	16.1	18.7	27.2	39.9
	(Fish scales, completely digested, unidentified)	10.7	7.2	13.0	9.9
	Fish larvae	0.9	2.2	1.1	0.1
Mollusca					
Gastropoda		5.4	2.9	3.3	1.1

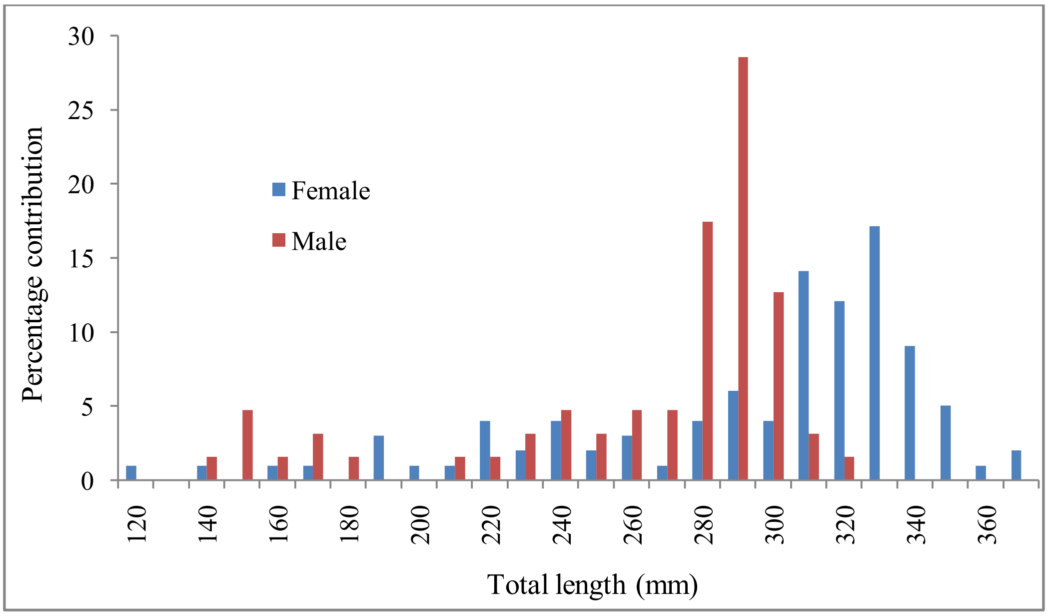


Figure 5.2.1. Percentage contribution of males and females in 20 mm size class for *Bythaelurus hispidus*

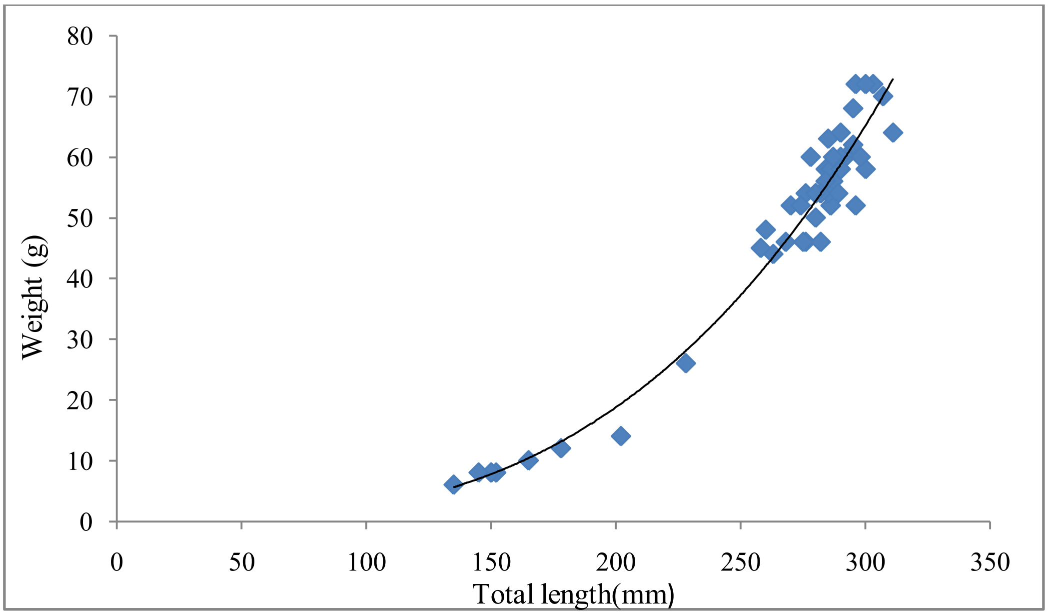


Figure 5.2.2. Length weight relation for males of *Bythaelurus hispidus* (W= 1.60 x 10-6 x TL $^{3.07}$)

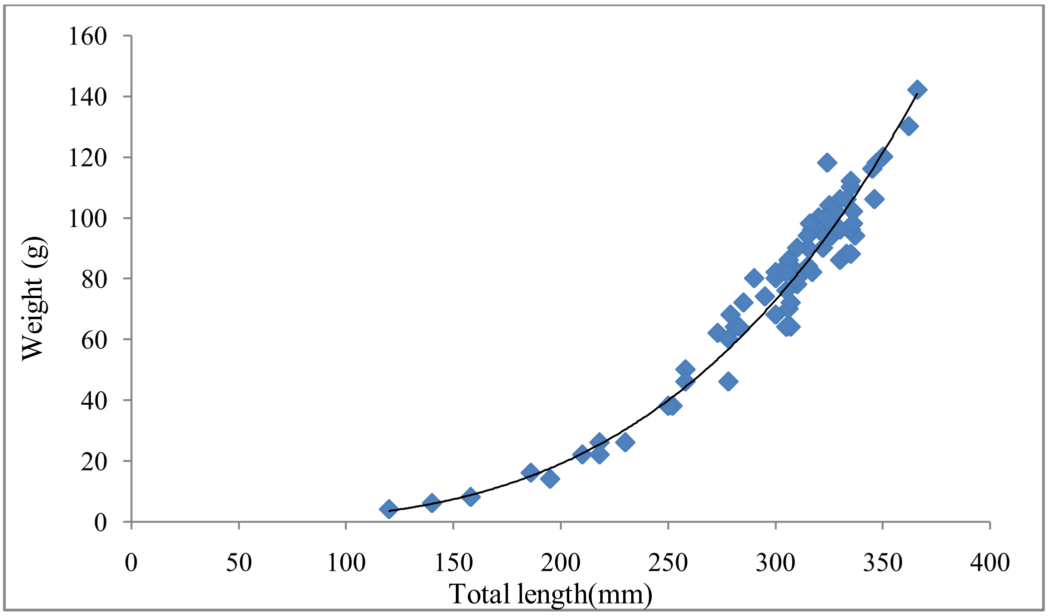


Figure5.2.3. Length weight relation for females of *Bythaelurus hispidus*

(W = 4.76 x 10-7 x TL $^{3.30}$)

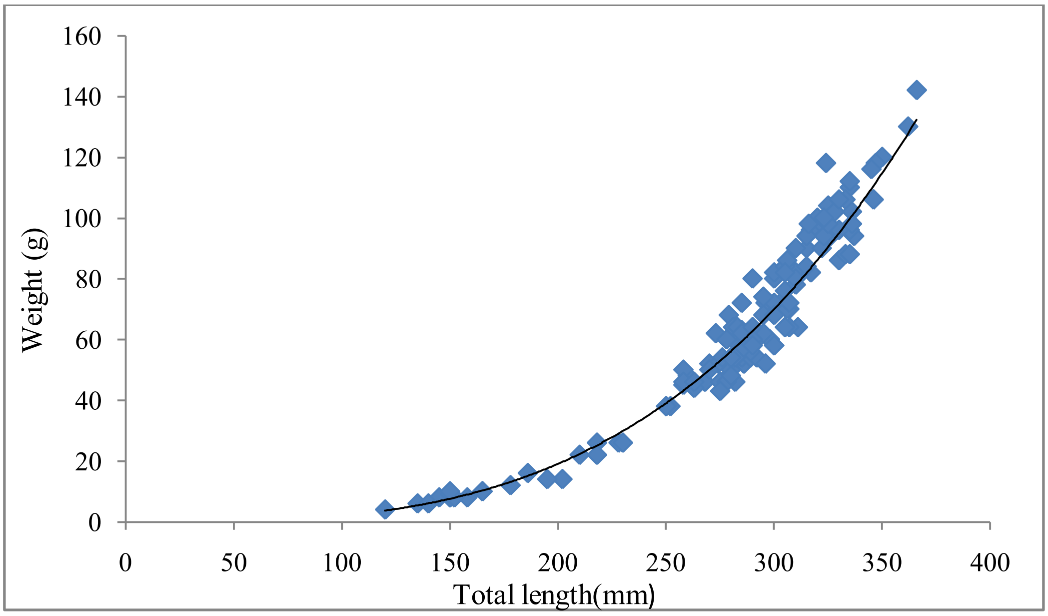


Figure 5.2.4. Length weight relation for combined sexes of *Bythaelurus hispidus* (W= 5.99 x 10-7 x TL $^{3.25}$)

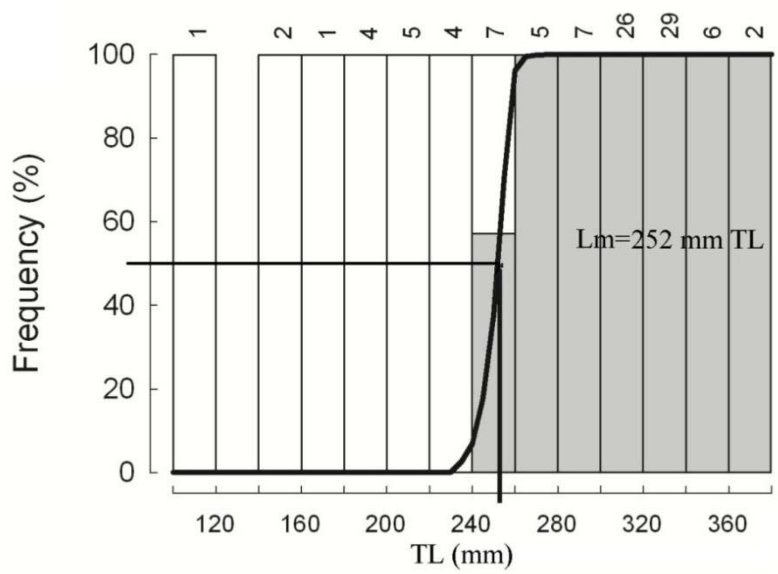


Figure 5.2.5. Length at first maturity (L_m) for *Bythaelurus hispidus* females (Lm=252mm TL)

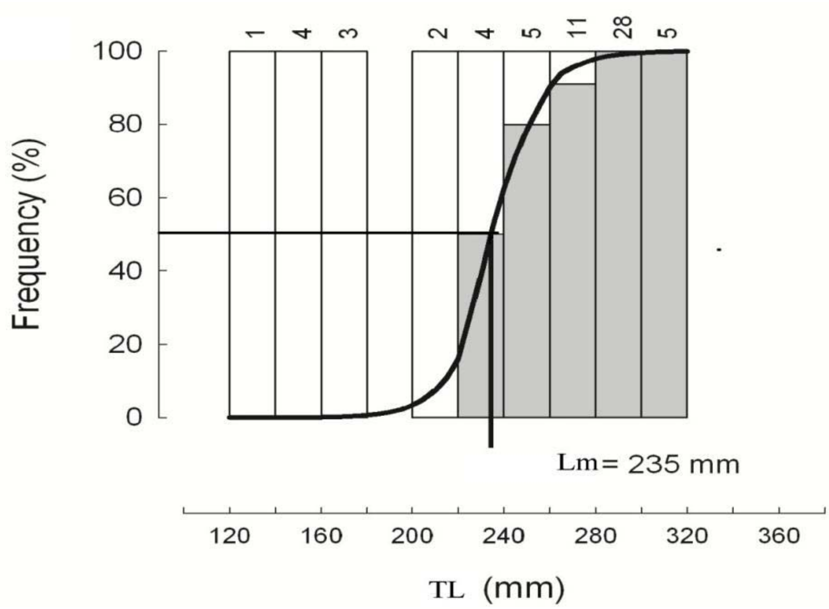


Figure 5.2.6. Length at first maturity (L_m) for *Bythaelurus hispidus* male (Lm=235 mm TL)

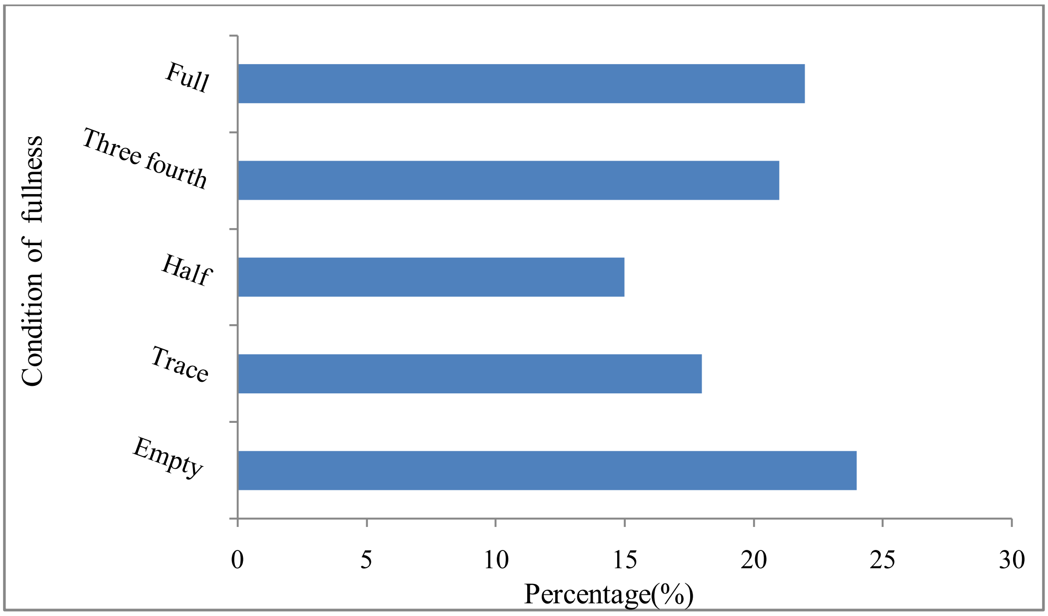


Figure 5.2.7. Index of Stomach Fullness (%) of prey items in the gut of *Bythaelurus hispidus*

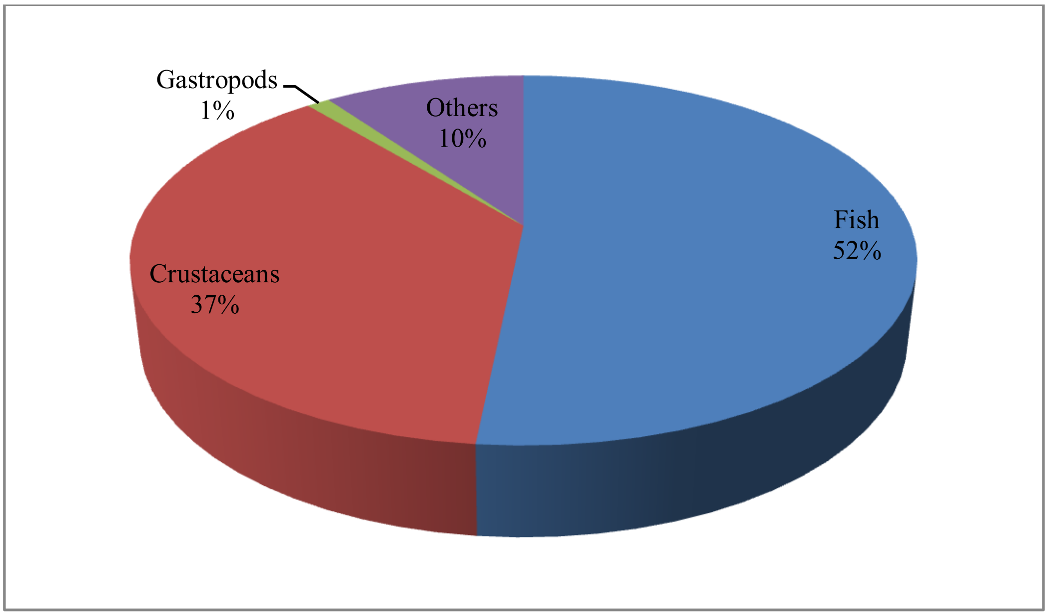


Figure 5.2.8. Index of Relative Importance (%IRI) of prey items in the gut of *Bythaelurus hispidus*

5.3. Biology of bramble shark *Echinorhinus brucus* (Bonnaterre, 1788)

The deep-water shark genus *Echinorhinus* Blainville (Squaliformes: Echinorhinidae) consists of two species, the bramble shark *Echinorhinus brucus* (Bonnaterre, 1788) with a patchy, almost circumglobal distribution, and the prickly shark *E. cookie* Pietschmann, 1928 with a scattered distribution in the Pacific Ocean (Last and Stevens, 2009). *Echinorhinus brucus* was originally described as *Squalus brucus* by Bonnaterre (1788) from North Atlantic. It is a large species, attaining at least 326 cm TL and occurs on or near the bottom of continental shelves and slopes at depths of 200–900 m depths (Caille and Olsen, 2000; Compagno *et al.*, 2005 a).

Studies on fishery, biology and distributional data on *E. brucus* is largely limited to single records and observations. The IUCN Red List of Threatened Animals has assessed the status of *E. brucus* as Data Deficient (Paul, 2003) due to paucity of available information available and the sporadic nature of distributional records.

Silas (1969) and Silas *et al.* (1969) (n=1), based on the exploratory survey of *R/V Varuna* in 1968, and Nair and Lal Mohan (1971) (n=1) provided the first reliable records of *E. brucus* from Indian continental slope waters. Incidental catches of few specimens of *E. brucus* in Indian waters have since been recorded by Nair and Thulasidas (1984) (n=2), Appukuttan and Nair (1988) (n=1), Joel and Ebenzer (1991) (n=2), Balasubramanian *et al*. (1993)(n=18), Manojkumar *et al*. (2002)(n=1), Patel *et al.* (2005), Joshi *et al.* (2008) (n=18, study was in 2000-2002). considerable landings of *E. brucus* from deep-water commercial fisheries have also been recorded in Indian waters of late (Vivekanandan and Sivaraj, 2008; Akhilesh *et al.*, 2011).

Although currently there is no targeted fishery for *E. brucus* in Indian waters, it is one of the most common sharks present in the bycatch of the bottom longline and bottom set gillnet fisheries that target gulper sharks (*Centrophorus* spp) and is also landed as bycatch of the deep-sea shrimp trawls (DSST) in the southwest and southeastern coasts of India. Deep-water sharks are amongst the most poorly studied chondrichthyans and published biological data on *E. brucus* is extremely sparse. The present study provides new information on the biology of *E. brucus* based on observations at Kochi (Kerala) a major elasmobranch landing centre in the west coast of India. Understanding biological characteristics of chondrichthyes are important in creating management plans, especially when it's a major portion of bycatch.

Materials

Weekly surveys at the Cochin Fisheries Harbour (CFH), Kerala (Fig. 4.1) in southwest coast of India were conducted during 2008 and 2011 to determine the species and size composition of the chondrichthyan landings. *Echinorhinus brucus* were observed in the landings of the deep-sea shrimp trawl (DSST) fishery (operating at 200–500 m depth), and bottom set gillnet and longline fisheries (operating in 250–1200 m depth) along the southwest coast of India.

Results

Sex and size composition of the landings

More than 5282 individuals were observed and 5282 no of *E. brucus* were individually recorded at Kochi between 2008 and 2011, 3916 were females, 1366 were male. Thus, the overall sex ratio (females to males) of the landings was 3.83: 1. Although females were far more abundant in the landings in most months, the sex ratio varied considerably in the months surveyed e.g. 19.3:1 in December 2009 and

0.6:1 in September 2009 period. Percentage contribution of males and females to monthly landing is provided (Fig. 5.3.1-5.3.5)

Females and males ranged from 46–318 and 51–300 cm TL, respectively. The monthly length frequency distributions (pooled years) did not show any clear trends (Fig. 5.3.6). In all months, landings were represented by a wide size range of individuals.

Length weight relationship

A total of 184 individuals (48–254 cm TL) was used to generate the length-weight relationship for this species as given below (Figure 5.3.7-5.3.9).

Length weight relation (Males) : $W= 1.84 \times 10^{-6} \times TL^{3.22}$ ($r^2 = 0.98$)

Length weight relation (Females) : $W=3.3 \times 10^{-6} \times TL^{3.14}$ ($r^2 = 0.98$)

Length weight relation (Pooled) : $W = 1.82 \times 10^{-6} \times TL^{3.23}$ ($r^2 = 0.98$)

Reproductive biology

The higher ratio of females to males recorded from the landings (3.8:1) suggests sexual segregation in this species. Unequal sex ratios can be the result of sexual segregation by depth, area or gear selectivity. Since *E. brucus* females and males attain similar sizes, gear selectivity is not likely a contributing factor. Bathymetric segregation or segregation by area are the more likely causes for the far larger number of females than males in the landings. Yano and Tanaka (1988) and Wetherbee (1996) have provided evidence for sexual segregation in deep-water sharks in their habitat. Clarke *et al.* (2001) found that females and males of the leafscale gulper shark *Centrophorus squamosus* in the west of Ireland and Scotland are segregated by sexes and maturity stage at different depths. Bañón *et al.* (2006) found that males of *C. squamosus* were more than females off northwestern Spain, compared to off the western British Isles where more females were recorded than males. More detailed information on the catches of *E. brucus* from corresponding bathymetric zones is required to better understand the segregation of this species in Indian waters.

As with other squaliform sharks, *Echinorhinus brucus* is an aplacental viviparous (previously termed ovoviviparous) species whereby females give birth to live young and there is no direct connection between embryo and the mother, e.g. via a placenta. The developing embryo obtains all of its nutrients from an external yolk sac with birth occurring soon after the yolk is completely absorbed.

