Studies on demersal fish community along the fishing grounds of Goa, West coast of India

Thesis submitted to Goa University

for the degree of Doctor of Philosophy

in

Marine Sciences

by

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I$I !! Shree Ganeshai Namah !! I$I

Dedicated to my family and fishermen community

Statement

As required by the University ordinance OB.9, I state that the present thesis entitled "***Studies on demersal fish community along the fishing grounds of Goa, West coast of India***" is my original contribution and the same has not been submitted on any previous occasion. To the best of my knowledge the present study is the first comprehensive work of its kind from the area mentioned.

The literature related to the problem investigated has been cited. Due acknowledgements have been made wherever facilities and suggestions have been availed of.

Dinesh T. Velip

Certificate

This is to certify that the thesis entitled "***Studies on demersal fish community along the fishing grounds of Goa, West coast of India***", submitted by **Mr. Dinesh Tolu Velip** for the award of Doctor of Philosophy in Marine Sciences is based on his original studies carried out by him under my supervision. The thesis or any part thereof has not been previously submitted for any degree or diploma in any Universities or Institutions.

Prof. C.U. Rivonker
Research Guide
Department of Marine Sciences
Goa University

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General Introduction

1.1. Background information

The word 'Demersal' means 'dwelling at or near the bottom of a water body' and pertaining to fish as in 'demersal fish' and 'fishery'. Demersal fishes inhabit lower regions of the water column and the underlying substratum of mud, sand, gravel, rocks, etc. In coastal waters, these communities are found at shallow depths (< 30 m), hence there is no clear distinction between demersal and pelagic fishery. The higher productivity and habitat heterogeneity of benthic or demersal environment in nearshore coastal waters and associated habitats (estuaries, mudflats, mangroves, sea grass meadows etc.) supports rich and diversified flora and fauna (Blaber *et al.*, 2000; Beck *et al.*, 2003). All organisms inhabiting these habitats interact among themselves for their survival, proliferation and for trophic needs through the formation of linkages, associations or assemblages representing to distinct communities (Cury *et al.*, 2001; Pascual and Dunne, 2006).

The composition and structure of a fish community is determined by biological processes such as feeding and reproduction which are vital to their existence and proliferation (Muchlisin, 2014). The ecological functioning of fish assemblages greatly depends on the trophic status of the species (Kulbicki *et al.*, 2005). Food and feeding ecology enables to determine the roles of different species within the ecosystem (Hajisamae *et al.*, 2003) and also helps to understand the effects of competition and predation on community structure (Krebs, 1999). On the other hand, the population dynamics is determined by the reproductive potential of a species within an assemblage or community (Nikolsky, 1969; Hilborn and Walters, 1992; Hunter *et al.*, 1992), which in turn is determined by the state of energy, reserves (Kasiri *et al.*, 2012). The reproductive biology of a species determines its productivity, and hence a population's resilience to exploitation and other human-induced changes (King, 1995; Mayol *et al.*, 2000).

The coastal regions up to 60 km from the coastline are densely populated by around 60 % of the world's human population (UNEP, 1996; Adhikari *et al.*, 2010), and around 20 % of the population is known to inhabit biodiversity hotspots (Cincotta *et al.*, 2000). Consequently, the coastal marine ecosystems are vulnerable to various anthropogenic activities such as over-exploitation of resources, destruction, pollution and alteration of natural habitats (estuaries, mangroves, beach vegetation, mudflats) (Kaiser *et al.* 2002; Kennish, 2002; Orth *et al.*, 2006; Vennila *et al.*, 2014) in order to suffice the needs of coastal population. Moreover, these ecosystems are also threatened by the natural calamities such as cyclones, climatic shifts, etc. resulting in widespread and deleterious consequences (Senapati and Gupta, 2014). Among the anthropogenic activities, bottom trawling is one of the most destructive fishing activity, leading to alteration of microhabitats on the seafloor as well as indiscriminate removal and large scale mortality of non-targeted fauna and juveniles of targeted species in the form of by-catch (Labropoulou and Papacostantinou, 2005; Velip and Rivonker, 2015b). Long-term trawling activity and the resultant large scale by-catch generation may lead to reduction in species diversity (Bianchi *et al.*, 2000; Hall *et al.*, 2000) and alterations in demersal community structure (Longhurst and Pauly, 1987; Jackson *et al.*, 2001; Jennings *et al.*, 2005).

India with a coastline of 8118 km and 2.02 million km^2 of Exclusive Economic Zone (EEZ) is a rich abode of variety of marine floral and faunal assemblages (Venkataraman and Wafar, 2005). The west coast of India is characterized by rocky shores and headlands, and experiences intense upwelling associated with the Southwest monsoon (Madhupratap *et al.*, 2001). Goa, along the central west coast of India, with a coastline of about 105 km and an EEZ of around 90,850 km^2 (Wagle, 1993; Gaonkar *et al.*, 2006) is marked with diverse marine habitats including reefs (Rodrigues *et al.*, 1998), mangroves, mudflats, bays, estuaries (Ansari *et al.*, 1995; Shetye *et al.*, 2007), and sandy and rocky shores (Hegde *et al.*, 2016). These habitats inhabit diversified demersal faunal assemblages which support large-scale marine fisheries along the nearshore coastal waters forming the potential fishing grounds of Goa. The fishery potential of this region has also been emphasized earlier by Rao and Dorairaj (1968), Prabhu and Dhawan (1974) and Ansari *et al.* (1995). These fishing grounds are subjected to continuous exploitation by mechanized trawlers throughout the year except during southwest monsoon owing to fishing ban (Goa, Daman and Diu Marine Fishing Regulation Rules, 1981) along the region.

In Goa, around 90 % of the population consumes fish as their principal protein source and around 30,225 people derive their livelihood directly from fishery resources (Fish Trails, 2015). In recent years, mechanized fishing activities have put the fishery resources of Goa under tremendous pressure resulting in indiscriminate removal and large-scale mortality of demersal fauna (Velip and Rivonker, 2015b). Apart from this, the coastal waters are subjected to varied sources of anthropogenic inputs (dredging, construction, effluent discharge, sewage pollution, transportation, etc.) leading to habitat degradation and consequent loss of biodiversity which on large scale could alter normal ecosystem functions and may result in population declines. The severity of the above issues demands a holistic approach to have better insight on eco-biology of demersal fisheries and management of trawl by-catch. Therefore, continuous monitoring of the demersal faunal community of the region along with a regular update of demersal faunal database is mandatory.

1.2. Literature review

Review of literature pertaining to Indian marine fauna revealed several pioneering contributions by European naturalists (Bloch, 1785, 1787, 1801; Lacépède, 1803; Russell, 1803; Hamilton, 1822; Bleeker, 1853; Blyth, 1858, 1860a, b; Day, 1865) during 18th and 19th centuries. Sir Francis Day (1876–1878, 1888, 1889) provided a detailed account of 1100 marine and estuarine species from the Indian sub-continent. Thereafter, Alfred William Alcock (1895, 1896, 1898a, 1899a, b, 1900) carried out prolific taxonomic work on 605 brachyuran species of India and adjoining British colonies. Alcock also prepared descriptive catalogues of 169 deep-sea fishes (1899c), 27 dromidean brachyura (1901a), 117 macrura and anomala (1901b), 89 anomura (1905), and 21 penaeid prawns (1906). Gardiner (1903 – 1906) described the marine fauna of Lakshadweep and Maldives archipelagos. Kemp (1915) described the marine fauna of Chilka Lake. Post-independence efforts (Silas *et al.*, 1983; Mookherjee, 1985; Kurian and Sebastian, 1986; Rao *et al.*, 1992; Rao and Rao, 1993; Rao, 2003; Raje *et al.*, 2007) were based on regional studies of various fish and shellfish fauna.

Demersal marine fish communities have been studied worldwide (Elliot *et al.*, 2007), a majority of which represent the Indo-Western Pacific fish assemblages (Rainer and Munro, 1982; Wallace *et al.*, 1984; Blaber *et al.*, 1994, 1995; Loneragan *et al.*, 1989; Blaber and Milton, 1990; Potter *et al.*, 1990; Ansari *et al.*, 1995, 2003; Harrison and Whitfield, 1995, 2006; Martin *et al.*, 1995; Bianchi, 1996; Potter and Hyndes, 1999; Kuo *et al.*, 2001; Hajisamae *et al.*, 2003; Harrison, 2003; Khongchai *et al.*, 2003; Lugendo *et al.*, 2007; Haicheng and Weiwei, 2009; Hajisamae, 2009; Yemane *et al.*, 2010) of pristine as well as highly impacted coastal habitats through spatio-temporal and trophic analyses of the constituent fish populations. Few of these studies (Loneragan *et al.*, 1989; Martin *et al.*, 1995; Kuo *et al.*, 2001; Ansari *et al.*, 2003; Lugendo *et al.*, 2007; Haicheng and Weiwei,

2009) demonstrated the role of environmental anomalies in determining the composition of biotic communities.

Studies from European temperate and boreal waters Pomfret *et al.*, 1991; Elliot and Dewailly, 1995; Marshall and Elliot, 1998; Mathieson *et al.*, 2000; Gordo and Cabral, 2001; Lobry *et al.*, 2003; Prista *et al.*, 2003; Labropoulou and Papaconstantinou, 2005; Leitao *et al.*, 2007; Selleslagh and Amara, 2008) revealed the importance of salinity, temperature and depth in structuring the species assemblages of these environments.

Published literature from African estuaries (Albaret *et al.*, 2004; Guillard *et al.*, 2004; Simier *et al.*, 2006) revealed spatio-temporal variability in fish diversity and distribution within the Gambia estuary in relation to environmental variables and suggested the use of this estuarine system as a reference to study the effects of climatic perturbations on the estuarine fish communities.

Studies on fish assemblages from the Atlantic coast of Americas (Yanez-Arancibia *et al.*, 1980; Paiva-Filho *et al.*, 1987; Villarroel, 1994; Araujo *et al.*, 1998, 2002; Garcia *et al.*, 1998; Araujo and Costa de Azevedo, 2001; Nagelkerken and van der Velde, 2004; Barletta *et al.*, 2008; Gonzalez-Castro *et al.*, 2009) revealed the role of salinity in determining the species composition, abundance and diversity of demersal fish communities. On the other hand, literature from the Pacific coast of the Americas (Allen and Horn, 1975; Bartels *et al.*, 1983; Amezcua-Linares *et al.*, 1987; Monaco *et al.*, 1992; Wolff, 1996; Gonzalez-Acosta *et al.*, 2005) suggested that interplay between the physico-chemical (salinity, depth, temperature and proximity to the sea) and biological factors (food availability, reproduction and migration patterns) determined composition and structure of demersal fish communities.

Studies pertaining to demersal environment indicated that the productivity of this region in coastal waters is governed by both the physico-chemical and biological factors which in turn enhance the demersal fisheries. These includes, the primary productivity (phytoplankton) of overlying waters (Flint and Rabalias, 1981; Hobson *et al.*, 1995); bioturbation (Welsh 2003); riverine runoff, fecal pellets and carcasses of surface dwelling organisms, bottom topography or habitat heterogeneity giving favourable substratum and sufficient food for growth and proliferation of benthic organisms (Steele, 1974; Mills and Fournier, 1979; Smetacek 1985; Sebens, 1991; Azevede *et al.*, 2006). Thus, the surface and benthic productivity and the processes like bioturbation contributes to enhancement of demersal fishery through bentho-pelagic coupling of food chain or direct trophic linkages (Steele, 1974; Mills and Fournier, 1979; Welsh 2003; Lassalle *et al.*, 2011; Baustian *et al.*, 2014). Demersal fishery accounts to around 45 % to the Indian fisheries (CMFRI, 2015a). Major demersal fishery resources along the Indian coast includes catfishes, lizardfishes, threadfin breams, croakers, silver bellies, soles, penaeid and non-penaeid prawns, cephalopods etc. (CMFRI, 2015a). The review also revealed comprehensive studies pertaining to biological aspects of Indian finfishes (food and feeding, reproductive biology) attempted by several researchers to understand the complex relationships among finfishes and their population dynamics. Several studies have elucidated food and feeding dynamics and trophic interactions among different groups of finfishes (Bapat and Bal, 1952; Kuthalingam, 1965; Suseelan and Nair, 1969; Nair, 1980; Jayaprakash, 2000; Vivekanandan, 2001; Abdurahiman *et al.*, 2007; Manojkumar, 2008; Sudheesan *et al.*, 2009; Abdurahiman *et al.*, 2010; Thangvelu *et al.*, 2012 and Rohit *et al.*, 2015). Apart from this, there have been several studies dealing with reproductive biology of finfishes (Bhusari, 1975; Muthiah, 1982; Ghosh *et al.*, 2009; Abraham *et al.*, 2011; Ghosh *et al.*, 2014; Rajesh *et al.*, 2015 etc.) including maturity, spawning and breeding (Devadoss, 1969, 1979; Murty and Ramalingam, 1986; Narasimham, 1994; Manojkumar, 2011; Raje *et al.*, 2012) and fecundity (Rao, 1967; Balan, 1965; Rao, 1986; Manojkumar, 2011) along the west coast of India.