Ovarian and uterine fecundity of *E. brucus* in this study, based on 80 pregnant females, was 12–38 and 10–36, respectively. The number of embryos or *in utero* eggs varied considerably between specimens of different sizes. Previously published records of pregnant females of *E. brucus* are very sparse. Cadenat and Blanche (1981) reported 15 embryos from a 228 cm TL pregnant female off the Ivory Coast. Bass *et al*. (1976) reported 24 embryos, average 16.5 cm TL, from a 213 cm TL pregnant female off southern Africa. Joel and Ebenzer (1991) reported 52 embryos from a 262 cm TL female from off Thoothoor in India, which ranged in size from 36 to 54 cm TL, and Balasubramanian *et al.* (1993) reported 40 embryos in a 272 cm TL female from off Tuticorin, India. Appukkutan and Nair (1988) reported on a mature female of 181 cm TL containing 17 large yolked oocytes (39–70 mm diameter) from the Gulf of Mannar. Thus, the litter size of *E. brucus* is 10–52 embryos. Based on the largest recorded embryo size (42 cm TL) and the smallest free-swimming individual recorded in the present study (46 cm TL), the size at birth of *E. brucus* is 42–46 cm TL. This is similar to the birth size of 40–50 cm TL suggested by Compagno *et al.* (2005) for this species.

A total of 431 individuals (256 females and 175 males) of *E. brucus* were used for biological studies. In this study, females and males of *E. brucus* were found to mature at similar sizes with L_m of 189 TL and 187 cm TL, respectively. This contrasts with Barrul and Mate (1996) who reported that sexual maturity in *E. brucus* occurs between 213 and 231 cm in females and 150 and 174 cm in males. However, this was likely to be based on only small samples sizes. Compagno *et al.* (2005 a) suggested that females probably mature at 200–220 cm TL and males at <150 cm TL. Henderson *et al.* (2007) reported two females of 182 cm TL caught off Oman were mature and Appukkutan and Nair (1988) reported a mature female 187.5 cm TL off India. It appears that the size of males at maturity is larger than previously suggested, possibly due to the assumption that males attain a far smaller maximum size than females as is the case for many other squaliform sharks or could be due to difference in criteria used for assessing maturity. The estimates of maturity found in this study are considered more accurate than previously documented due to the far larger sample size. Although size at maturity can vary regionally, evidently very low sample sizes can only provide very rough estimates of maturity. Mature females, with ovaries containing large oocytes (20–60 mm diameter), ranged from 168–254 cm TL. The smallest female with mature oocytes was 170 cm TL and the largest immature female was 220 cm TL. Mature females were observed in all months of the year. The Lm of females at maturity was estimated at 189 (181–191) cm TL (Fig.5.3.10). A total of 80 pregnant females were observed in the present study, with uterine fecundity ranging from 10–36. During the present study gravid females or with developing/ mature oocytes and embryos were observed in all months which could suggests a, non-seasonal reproductive cycle. Late-term embryos, ranging in size from 35–42 cm TL, had yolk sacs fully absorbed with either the yolk-sac stalk still attached or with a scar where it was located. Late-term embryos lacked enlarged thorns (enlarged denticles), but small free-swimming pups possessed small to medium-sized thorns (Fig. 5.3.7). Thus, the thorns must develop rapidly following parturition. The smallest free-swimming individual was 46 cm TL, and the largest free-swimming individual with an umbilical scar was 62 cm TL.

All maturity stages of male, *E. brucus* were represented. The smallest mature male recorded was 172 cm TL, while the largest immature male was 198 cm TL. The vast majority of males larger than 190 cm TL possessed fully calcified claspers, while most between 150–180 cm TL possessed partially calcified claspers. The Length of males at maturity (Lm) was estimated at 187 (184–191) cm TL (Fig. 5.3.11)

Food and feeding

The majority of stomachs examined were empty or containing only highly digested food which could not be identified. Since *E. brucus* is a low value component of the harvest and the cost of ice is high, they are mostly not iced (used for salting and drying) and those landed are generally in poor condition with the stomach contents are highly decomposed. Of the 431 stomachs examined, only 113 (26%) specimens were observed with gut contents while 318 (74%) were empty. Of those containing food, 15% contained trace contents only, 26% were a quarter full, 22% were half full, 37% were three quarters full and no stomachs were full (Fig.5.3.12). The analysis of stomach contents (% IRI) revealed that *E. brucus* feeds primarily on crustaceans (69%), followed by teleosts (26%), e.g. *Hoplostethus* spp., *Gephyroberyx* spp. and

Saurida spp. (Table 5.3.1, Fig.5.3.13). Smaller sharks fed exclusively on crustaceans. Dietary items such as tuna, carangids and sardine observed in the gut were possibly are the baits used in longlines.

The prey of *Echinorhinus brucus* based on the 113 stomachs which contained food was quite diverse with crustaceans, cephalopods, teleosts and elasmobranchs are recorded as prey items. Not surprisingly the diet consisted of numerous deep-water teleost and crustacean species which were present in the catches of the deep-water shrimp trawl fisheries. Similar feeding habits were found in other deep-sea sharks occupying similar habitat (Jakobsdottir, 2001). Silas and Selvaraj (1972) reported Indian lizardfish *Synodus indicus* (Day, 1873) and the schilbeid *Clupisoma* sp. in the stomach contents. The latter report is interesting in that assuming identifications of the teleosts were accurate, the lizardfish mentioned in Silas and Selvaraj (1972) being a typically a shallow coastal dweller while *Clupisoma* are freshwater/brackish species suggest this particular individual was likely well inshore or in estuarine waters, but this cannot be ascertained. Appukkutan and Nair (1988) have reported half digested deep-sea fishes in the stomach of a mature female individual.

The present study provides the first detailed account on the biology of *Echinorhinus brucus* and provides details of the significant bycatch of this species from deep-water fisheries operating off the southwest coast of India at depths of 250–1200 m. This species was landed throughout the year suggesting that relatively large population of *E. brucus* occurs in this region and is subject to considerable fishing pressure. However, given the presumed low turnover rates of this species and evidence of population depletions for many deep-sea species in other parts of world, the large volume of catches of this species in Indian coast is of particular concern. It is desirable to ensure sustainability through self-regulation by fishermen regarding mesh size, closed season during heavy bycatch and spawning season etc. Indian elasmobranch fisheries are one of the largest in the world, but are currently not well managed or monitored with supporting biological data and rapid declines in the stock may likely to occur in the future if proper management strategies are not developed soon.

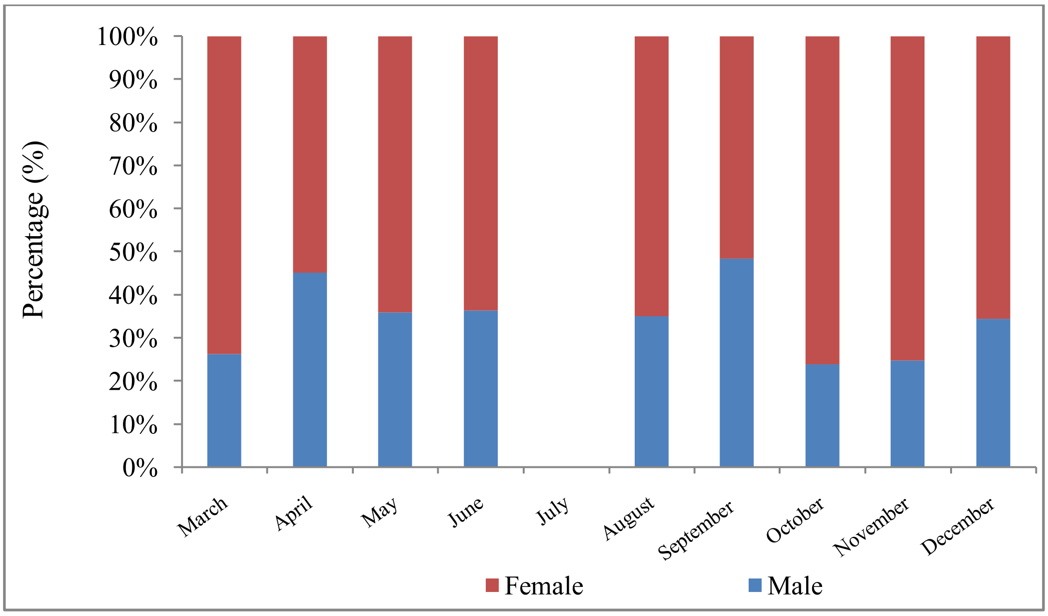


Figure 5.3.1. Monthly percentage contribution of males and females for *Echinorhinus brucus* in 2008.

Table 5.3.1. Percentage contribution by number (% N), mass (% M), occurrence (% O) as well as the Index of Relative Importance (% IRI) of prey items in the stomach contents of *Echinorhinus brucus* from southwest coast of India

	Prey items	%N	%W	%O	%IRI
Crustacea	-Portunidae				
	Charybdis sp.	4.7	0.4	7.1	2.4
	Aristeidae				
	Aristeus sp	4.7	1.3	11.5	4.6
	Pandalidae				
	Heterocarpus sp	2.4	0.6	5.3	1.0
	Plesionika sp.	13.2	4.8	2.7	3.1
	Penaeidae				
	Metapenaeus sp	1.5	0.3	0.9	0.1
	Oplophoridae				
	Oplophorus sp	3.2	0.6	3.5	0.9
	Squillidae				
	Squilla sp.	1.8	0.7	1.8	0.3
	Other				
	Unidentified shrimp	36.8	7.5	18.6	54.0
	Unidentified crab	3.8	1.4	8.0	2.7
Mollusca	Cephalopoda				
	Unidentified squid	2.6	1.8	2.7	0.8
	Unidentified octopus	3.2	5.0	1.8	1.0
Elasmobranchii					
	Unidentified shark	0.9	4.8	1.8	0.7
Teleostei	Clupeidae				
	Unidentified clupeid*	1.2	2.4	3.5	0.8
	Synodontidae				
	Saurida spp	4.1	8.1	2.7	2.1
	Priacanthidae				
	Priacanthus sp.	2.1	9.8	4.4	3.4
	Trachichthyidae				
	Gephyroberyx darwini	2.6	22.4	3.5	5.8
	Hoplostethus sp.	3.2	13.7	6.2	6.9
	Carangidae				
	Unidentified carangid*	2.6	10.7	6.2	5.4
	Scombridae				
	Unidentified scombrid*	1.8	3.6	3.5	1.2
Other					
	(Fishscales, completely digested, unidentified)	3.5	0.4	10.6	2.7

*most likely bait from long lines

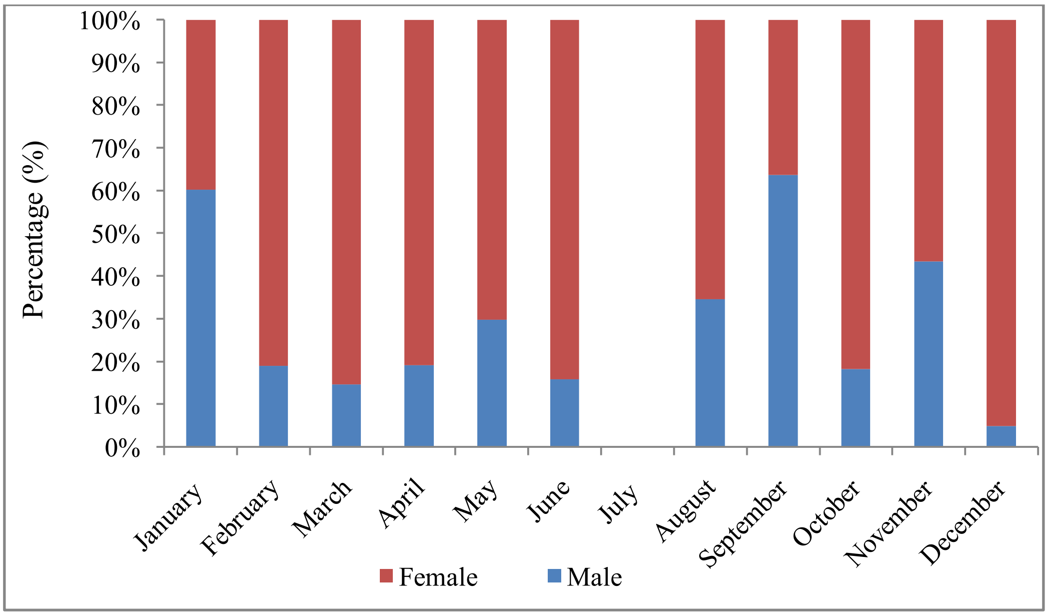


Figure 5.3.2. Monthly percentage contribution of males and females for *Echinorhinus brucus* in 2009.

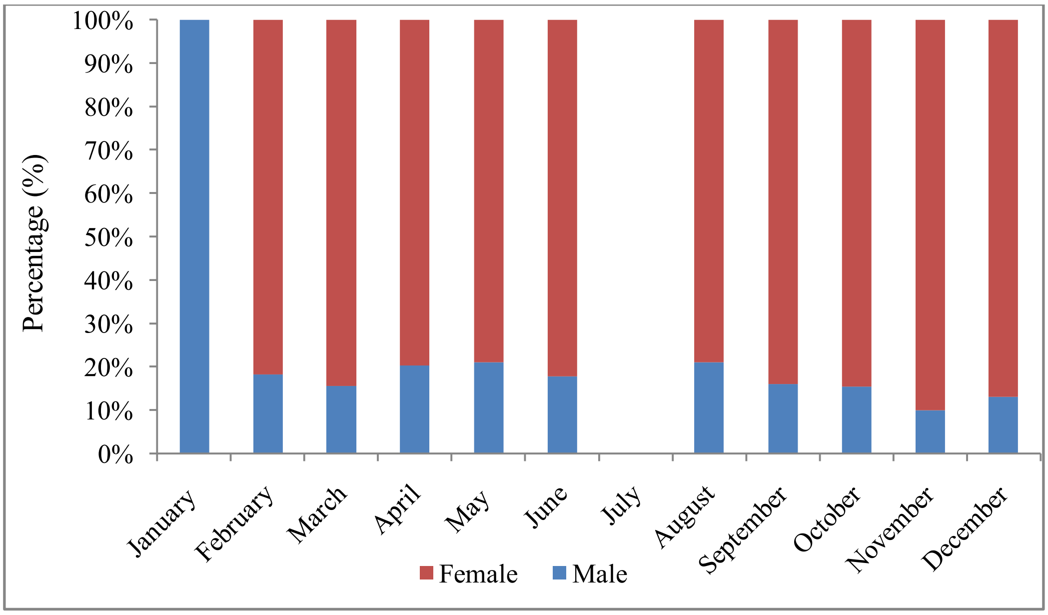


Figure 5.3.3. Monthly percentage contribution of males and females for *Echinorhinus brucus* in 2010.

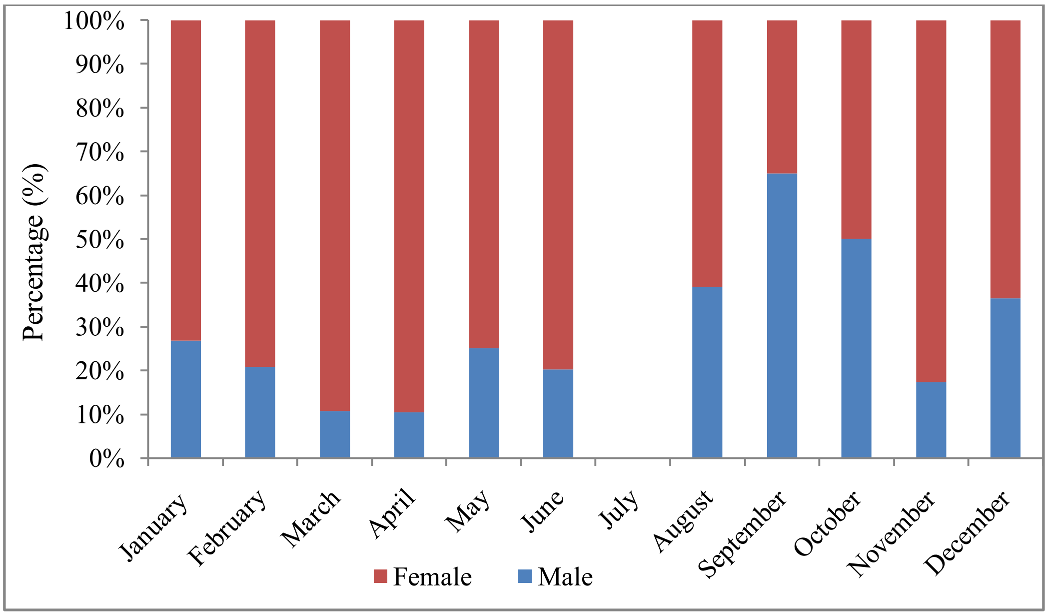


Figure 5.3.4. Monthly percentage contribution of males and females for *Echinorhinus brucus* in 2011.

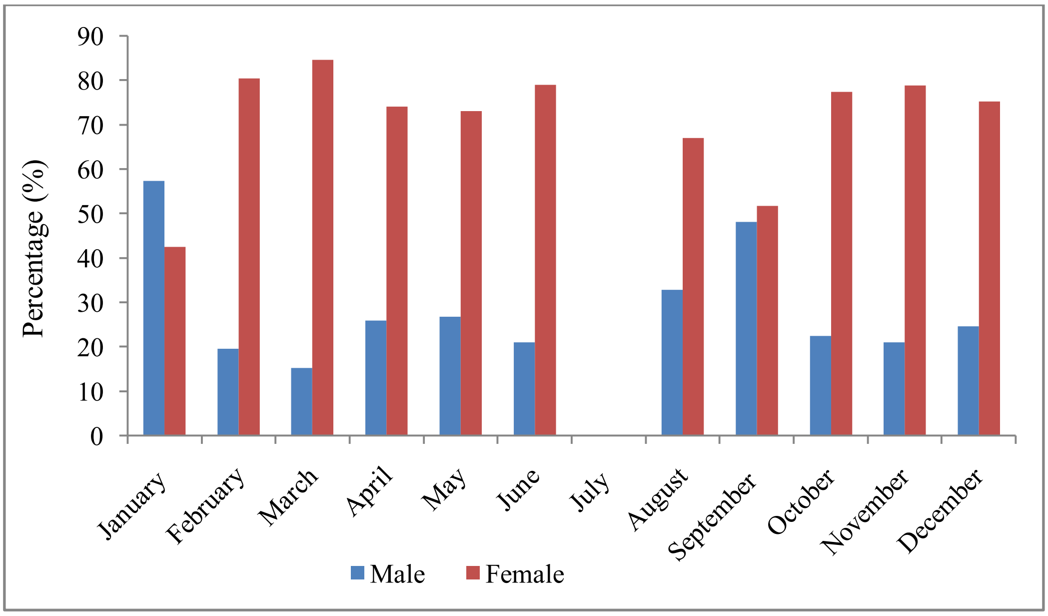


Figure 5.3.5. Monthly percentage contribution of males and females of *Echinorhinus brucus* during study period (pooled for 2008-2011).

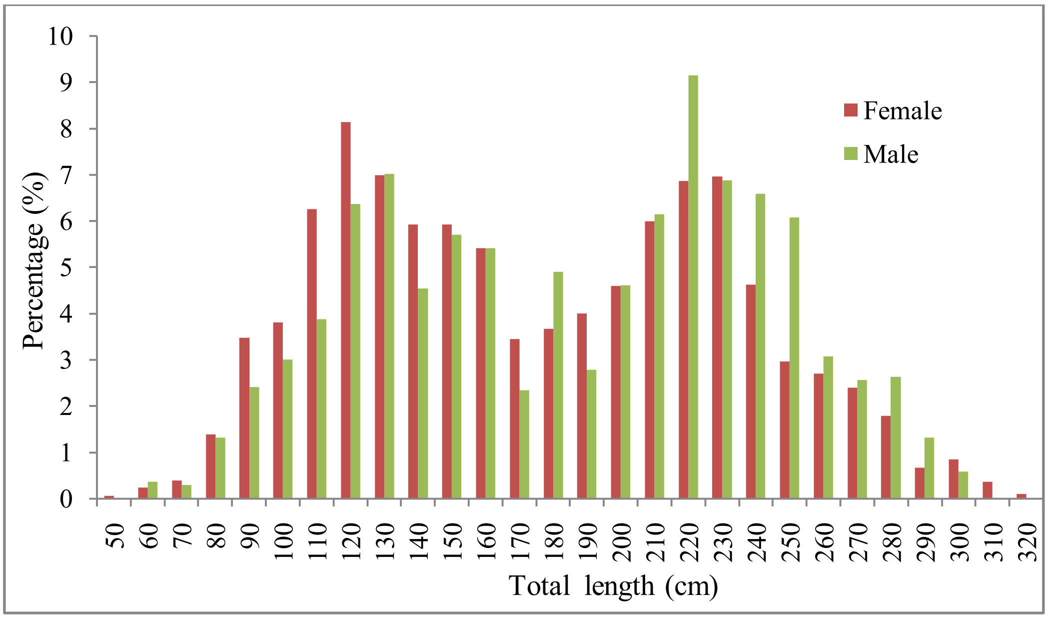


Figure 5.3.6. Percentage contribution of males and females of *Echinorhinus brucus* in 10 cm TL size class during study period.