Rapid development of mechanized fishing activities has put tremendous fishing pressure on marine ecosystems resulting in generation of huge amount of 'by-catch', especially through bottom trawling, with deleterious consequences to commercial fisheries. Its severity is maximised in tropical coastal waters (Bijukumar and Deepthi, 2006) owing to high species diversity. The bottom trawling is widely reported to exert several negative impacts on aquatic ecosystem including species and biomass loss (Bianchi *et al.*, 2000; Hall *et al.*, 2000; Velip and Rivonker, 2015b), alterations in community structure (Jackson *et al.*, 2001; Jennings *et al.*, 2005), trophic displacement (Murawski, 1995), physical damages to ecosystem destroying vital benthic habitats (Bijukumar and Deepthi, 2006; Rao et al., 2013) etc. However, only few studies (Bijukumar and Deepthi, 2006; Dineshbabu *et al.*, 2010, 2012; Gibinkumar *et al.*, 2012) have attempted to address the issues pertaining to bottom trawling and its associated impacts on coastal ecosystem especially through bycatch along the Indian coast. Apart from this, few studies have also stressed upon usage of by-catch reduction devices (Sabu, 2008; Boopendranath *et al.*, 2010; Pravin *et al.*, 2011) as well as its utilization (Zynudheen *et al.*, 2004; Dineshbabu *et al.*, 2013) along the Indian coast.

Published literature on the demersal faunal resources of Goa (Rao and Dorairaj, 1968; Prabhu and Dhawan, 1974; Ansari *et al.*, 1995) suggests that there exists a structural and seasonal variation in the distribution and occurrence of these resources. Further, Ansari *et al.* (2003) studied the environmental influence on trawl catches of bay-estuarine systems of Goa and stated that the environmental variables such as dissolved oxygen (DO), sediment pH, chlorophyll *a*, particulate organic carbon, seston and macro-benthic density control the temporal variations in trawl catches. Shamsan and Ansari (2010) studied the reproductive biology of *Sillago sihama* and Hegde *et al.* (2014) attempted to study the feeding ecology of elasmobranchs from Goan waters. Additionally, a recent study by Hegde *et al.* (2016) revealed seasonal variations in habitat selection and catch trends of sciaenids. Apart from these, the studies by Padate *et al.* (2010a, b), Kumbhar and Rivonker (2012), Hegde and Rivonker (2013), Hegde *et al.* (2013), Padate *et al.* (2013a, b) and Velip and Rivonker (2015a) have updated the information regarding the species composition and bio-geography of few species from the region. The review suggested that the available information on demersal fishery resources of Goa is preliminary and does not provide a complete understanding of seasonal and spatial variations. Moreover, there is a scarcity of literature pertaining to eco-biology and by-catch studies from the coast.

It is apparent from the above-cited literature that the information on various aspects of demersal faunal resources along the coast is scanty and does not provide adequate information of community structure, by-catch and eco-biological aspects. The existing lacunae in the available information on demersal faunal resources of Goa restrict sustainable exploitation and efficient management of these resources. Against this background, the present study was designed to focus primarily on demersal fish community structure, spatio-temporal variations, by-catch composition, trophic dynamics and reproductive aspects of demersal faunal resources of Goa with the following objectives:

1.3. Objectives

1. Seasonal variation of demersal fish and by – catch composition.
2. To study biological processes of few selected species.
3. To study the trophic relations among co-inhabitant species.

Chapter 2 -

Materials and Methods

2.1. Study area

Goa, with a coastline of about 105 km along NNW–SSE (Lat:14°53'54" N to 15°48'00" N, Long:73°40'33" E to 74°20'13" E), facing the Arabian Sea (Figure 2.1) exhibit diverse geological and ecological features forming an integral part of the central west coast of India (Wagle, 1993). It has a continental shelf of about 10 million hectares and potential fishing area of around 20,000 km^2 (Monteiro, 2006). The seafloor comprises of silty-clay sediment up to 50 m and sandy-silt substratum from 50 to 100 m depth (Modassir and Sivadas, 2003) with an average slope of 1.50 m km^{-1} up to approximately 55 m depth. The bathymetry is marked with patches of coral reefs (Rodrigues *et al.*, 1998) and submerged rocks extending from the cliffs and promontories along the adjacent rocky shores (Wagle and Kunte, 1999). The overlying coastal waters perennially receive nutrient-rich freshwater influx from the adjoining estuaries, particularly from the Mandovi–Zuari estuarine complex (Wafar *et al.*, 1997; Qasim, 2003). The two major rivers namely the Mandovi and the Zuari are connected to the Arabian Sea by Aguada (4 km long) and Mormugao bays (14 km long),

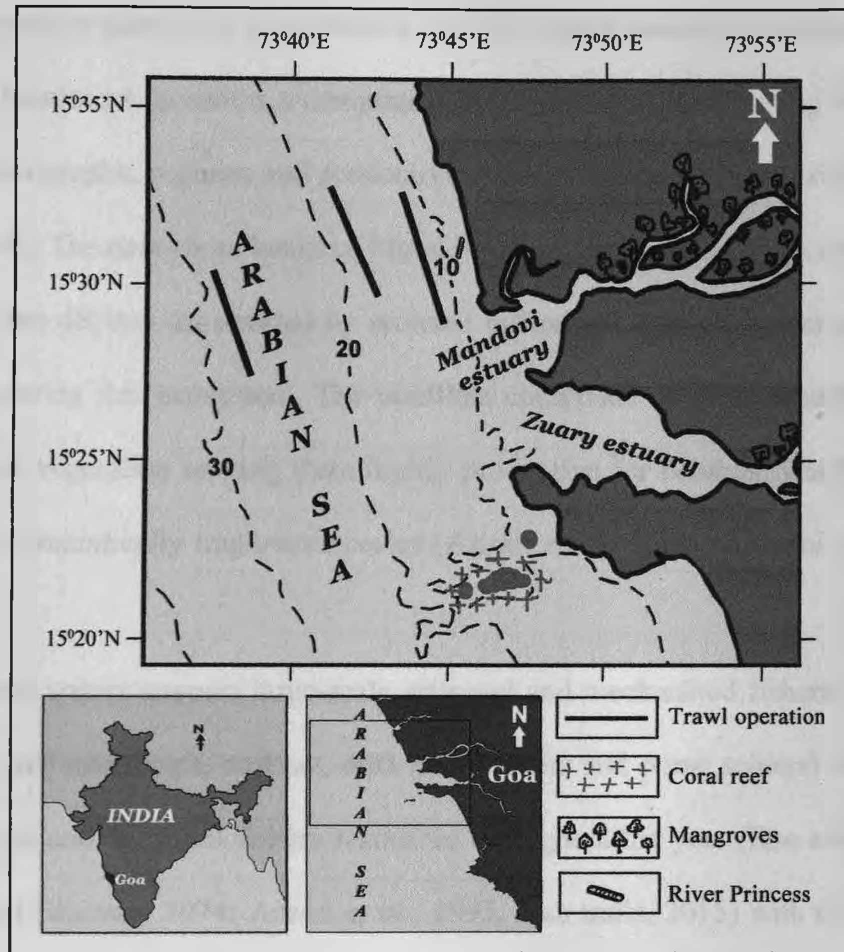


Figure 2.1. Map of the study area indicating trawl operations

respectively (Rao and Rao, 1974; Shetye *et al.*, 2007). The tides in the region are of semi-diurnal nature (Qasim and Sen Gupta, 1981) and carry saltwater up to a considerable distance upstream.

The Goan coast receives maximum precipitation and the coastal waters experience strong upwelling during Southwest monsoon accompanied by stormy weather resulting in marked differences in hydrographic regimes and productivity, thus contributing to the rich fishery (Ansari *et al.*, 1995). The near shore banks of Mandovi-Zuari estuarine complex are filled with silt, clay and the detritus transported by riverine influx and flanked by dense mangrove vegetation rendering this ecosystem. The mudflats comprises of loose muddy soil bordered by mangrove vegetation making them highly productive for benthos, which further support variety of economically important species (Ansari *et al.*, 1995; Kulkarni *et al.*, 2003).

The adjacent coastal waters support large-scale artisanal and mechanised fisheries (beach seine, shore seine, gill nets, traps, cast net, drift net, trawlers and purse seiners) to exploit the abundant pelagic and demersal fishery resources throughout the year (Rao and Dorairaj, 1968; Prabhu and Dhawan, 1974; Ansari *et al.*, 1995, Fish trails, 2015) with the exception of the 61 day legislative ban on fishing (Goa, Daman and Diu Marine Fisheries Rules, 1981). The mechanization of fishing crafts, especially of bottom trawlers and the subsequent expansion of fishing activity led to intensive exploitation of the fishery resources. Further, the development of fishing jetties and infrastructure for tourism industry and human settlements along with other human activities like mining and the subsequent ore transport along the riverine channels (Nigam *et al.*, 2002), modifications of natural habitats for aquaculture farms (De Sousa, 2007), disposal of sewage (Ramaiah *et al.*, 2007) and agricultural effluents (Sardessai and Sundar, 2007), have exacerbated the pressure on estuarine and nearshore coastal ecosystems.

2.2. Sample collection

The present study involved of three years of fortnightly faunistic surveys onboard single-day commercial shrimp trawler along the near shore coastal waters of Goa, Central West coast of India down to 30 m depth (Figure 2.1). The sampling period extended from November, 2010 to May 2013 with an exception of two months legislative ban from June to July. A 15 m long shrimp trawler employing trawl net with 20 m head and foot rope lengths and mesh sizes of 25 mm at mouth, 15 mm in middle or belly and 9 mm at cod end was towed at a speed of about 2-3 knots for an average of 5 – 6 hours daily. Geographical position of sampling stations was recorded with 12-channel GPS and the corresponding depth was obtained from Naval Hydrographic Chart no. 2022. Altogether 100 trawl hauls were taken during the study with a total effort of 181 hours (Table 2.1).

Once the haul was taken onboard, it was initially examined for species composition and subsequently five random sub-samples of approximately 1 kg each were collected prior to sorting to assess community structure. Thereafter, trash fauna were also sub-sampled in similar way. Quantitative assessment (weighing) of different target and commercial by-catch faunal groups and discarded by-catch (trash fauna) was done on-board fishing trawler. Additionally, specimens of different sizes of selected species were collected to study biological aspects. All the samples were temporarily preserved in ice and brought to the laboratory. At the laboratory, the abundance of representative species was quantified after sorting and identifying the mixed catch. Additionally, lengths of discarded by-catch samples were also recorded.

In addition to these, water samples were collected to study environmental parameters (temperature, dissolved oxygen (D.O.) and salinity) at the beginning of trawl haul. Water temperature was recorded on-board using mercury thermometer. Water samples for salinity were collected in 200 ml plastic bottles, and those for estimation of

Table 2.1. Details of trawl sampling carried out along the potential fishing grounds of Goa