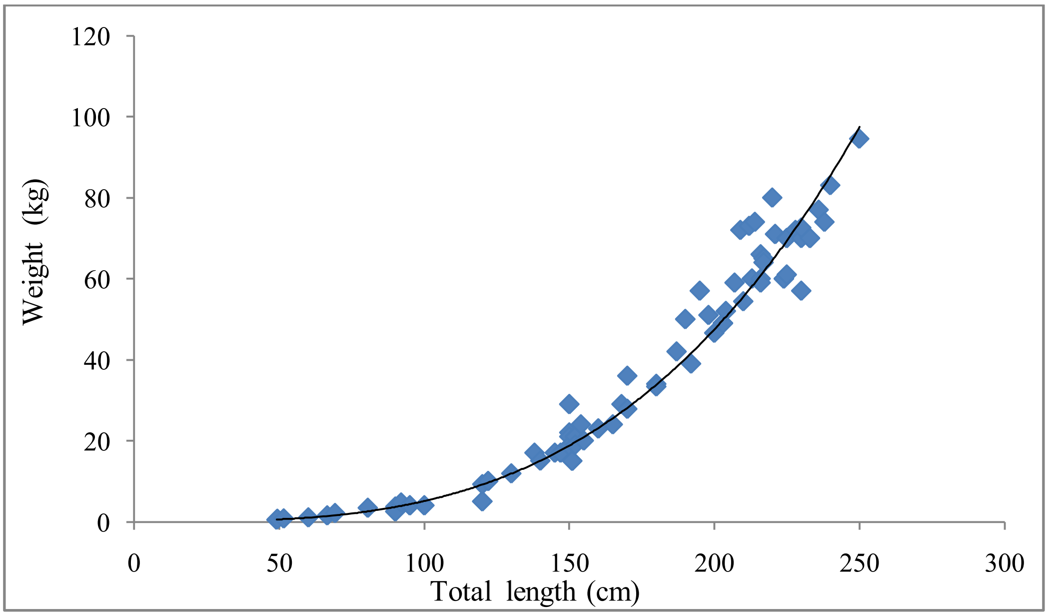


Figure 5.3.7. Length weight relation for males *Echinorhinus brucus* ($W= 3.3 \times 10^{-6} \times TL^{3.14}$)

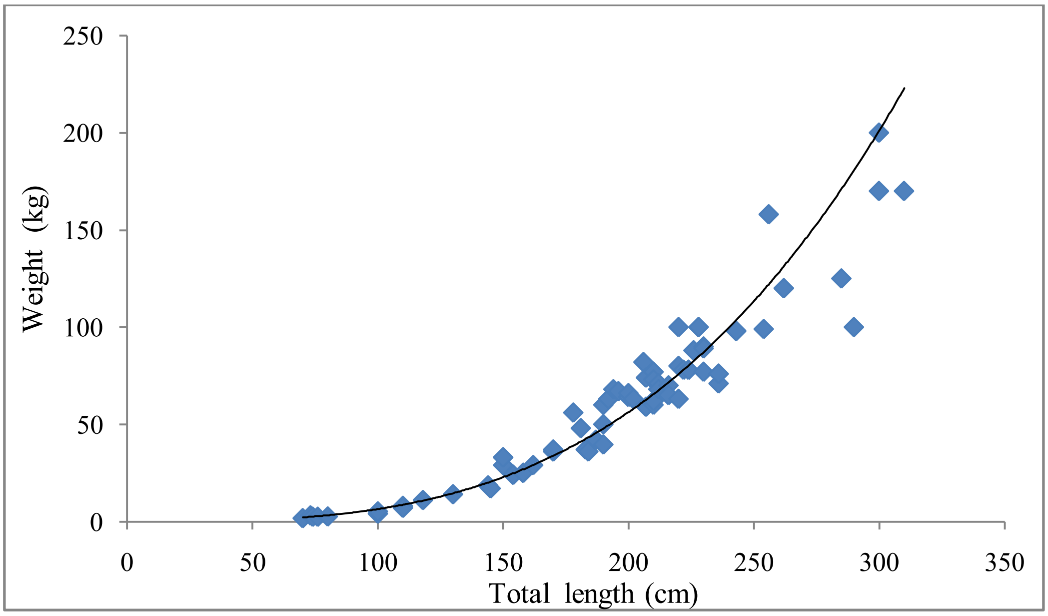


Figure 5.3.8. Length weight relation for females of *Echinorhinus brucus*

(W= 1.84 x 10^{-6} x TL $^{3.22}$)

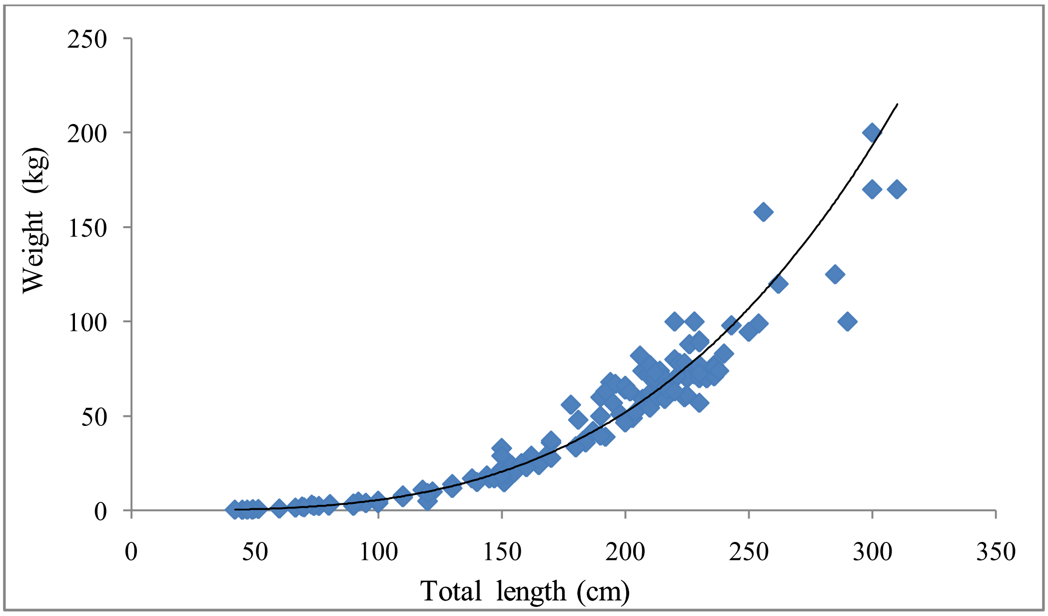


Figure 5.3.9. Length weight relation for pooled sexes of *Echinorhinus brucus*

(W=1.82 x 10^{-6} x TL $^{3.23}$)

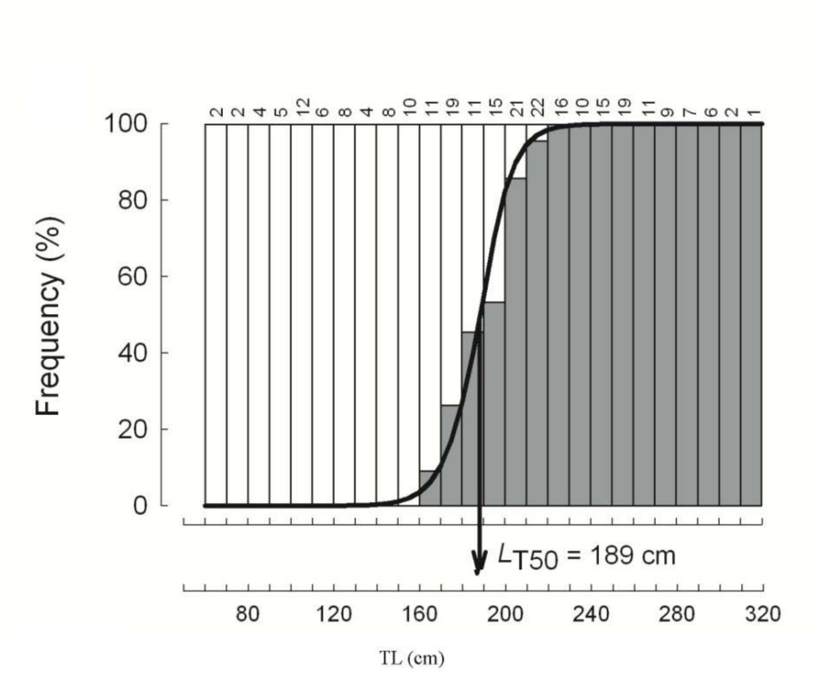


Figure 5.3.10. Length at first maturity for *Echinorhinus brucus* females (Lm=189 cm TL)

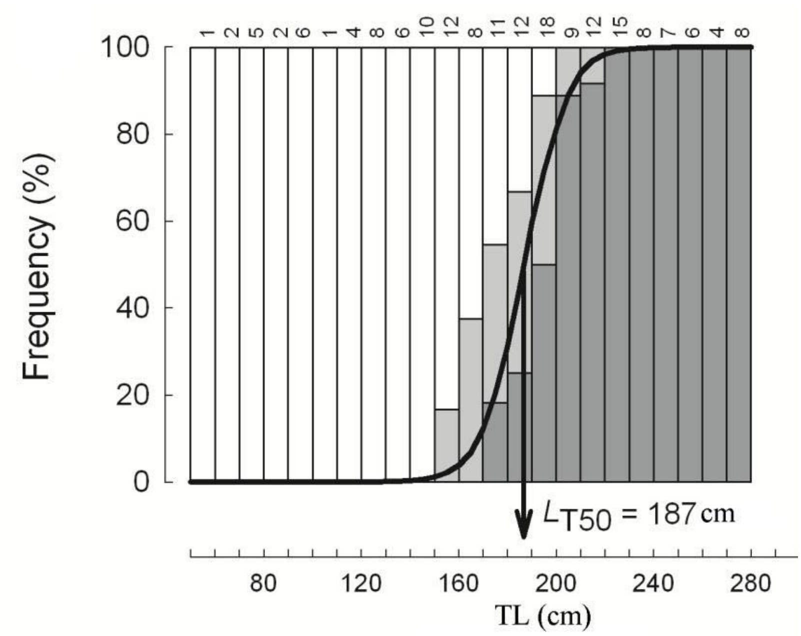


Figure 5.3.11. Length at first maturity for *Echinorhinus brucus* males (Lm=187 cm TL)

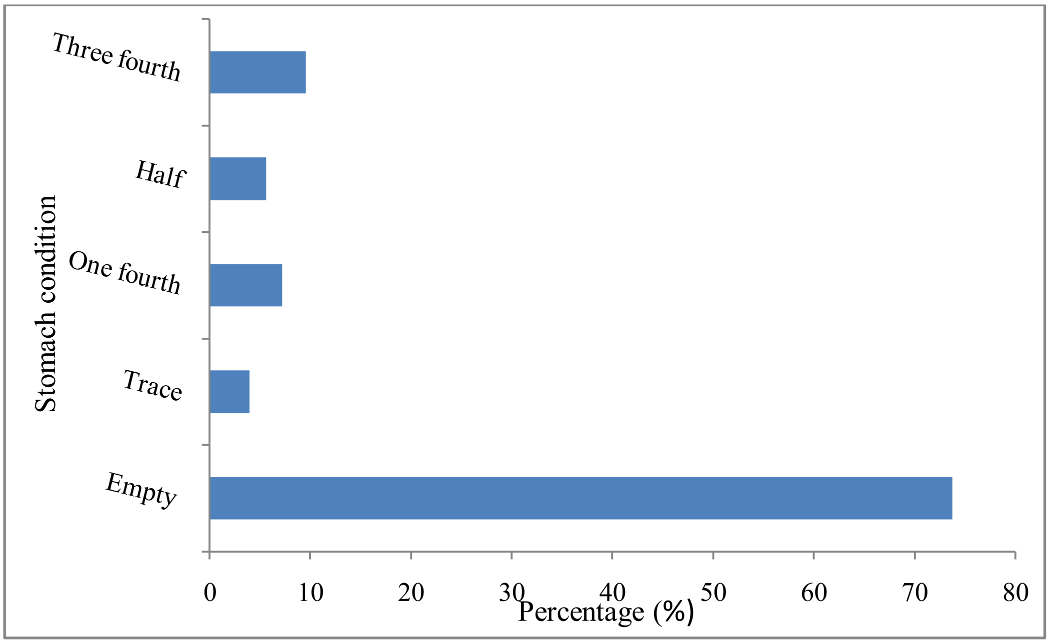


Figure 5.3.12. Percentage stomach conditin of *Echinorhinus brucus*

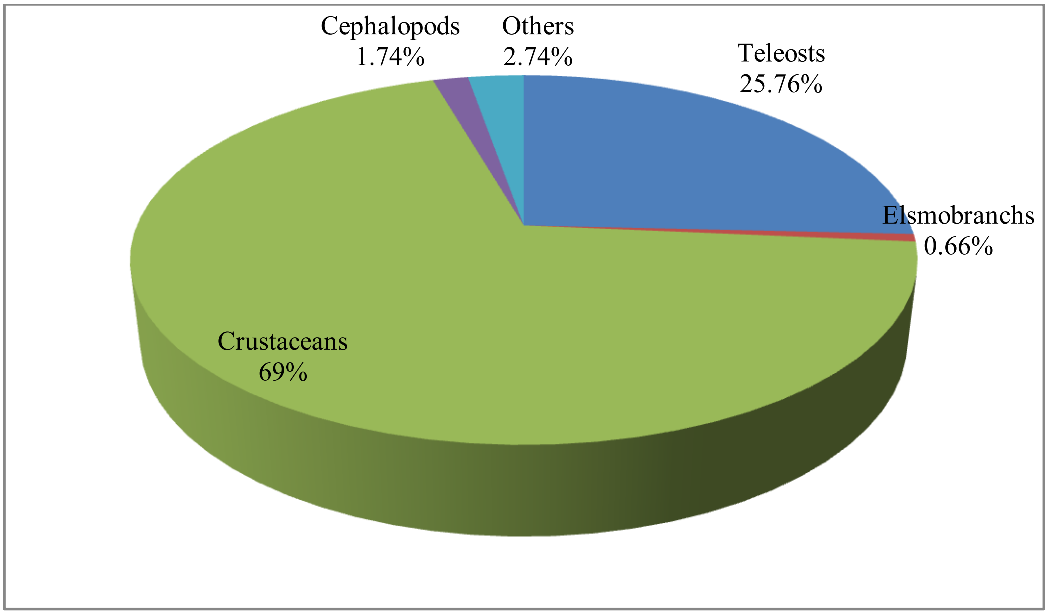


Figure 5.3.13. Index of Relative Importance (%IRI) of prey items in the stomach contents of *Echinorhinus brucus*

Conclusion

The *K* selected life history of elasmobranchs makes them highly susceptible to fishing and the extremely unproductive nature of many deep-water chondrichthyan species makes a great concern about the ability to sustain such exploitation (Morato *et al.*, 2006).

A large proportion of deep-water chondrichthyans are assessed as Data Deficient by the IUCN and species specific biological data is critical for future management of such species (Kyne and Simpfendorfer, 2010). Understanding the biological characters of exploited deep-sea chondrichthyans in relation to habitat and geography are important for making management and conservation plans, as the commercial fishery along the coastal waters of India are moving to more deeper areas.

The present study gives a better understanding of the dynamics of the deepwater shark resources from Indian waters. Results indicate that these sharks exploited in southern coasts of India by different gears have a K selected life history characteristic, which cannot support a high level fishing mortality either as targeted or bycatch fishery and could lead to decline or stock collapse ultimately if sustainable fishing practices are not followed. Biological data presented here from the southwest coast of India will useful for the creation of NPOA for sharks in India.

More detailed studies on the biology of the exploited deep-water chondrichthyans are required for creation of management strategies and to ensure sustainability. This study provides new detailed biological data on deep-sea sharks of Indian waters, including size at maturity, reproductive mode, and feeding habits, which is essential for fisheries management of such exploited deepwater species. Understanding and accumulation of information on diversity of exploited chondrichthyan along with their life history data (age, growth and reproduction, fecundity) on geographical basis should be priority to biologists and fishery research institutes for the formulation of fisheries management plans (Cope, 2006).

Chapter 6

Stock assessment and population dynamics of bramble shark, Echinorhinus brucus (Bonnaterre, 1788)

Chapter 6

Stock assessment and population dynamics of Echinorhinus brucus

To achieve sustainable fishery through rational exploitation, it is essential to have reliable data on population parameters and life history traits of exploited taxa. For the better understanding of the population status, exploitation trend can be used as the base data. Even though there are studies on the fishery and biology of elasmobranchs from Indian waters, studies on age, growth and population dynamics are meagre. Most of the studies were restricted to pelagic and coastal small species. Nair (1976) studied the age and growth of the Spadenose shark *Scoliodon laticaudus* from Bombay waters using length frequency method. Krishnamoorthi and Jagadis (1986) investigated the population dynamics of the Milk shark, *Rhizoprionodon acutus* in Madras waters. Kasim (1991) discussed about the population dynamics of *Scoliodon laticaudus* and *Rhizoprionodon acutus* from Gujarat waters. Mathew and Devaraj (1997) described the population dynamics of the shark *Scoliodon laticaudus* in the coastal waters of Maharashtra. Devadoss (1998 a) worked on the growth and population parameters of *Scoliodon laticaudus* from Calicut coast. Kasim *et al.* (1999) studied the age, growth and mortality of Spottail shark *Carcharhinus sorrah* from Tuticorin waters. Marichamy *et al.* (1999) studied the age and growth of ray *Himantura bleekeri* off Tuticorin. Soundararajan and Roy (2004) studied the age and growth of deep-sea sharks *Centrophorus acus* and *Squalus megalops* from Andaman waters. Manjusha *et al*. (2011) studied the population dynamics of hammerhead shark

Sphyrna zygaena from Kerala coast. Manojkumar *et al.,* (2012) studied the population parameters of *Carcharhinus limbatus* along Malabar coast (Table.1).

Table. 6.1. The von Bertalanffys growth parameters for elasmobranchs in the Indian waters

Species	L_∞ (mm)	K(annual)	t_o (year)	Area	Reference
Scoliodon laticaudus	755	0.27	-0.57	Mumbai	Nair (1976)
S. laticaudus (M)	680	1.08	-0.01	Veraval	Kasim (1991)
S. laticaudus (F)	749	0.88	-0.01	Veraval	Kasim (1991)
Rhizoprionodon acutus (M)	1054	0.65	-0.05	Veraval	Kasim (1991)
Rhizoprionodon acutus (F)	1060	0.61	-0.05	Veraval	Kasim (1991))
S.laticaudus	740	0.68	-0.13	Maharashtra	Mathew and Devaraj (1997)
S. laticaudus (M)	715	0.36	0.59	Calicut	Devadoss (1998)
S. laticaudus (F)	676	0.41	0.59	Calicut	Devadoss (1998)
Carcharhinus sorrah	1658	0.33	-0.09	Tuticorin	Kasim *et al.* (1999)
Himantura bleekeri (M)	1242	0.56	0.01	Tuticorin	Marichamy *et al.* (1999)
Himantura bleekeri (F)	1303	0.50	0.01	Tuticorin	Marichamy *et al.* (1999)
Centrophorus acus	1100	0.2	2.37	Andaman Sea	Soundararajan and Roy (2004)
Squalus megalops	770	0.2	1.08	Andaman Sea	Soundararajan and Roy (2004)
Sphyrna zygaena	3620	0.23		Kerala	Manjusha *et al.* (2011)
Carcharhinus limbatus	3020	0.45		Calicut	Manojkumar *et al.* (2012)

Considering the highly vulnerable nature of deep-sea chondrichthyans, it is very much essential to estimate the growth, population parameters and mortality for the sustainability of the exploited deep-sea elasmobranch. Estimated landings of deep-sea bramble shark, *Echinorhinus brucus* from the Indian EEZ by the commercial fishing vessels are substantial compared to any other countries, which is occurring as by-catch in hooks and line, long line, gillnet and trawl nets operating in deeper waters. Due to increasing fishing effort in recent years, the fishing pressure on this resource is increasing. There is no information on growth and mortality of *E.brucus* from Indian waters. Information on the age structure, population parameters are important for formulation of management measures for sustainable exploitation. Present study was undertaken to understand the intensity of exploitation and to assess the status of *E. brucus* in Indian waters.

Materials and methods

The data of *Echinorhinus brucus* for the present study was collected from Cochin Fisheries Harbour (Kerala), India. They were mainly landed as the by-catch of targeted deep-sea shark fishery and deep-sea shrimp trawlers. The details of length, weight, sex were taken by following standard methods. The total length (TL) of the shark was measured from the most anterior part of the head with mouth closed to the farthest tip of the caudal fin (upper lob) and recorded to nearest centimeter (cm). The total weight (W) of the fish was recorded to the nearest gram (g) for stock assessment. Length data were grouped into 10 cm length groups and mid point is used for study.

Age and growth

Length frequency data was collected biweekly from Cochin Fisheries Harbor of Kochi (Kerala), India for the period from January 2009 to December 2011. The weight of measured sample (shark) was taken to nearest gram. The length was measured from the anterior most part of the body to the end of caudal fin to the nearest centimeter (cm). Total catch of the species on the day of observation was noted. The length frequency data was grouped into 10 cm class interval and raised for the day and subsequently for the month using the method of Sekharan (1962). Frequency in a particular length class was multiplied by the raising factor for the day to get the daily raised numbers:

Raised factor for the day = Day's catch / sample weight

Daily raised numbers were calculated for all landing centre days of sampling in a month and summed up, and the sum of daily raised numbers was multiplied with monthly raising factor to get the monthly raised numbers as following:

Monthly Raising factor = Average catch for sampling days /Total catch for sampling days x Total fishing days in month

Month's raised numbers = monthly raising factor x sum of daily raised numbers

Monthly raised values were fed into FiSAT program to estimate various parameters of growth, mortality, yield and stock.

The pattern of growth of most fish species can be expressed using von Bertalanffy growth equation (VBGF) (1938) given as:

$$L_t = L_\infty (1-e^{-K(t-t_0)})$$

Where: L_t is the mean length at age t

L_∞ is the asymptotic length

K is the growth coefficient

t_0 is the age at zero length (initial condition parameter)

In the present study a number of methods were used to arrive at a reasonable estimate of growth parameters, employing computer based FiSAT program developed by Gayanilo *et al.* (1996).

The methods used for the study of growth include:

1. Gulland and Holt plot (1959) employing FiSAT
2. Ford-Walford plot (Ford, 1933, Walford, 1946), L_t against L_{t+1}
3. ELEFAN method developed by Gayanilo *et al.* (1988) using FiSAT program
4. Munro's method (1982)
5. t_0 was estimated by using Pauly's method (Pauly, 1979 a).

Bhattacharya method (1967)

This method is useful for splitting a composite distribution into separate normal distributions, each representing a cohort of fish, from the overall distribution starting on the left-hand side of the total distribution. Once the first normal distribution has been determined it is removed from the total distribution and same procedure is repeated as long as it is possible to separate normal distributions from the total distribution.

Mean lengths, population sizes (in numbers), standard deviations and separation index (SI) for the age groups identified, These results are automatically saved to disk as a "mean and standard deviation" file. The mean lengths obtained from this method was used for the calculation of growth parameters by Gulland and Holt Plot (1959).

Gulland and Holt plot (1959)

Another method for estimating L_∞ and K from growth data is provided by the feature that a plot of size increments per unit time against mean size (for the increment in question) gives a straight line, whose slope, with sign changed, closely corresponds to the value of K.

$$L_2-L_1/t_2-t_1 = a - K\bar{L}$$

Where $\bar{L} = (L_1 + L_2)/2$

And where, L_1 and L_2 are successive lengths, pertaining to times t_1 and t_2 respectively (Gulland and Holt, 1959).

This equation has the form of a linear regression y = a+ b x, with:

$$x = \bar{L} \text{ and } y = L_2 - L_1/t_2-t_1$$

The intercept "a" and slope "b" of which provide values of K and L_∞ through the relationships:

$$K = -b \quad \text{and,} \quad L_\infty = a/K$$

The method uses normal size-at-age data, at equal or unequal intervals, granted that the values of (t_2-t_1) stay small in relation to the longevity of fish.