Sr. No.	Date	Area	Geographical position	Depth (m)	Duration (min)
1	17-11-2010	Off Candolim	15° 08' 54.4" N; 73° 56' 04.4" E to 15° 31' 25.8" N; 73° 44' 42.2" E	5	90
2	17-11-2010	Off Candolim	15° 31' 25.8" N; 73° 44' 42.2" E to 15° 31' 18.7" N; 73° 44' 36.2" E	6	105
3	17-11-2010	Off Candolim	15° 31' 18.7" N; 73° 44' 36.2" E to 15° 31' 17.6" N; 73° 44' 35.9" E	10	110
4	08-12-2010	Off Aguada – Candolim	15° 27' 41.8" N; 73° 49' 59.1" E to 15° 31' 25.1" N; 73° 44' 55.3" E	7	85
5	08-12-2010	Off Candolim – Calangute	15° 31' 25.1" N; 73° 44' 55.3" E to 15° 30' 48.6" N; 73° 45' 38.7" E	7	65
6	08-12-2010	Off Candolim – Calangute	15° 30' 48.6" N; 73° 45' 38.7" E to 15° 32' 05.3" N; 73° 45' 13.1" E	5	105
7	08-12-2010	Off Calangute	15° 32' 05.3" N; 73° 45' 13.1" E to 15° 32' 08.9" N; 73° 45' 06.9" E	7	125
8	25-01-2011	Off Calangute	15° 31' 25.3" N; 73° 44' 42.9" E to 15° 32' 05.1" N; 73° 43' 51.7" E	9 – 10	130
9	25-01-2011	Off Calangute	15° 31' 16.7" N; 73° 44' 06.9" E to 15° 31' 39.3" N; 73° 43' 46.4" E	12	20
10	02-02-2011	Off Candolim – Calangute	15° 30' 23.6" N; 73° 44' 34.1" E to 15° 33' 48.4" N; 73° 42' 43.5" E	7	111
11	02-02-2011	Off Calangute – Baga	15° 33' 48.4" N; 73° 42' 43.5" E to 15° 31' 01.4" N; 73° 43' 51.8" E	11	120
12	02-02-2011	Off Calangute – Baga	15° 31' 01.4" N; 73° 43' 51.8" E to 15° 33' 32.3" N; 73° 42' 26.0" E	10	85
13	16-02-2011	Off Calangute	15° 31' 36.2" N; 73° 44' 46.7" E to 15° 32' 55.4" N; 73° 44' 23.9" E	4	90
14	16-02-2011	Off Calangute	15° 32' 55.4" N; 73° 44' 23.9" E to 15° 31' 21.8" N; 73° 44' 42.3" E	4	107
15	16-02-2011	Off Aguada fort – Siquerim	15° 31' 21.8" N; 73° 44' 42.3" E to 15° 29' 24.0" N; 73° 45' 41.7" E	5	68
16	09-03-2011	Off Calangute	15° 31' 37.0" N; 73° 44' 44.7" E to 15° 32' 28.0" N; 73° 44' 23.1" E	5	118
17	09-03-2011	Off Candolim – Calangute	15° 31' 19.5" N; 73° 44' 25.1" E to 15° 31' 43.6" N; 73° 42' 51.7" E	13	120
18	09-03-2011	Off Candolim – Calangute	15° 32' 14.1" N; 73° 44' 02.7" E to 15° 31' 11.2" N; 73° 44' 22.1" E	7	80
19	11-03-2011	Off Candolim – Baga	15° 30' 55.9" N; 73° 42' 53.2" E to 15° 34' 08.9" N; 73° 41' 16.1" E	16 – 17	145
20	11-03-2011	Off Candolim – Baga	15° 34' 08.9" N; 73° 41' 16.1" E to 15° 30' 31.7" N; 73° 41' 53.8" E	17 – 19	120
21	11-03-2011	Off Candolim – Baga	15° 30' 31.7" N; 73° 41' 53.8" E to 15° 33' 52.8" N; 73° 42' 09.7" E	13 – 19	130
22	11-03-2011	Off Candolim – Baga	15° 34' 31.1" N; 73° 41' 58.8" E to 15° 30' 19.3" N; 73° 41' 49.1" E	13 – 17	150
23	12-03-2011	Off Candolim – Baga	15° 31' 13.4" N; 73° 42' 01.7" E to 15° 34' 20.6" N; 73° 40' 23.4" E	19	140
24	12-03-2011	Off Candolim – Baga	15° 34' 53.0" N; 73° 40' 18.4" E to 15° 30' 45.4" N; 73° 41' 34.9" E	18 – 20	155

25	13-04-2011	Off Candolim – Calangute	15° 30' 09.9" N; 73° 42' 36.4" E to 15° 31' 54.5" N; 73° 45' 09.1" E	2 – 3	60
26	13-04-2011	Off Calangute	15° 31' 54.5" N; 73° 45' 09.1" E to 15° 32' 27.4" N; 73° 44' 20.7" E	2 – 5	85
27	13-04-2011	Off Calangute	15° 31' 24.6" N; 73° 44' 34.9" E to 15° 31' 24.9" N; 73° 44' 30.2" E	4 – 5	100
28	13-04-2011	Off Aguada fort – Candolim	15° 30' 22.9" N; 73° 45' 36.0" E to 15° 28' 54.0" N; 73° 45' 48.5" E	2 – 3	60
29	23-04-2011	Off Aguada fort – Siquerim	15° 28' 83.7" N; 73° 45' 75.5" E to 15° 30' 0.07" N; 73° 45' 60.2" E	2 – 3	75
30	23-04-2011	Off Aguada fort – Candolim	15° 29' 81.5" N; 73° 45' 67.1" E to 15° 30' 48.8" N; 73° 45' 58.7" E	2 – 3	85
31	23-04-2011	Off Aguada fort – Candolim	15° 30' 48.8" N; 73° 45' 58.7" E to 15° 28' 71.4" N; 73° 45' 89.6" E	2 – 3	105
32	23-04-2011	Off Aguada fort – Candolim	15° 30' 42.6" N; 73° 45' 61.5" E to 15° 29' 07.6" N; 73° 46' 03.1" E	2 – 3	50
33	05-05-2011	Off Siquerim – Calangute	15° 30' 01.5" N; 73° 44' 30.7" E to 15° 32' 14.2" N; 73° 43' 33.3" E	5	110
34	28-09-11	Off Siquerim – Calangute	15° 30' 38.5" N; 73° 45' 35.7" E to 15° 31' 37.9" N; 73° 45' 20.6" E	5	45
35	28-09-11	Off Candolim – Calangute	15° 31' 46.6" N; 73° 45' 06.5" E to 15° 30' 38.8" N; 73° 45' 40.0" E	6	45
36	28-09-11	Off Candolim – Calangute	15° 30' 38.8" N; 73° 45' 40.0" E to 15° 31' 44.2" N; 73° 45' 15.0" E	6.5	80
37	28-09-11	Off Aguada fort – Siquerim	15° 30' 09.7" N; 73° 45' 42.3" E to 15° 29' 12.7" N; 73° 45' 48.9" E	6	30
38	16-11-11	Off Siquerim – Calangute	15° 30' 59.5" N; 73° 44' 13.8" E to 15° 32' 30.6" N; 73° 43' 32.3" E	8	110
39	16-11-11	Off Siquerim – Calangute	15° 31' 04.3" N; 73° 44' 17.4" E to 15° 32' 34.9" N; 73° 43' 29.2" E	7	110
40	16-11-11	Off Siquerim – Calangute	15° 31' 03.8" N; 73° 44' 13.4" E to 15° 32' 31.3" N; 73° 43' 47.0" E	7	115
41	07-12-11	Off Candolim – Calangute	15° 31' 43.0" N; 73° 44' 50.2" E to 15° 32' 18.4" N; 73° 43' 50.3" E	10	105
42	07-12-11	Off Calangute	15° 31' 30.3" N; 73° 44' 13.1" E to 15° 31' 37.3" N; 73° 43' 52.3" E	10	130
43	07-12-11	Off Calangute	15° 31' 37.3" N; 73° 43' 52.3" E to 15° 32' 13.7" N; 73° 43' 24.3" E	9	90
44	29-12-11	Off Calangute – Baga	15° 32' 07.6" N; 73° 43' 05.8" E to 15° 34' 44.3" N; 73° 43' 13.1" E	7 – 8	155
45	29-12-11	Off Calangute – Baga	15° 34' 49.5" N; 73° 43' 18.3" E to 15° 32' 56.3" N; 73° 43' 20.2" E	9	150
46	29-12-11	Off Calangute – Baga	15° 32' 33.2" N; 73° 43' 54.7" E to 15° 34' 28.3" N; 73° 43' 09.6" E	7	55
47	11-01-12	Off Calangute – Baga	15° 31' 23.7" N; 73° 44' 27.0" E to 15° 34' 24.9" N; 73° 42' 12.0" E	13	135
48	11-01-12	Off Calangute – Baga	15° 34' 24.9" N; 73° 42' 12.0" E to 15° 31' 45.0" N; 73° 44' 11.2" E	13	125
49	11-01-12	Off Siquerim	15° 31' 45.0" N; 73° 44' 11.2" E to 15° 31' 24.0" N; 73° 44' 20.1" E	13	125
50	21-01-12	Off Candolim	15° 30' 36.9" N; 73° 42' 40.8" E to 15° 31' 15.1" N; 73° 41' 40.5" E	22	160
51	21-01-12	Off Calangute	15° 31' 17.1" N; 73° 43' 21.9" E to 15° 32' 30.1" N; 73° 44' 01.2" E	15	95

52	21-01-12	Off Calangute	15° 32' 30.1" N; 73° 44' 01.2" E to 15° 32' 09.4" N; 73° 44' 14.9" E	11	90
53	10-02-12	Off Candolim – Calangute	15° 31' 09.7" N; 73° 44' 48.5" E to 15° 32' 21.1" N; 73° 44' 30.1" E	10	120
54	10-02-12	Off Calangute	15° 32' 21.1" N; 73° 44' 30.1" E to 15° 32' 42.3" N; 73° 44' 32.1" E	9	120
55	10-02-12	Off Calangute	15° 32' 52.8" N; 73° 44' 26.8" E to 15° 31' 26.8" N; 73° 44' 44.1" E	10	105
56	29-02-12	Off Calangute	15° 31' 04.8" N; 73° 44' 43.7" E to 15° 32' 33.7" N; 73° 44' 03.7" E	12	110
57	29-02-12	Off Candolim – Calangute	15° 31' 04.8" N; 73° 44' 43.7" E to 15° 33' 30.5" N; 73° 42' 28.1" E	14	140
58	29-02-12	Off Calangute	15° 32' 11.7" N; 73° 42' 38.8" E to 15° 31' 31.0" N; 73° 44' 48.4" E	9	90
59	15-03-12	Off Aguada fort – Baga	15° 29' 42.7" N; 73° 41' 01.9" E to 15° 34' 18.5" N; 73° 38' 15.1" E	21	170
60	15-03-12	Off Calangute – Baga	15° 34' 29.1" N; 73° 38' 10.5" E to 15° 32' 02.7" N; 73° 40' 26.0" E	24	130
61	29-03-12	Off Candolim	15° 31' 19.1" N; 73° 44' 03.0" E to 15° 31' 13.5" N; 73° 43' 32.6" E	16	175
62	29-03-12	Off Candolim – Calangute	15° 31' 25.6" N; 73° 44' 24.1" E to 15° 31' 58.9" N; 73° 44' 30.0" E	10	115
63	29-03-12	Off Siquerim – Calangute	15° 31' 58.9" N; 73° 44' 30.0" E to 15° 30' 55.1" N; 73° 45' 30.2" E	5	40
64	11-04-12	Off Aguada fort – Siquerim	15° 29' 49.2" N; 73° 40' 13.5" E to 15° 31' 11.7" N; 73° 38' 31.3" E	24	190
65	11-04-12	Off Siquerim – Candolim	15° 31' 03.2" N; 73° 38' 34.1" E to 15° 30' 03.3" N; 73° 39' 30.7" E	24	170
66	29-04-12	Off Siquerim – Baga	15° 30' 03.9" N; 73° 41' 25.0" E to 15° 34' 30.9" N; 73° 39' 01.3" E	22	175
67	29-04-12	Off Siquerim – Baga	15° 34' 35.4" N; 73° 38' 57.8" E to 15° 30' 41.5" N; 73° 41' 01.9" E	21	140
68	15-05-12	Off Aguada fort – Baga	15° 29' 49.3" N; 73° 42' 29.5" E to 15° 33' 57.6" N; 73° 39' 49.9" E	20	180
69	15-05-12	Off Siquerim – Baga	15° 33' 46.0" N; 73° 39' 47.5" E to 15° 29' 38.8" N; 73° 40' 53.1" E	21	125
70	30-10-12	Off Siquerim – Baga	15° 30' 08.2" N; 73° 43' 05.2" E to 15° 33' 46.8" N; 73° 41' 09.0" E	17 – 18	155
71	30-10-12	Off Siquerim – Baga	15° 33' 46.8" N; 73° 41' 09.0" E to 15° 30' 44.5" N; 73° 42' 01.0" E	16	135
72	30-10-12	Off Siquerim – Baga	15° 30' 44.5" N; 73° 42' 01.0" E to 15° 35' 27.4" N; 73° 41' 32.8" E	17	170
73	30-10-12	Off Siquerim – Baga	15° 35' 27.4" N; 73° 41' 32.8" E to 15° 30' 38.5" N; 73° 43' 10.6" E	17	160
74	05-11-12	Off Siquerim – Baga	15° 30' 59.5" N; 73° 43' 26.7" E to 15° 35' 14.5" N; 73° 41' 02.8" E	16	190
75	05-11-12	Off Candolim – Baga	15° 35' 53.4" N; 73° 40' 46.6" E to 15° 31' 28.5" N; 73° 42' 49.2" E	18	165
76	29-12-12	Off Calangute	15° 31' 59.5" N; 73° 44' 42.4" E to 15° 31' 31.0" N; 73° 44' 43.5" E	8	95
77	29-12-12	Off Calangute	15° 31' 31.0" N; 73° 44' 43.5" E to 15° 32' 36.0" N; 73° 44' 29.2" E	10	135
78	29-12-12	Off Candolim – Calangute	15° 31' 26.6" N; 73° 45' 20.4" E to 15° 30' 47.7" N; 73° 45' 34.6" E	5	25