Ford - Walford plot (Ford, 1933; Walford, 1946)

For estimation of parameters of VBGF the Ford-Walford plot (Ford 1933, Walford 1946) was used. This method has been widely applied because the plot could be used to obtain a quick estimate of L∞ without calculations. It is the simplest methods of estimating the parameters of the von Bertalanffy' s equation for data representing equal time intervals. The method is based on a rewritten version of the VBGF:

$$L_{t+1} = L_\infty (1-\exp[-K]) + L_t \exp(-K)$$

This equation is of a linear form

$$L_{t+1} = a + b\, L_t$$

Length at age t (L_t) can be plotted against length at age at a constant specific period later. The straight line fitting these data will have a slope of b = exp (-K) and an intercept on the y-axis of a = L_∞ (1-exp [-K]). These values were employed to estimate K and L_∞ as:

$$K = -\ln(b)$$

$$L_\infty = a / (1-b)$$

Here L_t, L_{t+1} pertain to length separated by constant time interval (1= year, month or week, etc.)

Electronic Length Frequency Analysis (ELEFAN) method

The ELEFAN system was initially developed by Pauly and David (1980, 1981) and Pauly (1982) for the estimation of growth parameters and mortality in fish populations, and later improved by Brey and Pauly (1986) and Brey *et al.,* (1988). Most of its implementations are in BASIC and are designed to use on microcomputers. The system has recently been revised, expanded and presented as a comprehensive software package, which incorporates various new routines for length-based fish stock assessment (Gayanilo *et al.,* 1988; Gayanilo and Pauly, 1989). The identification of modes (or peaks) is obtained through a so-called "restructuring" procedure. After restructuring sample, either a positive value (peak), or negative value (trough) or a zero value corresponds to each length class.

The groups (runs) of adjacent length intervals with positive values are assumed to potentially represent cohorts. The Available Sum of Peaks (ASP) is the sum, for all samples, of the points with a maximum value in each "run" of positive values. To fit the growth model (VBGF) ELEFAN traces numerous growth curves through the restructured data according to a set of growth parameters chosen by the user. For a given combination of growth parameters, the Explained Sum of Peaks (ESP) is the sum of all points (negative and positive) over which each curve runs, the best combination of parameters will produce a curve which hits most peaks avoids most troughs and thus obtains the highest ESP value. The relation ESP/ASP may range from a negative value to unity (depending on data) and higher values indicate better fit and the goodness of fit index (R_n) is defined by:

$$R_n = 10^{ESP/ASP}/10$$

Munro's Method (1982)

This method, based on Munro (1982), uses growth increment data to estimate L_∞ and K, or K alone, given L_∞. Input data are the same as the growth increment data file. The formula is given as:

$$K = [\ln(L_\infty - L_m) - \ln(L_\infty - L_r)]/(t_r - t_m)$$

Where, L_m is the length at marking (initial reading), L_r is the length at recapture, and t_m and t_r the corresponding dates.

The calculated values of K are close to each other when an optimal value of L_∞ has been selected, and differ widely from each other when the selected value of L_∞ is too high or too low.

Thus by calculating, for a given value of L_∞ the coefficient of variation of the K-values C.V. of:

K= standard deviation of the K values / mean value of K

One may select by trial and error the value of L_∞, which produces the lowest coefficient of variation for given set of data.

This method resembles the (forced) Gulland and Holt plot (1959) in that data for unequal intervals can be used. It has however, the distinct advantage over the Gulland and Holt plot of providing accurate solutions (K values) irrespective of the length of the time intervals (t_1-t_2 values).

Estimation of "t_0" by Pauly (1979 a)

In the present study the empirical formula developed by Pauly (1979 a) was used to estimate t_0. $\log(-t_0) = -0.3922 - 0.2752 \log L_{inf} - 1.038 \log K$.

Mortality Parameters

The key parameters used to describe the rate of death are called the "mortality parameters". The total mortality rate of the cohort (batch of fish having approximately the same age and belonging to the same stock) Z is the sum of the instantaneous rate of fishing mortality F, which is caused by the fishing operation and the instantaneous rate of natural mortality M which includes deaths caused by all other factors other than fishing like lack of food, competition, predation, and old age.

Estimation of Total Mortality

The estimation of Z requires either knowledge of the growth parameters of a stock, or that the age of at least a few fish is known. In fish stock assessment, estimation of total instantaneous rate of mortality Z is a prerequisite for understanding the dynamics of exploited fish populations. If the distribution of the population is known, then estimation of Z is quite straight forward.

There are various methods available for estimating Z using of growth parameters along with the length –frequency data.

Length-Converted Catch Curve (Pauly, 1983, 1984 ab)

Length-converted catch curves allows direct estimation of Z from length-frequency data, have the added advantage over “age-structured” catch curves, allowing a number of inferences to be drawn through detailed examination of the left, ascending arm of the curve, which is generally ignored in catch-curve analysis.

Length converted catch curves are created by plotting $\ln(Ni/\Delta t)$against relative age t_i, a first estimate of Z is obtained when the following function is adjusted to the points of the right descending arm of the catch curve:

$$\ln(N_i/\Delta t_i) = a + b\ t_i$$

N_i is the number of fish in length class i, Δt_i is the time needed for the fish to grow through length class i, t_i is the age (or the relative age) corresponding to the mid length of class i, and where b, with sign changed, is an estimate of Z.

To make the catch curve usable for length data, it is necessary to convert length data into age data using the inverse von Bertalanffy’ s growth equation:

$$t_{(L)} = t_0 - 1/K \ln(1-(L_t/L_\infty))$$

The age corresponding to a certain length can be calculated when t_0 is assumed to be zero.

Beverton and Holt Method (1956)

The equation, proposed by Beverton and Holt (1956) is more generally used to estimate Z from the mean size in the catch when used in conjunction with the generalized VBGF, it has the form:

$$Z = K (L_\infty - \bar{L}) / (\bar{L} - L')$$

Where, $\bar{L}$ is the mean length of all fish ≥ L', the latter being the smallest length of the fish fully represented in the length-frequency data at hand. L' is some length for which all fish of that length and longer are under full exploitation (L' is the lower limit of the corresponding length interval).

Jones and van Zalinge's Method (1981)

When length-frequency data or catch-at-length data are available which conditions can be considered constant, several methods can be used to estimate Z, which are less crude than the ones presented above.

This method proposed by Jones to estimate Z/K, the basic equation in Jones method, expressed in terms of the generalized VBGF, has the form of linear regression:

$$\ln (C_{Li,\infty}) = a + b * \ln (L_\infty - L_i)$$

where,

$C_{Li,\infty}$ is the cumulative catch (computed from the highest length class with non-zero catch) corresponding to length class I and L_i is the lower limit of length class i. The slope b, is an estimate of Z/K.

Powell – Wetherall Method

Wetherall *et al.*, (1987) suggested a method by which L_∞ and Z/K can be estimated. The formula is given as

$$(\bar{L} - L') = a + b * L'$$

Where,

$$\bar{L} = (L_\infty + L') / (1 + (Z/K))$$

From which, $Z/K = -(1+b) / b$ and $L_\infty = -a/b$

or $b = -K / (Z+K)$ and $a = -b * L_\infty$

L' is the smallest length of fish; $\bar{L}$ is the mean length of all fish longer or equal to L',

Thus plotting the $L - L'$ against L' gives a linear regression from which "a" and "b" can be estimated and hence L_∞ and Z/K. Both this method and Beverton and Holt formula are based on the assumption of constant parameter system, which reduces its applicability.

Natural Mortality Coefficient

In most cases it is easier to estimate total mortality than to partition it into its fishing mortality and natural mortality components.

In stock, which catch values for a range of different levels of fishing effort, and a series of annual total mortality estimates are available. Natural mortality may be estimated as following as:

$$Z = F + M$$

and, $F = q*f$

where, q is the catchability coefficient and f is fishing effort

$$Z = M + q*f$$

But natural mortality rate of a species is likely to be related to environment factors as well as it evolved life history pattern. Also can be considered that natural mortality rate required to reduce It has been demonstrated by various authors that the values of the parameter K of the VBGF are closely linked with longevity in fish (Beverton and Holt, 1959) and longevity related to mortality (Holt, 1965).

Fish species with a high K value have a high M-value, and species with a low K value have a low mortality. A slow growing species (low K) simply cannot bear high natural mortality; if it happen, it would soon become extinct. Beverton and Holt (1959) found that values of the ratio M/K mostly lie in the range of 1.5 to 2.5. Natural mortality must also be linked to L_∞ or the maximum weight of the species W_∞, since large fish have fewer predators than small fish. In present investigation, a number of methods were tried for the estimation of natural mortality coefficient.

Pauly's Formula (1980 b)

Pauly (1980 b) analyzed data from a large number of fish species in an attempt to obtain a general relationship to predict natural mortality from the von Bertalanffy' s growth parameters K (per year) and L_∞ (cm) total length being the asymptotic size of that stock, T [mean annual habitat temperature (in °C)]. As the habitat of the species is deeper layer of ocaeanic realm, the temperature for the present study is taken as 15^0C. Based on data from different fish stocks Pauly estimated the empirical linear relationship of natural mortality as:

$$\ln(M) = – 0.0152 – 0.279 \ln(L_\infty) + 0.6543 \ln(K) +0.463 \ln(T)$$

Rikhter and Efanov (1976)

Demonstrated that fish with a high natural mortality mature early in life and start to reproduce early. That shows a close association between M and T_{m50} the age when 50% of the population is mature (also called the age massive maturation)

$$M = [1.521/ (T_{m50}{}^{0.720})] – 0.155 \text{ per year}$$

They also suggested that T_{m50} should be equal to the "optimum age "defined as the age at which the biomass of a cohort in maximal.

Alagaraja (1984) Formula

Alagaraja (1984) defined the natural life span of a fish (or longevity) as the age at which 99% of the cohort-died if it has been exposed to natural mortality only (i.e. Z = M). If T_m stands for longevity and $M_{1\%}$ stands for the natural mortality corresponding to 1% survival then:

$$M_{1\%} = -\ln (0.01)/ T_m$$

Cushing's (1968) formula

Assuming natural mortality in virgin state is 99% by the time the fish reaches maximum age (T_{max}). The formula is given as:

$$Z = M = 1/T_{max} –1 \ln N_t / N_{t\,max}$$

Where N_t is number of one year old fish, $N_{t\,max}$ the number at maximum age of fish in the population. In the unexploited state, if the number of one year old fish is taken as 100 and then number surviving to an age of T_{max} it can be written as,

$$Z=M= (1/T_{max} – 1) \ln 100/1$$

With slight modification of the formula as T_{max} was taken instead of T_{max-1}.

Srinath's empirical formula (1998)

By following Alagaraja's approach, Srinath (1998) gave empirical formula, which was derived as a function of von Bertalanffy growth parameter K and expressed as:

$$M = 1.53\ K$$

Exploitation Rate (E) and Exploitation Ratio (U)

The exploitation ratio (U) is defined as a fraction of fish present at the beginning of a year i.e., caught during the year. It is estimated by the following formula,

$$U = (F/Z) * (1 - e^{-z})$$

The exploitation rate (E) is defined as the fraction of a year class recruits i.e., caught during all the years of its existence (Ricker, 1975). It is estimated as, $E = F / Z$

Stock assessment

Length frequency data were collected weekly from Cochin Fisheries Harbour, Kochi India. The same was raised for the day and subsequently for the month. This formed the basis of analysis for growth and mortality parameters, and also used for stock assessment analysis.

Probability of capture (Pauly, 1984 a)

The mesh size can be suitably regulated to increase the probability of capture. This length or age is designated, as L_c or t_c is the length or age at which 50% of the fishes become vulnerable to the gear in question. It happens to be one of the important parameters for the estimation of Y_w / R for Beverton and Holt's yield-per-recruit model. It is necessary to find out various probabilities of catching 25%, 50%, and 75% of fish entering the net for selection ogive method, which gives more realistic results (Sparre and Venema, 1998). Accordingly the number of fish that would have been caught is estimated first by backward extrapolation of converted catch curve used for the estimation of Z by Pauly (1980a). The L_{c25}, L_{c50} and L_{c75} were estimated from gear selection curve generated from the probability of capture out of which the L_{c50} values were used for the further calculations. These parameters were estimated by following Pauly (1984) employing FiSAT.

Length structured Virtual Population Analysis or Cohort Analysis (Pauly, 1984a)

Originally given as age structured model by Fry (1949, 1957) and Pope (1972), the length structured model was given by Jones (1984). This method utilizes basically the same approach as the age-structured VPA but is adapted to accommodate length frequencies. In this method the reconstruction of the entire population is made from the length frequency data raised to the annual catch with input of growth parameters like L_∞, K, M and assumption of a terminal value of F or F/Z. The growth and length-weight parameters estimated (in gm/cm) were used for this method.

Relative yield and Biomass-per-recruit

The original yield-per-recruit model of Beverton and Holt (1957) has modified by Beverton and Holt (1966) to give the relative yield-per-recruit (Y'/R) and biomass- per-recruit (B'/R). The L_c can be taken from knife-edge selection method suggested by Beverton and Holt (1957)

Relative yield-per-recruit (Y'/R) is computed from:

$Y/R' = E * U^{M/K} * [1- \{3U/(1+m)\}+\{3U^2/(1+2m)\} - \{U^3/(1+3m)\}]$

Where, $U = 1-(L_c/L_\infty)$; $m = (1-E)/(M/K) = (K/Z)$ and $E=F/Z$

Relative biomass-per-recruit (B'/R) is estimated from the relationship

$$B'/R = (Y'/R)/F$$

While, E_{max}, $E_{0.1}$ and $E_{0.5}$ are estimated by using the first derivative of this function.

In FiSAT package „E_{max}' represents the exploitation rate which produces maximum

yield.

The Y'/R and B'/R were calculated at different exploitation ratios by keeping the L_{c50}

as constant.

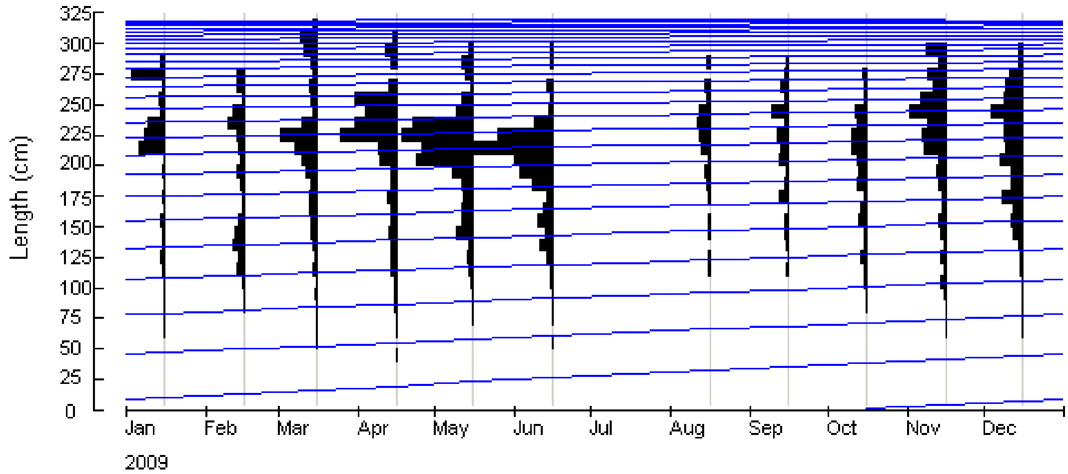
Similarly with different exploitation ratios (E) on the X-axis and different sizes at first capture by using L_c/L_∞ ratios on Y-axis the iso-values of Y'/R were plotted to generate the yield isopleth diagram.

The output of this process are Plots of Y'/R vs. E = (F / Z) and of B'/R vs. E, from which E_{max} (exploitation rate which produces maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at E=0) and $E_{0.5}$ (value of E under which the stock has been reduced to 50% of its unexploited biomass) are also estimated.

Results

Estimation of growth parameters

A number of methods were used for the estimation of growth parameters. Length-based stock assessment methods were used for the present study. The monthly length frequency of *Echinorhinus brucus* was analyzed using the FiSAT Computer Program (Gayanilo *et al.,* 1996).The parameters of von Bertalanffy's growth functions (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 (Pauly and David, 1981). However, the basic methods used are; modal progression analysis using Bhattacharya analysis, and ELEFAN technique using FiSAT. The rest of methods are primarily based on the results obtained by these methods of plot, all were computer based using FiSAT programme (Windows version). ELEFAN technique employing FiSAT programme gave an estimate of L_∞ as 333 cm TL and K of 0.12/year with Rn value of 0.129 (Fig. 6.1). The mean length decomposed by Bhattacharya's method (1967) using FiSAT programme were connected applying modal progression method (Fig. 6.2) and was used to calculate growth parameters. L_∞ and K by Gulland and Holt plot (1959) were estimated at 333 cm and 0.21/year, respectively (Fig. 6.3). Powell and Wetherall plot gives the preliminary estimates of growth parameters, gave L_∞ of 335 cm and Z/K of 4.478 (Fig. 6.4). Munro's method, L_∞ and K were estimatd as 333 cm and 0.14/year respectively (Fig. 6.5). Ford-Walford plot L_∞ and K were estimatd as 333 cm and 0.14/year respectively. From the growth parameters estimated by all these methods (Table. 6.2), L_∞ and K of 333 cm and 0.12/year obtained by ELEFAN method appears to be more reasonable and hence considered for further calculations of population parameters.



L_{∞} =333 cm and K=0.12 year^{-1}, C =0, WP =0, and Rn= 0.129

Figure 6. 1. Growth curve of *Echinorhinus brucus* employing ELEFAN (3 years combined)

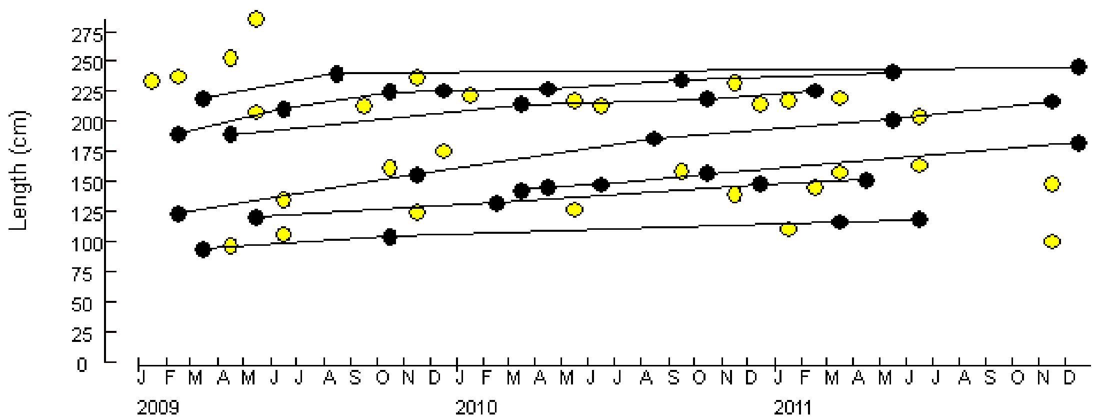


Figure 6. 2. Linking of means employing Bhattacharya method using FiSAT

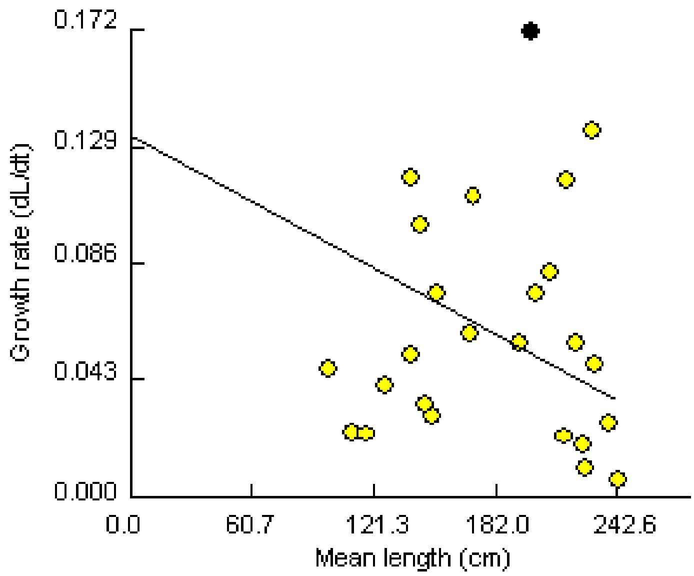


Figure 6. 3. Gulland and Holt's plot for estimation L_∞ and K (Black circled points were not used for estimation of growth parameters)

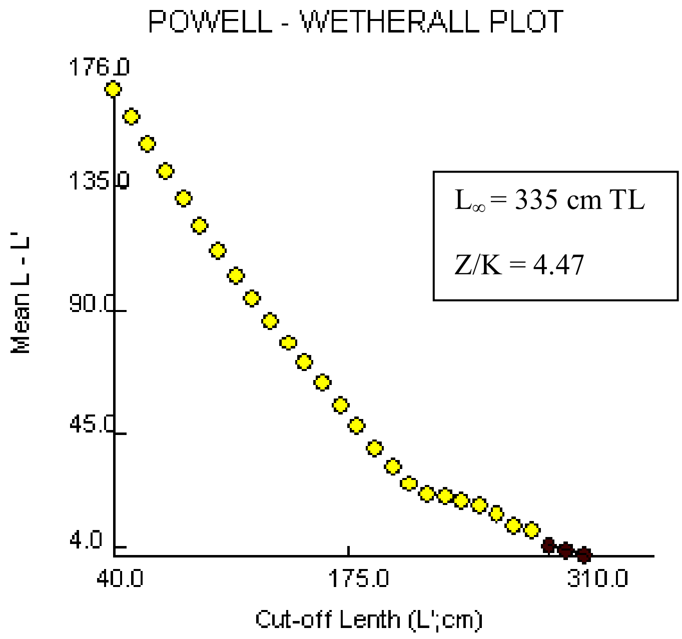


Figure 6. 4. Powell and Wetherall plot for estimation of L_∞ and Z/K

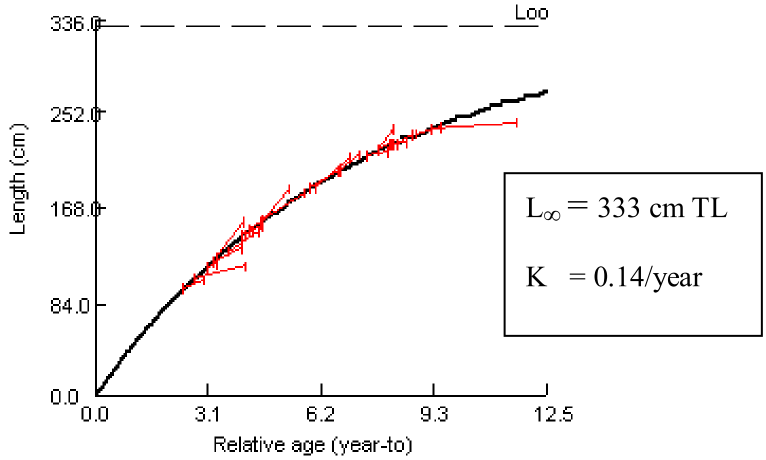


Figure 6. 5. Munro's plot for estimation of L_∞ and K

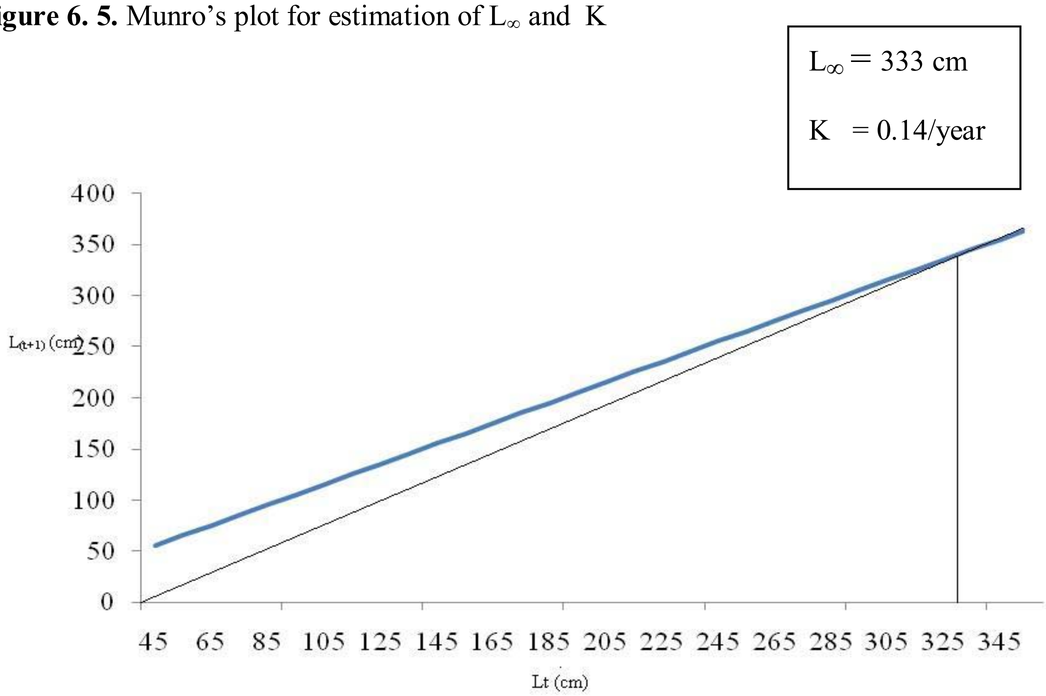


Figure 6.6. Ford-Walford plot for estimation of L_∞ and K

Table 6.2. Growth parameter of *Echinorhinus brucus* estimated by various methods

Sl. No.	Method employed	L_∞ (cm, TL)	K /Year
1	ELEFAN technique	333	0.12
2	Gulland and Holt plot (1959)	333	0.21
3	Powell and Wetherall Plot	335	4.478 Z/K
4	Munro's method (1982)	333	0.14
5	Ford-Walford plot	333	0.14

The Pauly and Munro's (1984) phi-prime (ϕ) value of growth performance index was obtained as phi-prime (ϕ') = $\log_{10} K + 2 \log_{10} L_\infty$, phi-prime (ϕ) for the present studywas 4.12

Estimation of t_o by Pauly, (1979 b)

By using Pauly's method, t_o was estimated as -0.0616 years.