79	17-01-13	Off Calangute	15° 31' 44.1" N; 73° 44' 41.5" E to 15° 31' 54.6" N; 73° 44' 19.2" E	7	85
80	17-01-13	Off Calangute – Baga	15° 32' 42.3" N; 73° 43' 36.9" E to 15° 34' 31.0" N; 73° 42' 38.5" E	9	175
81	17-01-13	Off Aguada fort – Siquerim	15° 30' 15.4" N; 73° 45' 28.6" E to 15° 29' 11.6" N; 73° 45' 50.7" E	5	40
82	07-02-13	Off Candolim – Calangute	15° 31' 29.9" N; 73° 44' 36.9" E to 15° 31' 21.3" N; 73° 44' 33.6" E	10 – 11	100
83	07-02-13	Off Candolim	15° 31' 09.7" N; 73° 45' 27.7" E to 15° 31' 09.9" N; 73° 45' 29.1" E	4 – 5	45
84	07-02-13	Off Candolim	15° 31' 09.9" N; 73° 45' 29.1" E to 15° 30' 56.5" N; 73° 45' 30.2" E	5	55
85	05-03-13	Off Calangute	15° 31' 36.6" N; 73° 44' 50.8" E to 15° 32' 26.8" N; 73° 43' 49.9" E	10	110
86	05-03-13	Off Calangute – Baga	15° 32' 26.6" N; 73° 43' 10.0" E to 15° 33' 10.3" N; 73° 42' 31.3" E	13	120
87	05-03-13	Off Baga	15° 33' 10.3" N; 73° 42' 31.3" E to 15° 33' 08.6" N; 73° 42' 25.2" E	15	95
88	26-03-13	Off Calangute	15° 31' 39.0" N; 73° 44' 26.8" E to 15° 32' 00.8" N; 73° 43' 49.5" E	11	120
89	26-03-13	Off Calangute	15° 32' 00.8" N; 73° 43' 49.5" E to 15° 32' 54.9" N; 73° 42' 28.6" E	12	130
90	26-03-13	Off Calangute	15° 31' 35.8" N; 73° 45' 19.2" E to 15° 31' 20.2" N; 73° 45' 26.6" E	5	45
91	16-04-13	Off Calangute	15° 31' 33.2" N; 73° 44' 14.0" E to 15° 31' 36.8" N; 73° 43' 13.3" E	12	130
92	16-04-13	Off Candolim – Calangute	15° 31' 36.8" N; 73° 43' 13.3" E to 15° 30' 59.8" N; 73° 41' 47.8" E	13 – 16	110
93	16-04-13	Off Candolim	15° 30' 59.8" N; 73° 41' 47.8" E to 15° 31' 12.1" N; 73° 42' 38.1" E	17	115
94	25-04-13	Off Candolim – Calangute	15° 30' 58.9" N; 73° 45' 31.6" E to 15° 31' 28.4" N; 73° 45' 16.5" E	4 – 5	50
95	25-04-13	Off Calangute	15° 31' 28.4" N; 73° 45' 16.5" E to 15° 32' 40.2" N; 73° 45' 25.5" E	5 – 6	60
96	25-04-13	Off Calangute	15° 31' 35.1" N; 73° 44' 44.0" E to 15° 31' 57.3" N; 73° 44' 25.3" E	8 – 9	100
97	25-04-13	Off Calangute	15° 31' 53.7" N; 73° 44' 47.3" E to 15° 32' 06.8" N; 73° 44' 45.7" E	8 – 9	85
98	16-05-13	Off Calangute	15° 31' 21.6" N; 73° 44' 26.1" E to 15° 31' 26.2" N; 73° 43' 55.5" E	10 – 11	120
99	16-05-13	Off Calangute	15° 31' 26.2" N; 73° 43' 55.5" E to 15° 31' 42.9" N; 73° 43' 23.4" E	12	125
100	16-05-13	Off Candolim – Calangute	15° 31' 42.9" N; 73° 43' 23.4" E to 15° 31' 16.2" N; 73° 43' 39.8" E	9 – 10	100

D.O. was collected in 125 ml borosil glass stoppered bottles. The D.O. samples were fixed on-board using Winkler's reagent and brought to the laboratory. At the laboratory, salinity was estimated using Mohr-Knudsen titration method, and D.O. using Winkler's method (Strickland and Parsons, 1968).

2.3. Taxonomic identification and Morphometry

At the laboratory, representative specimen of each species was washed thoroughly and photographed to elucidate the distinguishing morphological characteristics. In addition, minute morphological details were studied and recorded with the help of Camera lucida diagrams using an Olympus SZX-DA 3 M01330 microscope and stereo-zoom microscope (Olympus SZX – 16). Subsequently, the samples were identified using conventional taxonomic methods involving phenotypic analysis (morphology, colour, texture patterns, meristic counts, etc.) and morphological measurements. Taxonomic identification was done following published taxonomic literature: finfishes (Day, 1878; Fischer and Whitehead, 1974; Fischer and Bianchi, 1984; Talwar and Kacker, 1984; Talwar and Jhingran, 1991); prawns (George, 1980; Kurian and Sebastian, 1986; Chan, 1998); shrimps (Banner and Banner, 1966; Sakai, 1999); stomatopods (Manning, 1978; Manning, 1998); brachyuran crabs (Alcock, 1895, 1896, 1899a, 1900; Chhapgar, 1957; Sakai, 1976; Manning & Holthuis, 1981; Sethuramalingam and Khan, 1991; Wee and Ng, 1995; Jeyabaskaran *et al.*, 2002); anomuran crabs (Khan, 1992; Boyko, 2002); molluscs (Silas *et al.*, 1983; Roper *et al.*, 1984; Apte, 1998; Rajagopal *et al.*, 1998); echinoderms (Clark and Rowe, 1971); sea snakes (Rasmussen, 2001). In addition to published literature, online databases such as Fishbase (Froese and Pauly, 2015), Sealifebase (Palomares and Pauly, 2015), and Hardy's internet guide to Marine Gastropods (Hardy, 2015) were also referred for species identification.

Morphometric analysis involved the measurement of morphological parameters of biological samples, derivation of morphometric retios and subsequent comparison with the published data (Froese and Pauly, 2014; Palomares and Pauly, 2014).

2.4. Preservation of samples

Representative specimens of each species identified were preserved in 5 % formaldehyde, except crustaceans which were preserved in 5 % buffered formalin (buffered with hexamethylenetetramine) to prevent fragmentation of appendages. All the samples are stored in appropriately labelled transparent plastic bottles, and deposited as reference vouchers at the Marine Biology Laboratory, Department of Marine Sciences, Goa University. Type specimens of new species (*Hexapus bidentatus*) are deposited in the Crustacea section of Indian Museum, Kolkata [Indian Museum Registration Number (IMRN): C6144/2 (Holotype) C6145/2 (Paratype I), C6146/2 (Paratype II)].

2.5. Stomach/Gut content analysis

The samples were washed, identified to the lowest possible taxonomic level, measured using a foot ruler (accuracy 1 mm), and weighed (accuracy 0.1 g) with an electronic weighing machine. Subsequently, their stomachs were removed and preserved in 10 % formaldehyde. The preserved stomachs were carefully emptied in petri-dishes and their contents were examined under compound microscope following the Gravimetric method (Hyslop, 1980). Stomach contents were identified to the lowest possible taxon (species/generic level) and the frequency of occurrence and weight of each prey taxa (accuracy 0.01 g) was recorded. Unidentified digested matter was categorized and weighed separately as 'digested matter'. In the case of microscopic prey items such as plankton, only abundance was recorded.