Estimation of length at age

The values of L_∞ and K estimated by ELEFAN were considered for the calculation of lengths attained by *E. brucus* at quarterly intervals using von Bertalanffy's growth formula, the total length attained by *E. brucus* were 150, 233, 278, 303 cm at the end of 5, 10, 15, 20 years of its life span respectively (Table 6.3 and Fig.6.7). The maximum size recorded during the period of study was 318 cm, and the corresponding age was estimated as 26 years. Thus, according to the present study the fishable life span of the species is 26 years.

Table 6.3. Average length attained by *Echinorhinus brucus* at different ages by von Bertalanffy's method

Age (t)	Length(Lt, cm)	Age(t)	Length(Lt, cm)	Age(t)	Length(Lt, cm)
1	38	20	303	39	330
2	71	21	306	40	330
3	101	22	309	41	331
4	127	23	312	42	331
5	150	24	314	43	331
6	171	25	316	44	331
7	189	26	318	45	331
8	205	27	320	46	332
9	220	28	321	47	332
10	233	29	323	48	332
11	244	30	324	49	332
12	254	31	325	50	332
13	263	32	326	51	332
14	271	33	327	52	332
15	278	34	327	53	332
16	284	35	328	54	332
17	290	36	329	55	333
18	295	37	329		
19	299	38	330		

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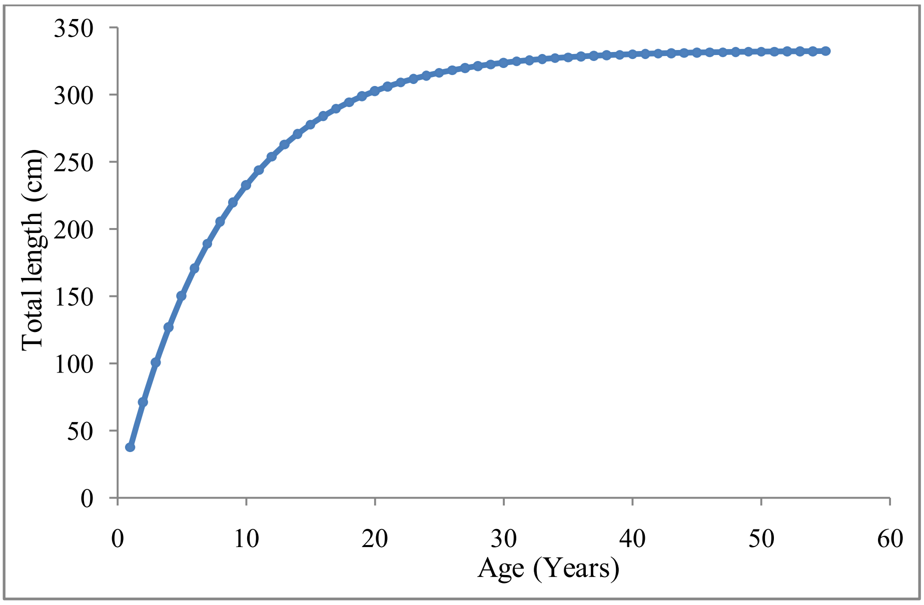

Figure 6.7. Average length attained by *Echinorhinus brucus* at different ages

Mortality

Total mortality coefficient (Z)

Values obtained for total mortality coefficient by different methods are presented in the Table 6.4. The Z obtained by length converted catch curve was 0.39 (Fig. 6.8) and by Jones and van Zalinge's cumulative catch curve 0.36 (Fig. 6.9). The other two methods viz. Beverton and Holt (Table 6.5) and Powel-Wetherall plot (Fig.6.4) gave Z of 0.62 and 0.54, respectively. The value of Z obtained by length converted catch curve was taken for further studies.

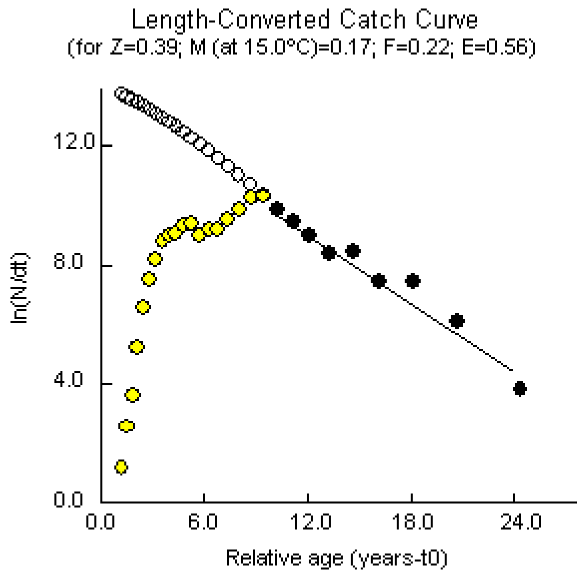

Figure 6. 8. Length converted catch curve for the estimation of Z

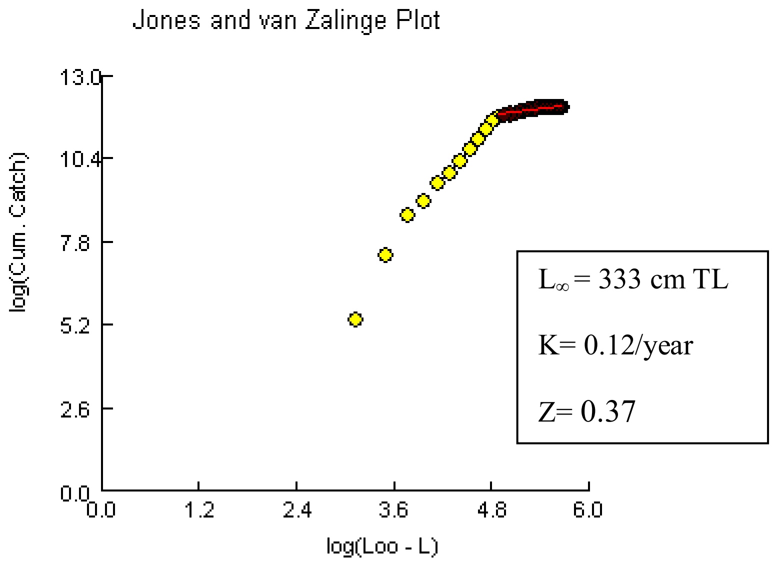

Figure 6.9. Jones and van Zalinge's plot for estimation of Z

Table 6.4. Total mortality (Z) of *Echinorhinus brucus* estimated by various methods

Methods	Total Mortality (Z)
Length converted catch curve method (1982)	0.39
Beverton and Holt method (1956)	0.44
Powell-Wetherall method	0.53
Jones and van Zalinge method(1981)	0.37

Table 6.5. Details of estimation of Z by Beverton and Holt method (from descending limb)

Mid length (cm)	Frequency (f)	Mid length * Frequency
45	1	45
55	4	220
65	11	715
75	60	4500
85	247	20995
95	670	63650
105	1370	143850
115	2534	291410
125	3245	405625
135	3771	509085
145	5038	730510
155	5946	921630
165	4005	660825
175	5198	909650
185	5778	1068930
195	8523	1661985
205	13281	2722605
215	23508	5054220
225	23712	5335200
235	16764	3939540
245	12900	3160500
255	8865	2260575
265	5521	1463065
275	6787	1866425
285	3073	875805
295	3970	1171150
305	1404	428220
315	222	69930
Sum=	166408	35740860

L mean = 256 cm

L' = 235 cm

L_∞=333 cm TL

$Z = K (L\infty - Lmean) / (Lmean - L')$ Z = 0.44/year

Natural mortality coefficient (M)

The natural mortality coefficient M was estimated by a number of methods (Table 6.6). Using Cushing's formula the M was estimated as 0.12. Here T_{max} was estimated as 25 years by employing inverse von Bertalanffy's growth formula. Alagaraja's method gave M of 0.18 while Rikhter and Effanov's method gave M of 0.17 with age of massive maturation taken as 8 years and Srinath's methods gave estimation of M as

0.18. While, using Pauly's empirical formula M value estimated as 0.17. The average of all methods comes to 0.164 which close to that of Pauly, s method. So M of 0.17 estimated by Pauly's method was taken for further calculation.

Table 6.6. Estimation of natural mortality (M) by various methods

Methods	Natural Mortality (M)
Cushing's method (1968)	0.12
Alagaraja's method (1984)	0.18
Rikhter and Effanov formula (1976)	0.17
Srinath's formula (1998)	0.18
Pauly's formula (1980b)	0.17

Fishing mortality (F)

The annual fishing mortality coefficient (F) was estimated by subtracting natural mortality (M) from total mortality coefficient (Z) as 0.22.

Exploitation Rate (E) and Exploitation Ratio (U)

With estimated total mortality coefficients (Z) of 0.39 and fishing mortality (F) of 0.22, the exploitation ratio (U) was calculated as 0.18 and exploitation rate (E) as 0.56.

Table 6.7. Values of different population parameters of *Echinorhinus brucus*

Population parameters	**Parameters**
Asymptotic length (L_∞) in cm	333
Growth coefficients (K) / year	0.12
t_o	-0.0616 yr
Total mortality (Z)	0.39
Natural mortality (M)	0.17
Fishing mortality (F)	0.22
L_c	199
L_c / L_∞	0.6
M/K	1.42
Exploitation rate (E)	0.56
Exploitation ratio (U)	0.18
Phi prime (Φ)	4.12

Recruitment pattern

Results of the analysis of recruitment pattern of *E. brucus* during the study period are shown in Fig 6.10. This can be interpreted as continuous recruitment throughout the year, with a single peak around May. The percent recruitment varied from 1% to 16%. The highest (16%) and lowest (11%)) percent recruitment was observed in the months of May and January respectively (Fig 6.10).

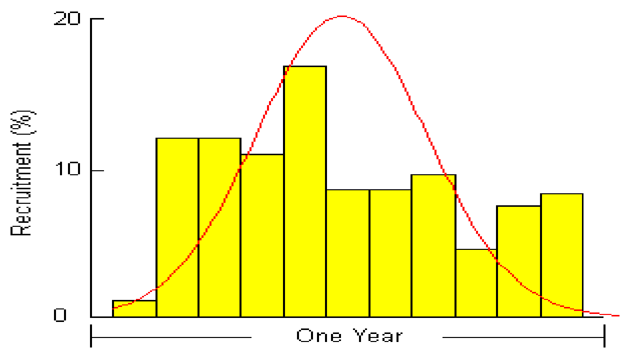

Figure 6.10. Annual recruitment pattern of *Echinorhinus brucus* from the southwest coast of India

Stock assessment

Probability of capture

The annual length frequency data from January 2009 to December 2011 was pooled, using Beverton and Holts method (1956) the frequency, cumulative frequency and cumulative percentage were calculated which gave L_{c50} (Length at which 50% of fish become vulnerable to the gear) as 199 cm TL for combined gears, the probability of capture for trawl selection was derived Lc_{25} as 183 cm TL (Fig.6.11) and the same was taken as an input parameter for calculation of yield and relative yield and yield isopleth diagram.

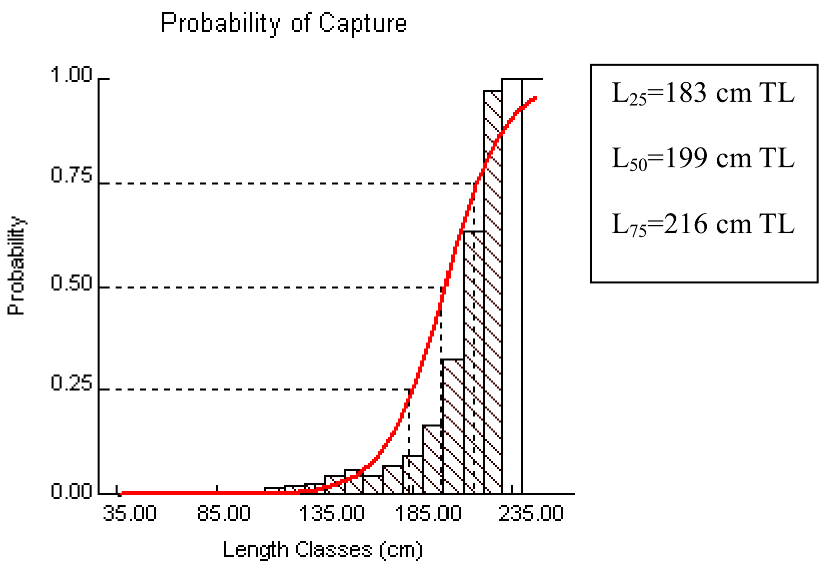

Figure 6.11. Probability of capture for L_{c50}

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 0.6 and 1.42 respectively (Fig 6.12). The plot of relative yield per recruit (Y'/R) against E is shown in Fig. 6.13, where the maximum Y'/R (0.051) was obtained at E_{max}= 0.391 and as the exploitation rate increases beyond this value, relative yield per recruit decreases. Both $E_{0.1}$ (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 as 0.321 and 0.256 and the corresponding Y'/R are 0.044 and 0.036 respectively. The calculated E value based on F and Z was 0.56 which gives Y'/R 0.054.

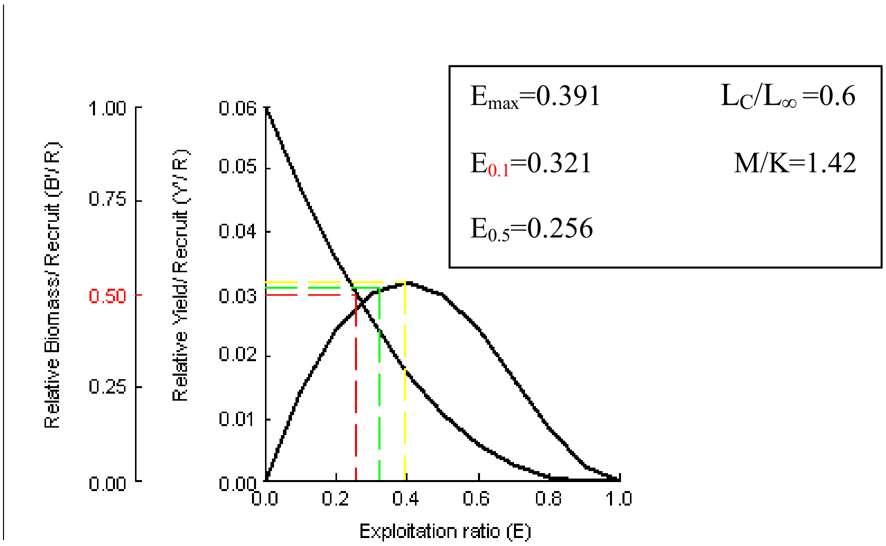

Figure 6.12. Relative yield per recruit Y'/R and biomass per recruit B'/R

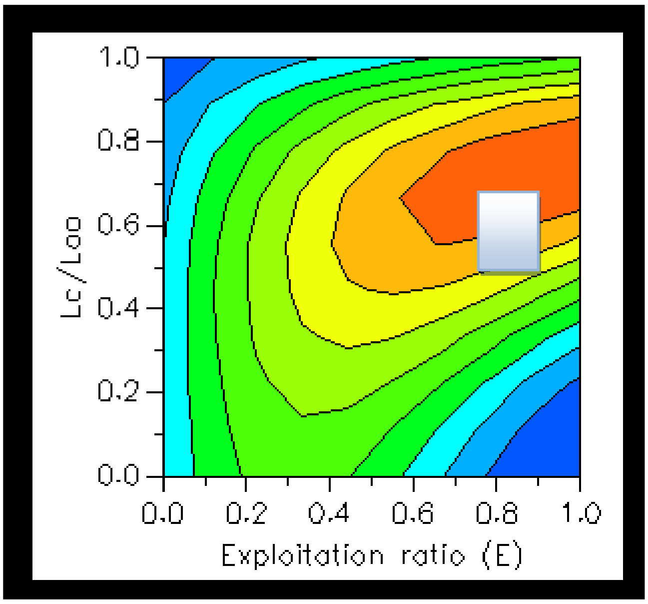

Figure 6.13. Yield isopleth of *Echinorhinus brucus* showing the present Y'/R

Length structured Virtual Population Analysis (VPA) or Cohort Analysis

The input parameters used for VPA were L_∞ of 333 cm, K of 0.12/year, M of 0.17, 'a' as 0.0000182 and 'b' as 3.23 from length-weight studies. The terminal fishing mortality was assumed to be 0.5. The main loss in the stock upto 91-100 cm

TL size was due to natural mortality. Fishes become more vulnerable to the gear after this size and mortality due to fishing starts increasing. The highest fishing mortality was 0.26 in the length group of 291-300 cm TL followed by 0.24 for the length group 221-230 cm TL. The largest number of fish caught (4615) from the length group 111-120 cm TL followed by 221-230 cm TL (4116) with fishing mortality 0.1 and 0.24 respectively. The estimated fishing mortality (0.22) experienced at the size of 211-230 cm TL. An increase in fishing mortality was observed from the length group 201-210 cm TL onwards. The mean F from the fully recruited groups 221 - 320 cm TL was 0.28 (Table 6.8, and Fig. 6.14). Assuming the terminal fishing mortality (Ft) was 0.5 for the largest length group (311-320 cm TL), the number surviving in the sea is 95, The biomass increased from 317 t in the size class 41-50 cm TL to the maximum (14079.86 t) in the size class 211-220 cm TL and gradually reduced to 312.6 t in the largest length group 311-320 cm TL.

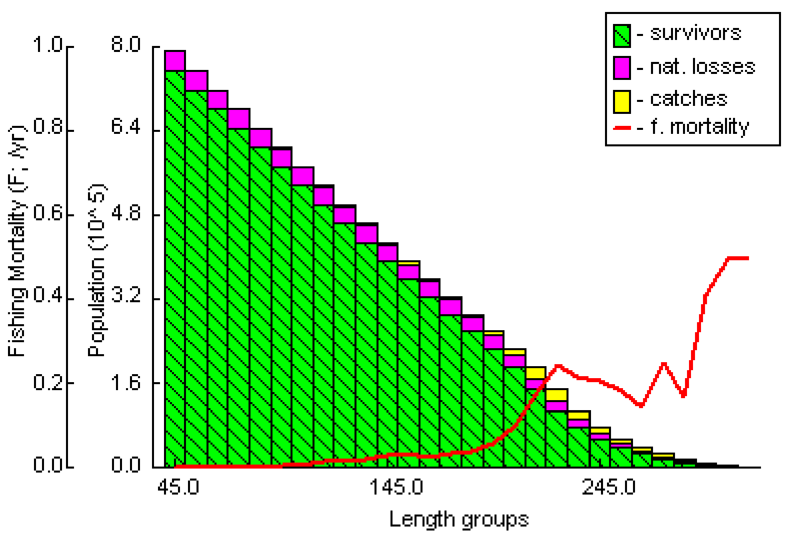

Figure 6.14. Length structured VPA for *Echinorhinus brucus* for the years 2009-2011.

Table 6.8. Length structured VPA for *Echinorhinus brucus* for the years 2009-2011

Length class (cm, TL)	Catch (nos.)	Population (N)	Fishing mortality (F)	Steady state biomass (t)
41-50	32	191879	0.0006	317.01
51-60	92	182478	0.0017	558.51
61-70	178	173160	0.0033	899.28
71-80	665	163905	0.0127	1352.99
81-90	1647	154331	0.0322	1925.25
91-100	2359	143991	0.0476	2614.47
101-110	3343	133208	0.0702	3409.79
111-120	4615	121770	0.1021	4277.96
121-130	4247	109471	0.0998	5205.02
131-140	3201	97990	0.0798	6224.21
141-150	3033	87969	0.0801	7330.99
151-160	2901	78498	0.0814	8481.47
161-170	1581	69542	0.047	9735.49
171-180	2334	62238	0.0735	11033.21
181-190	2148	54505	0.0725	12244.65
191-200	2367	47320	0.0864	13348.73
201-210	3268	40294	0.1323	14070.24
211-220	4007	32828	0.1882	14079.86
221-230	4116	25202	0.2367	13262.44
231-240	2872	18131	0.2083	12058.66
241-250	2320	12914	0.2156	10727.38
251-260	1611	8764	0.1968	9253.09
261-270	1143	5762	0.188	7760.4
271-280	963	3585	0.2296	6015.08
281-290	385	1909	0.1377	4487.73
291-300	429	1049	0.2661	2884.98
301-310	129	346	0.1804	1421.53
311-320	71	95	0.5	312.59

Discussion

Bramble shark, *Echinorhinus brucus* is a poorly known deepwater shark, occurring at 200-1000 m depths and also occasionally caught in shallow waters. In southern coasts of India, it occurs mainly as bycatch in various gears. Though there are investigations on the population parameters of elasmobranchs from Indian waters (Table. 6.1), most of the studies were limited to coastal species.

So far, no study has been carried out on the stock parameters of Echinorhinidae. Understanding the population parameters are important in management of the fishery as the deepwater elasmobranchs are highly vulnerable to exploitation and *E. brucus* occurs as heavy bycatch in deep-sea shrimp trawls and longlines for deep-sea gulper sharks along the southern coasts of India. Present study forms the first work on the population parameters of *E. brucus.*

The L_∞ and K values of *E. brucus* was estimated as L_∞ = 333 cm and K = 0.12/year. The K values obtained in the present study are similar to the values of the growth parameters of deepwater chondrichthyans reported, showing slow to moderate growth (Cortes, 2000). The comparative growth coefficient study of chondrichthyans worked out by Cailliet (1990) and Cailliet and Goldman (2004) shows that a wide range of K values can be used to interpret the life history traits of deep-sea chondrichhayans, which can vary from 0.05/year in *Dipturus pullopunctata* (Walmsley-Hart *et al.*,1999) to 1.3/year in *Rhizoprionodon taylori* (Simpfendorfer, 1993). Most of the deep-sea chondrichthyan have a low K value as in *Squalus megalops* 0.12/year (Avsar, 2001) and *Alopias superciliosus* with even lower K value 0.088-0.092/year (Liu *et al.*, 1998).

Branstetter (1987) and Branstetter and Musick (1994) classified VBGF growth coefficient values as slow (0.05-0.1/year), moderately slow (0.1-0.2/year) and, fast growing (0.2-0.5/year) species. From the study it can it is confirmed that *E. brucus* is a moderately slow growing species.

In present study, using length-frequency data a number of methods have been used for the estimation of growth and the results of ELEFAN with L_∞ as 333 mm and K as 0.12/ year were used for further inputs in estimation of various population parameters.

The phi prime (Φ) is one of the parameters, which determines a relationship between L_∞ and K. The phi prime estimated in the present study was 4.12 indicates to a greater extent the estimation of L_∞ and K is justified.

The mortality coefficient Z was estimated by four different methods, Powell-Wetherall plot is basically a method to obtain the first approximation of L_∞ and K (gives Z/K). The Beverton-Holt gives a value of 0.44, followed by Powell-Wetherall (0.53). Jones and van Zalinge's method gave the lowest value of Z (0.37). However, length converted catch curve is considered as the appropriate method to find out Z, which is 0.39 and has been taken for further analysis.

Most of the deep-sea chondrichthyans have low natural mortality (M) due to low predation and high juvenile survival rate, but the vulnerability to fishing gear will b very high. A number of methods have been used for the estimation of M. This study also clearly shows the natural mortality coefficient obtained by Pauly's formula was 0.17. Coelho and Erzini (2005) also suggested similar M values for deep- sea sharks *Etmopterus pusillus* as 0.167 – 0.255/year and 0.210-0.416/year for *E. spinax.* In the case of deepwater species, ICES holds the value of fishing mortality (F) is equal to M as a precautionary approach. The highest F (0.22) value estimated in this study is higher than M shows the increasing exploitation of the species. Often M/K ratio, which ranges from 1–2.5 (Beverton and Holt, 1959) in most of fish, becomes a method of testing the accuracy of estimation of M. In the present study the M/K ratio (1.42) of the species fall in that range thus providing the consistency of the same on the M/K ratio.

The exploitation rate (E) and exploitation ratio (U) values estimated as 0.56, 0.18 respectively. Gulland and Holt (1959) suggested that the optimum value of E is 0.5 above which the stock under study is overexploited. As the estimated E is slightly above the optimum value of E(0.5) the stock can be considered as over- exploited and the catch of *E. brucus* in southern coast of India is also showing the declining trend (Akhilesh *et al.*, 2013 d). The higher exploitation ratio (0.56) obtained in the study may perhaps be due to bycatch in all the gears operating in deeper waters

Stock assessment

In the present investigation no data could be collected during in the July month of 2009, 2010 and 2011 because the onset of monsoon and bad weather condition, restricting the fishers to venture into the deeper areas of the sea followed by the closed season from 15th June to 31st July. The length at first capture (Lc) in the present study is estimated to be 199 cm TL. Several researchers reported that sexual maturity in *E. brucus* occurs between 182 and 231 cm TL in females and 150 and 187 cm TL in males (Barrul and Mate, 1996; Compagno *et al.,* 2005 a; Henderson *et al.,* 2007; Akhilesh *et al.,* 2013 d). However, the length at first capture in the present study (199 cm) is in the maturity size range for the species indicating there is tremendous pressure on the *E. brucus* stock in the southwest coast of India.

Decreasing the fishing pressure will give the chance to the shark to spawn before being caught in great numbers.

In present study, the knife-edge procedure gave E_{max} of 0.39. The basic assumption of knife-edge selection is that fishes below the length at first capture will not be retained by the net. The E value calculated using F/Z as 0.56.

As a rule of thumb, Z/K > 1 indicates that the fish is mortality dominated and if less than 1 it is growth dominated. However in present study the Z/K of 4.48 indicates that the population is highly mortality dominated. Probably in Indian waters most of the species are highly mortality dominated. According to Pauly and Soriano (1986) in the yield contours (isopleth diagram) where L_c /L_∞, E and M/K ratio are compared, the stock are classified into four quadrant, in the present case with L_c/L_∞ of 0.6 and E of 0.56 it belongs to quadrant C which implies that large specimen can be caught at higher efforts and fishery is stabilized and developed. The species presently investigated fits under the same category and probably a slight reduction of effort may give sustained fishery.

In long term basis, reducing L_c /L_∞ is suggested so that length at first capture to be increased from present level of 199 cm TL. As this species is landed as by catch of shrimp trawl, implication of such suggestion may not practically possible. The length cohort analysis shows that the F for this species has shown an increasing trend for the large size groups. The chief reason for this may be that the smaller size groups are discarded due to less market value or that groups are not represented in the fishing ground and the death for this group is due natural cause.

VPA revealed that F increases to maximum of 0.20 - 0.23 at 221-230 cm TL, after this point it decreases to 0.18 - 0.19 at 261-270 cm TL and abruptly increases to 0.26 - 0.28 at 291-300 cm TL. The reason for this sudden increase in F possibly due to larger sharks is coming as bycatch. Fishing mortality exceeds natural mortality from 224.5 cm TL onwards. The mean F from the fully recruited groups 221 - 320 cm TL was 0.28

This study revealed that the recruitment pattern of *E. brucus* shows a continuous one with a single peak per year. The highest (17%) and lowest (1%)) percent recruitment takes place in May and January (Fig. 6.10).

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 and the value were worked out as were 0.6 and 1.42. The fishes with low K values are characteristic with low natural mortality, K value in the present study is 0.12/year and the corresponding M value is 0.17. Therefore the M/K ratio of E. *brucus* is found to be 1.4. The M/K ratio is found to be constant among the closely related species and the M/K ratio in fishes generally falls within the limit of 1.5-2.5 (Beverton and Holt, 1959). The exploitation rate (E) is 0.56. When E is more than 0.5 for the stocks, are supposed to be over fished (Gulland, 1971). The results of the present study ascertain the need for monitoring the fishing effort targeting *E. brucus* along the southwest coast of India.

Chapter 7

Checklist of Indian chondrichthyans

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Being one of the mega diverse country, India has different climatic, ecological and bio-geographic zones and a diverse faunal and floral groups in its ecosystems. Conservation and management of this diversity is important in maintaining the equilibrium of the ecosystem and for their potential usage for humanity. Conservation, management and sustainable utilisation depend upon the quantitative and qualitative assessment of biodiversity, taxonomic identity and understanding the taxa in concern (Narendran, 2001; Agnarsson and Kuntner, 2007; Prathapan *et al.*, 2009).

Large amounts of research funding and effort has been invested in inventorying the biodiversity of India. However, our current taxonomic and systematic knowledge on certain groups are inadequate, scattered and mostly unorganised (Narendran, 2001; Hariharan and Balaji, 2002; Kumaran, 2002; Aravind *et al.*, 2004; Das *et al.*, 2006; James, 2010; Vishwanath and Linthoingambi, 2010; Wafar *et al.*, 2011).Understanding the fauna and its diversity in specific habitats/ecosystems/regions of country with their distribution pattern and phylogeography is the baseline data for all future studies and formulation of conservation and management plans.

Chondrichthyans are widely distributed in all oceans, but are most diverse in tropical and subtropical Indo-Pacific Ocean (Bonfil, 2002). Chondrichthyans are one of the most vulnerable groups on planet earth due to their biological characteristics and the global concern over these apex predators due to the over exploitation leading to stock decline (Smith *et al.,* 1998; Baum *et al.,* 2003; Garcia *et al.,* 2008; Dulvy *et al.,* 2014).

Elasmobranch research is limited from region despite the rich diversity, long history and huge fishery. The prime *impediment* in elasmobranch research is the lack of good taxonomic research due to decline in expertise. Pushpangadan and Nair (2001) and Bhaskaran and Rajan (2010) commenting on the issues and challenges in Indian taxonomic research critically commented on the need for a national consortium, collaborations and the need for state of the art museums and collections for advanced taxonomic studies. The absence of dedicated studies can be attributed as the prime reason for the non-existence of comprehensive taxonomic studies/revisions and conclusive checklists. This chapter presents an extended, updated checklist of elasmobranchs reported from Indian waters, together with comments on their taxonomic status and validity of their occurrence reports from India.

Method

Present chondrichthyan checklist is based on a review of available publications, monographs, catalogues on the diversity, taxonomy, life history (biology, food and feeding, stock assessments), ecology, fishery and exploratory surveys from Indian Seas. Elasmobranchs identified/ encountered during the field and exploratory surveys between 2008-2013 by the authors and information shared by colleagues are also included in the list to make it a comprehensive list. Validity status and occurrence from the region was confirmed and evaluated following recent publications and Eschmeyer (2014). Species have been assigned to either one of the following IUCN (2013) Red List categories: Critically Endangered (CR), Endangered (EN), Vulnerable (VU); Near Threatened (NT), Least Concern (LC) or Data Deficient (DD) or Not Evaluated (NE).

Results

Diversity and taxonomic status of Indian chondrichthyans

Chondrichyans found in the Indian seas have been catalogued by several researchers but a conclusive inventory is elusive. Day (1889) reported 69 species, Misra (1952) reported 52, Misra (1969) reported 114 species and Talwar & Kacker (1984) reported 76 species. Raje *et al.* (2002) listed 110 elasmobranch species from the Indian waters. Venkataraman *et al*. (2003) prepared a field identification handbook on sharks containing 72 species, and later Raje *et al*. (2007) listed 84 elasmobranchs from the commercial fishery. These publications during different periods have recorded between 84 and 114 species occurring the Indian seas.

The study provides a checklist of 227 chondrichthyan species (from 11 orders and 41 families) recorded/listed from Indian seas (Table. 7.1). In this combined list many species have uncertain status ie, 12 % (27) species listed to be occurring have questionable status with regard to their occurrences since their distribution range doesn’t fall within Indian Seas as per recent studies. For example, Yellowspotted catshark *Scyliorhinus capensis* (Smith, 1838) is known only from southeast Atlantic Ocean (See Eschmeyer *et al.,* 2014) but is listed as occurring in India (See Gunther, 1870; Day, 1878); and 17% (38) species listed from India need additional confirmation (could have distribution range including India or parts of Indian seas, but needs taxonomic reports for confirmation rather than listing). Excluding species with uncertain status and several undescribed common species, the valid species from Indian waters is 159. This list includes more than 40 additional species over those reported by previous workers (Raje *et al.*, 2007), but we believe it is still incomplete.

Chondrichthyan species diversity of Indian seas are higher and of similar composition to that reported in the tropical Indian Ocean regions like, from the Arabian Gulf (43 sharks) (Moore *et al.*, 2012); from Sri Lanka (92 elasmobranchs) (Moron *et al.*, 1998; De Silva, 2006), and species from the Maldives (32 sharks) (Anderson and Ahmed, 1993), Philippines (160 species) (Compagno *et al.*, 2005 b).

The taxonomic problems with regard to Carcharhiniformes, Squaliformes and Myliobatiformes are yet to be resolved, which would definitely recognize higher diversity in Indian seas. In Squaliformes, 23 species are are listed from India of which 56 % is having uncertain status. Which is clear that there exixists confusion and inconsistencies in species identification with usage of in valid /misapplied names, complex taxonomic histories and the presence of several undescribed species in commercial fishery, posting impediments for arriving at conclusions on species listings. In turn, this result in poor catch and export data and management implications. There are many confusions persisting in similarly looking species occurring in Indian seas, which need to be critically studied and compared through collaborative studies.

Possibly most of the common cosmopolitan species, and those reported from Indian Ocean and western Pacific could be present in Indian waters, with the number greater than the latest reports, but it should be noted that for those having wide distribution range it could be a complex of more species (See White *et al.*, 2010a). Deep-sea chondrichthyans of India are one group which is mostly overlooked. Though most of the species of same genera look alike and are possibly widely distributed, their genetic and specific morphological data are needed to clarify taxonomic status

Many chondrichthyan description from Indian waters by earlier ichthyologists were synonymised or are considered invalid at present (Table. 2.2), but it should be noted that several species which were synonymised earlier are being resurrected using advanced studies and wide geographical samplings (Marshal *et al.*, 2009; Ebert *et al.*, 2010; White *et al.*, 2010 abc). Therefore, there is a possibility that many Indian species also would resurrected if there were studies that are more focused and in-depth.

Indian material of all the species listed from India are not available in any of Indian or foreign collections, which increases in resolving taxonomic issues. Though checklist is supposed to give the reference collection numbers (See Compagno *et al.*, 2005; Ebert *et al.*, 2013) but absence of good Indian specimen collections and cataloguing hinders this effort, which suggests that national museums and referral collections should have priority approach to avail all the Indian materials in custody, which is very much important in taxonomic research.

Conservation status of Indian chondrichthyans

Excluding the species with uncertain status (questionable and those needs confirmatory reports), the total number of Indian elasmobranch species are 159 of which, 3.8% are Critically Endangered (CR), 5.0% are Endangered (EN), 25.2% are Vulnerable (VU), 20.8% are Near Threatened (NT), 8.8% is of Least Concern (LC) status, 26.4% are Data Deficient (DD), 10.13 % Not Evaluated (NE) against the criteria (Table 7.1, Fig. 7. 1).

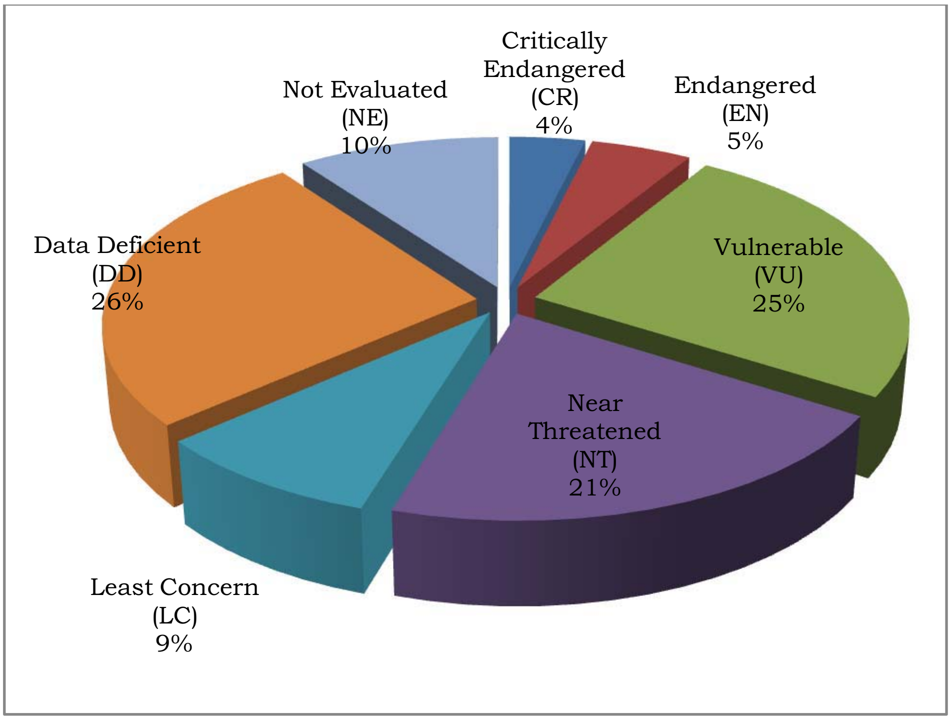

Figure 7. 1. Conservation status of Indian chondrichthyans

In 1999, FAO developed a frame work for the conservation of elasmobranchs, which recommended all states to prepare the management policies and develop National Plans of Action (NPOA) to identify information gaps, issues and priorities for their conservation and management. Despite several international commitments, there has been little action undertaken to better understand, manage and protect elasmobranch species in India other than IWPA, 1972. At present India do not have a National Plans of Action for conservation and management of elasmobranchs, but the preparation of plans for regional management is underway. However, under the Indian Wildlife (Protection) Act, 1972 ten elamsobranchs are protected in Schedule I part

2(A) (MoEF, 2001). And recently by policy of Prohibition of shark finning in the Sea was created by MoEF, 2013 as precautionary approach.

Conclusion

This century is called the century of extinctions (Dubois, 2003; Dubois, 2010). Over exploitation and habitat degradation/alteration are major concerns for biodiversity decline and extinction of species. There is an urgent need for cataloguing the diversity before it goes extinct without knowing their presence. Proper species identification is necessary for knowing, cataloguing and monitoring biodiversity (Vecchione *et al.,* 2000). Taxonomic soundness in reports, publications and data are very essential, since they are used in conservation, management and formulation of policies (Kholia and Jenkins, 2011).

Recent chondrichthyan taxonomic studies around the world (e.g. Indonesia, Taiwan and Australia) have resulted in a renaissance, with many new species descriptions and increased taxonomic resolution of species complexes (Last, 2007; Last *et al.,* 2008, 2010), which suggests that a systematic taxonomic study and a changed outlook on this group in Indian waters with wide regional sampling, molecular studies, comparisons and collaborations would likely to identify a greater diversity of fauna and validity of many currently used names in India.

In recent years, several new species have been added to the list of elasmobranch faunal diversity of Indian seas (Akhilesh *et al.*, 2010; Babu *et al.,* 2011; Benjamin *et al.,* 2012; Kizhakudan and Rajapackiam, 2013; Bineesh *et al.,* 2014) due to extension of fishing to newer and deeper area, indicating an unnoticed species richnesss in Indian waters. According to White and Last (2012), Indian waters are most poorly known in its elasmobranch fauna and more scientific exploration and investigations are needed in the region, which will increase understanding of its fauna. In recent years, the use of molecular and genetic data have shown good discriminating capacity in species with morphological similar and overlapping characters. Hebert *et al.* (2003) proposed global identification system for animals by using mitochondrial gene, cytochrome c oxidase subunit 1 (COI) to differentiate vast majority of animals species including the discovery of new or cryptic species. DNA barcoding technique (ie, is the sequencing a region of mitochondrial cytochrome oxidase I gene) for rapid and accurate species identification including their life stages. In India advanced technologies in chondrichthyan have been used by Bineesh et al., 2013; Pavan-Kumar *et al.*, 2013). Examples and case studies in White and Last (2012) suggests the need for studies with molecular support and wide geographical sampling in the Indian Ocean region which would re-establish the validity of several unrecognized species.

NBAP (2008) states that "The implementation of Biological Diversity Act and National Environmental Policy 2006 would be difficult without having adequate number of trained taxonomists". Indian Wildlife (Protection) Act, 1972 lists 10 elasmobranchs in Schedule I part 2(A), (MoEF, 2001), which will have to be identified accurately in the field for protection. However, absence of *Carcharhinus hemiodon* (Müller and Henle, 1839), *Glyphis glyphis* (Müller and Henle, 1839 and *Glyphis gangeticus* (Müller and Henle, 1839) in recent collections is a question of non-availability or going unnoticed because of identifying difficulties (See Compagno *et al.*, 2003; Compagno, 2007; Compagno *et al.*, 2009). Another species listed in IWPA, 1972 is *Himantura fluviatilis* (Hamilton, 1822) which is a junior synonym of *Pastinachus sephen* (Forsskål, 1775) (See Eschmeyer, 2014). Recently *P. sephen* was considerd as a complex with new species described and re-surrected (Last *et al.*, 2005, 2010 ab) (of which at least two species are available in India). Knowing the taxonomic identity of the species in India has huge impact on the conservation and management as well as enforcement of law (Prathapan *et al.*, 2009).

Indian marine fisheries research institutes (eg. CMFRI, FSI, CIFT, NIO, ICAR Complexes Goa, Andaman, CMLRE, ZSI) along with few universities covers all coastal areas. This network can be utilized for cataloguing our faunal diversity. Collaborative research and scientific interactions within the country overcoming constraints will provide great impetus to understanding the diversity of our ocean.

In this chapter, all recent additions to Indian elasmobranch fauna, with recent taxonomic changes and validity status are included. Still there are many unrecognized species occurring in Indian seas. Future research priorities should be aimed at better understanding these vulnerable groups, cataloguing diversity, maintaining reference collections and capacity building in elasmobranch taxonomy with multinational and multi institutional collaboration.

Table 7.1. Checklist of chondrichthyans listed/reported from India

Order /Family	Species	Validity in India	IUCN status (Global)
CHIMAERIFORMES			
RHINOCHIMAERIDAE	*Neoharriotta pinnata* (Schnakenbeck, 1931)		**DD**
	Neoharriotta pumila Didier & Stehmann, 1996	Needs confirmatio	**DD**
	Rhinochimaera atlantica Holt & Byrne, 1909	Questionabl	**LC**
	Harriotta raleighana Goode & Bean, 1895	Questionabl	**LC**
CHIMAERIDAE	*Chimaera monstrosa* Linnaeus 1758	Questionabl	**NT**
	Hydrolagus cf *africanus* (Gilchrist, 1922)		**DD**
HEXANCHIFORMES			
HEXANCHIDAE	*Hexanchus griseus* (Bonnaterre, 1788)		**NT**
	Hexanchus nakamurai Teng, 1962	Needs confirmatio	**DD**
	Heptranchias perlo (Bonnaterre, 1788)		**NT**
	Notorynchus cepedianus (Péron, 1807)	Needs confirmatio	**DD**
ORECTOLOBIFORMES			
HEMISCYLLIIDAE	*Chiloscyllium arabicum* Gubanov, 1980		**NT**
	Chiloscyllium griseum Müller & Henle, 1838		**NT**
	Chiloscyllium indicum (Gmelin, 1789)		**NT**
	Chiloscyllium plagiosum (Bennett, 1830)		**NT**
	Chiloscyllium punctatum Müller & Henle, 1838		**NT**
	Chiloscyllium hasselti Bleeker, 1852	Needs confirmatio n	**NT**
	Chiloscyllium burmensis Dingerkus & DeFino, 1983	Needs	**DD**
STEGOSTOMATIDAE	*Stegostoma fasciatum*(Hermann, 1783)		**VU**
GINGLYMOSTOMATIDAE	*Nebrius ferrugineus* (Lesson, 1831)		**VU**
	Ginglymostoma cirratum (Bonnaterre, 1788)	Questionabl	**DD**
RHINCODONTIDAE	*Rhincodon typus* Smith, 1828		**VU**
LAMNIFORMES			
ODONTASPIDIDAE	*Carcharias taurus* Rafinesque, 1810		**VU**
	Odontaspis ferox (Risso, 1810).		**VU**
	Odontaspis noronhai (Maul 1955)		**DD**
ALOPIIDAE	*Alopias pelagicus* Nakamura, 1935		**VU**
	Alopias superciliosus (Lowe, 1841)		**VU**
	Alopias vulpinus (Bonnaterre, 1788)		**VU**
LAMNIDAE	*Carcharodon carcharias* (Linnaeus,1758)	Questionabl	**VU**
	Isurus oxyrinchus Rafinesque, 1810		**VU**
	Isurus paucus (Guitart Manday, 1966)		**VU**
PSEUDOCARCHARIIDAE	*Pseudocarcharias kamoharai* (Matsubara, 1936)		**NT**

Order /Family	Species	Validity in India	IUCN status (Global)
CARCHARHINIFORMES			
SCYLIORHINIDAE	*Apristurus indicus* (Brauer, 1906)	Questionable	**DD**
	Apristurus investigatoris (Misra, 1962)		**DD**
	Apristurus microps (Gilchrist, 1922)	Questionable	**LC**
	Apristurus saldanha (Barnard, 1925)	Questionable	**LC**
	Apristurus canutus Springer & Heemstra, 1979	Questionable	**DD**
	Atelomycterus marmoratus (Bennett, 1830)		**NT**
	Cephaloscyllium silasi (Talwar, 1974)		**DD**
	Cephaloscyllium sufflans (Regan, 1921)	Questionable	**LC**
	Halaelurus buergeri (Müller & Henle, 1838)	Questionable	**DD**
	Halaelurus natalensis (Regan, 1904)	Questionable	**DD**
	Halaelurus quagga (Alcock, 1899)		**DD**
	Halaelurus boesemani Springer & D'Aubrey, 1972	Needs confirmation	**DD**
	Bythaelurus lutarius (Springer & D'Aubrey, 1972)	Needs confirmation	**DD**
	Bythaelurus hispidus (Alcock, 1891)		**DD**
	Holohalaelurus punctatus (Gilchrist, 1914)	Needs confirmation	**EN**
	Scyliorhinus capensis (Müller & Henle, 1838)	Questionable	**NT**
PROSCYLLIIDAE	*Eridacnis radcliffei* Smith, 1913		**LC**
	Eridacnis sinuans (Smith, 1957)	Questionable	**LC**
	Proscyllium magnificum Last & Vongpanich, 2004		**NE**
PSEUDOTRIAKIDAE	*Planonasus* sp. (Sensu Akhilesh *et al.*, 2010)		**NE**
TRIAKIDAE	*Iago omanensis* (Norman, 1939)		**LC**
	Iago sp. A [*sensu* Compagno *et al.*, 2005]		**NE**
	Mustelus mangalorensis Cubelio, Remya & Kurup, 2011	Holotype possibly lost	**NE**
	Mustelus mosis Hemprich & Ehrenberg, 1899		**DD**
HEMIGALEIDAE	*Chaenogaleus macrostoma* (Bleeker, 1852)		**VU**
	Hemigaleus microstoma Bleeker, 1852		**VU**
	Paragaleus randalli Compagno, Krupp & Carpenter, 1996		**NT**
	Hemipristis elongata (Klunzinger, 1871)		**VU**
CARCHARHINIDAE	*Carcharhinus altimus* (Springer, 1950)		**DD**
	Carcharhinus amblyrhynchoides (Whitley, 1934)		**NT**
	Carcharhinus amblyrhynchos (Bleeker,1865)		**NT**
	Carcharhinus albimarginatus (Ruppel,1837)		**NT**

Order /Family	Species	Validity in India	IUCN status (Global)
	Carcharhinus amboinensis (Müller & Henle, 1839)		**DD**
	Carcharhinus brevipinna (Müller & Henle, 1839)		**NT**
	Carcharhinus dussumieri (Müller & Henle, 1839)		**NT**
	Carcharhinus falciformis (Müller & Henle, 1839)		**NT**
	Carcharhinus hemiodon (Müller & Henle, 1839)*		**CR**
	Carcharhinus leucas (Müller & Henle, 1839)		**NT**
	Carcharhinus limbatus (Müller & Henle, 1839)		**NT**
	Carcharhinus longimanus (Poey, 1861)		**VU**
	Carcharhinus macloti (Müller & Henle, 1839)		**NT**
	Carcharhinus melanopterus (Quoy & Gaimard, 1824)		**NT**
	Carcharhinus obscurus (Lesueur,1818)		**VU**
	Carcharhinus sealei (Pietschmann, 1913)	Needs confirmation	**NT**
	Carcharhinus sorrah (Müller & Henle, 1839)		**NT**
	Galeocerdo cuvier (Péron & Lesueur, 1822)		**NT**
	Glyphis gangeticus (Müller & Henle, 1839)		**CR**
	Glyphis glyphis (Müller & Henle, 1839)	Needs confirmation	**EN**
	Lamiopsis temminckii (Müller & Henle, 1839)		**EN**
	Lamiopsis tephrodes (Fowler 1905)	Needs confirmation	**NE**
	Loxodon macrorhinus Müller & Henle, 1839		**LC**
	Negaprion acutidens (Rüppell, 1837)		**VU**
	Prionace glauca (Linnaeus, 1758)		**NT**
	Rhizoprionodon acutus (Rüppell, 1837)		**LC**
	Rhizoprionodon oligolinx Springer, 1964		**LC**
	Scoliodon laticaudus Müller & Henle, 1838		**NT**
	Triaenodon obesus (Rüppell, 1837)		**NT**
SPHYRNIDAE	*Eusphyra blochii* (Cuvier, 1817).		**NT**
	Sphyrna lewini (Griffith & Smith, 1834)		**EN**
	Sphyrna mokarran (Rüppell, 1837)		**EN**
	Sphyrna zygaena (Linnaeus, 1758)		**VU**
	Sphyrna tudes (Valenciennes, 1822)	Questionable	**VU**
SQUALIFORMES			
SQUALIDAE	*Squalus blainville* (Risso, 1827)	Needs confirmation	**DD**
	Squalus acanthias Linnaeus, 1758	Needs confirmation	**VU**
	Squalus megalops (Macleay, 1881)	Needs confirmation	**DD**
	Squalus mitsukurii Jordan & Snyder, 1903	Needs confirmation	**DD**
	Squalus cf. *lalannei* Baranes, 2003		**DD**

Order /Family	Species	Validity in India	IUCN status (Global)
CENTROPHORIDAE	*Centrophorus moluccensis* Bleeker, 1860	Needs confirmation	**DD**
	Centrophorus uyato Rafinesque, 1810	Needs confirmation	**NE**
	Centrophorus cf. *granulosus* (Bloch & Schneider, 1801)		**VU**
	Centrophorus lusitanicus Bocage & Capello, 1864	Needs confirmation	**VU**
	Centrophorus squamosus (Bonnaterre, 1788)		**VU**
	Centrophorus atromarginatus Garman, 1913		**DD**
	Centrophorus cf. *zeehaani* White, Ebert & Compagno 2008		**NE**
	Deania profundoroum (Smith & Radcliffe, 1912)		**LC**
ETMOPTERIDAE	*Centroscyllium ornatum* (Alcock, 1889)		**DD**
	Centroscyllium fabricii (Reinhardt, 1825)	Needs confirmation	**LC**
	Etmopterus granulosus (Günther, 1880)	Needs confirmation	**LC**
	Etmopterus pusillus (Lowe, 1839)		**LC**
	Etmopterus spinax(Linnaeus, 1758)	Needs confirmation	**LC**
	Etmopterus baxteri Garrick, 1957	Needs confirmation	**LC**
	Etmopterus lucifer Jordan & Snyder, 1902	Needs confirmation	**LC**
SOMNIOSIDAE	*Centroselachus crepidater* (Bocage & Capello, 1864)		**LC**
	Zameus squamulosus (Günther, 1877)		**DD**
ECHINORHINIDAE	*Echinorhinus brucus* (Bonnaterre, 1788)		**DD**
	Echinorhinus cookei Pietschmann, 1928	Questionable	**NT**
PRISTIFORMES			
PRISTIDAE	*Anoxypristis cuspidata* (Latham, 1794)		**EN**
	Pristis microdon Latham, 1794		**CR**
	Pristis pectinata Latham, 1794		**CR**
	Pristis pristis (Linnaeus, 1758)		**CR**
	Pristis zijsron Bleeker, 1851		**CR**
SQUATINIFORMES			
SQUATINIDAE	*Squatina squatina* (Linnaeus, 1758)	Questionable	**CR**
	Squatina africana Regan, 1908	Needs confirmation	**DD**
TORPEDINIFORMES			
TORPEDINIDAE	*Torpedo panthera* Olfers, 1831		**DD**
	Torpedo fuscomaculata Peters, 1855	Needs confirmation	**DD**
	Torpedo sinuspersici Olfers, 1831	Needs confirmation	**DD**
	Torpedo marmorata Risso, 1810		**DD**
	Torpedo zugmayeri Engelhardt, 1912		**NE**

Order /Family	Species	Validity in India	IUCN status (Global)
NARCINIDAE	*Benthobatis moresbyi* Alcock, 1898		**DD**
	Narcine brunnea Annandale, 1909		**NE**
	Narcine lingula Richardson, 1840		**DD**
	Narcine prodorsalis Bessednov, 1966	Needs confirmation	**DD**
	Narcine timlei (Bloch & Schneider, 1801).		**DD**
	Narcine cf *oculifera* Carvalho, Compagno & Mee, 2002		**DD**
	Narcine maculata (Shaw, 1804)		**DD**
NARKIDAE	*Heteronarce prabhui* Talwar, 1981		**DD**
	Narke dipterygia (Bloch & Schneider, 1801)		**DD**
RAJIFORMES			
RHINIDAE	*Rhina ancylostoma* Bloch & Schneider, 1801		**VU**
RHYNCHOBATIDAE	*Rhynchobatus laevis* (Bloch & Schneider, 1801)		**VU**
	Rhynchobatus australiae Whitley, 1939		**VU**
	Rhynchobatus djiddensis (Forsskål 1775)		**VU**
	Rhynchobatus palpebratus Compagno & Last, 2008		**NE**
RHINOBATIDAE	*Glaucostegus granulatus* (Cuvier, 1829)		**VU**
	Glaucostegus halavi (Forsskål, 1775)		**DD**
	Glaucostegus obtusus (Müller & Henle, 1841)		**VU**
	Glaucostegus thouin (Anonymous, 1798)		**VU**
	Glaucostegus typus (Anonymous [Bennett] 1830).		**VU**
	Rhinobatos annandalei Norman, 1926		**DD**
	Rhinobatos annulatus (Müller & Henle, 1841)		**LC**
	Rhinobatos holcorhynchus Norman, 1922	Needs confirmation	**DD**
	Rhinobatos lionotus Norman, 1926		**DD**
	Rhinobatos punctifer Compagno & Randall, 1987		**DD**
	Rhinobatos variegatus Nair & Lal Mohan, 1973		**DD**
ZANOBATIDAE	*Zanobatus schoenleinii* (Müller & Henle, 1841)	Questionable	**DD**
ANACANTHOBATIDAE	*Cruriraja andamanica* (Lloyd, 1909)		**DD**
RAJIDAE	*Amblyraja reversa* (Lloyd, 1906)	Needs confirmation	**DD**
	Dipturus sp. A (*Sensu* Bineesh *et al.*, 2013)		**NE**
	Dipturus johannisdavisi (Alcock 1899).		**DD**
	Dipturus crosnieri Seret, 1989	Needs confirmation	**VU**

Order /Family	Species	Validity in India	IUCN status (Global)
	Fenestraja mamillidens (Alcock, 1889)		**DD**
	Leucoraja circularis (Couch, 1838)	Needs confirmation	**VU**
	Okamejei powelli (Alcock, 1898)		**DD**
	*Okamejei*sp. A		**NE**
	Raja miraletus Linnaeus, 1758	Questionable	**LC**
	Raja texana (Chandler, 1921)	Questionable	**DD**
	Rostroraja alba (Lacepède, 1803)	Questionable	**EN**
MYLIOBATIFORMES			
HEXATRYGONIDAE	*Hexatrygon bickelli* Heemstra & Smith, 1980		**LC**
PLESIOBATIDAE	*Plesiobatis daviesi* (Wallace, 1967)		**LC**
DASYATIDAE	*Dasyatis bennetti* (Müller & Henle, 1841)	Needs confirmation	**DD**
	Dasyatis centroura (Mitchill, 1815)	Questionable	**LC**
	Dasyatis chrysonota (Smith, 1828)	Questionable	**LC**
	Dasyatis lata (Garman, 1880).	Questionable	**LC**
	Dasyatis microps (Annandale, 1908)		**DD**
	Dasyatis pastinaca (Linnaeus, 1758)	Needs confirmation	**DD**
	Dasyatis thetidis Ogilby, 1899	Needs confirmation	**DD**
	Himantura alcockii (Annandale 1909).		**NE**
	*Himantura draco*Compagno & Heemstra, 1984	Needs confirmation	**NE**
	Himantura uarnacoides (Bleeker, 1852)		**VU**
	Himantura fai Jordan & Seale, 1906		**LC**
	Himantura fava (Annandale 1909).		**NE**
	Himantura gerrardi (Gray, 1851)		**VU**
	Himantura granulata (Macleay, 1883)		**NT**
	Himantura imbricata (Bloch & Schneider, 1801)		**DD**
	Himantura cf. imbricata (Bloch & Schneider, 1801)		**NE**
	Himantura jenkinsii (Annandale, 1909)		**LC**
	Himantura leoparda Manjaji-Matsumoto & Last, 2008		**VU**
	Himantura marginata (Blyth, 1860)		**DD**
	Himantura pastinacoides (Bleeker, 1852)		**VU**
	Himantura polylepis Bleeker, 1852		**EN**
	Himantura uarnak (Forsskål, 1775)		**VU**
	Himantura undulata (Bleeker, 1852)		**VU**
	Himantura walga (Müller & Henle, 1841)	Need confirmation	**NT**
	Neotrygon kuhlii (Müller & Henle, 1841)		**DD**

Order /Family	Species	Validity in India	IUCN status (Global)
	Pastinachus sephen (Forsskål, 1775)		**DD**
	Pastinachus atrus (Macleay, 1883)		**NE**
	Pteroplatytrygon violacea (Bonaparte, 1832)		**LC**
	Taeniura lymma (Forsskål, 1775)		**NT**
	Taeniura meyeni (Müller & Henle, 1841)		**VU**
	Urogymnus asperrimus (Bloch & Schneider, 1801)		**VU**
GYMNURIDAE	*Gymnura japonica* (Schlegel, 1850)	Needs confirmation	**DD**
	Gymnura cf *micrura* (Bloch & Schneider, 1801)		**DD**
	Gymnura zonura (Bleeker, 1852)		**VU**
	Gymnura poecilura (Shaw, 1804)		**NT**
	Gymnura tentaculata (Müller & Henle, 1841)		**DD**
MYLIOBATIDAE	*Aetobatus flagellum* (Bloch & Schneider, 1801)		**EN**
	Aetobatus ocellatus (Kuhl, 1823)		**NE**
	Aetobatus narinari(Euphrasen, 1790)	Questionable	**NT**
	Aetomylaeus vespertilio (Bleeker 1851)		**EN**
	Aetomylaeus nichofii (Bloch & Schneider, 1801)		**VU**
	Aetomylaeus maculatus(Gray, 1832)		**EN**
	Aetomylaeus milvus (Müller & Troschel 1841)		**NE**
	Myliobatis aquila (Linnaeus, 1758)	Questionable	**DD**
MOBULIDAE	*Manta alfredi* (Anonymous)		**VU**
	Manta birostris (Walbaum, 1792)		**VU**
	Mobula mobular (Bonnaterre, 1788)	Needs confirmation	**EN**
	Mobula japanica (Muller & Henle, 1841)		**NT**
	Mobula diabolus shaw1804		**NE**
	Mobula thurstoni (Lloyd, 1908)		**NT**
	Mobula eregoodootenkee (Bleeker 1859)		**NT**
	Mobula kuhlii (Müller & Henle 1841).		**DD**
	Mobula tarapacana (Philippi 1892).		**DD**
RHINOPTERIDAE			
	Rhinoptera javanica Müller & Henle, 1841		**VU**
	Rhinoptera jayakari Boulenger, 1895		**NE**
	Rhinoptera sewelli Misra, 1947		**NE**
	Rhinoptera brasiliensis (Müller & Henle, 1841)	Questionable	**EN**

Chapter 8

Summary and Recommendations

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Due to the development of targeted deep-sea shark fishery and extension of fishing operations in to deeper waters, there were considerable landings of deep-sea chondrichthyans along the southwest coast especially at Cochin. Since most of the deepwater fauna are vulnerable to exploitation, it's important to understand its fishery, biology and diversity from the southwest coast of India. In this context present study was undertaken.

Summary

Taxonomy and diversity

- Deep-sea chondrichthyans of Indian waters are poorly known in every aspects including its taxonomy and diversity. Taxonomic account of deepwater species occurring in southern coasts of India was studied. Morphometric characters of 24 species with diagnostic features were provided. Study revealed rich and hidden diversity of deep-sea elasmobranch fauna. Highest diversity in the landings was observed at Cochin. Several species recorded during the present study was new to Indian waters (*Deania profundorum*, *Hexanchus griseus*, *Zameus squamulosus*) or to west coast of India (*Pseudocarcharias kamoharai*) and some species were recorded after a long period (*Halaelurus quagga*).
- A comprehensive checklist of chondrichthyans of Indian water created, which states that more than 159 species occurs in Indian waters.

Fishery

- During 2008-11, the highest Deep-sea chondrichthyan landing was observed in 2008 with 629 tonnes which decreased considerably to 228 tonnes in 2011, showing a 64% decline in catch from 2008.
- Fishery was dominated by species belonging to families, Alopiidae, Echinorhinidae, Centrophoridae, and Rhinochimaeridae.
- Though there were occasional landings of deep-sea elasmobranchs belonging to families Hexanchidae, Triakidae, Proscyllidae, Scyliorhinidae, Squalidae Rajidae and Plesiobatidae, their catch was very low, less than 2 tonnes/year . Proscyllidae (*Eridacnis*), Scyliorhinidae (*Apristurus, Cephaloscyllium*, *Halaelurus* and *Bythaelurus*), were caught only by deep-sea trawlers and doesn't account for fishery.
- The dominant gears contributed to the fishery was longlines/drift gillnets, contributed average 55.5% during the study period. Average contribution of targeted long lines, gillnet and trawls were 25.5%, 16.6 %, 2.4% respectively.
- Over all status of deep-sea chondrichthyan fishery at Cochin shows fishery is declining, which is a matter of concern.

Biology of deep-sea sharks

- Biological studies on three deep-sea sharks, *Echinorhinus brucus*, *Eridacnis radcliffei* and *Bythaelurus hispidus* were based on materials collected from Cochin Fisheries Harbour, Kerala or Sakthikulangara Fisheries Harbour (Kollam), Kerala.

- The study on food and feeding habits of three deep-sea sharks *E. brucus and E. radcliffei* and *B. hispidus* indicates that they are predominantly opportunistic carnivore, feeding on variety of organisms.
- The analysis of stomach contents revealed *Eridacnis radcliffei* feeds primarily on crustaceans (74.2%). The most common dietary item was shrimps (mostly *Aristeus* spp, *Ophlophorus* spp, *Plesionika quasigrandis*, *Heterocarpus* spp, etc) which comprised 63% of the dietary items, followed by fish remains (23.4%).
- Studies on reproductive biology study of *E. radcliffei* that the species have a Length at first maturity (Lm) at 170 mm and 183 mm TL for male and females respectively. Reproductive mode of *E. radcliffei* is an aplacental viviparous (previously termed ovoviviparous) and the uterine fecundity was only 1 or 2. The maximum size for females and males recorded in the present study, i.e. 257 and 235 mm TL respectively.
- *Bythaelurus hispidus* feeds on a a variety of prey, primarily fish. The majority of fish prey could not be identified to a narrower taxonomic unit than unidentified teleost (40%), followed by *Bregmaceros* sp. (10.28%) and Myctophidae (1.24%). The next most abundant prey group was crustaceans (37%), mostly *Aristeus* spp, *Plesionika* spp, and gastropods (1%). Muddy sediments were observed in 18 of the stomachs examined.
- The study on reproductive biology of *B. hispidus* revealed that, species have a length at first maturity (Lm) at 235 mm and 252 mm for male and females respectively. The reproductive mode is aplacental viviparous having a membranous egg case. Ovarian and uterine fecundity of *Bythaelurus hispidus*

was two. The maximum size for females and males recorded in the present study, i.e. 366 and 311 mm TL respectively.

- Dietary analysis of stomach contents revealed *Echinorhinus brucus* feeds on a variety of prey including crustaceans (69% IRI), finfishes (25.8% IRI), cephalopods (1.7% IRI) and elasmobranchs (0.7% IRI).
- The present study on reproductive biology reveals that *E. brucus* have a Length at first maturity for females and males was estimated at 189 and 187 cm TL. Females and males ranged from 46–318 cm and 51–300 cm TL.

Stock assessment and population dynamics of *Echinorhinus brucus*

- The present study is based on data collected from January 2009 to December 2011 from Cochin Fisheries Harbour, Kerala.
- The low 'K' value for *E. brucus* (0.12/yr) indicates that this species grows at a slower rate to attain the asymptotic length (333 cm TL) with a life span of 33 years. The exploitation ratio (E) is higher for *E. brucus* (0.56), with no scope to increase exploitation and creation of management plans as compared to the optimum exploitation of 0.39.
- There are no particular peaks in recruitment, indicating no seasonal pattern spawning.
- The size at capture L_{50} was estimated as 199 cm TL for *E. brucus*

  Using von Bertalanffy's growth formula, the length attained by *E. brucus* was 150, 233, 278, 303 cm TL at the end of 5, 10, 15, 20 years of its life span respectively. The maximum size recorded during the period of study was 318 cm, and the corresponding age was estimated at 26 years. Thus, according to the present study the fishable life span of the species is 26 years. The L_{max} for the species reported as 326 cm TL and the corresponding t_{max} was estimated to be 32 years.

- The smaller length groups faced only lower rate of fishing mortality. Selection ogive shows the relative yield per recruit is maximum at E 0.39 against E of 0.56 at present, which is higher than the optimum. Thompson and Bell predictive analysis for the species shows that there is decline in the catch and economic return at level of fishing

  0.18-0.2. However, it is difficult to suggest any changes in the effort for a multispecies, multigear and non targeted fishery, where a number of species are landed simultaneously.
- Average Total mortality rate (Z), natural mortality rate (M), and fishing mortality rate (F) were estimated to be 0.48, 0.17, 0.22, respectively.
- The exploitation rate (U) was calculated as 0.18 and exploitation ratio (E) as 0.56 indicating overexploitation of the stock.
- The length cohort analysis shows that the F for the species has an increasing trend for the large size groups. The chief reason for this may be the discard of smaller size groups also as the market demands the larger size. Size segregation in seasons, or juveniles and larger sharks may also play an important role.

Recommendations

- The need for more studies on chondrichthyan diversity, distribution and taxonomy is well established. Fauna of Indian region is poorly known due to many factors. Accurate identification of the species in the region, occurring in fishery is very important in supporting all other studies on the group and for its management.

- Use of advanced technologies like barcoding techniques in taxonomy should be promoted with reference collections maintaining in museums. Most of the Indian elasmobranchs are not available in Indian museums; these institutions should be provided with additional support in human resource and finance for dedicated surveys.
- Exploratory surveys for understanding diversity in virgin areas of EEZ where none of the commercial fishing vessels or earlier exploratory survey ships operated.
- National network in elasmobranch research can be created in collaboration with or more research centers, universities, research and educational institutions, NGO's which conducts diversity and fisheries research.
- Provide trainings to Indian researchers working in fisheries institutes and universities.
- The increased exploitation and vulnerability of the deep water chondrichthyans due to biological characters makes them highly susceptible to extinction. Therefore, it is essential to conduct more studies. Understanding the biological data is very much important in making management and conservation plans. Tagging studies for understanding the migratory behavior and studies using submersibles for habitat, ecology and behaviour should be initiated.
- Considering the high possibility of local extinction, chondrichthyan fishery and bycatch should be monitored in a better manner with inclusion of CPUE data. There should be continuous assessments of trends in fishery.
- Introduction of log sheets in all multiday fishing vessels, which will be highly useful in collecting catch and effort data accurately.

- Development of gear technology for reducing chondrichthyan bycatch in trawls.
- Better implementation of existing laws like Indian Wildlife (Protection) Act, 1972; mesh size regulations etc. and inclusion of additional species in the protected listing.
- Preparation of a National Plan of Action for the conservation and management of elasmobranchs including deep-sea fauna.

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Short Communication

Morphometric characteristics of the pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) caught off Cochin, southwest coast of India

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Abstract

The morphometric characteristics of the pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) are described for the first time from the Indian waters. The specimen was collected at Cochin in August, 2008. The mature male specimen measured 102 cm in total length, 47 cm in disc width, 35 cm in disc length and weighed 2.5 kg. The morphometric characteristics of the specimen were very similar to that described from the North Sea.

Keywords: Dasyatidae, stingray, *Pteroplatytrygon violacea,* Indian Ocean

Introduction

Pteroplatytrygon is a monotypic genus (Compagno, 1999; Nelson, 2006) and one of the six genera of family Dasyatidae (Myliobatiformes), which is the largest stingray family comprising about 68 species. In the Indian waters, 32 rays including 18 species of Dasyatidae have been reported (Raje *et al.,* 2002, 2007) and the presently described species *Pteroplatytrygon violacea* is a new addition. It was earlier considered as a rare species occurring only in the Mediterranean Sea (Tortonese, 1956), but later its distribution in the Indian, Pacific and Atlantic Oceans has been reported (McEachran and Capape, 1984; Mollet, 2002; Domingo *et al.,* 2005; Ellis, 2007; Froese and Pauly, 2008). However, reports from the Indian Ocean are very rare and restricted to the waters off South Africa and eastern Indonesia (White and Dharmadi, 2007). *P. violacea* has been reported in the exploratory survey of FORV *Sagar Sampada* along the southwest coast of India (Jayaprakash *et al.,* 2006) and in the fishery survey of *Matsya Vrusti* (Anon, 2007). This communication gives the first report on the morphometric characteristics of *P. violacea* from the Arabian Sea.

Material and methods

The pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) was collected from the Cochin Fisheries Harbour, Kerala in August 2008. The mature male specimen was obtained as by-catch from a tuna gillnetter, which operated at a depth of about 150 m. It measured 102 cm in total length (TL), 47 cm in disc width (DW) and 35 cm in disc length (DL) and weighed 2.5 kg. The morphometric measurements of the specimen were measured with a Mitutoyo digital vernier caliper with an accuracy of 0.5 mm. Morphometric characteristics were compared with the specimen from North Sea (BMNH 2007.7.3.1), which is deposited in the British Museum of Natural History (Ellis, 2007). The present specimen has been deposited in the National Marine Biodiversity Referral Museum at CMFRI, Cochin.

Results and Discussion

The pelagic stingray *P. violacea* (Bonaparte, 1832) is found in the open oceans and inshore bays. It is the only whiptail stingray known to inhabit epipelagic waters of oceans (Wilson and

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Short Communication

Morphometric characteristics of deepwater stingray *Plesiobatis daviesi* (Wallace, 1967) collected from the Andaman Sea

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Abstract

The present paper reports on the morphometric characteristics of two specimens of *Plesiobatis daviesi* collected during the deep-sea fishery resource survey of FORV *Sagar Sampada* in the northeastern Andaman Sea off Diglipur (13^{0} 14' N lat; 93^{0} 09' E long.) at 320 m depth and off Mayabandar (12^{0} 48' N lat; 93^{0} 07' E long.) at 369 m depth.

Keywords: Andaman Sea, deepwater stingray, *Plesiobatis daviesi*

Introduction

Plesiobatis daviesi (Wallace, 1967) belongs to monotypic family Plesiobatidae (Rajiformes) which was established by Nishida (1990). The species was formerly included under the genus *Urotrygon* (Nelson, 2006). *P. daviesi* is well distributed in the Indo-West and Central Pacific Oceans from South Africa to Hawaii (Froese and Pauly, 2009). Nair and Soundararajan (1973) reported *P. daviesi* (female; 534 mm TL) for the first time from Indian waters off Mandapam in the Gulf of Mannar (08^{0} 58' N lat. 79^{0} 16' E long.), southeast coast of India. Like most of the deep-sea organisms, studies on deepwater stingray *P. daviesi* are limited. This communication presents the morphometric characteristics of two female *P. daviesi* specimens collected from the northeastern Andaman Sea.

Material and Methods

An exploratory deep-sea fishery survey (cruise: No. 252) was carried out by FORV *Sagar Sampada* in the Andaman Sea (Fig. 1) of the Indian EEZ during 2007. Trawling was carried out during daytime using EXPO and HSDT nets at depths ranging from 300 to 700 m. A female *P. daviesi* measuring 156 cm total length (TL) with two spines, disc width 78 cm and weighing 15 kg (Fig. 2 and 3) was collected from the northeastern Andaman waters off Diglipur (13^{0} 14' N lat; 93^{0} 09'E long.) at 320 m depth and another one with a single spine measuring 92.5 cm TL and weighing 3 kg was collected off Mayabandar (12^{0} 48' N lat; 93^{0} 07' E long.) from 369 m depth. The specimens were identified following Wallace (1967) and Compagno (1986). Morphometric measurements were taken from formalin preserved (5%) specimens and comparisons (as % of TL) with earlier reports were made. Specimens were deposited in the National Biodiversity Referral Museum, CMFRI, Cochin, India (GA.7.6.1.1).

Results and Discussion

P. daviesi is mainly found on continental and insular slopes at a depth of about 275-680 m and is reported to attain at least 270 cm TL (Compagno, 1986; Nelson, 2006; White *et al.,* 2006). *P. daviesi* can be identified from the following characters: snout pointed, broadly angular and markedly produced; snout length > 6 times orbit diameter, tail with a lobe-like caudal fin, upper and lower caudal present. No dorsal fin or skin folds on side or undersurface of tail. Upper surface of the disc covered with prickles. The morphometric characteristics of the present specimens match with the representative described from South African waters even though slight variations were observed in certain characteristics (Table 1). This includes the

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New distributional records of deep-sea sharks from Indian waters

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Abstract

This paper reports the first documented record of three deepwater sharks from Indian waters *i.e.*, *Hexanchus griseus* (Hexanchidae), *Deania profundorum* (Centrophoridae), pygmy false catshark (undescribed) (Pseudotriakidae) and presents a taxonomic account of smooth lanternshark, *Etmopterus pusillus* (Etmopteridae) and leafscale gulper shark, *Centrophorus squamosus* (Centrophoridae), caught by hooks & line units operated in the Arabian Sea, west coast of India and landed at Cochin Fisheries Harbour (Kerala), southwest coast of India.

Keywords: Deep-sea sharks, new reports, Arabian Sea, Indian EEZ

Introduction

The Arabian Sea with its unique ecological features such as position between two land masses, presence of islands, features like oxygen minimum zone (OMZ), circulation pattern, currents, influence of monsoon and high saline water intrusion from Persian Gulf and Red Sea etc. supports a very diverse ichthyofauna. Reports on the diversity of deep-sea fish fauna especially that on deep-sea chondrichthyans from Indian waters are very few. Raje *et al.* (2007) listed 47 species of sharks in commercial landings along the Indian coast mainly from catches made within 100 m depths. However elasmobranchs are also known from deeper waters and probably many species, which are not yet recorded, occur in the unexploited/underexploited deep waters of the Indian EEZ.

The targeted deep-sea shark fishery in Indian waters, especially along the southwest and southeast coasts of India started lately after 2002 by the multiday shark fishermen of Thoothoor (Tamilnadu). The fishery targets gulper sharks (Centrophoridae) but many other deep-sea chondrichthyans occur as by catch, which were dominated by bramble shark, *Echinorhinus brucus* and chimaera, *Neoharriotta pinnata* besides several small sized deep-sea sharks, skates and rays which are often discarded. Cochin Fisheries Harbour (Kerala), is a major fishing base where chondrichthyans which are caught along the entire west coast of India by multiday deep-sea trawlers, longlines and hooks & line units are landed throughout the year. The species described in this communication were captured by hooks & line units specifically targeting for deep-sea sharks operated off southwest coast of India at depths beyond 250 m. Deep-sea sharks, *Hexanchus griseus* (Hexanchidae), *Deania profundorum* (Centrophoridae) and pygmy false catshark (undescribed) (Pseudotriakidae) represent new species records from the Indian EEZ. In this paper these species are described and the occurrence of *Etmopterus pusillus* and *Centrophorus squamosus* off southwest coast of India is confirmed.

Material and Methods

During weekly observations of fish landings at Cochin Fisheries Harbour (CFH), Cochin, southwest coast of India, specimens of *Hexanchus griseus, Centrophorus squamosus, Deania profundorum, Etmopterus pusillus* and pygmy false catshark (undescribed) were collected from the deep-sea hooks & line landings operated in the Arabian Sea during April 2008. Species identification was based on Compagno (1984), Smith and Heemstra (1986), Shirai and Tachikawa (1993) and Compagno *et al.*

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Aspects of the biology of the pygmy ribbontail catshark *Eridacnis radcliffei* (Proscylliidae: Carcharhiniformes) from the south-west coast of India

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Biological data are presented for the pygmy ribbontail catshark *Eridacnis radcliffei* based on specimens collected from the by-catch of the commercial deep-sea shrimp trawl fishery operating in the Arabian Sea off the south-west coast of India. A total of 549 individuals, from 101 to 257 mm total length (L_T) and 2·2 to 56 g, were collected. The L_T at first maturity (L_{T50}) of females and males was estimated at 183 and 170 mm, respectively, and analysis of stomach contents revealed that *E. radcliffei* feeds primarily on crustaceans.

Key words: Arabian Sea; diet; maturity; reproductive biology.

The pygmy ribbontail catshark *Eridacnis radcliffei* Smith 1913 (Proscylliidae: Carcharhiniformes) is one of the smallest living shark species and the smallest carcharhinoid shark, reaching only 257 mm total length (L_T). *Eridacnis radcliffei* was described from the Philippines and has a scattered distribution in the Indo–West Pacific, from East Africa to the Philippines. It occurs on or near muddy bottoms on the continental shelf and slope at depths of 71–766 m, and is reported to be abundant at several locations, *i.e.* off southern India and the Philippines (Compagno *et al*., 2005*a*). The *IUCN Red List of Threatened Animals* lists the status of *E. radcliffei* as 'Least Concern' as it is a small species that is not targeted by fisheries and inhabits a wide range of water depths including depths not available to commercial fisheries (McCormack *et al*., 2009). Of the three species in the *Eridacnis* genus, *E. radcliffei* is by far the most widely distributed with a geographical range extending from waters off Tanzania to the Philippines (Compagno *et al.,* 2005*a*). In comparison, Cuban ribbontail catshark *Eridacnis barbouri* (Bigelow & Schroeder 1944) is known from Florida and Cuba, and African ribbontail catshark *Eridacnis sinuans* (Smith 1957) from the east coast of South Africa. Compagno *et al*. (2005*b*) noted

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Article

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Rediscovery and description of the quagga shark, *Halaelurus quagga* (Alcock, 1899) (Chondrichthyes: Scyliorhinidae) from the southwest coast of India

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Abstract

The Quagga shark *Halaelurus quagga* (Alcock, 1899) is one of the poorest known scyliorhinid (Carcharhiniformes) sharks of the world, described from a single specimen collected from the Arabian Sea coast of India (off Malabar). Since its description, the only other published reports of this species are of specimens from Somalia. This paper reports on *H. quagga* from Indian waters, more than 100 years after its description, and only the third report of specimens of this species globally. A re-description of *H. quagga* is also provided based on the recent Indian specimens.

Key words: Rediscovery, *Halaelurus quagga,* Scyliorhinidae, Carcharhiniformes, Arabian Sea, India

Introduction

Indian waters support a diverse chondrichthyan fauna consisting of more than 150 known species (Raje *et al.,* 2007; Akhilesh *et al.*, in prep.), with the actual number probably being higher since there are no recent, exclusive studies on this group from the region. Of the reported shark species, some have a geographic distribution range restricted to the western Indian Ocean (Compagno *et al.,* 2005).

The Scyliorhinidae (Carcharhiniformes) is one of the largest and diverse shark families with 17 genera, 146 recognized and described species, and at least 19 recognized but undescribed species to date (Human & D.A. Ebert, unpub. data), which is continually expanding with several species being described since 2005 (Last *et al.,* 2008; Froese & Pauly, 2010). The Scyliorhinidae consist of very small sharks that have no commercial importance and very rarely occur as bycatch in shark fisheries of India.

Ten scyliorhinid shark species are reported from the Arabian Sea, of which two belong to the genus *Halaelurus*: *H. boesemani*, and *H. quagga* (Manilo & Bogorodsky, 2003; Human, in prep.). Compagno *et al.* (2005) recognised that the occurrence of *H. natalensis* needed confirmation; however previous reports of *H. natalensis* from the Arabian Sea are erroneous (Human, in prep.).

After the original description of *H. quagga* from the Arabian Sea coast of India (off Malabar), the only other reports of *H. quagga* came from off Somalia (Springer & D'Aubrey, 1972; Springer, 1979). The holotype is the only previously known specimen from India and this article presents the second report of *H. quagga* from Indian waters, over 100 years after its description. This is also the first report of a female and egg case for the species, and provides a re-description based on recent specimens collected from the southwest coast of India (Kerala coast), which are deposited at the Marine Biodiversity Museum at the Central Marine Fisheries Research Institute (CMFRI), Cochin, Kerala.

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Landings of whale sharks *Rhincodon typus* Smith, 1828 in Indian waters since protection in 2001 through the Indian Wildlife (Protection) Act, 1972

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Abstract Since 28th May 2001, Whale shark *Rhincodon typus* Smith, 1828 have received the highest protected status for an animal in India through the Indian Wildlife (Protection) Act, 1972 Schedule-1. However, landings have still been recorded off the Indian coast since 2001, mostly as incidental bycatch in commercial fishing operations, and other sightings have also been reported. In the 1990's, a targeted whale shark fishery existed off the Gujarat coast following increased demand for the flesh in some other Asian countries. Since the ban, landings of whale sharks have decreased substantially with only 79 recorded between 2001 and 2011. Landings were recorded in each year and in each month of the year with the highest landings in January and February. Between 2001 and 2011, the smallest specimen reported from Indian waters was a 94 cm TL individual and the largest was a 13.7 m TL individual, with most individuals recorded in the 4–6 m TL size class. Small juveniles of less than 3 m TL are rarely recorded in the literature and appear to be rarely observed globally. Between 2006 and 2011, seven juveniles of less than 3 m TL were recorded from two landing sites. Despite the continued landing of whale sharks along the Indian coasts since 2001, the protection of this species appears to have substantially reduced the catches with only incidental landings and strandings now evident. The protection status of whale sharks in India is generally well understood by fishers, but still there is need for further education regarding the current national legislation and vulnerability of the species.

Keywords India · Whale shark · *Rhincodon typus* · Landings · Strandings · Indian Wildlife Protection Act, 1972

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Introduction

The whale shark *Rhincodon typus* Smith 1828 (Orectolobiformes: Rhincodontidae) is the largest species of fish and has a circumglobal distribution in all tropical and temperate waters, excluding the Mediterranean Sea (Compagno et al. 2005). It is an epipelagic and neritic species found in coastal to oceanic waters and

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Notes on the Indian swellshark, *Cephaloscyllium silasi* (Scyliorhinidae: Carcharhiniformes) from deep waters off the west coast of India

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The Indian swellshark Cephaloscyllium silasi *is a poorly known deep water scyliorhinid (Carcharhiniformes) shark described from the south-west coast of India (off Kollam). Since the original description, reports of this species are absent due to rarity of specimens. This paper presents the first report of its egg case and also provides detailed morphological data about* C. silasi *based on recently collected materials.*

Keywords: morphology, *Cephaloscyllium silasi*, Scyliorhinidae, Carcharhiniformes, by-catch, Arabian Sea, India

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INTRODUCTION

Scyliorhinidae (Carcharhiniformes) is one of the largest and most diverse shark families with 17 genera, 146 recognized and described species and expanding (Yano *et al.*, 2005; Last *et al.*, 2008; Clark & Randall, 2011). Scyliorhinidae comprise very small sharks and have no importance in the commercial fishery of India. Ten scyliorhinid sharks are reported from the Arabian Sea, of which *Cephaloscyllium* is represented by only two species: Indian swellshark *Cephaloscyllium silasi* (Talwar, 1974); and balloon shark *Cephaloscyllium sufflans* (Regan, 1921) (Manilo & Bogorodsky, 2003).

For a long period after the original description by Talwar (1974) the validity status of *C. silasi* was under question; Springer (1979) in his review of the Scyliorhinidae family included *C. silasi* as a synonym of the quagga catshark *Halaelurus quagga* (Alcock, 1899). Compagno & Talwar (1985) discussing the generic character positioned the species in *Cephaloscyllium*. After the original description, reports of *Cephaloscyllium silasi* from the Arabian Sea coast of the Indian exclusive economic zone (EEZ) are absent. This paper is also the first report of the egg case for the species, and provides a detailed re-description based on recent specimens collected from deep waters off the south-west coast of India (Kerala coast).

MATERIALS AND METHODS

Three specimens of *Cephaloscyllium silasi* were collected occasionally during regular weekly observations of fish landings from 2008–2011 along the south-west coast of India as by-catch of commercial deep-sea shrimp trawlers operating in the Arabian Sea, off Kollam at 200–500 m depths. The specimens were collected from Sakthikulangara Fisheries Harbour (SFH), Kollam (Kerala). Species identification was based on Talwar (1974) and Compagno *et al.* (2005). Morphometric measurements of formalin (5%) preserved specimens were taken by following the method of Compagno (2001). Morphometric measurements for the egg case followed the method of Ebert *et al.* (2006). Tissue samples collected were preserved in 95% ethanol for genetic analysis. DNA was extracted by standard protocols (Miller *et al.*, 1988) and partial sequence information of the mitochondrial gene, cytochrome oxidase subunit I (COI) were generated using primers from Ward *et al.* (2005) for DNA barcoding purposes. Bidirectional sequencing was carried out using an ABI 3730 sequencer. Sequence data were submitted to the NCBI GenBank (Accession number: HM467791).

RESULTS

SYSTEMATICS

Family SCYLIORHINIDAE

Genus *Cephaloscyllium* Gill, 1862

The members of the genus *Cephaloscyllium* Gill, 1862 are known as swell sharks or balloon sharks related to their ability to inflate/swell body by swallowing seawater to deter predation and to settle the body among rocks or crevices (Nakaya *et al.*, 2013). *Cephaloscyllium* can be separated from other species of the family by the lack of labial furrows, presence of supraorbital crests on the chondrocranium, first dorsal fin location behind pelvic origin, second

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