2.6. Fish reproductive studies

The pre-identified samples were measured using a foot ruler (accuracy 1 mm), and weighed (accuracy 0.1 g) with an electronic weighing machine. Thereafter, the specimens were dissected and visually examined following Devadoss (1969) and Bhusari (1975) and the maturity stages were recorded. Subsequently, the gonads were removed, weighed using an electronic balance to nearest 0.001 g and preserved in Gilson's fluid (Bagenal, 1978). To assess fecundity and ova diameter, the gonads were washed thoroughly using 70 % alcohol (Bagenal, 1978), dried with the help of blotting paper and weighed. The fecundity was analyzed by weighing and counting 0.01 g of dried eggs. Absolute fecundity was calculated using the formula given by Bagenal (1967). Moreover, diameter of 150 random ova was measured from each ovary using ocular micrometer.

2.7. Data compilation and processing

2.7.1. Faunal composition

The taxa encountered during the present study were divided into seven broad taxonomic groups namely elasmobranchs, teleosts, crustaceans, molluscs, echinoderms, reptiles and cnidarians, and graphically represented to elucidate the percentage composition of each of the above mentioned groups. Moreover, a list of total taxa was tabulated along with the status of reporting from the study area (Table 3.1). Further, the common names of all the species recorded during the present study are provided in appendix 3.1.

2.7.2. Faunal abundance and weight

Raw data (abundance and / or weight) of respective species or group from five sub-samples of each trawl haul were computed as follows

$X = (x_1 + x_2 + x_3 + x_4 + x_5) / 5$

Where, 'x' denotes the abundance / weight of a species or group in a sub-sample.

The raw data was standardized to a 60-minute tow in view of the variability in trawling duration throughout the study, and subsequently extrapolated to the total trawl using the following equations

Standardization to 60-minute / per hour:

$X' = (X * 60) / t_{act}$

where, t_{act} = actual trawling duration (in minutes)

X = data value (abundance or weight of a species or group) for t_{act}

X' = data value (abundance or weight of a species or group) for 60-minute haul

Extrapolation to total trawl catch:

$X_{tot} = (W_{tot} * X') / W_{ss}$

where, W_{tot} = total weight of trawl catch

X' = data value (abundance or weight of a species or group) for 60-minute haul

W_{ss}= weight of sub-sample

X_{tot}= data value (abundance or weight of a species or group) for entire trawl catch

Thereafter, the data were segregated into major faunal groups namely elasmobranchs, teleosts, crustaceans, molluscs, echinoderms, reptiles and cnidarians to estimate their contribution to the total trawl catch. Additionally, the monthly trends in abundance of the major faunal groups and their respective sub-groups were computed and graphically plotted to study the temporal variations. The abundance and weight is expressed as number per hour ($No.h^{-1}$) and kilogram per hour ($Kg.h^{-1}$) respectively. Spatial and temporal (monthly and seasonal) comparisons of abundance of faunal groups were analyzed by two-way Analysis of Variance (ANOVA; Sokal and Rohlf, 1987).

2.7.3. Species diversity indices

The species diversity indices namely Shannon-Weiner's diversity index "H'" (Shannon and Wiener, 1963); Margalef species richness "SR" (Margalef, 1968) and species dominance "D" (Simpson, 1949) were used in the present study to examine species diversity of the region as the region supports multispecies fishery and is subjected to increased fishing pressure especially through bottom trawling which indiscriminately removes benthic fauna. Further, some species occurred in higher abundances during some of the months of study period. Moreover, these diversity indices are being widely used and recognized by the scientific community. The diversity indices were computed using PAST version 2.07 statistical software (Hammer *et al.*, 2001).

2.7.4. Dietary attributes

Vacuity index (VI) is the ratio of number of empty stomachs to the total stomachs analyzed (Biswas, 1993); expressed in percentage and is calculated as follows

VI (%) = (No. of empty stomachs / No. of stomachs examined) X 100

The importance of each prey item by its occurrence, number and weight or volume was quantified by Index of Relative Importance (IRI; Pinkas *et al.*, 1971). The IRI for each prey item was calculated as:

Index of Relative Importance (IRI_i) = (% N_i+ % W_i) X % FO_i

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

In order to improve the interpretation of IRI, the index was expressed as percentage (% IRI; Cortés, 1997).

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

$$S = 100\,(1 - \tfrac{1}{2} \Sigma\, |P_{xi} - P_{yi}|)$$

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

Trophic level denotes the position of an organism within the food web (Odum and Heald, 1975), and was calculated following Cortés (1999) as:

$$Trophic\ Level\ (TrL) = 1 + \left(\sum_{j=1}^{n} \mathrm{W}_i \times \mathrm{T}_i\right)$$

where, W_i is the percentage contribution by weight of i^{th} prey item, T_i is the trophic level of the i^{th} prey item and "*i*" is the number of prey categories. The trophic levels of prey species were obtained from Vivekanandan *et al.* (2003, 2009).

The level of specialization of each predator based on the number of prey species (Krebs, 1989) was examined through the index of diet breadth (Levins, 1968) and was calculated as

$$B = \left(\frac{1}{n-1}\right)\left(\left(\frac{1}{\sum_{i.j=1}^{n} \mathrm{P}_{ij^2}}\right) - 1\right)$$

where, 'B' is the diet breadth, 'P_{ij}' is the proportion of diet of the predator '*i*' that is made up of prey item '*j*', and '*n*' is the number of prey categories.

This index ranges from 0 to 1; low values (< 0.5) indicate a diet dominated by few prey items or specialized feeder, while higher values (> 0.5) indicate a generalized feeding or higher prey diversity.

2.7.5. Reproductive traits

Gonado-somatic Index (GSI) is the ratio of fish gonad weight to body weight. It is used to determine the duration and intensity of breeding, and was calculated following June (1953) and Yuen (1955) as follows

$$Gonado - somatic\ Index\ (GSI) = \left(\frac{Weight\ of\ Gonad}{Weight\ of\ Fish}\right) \times 100$$

The fecundity of fish is defined as the number of eggs ripening between current and next spawning period in a female (Bagenal and Tesch, 1978), and was calculated following Bagenal (1967) as

$$Fecundity\ (F) = \left(\frac{Total\ weight\ of\ Ovary}{Weight\ of\ enumerated\ eggs}\right) \times Number\ of\ enumerated\ eggs$$

Ova diameter at different stages of maturity of female fish was measured using ocular micrometer with the help of N 300 M compound microscope

Calibration of Ocular micrometer:

The ocular micrometer (OM) was calibrated using the stage micrometre (SM) as follows

1 division of SM = 0.01 mm = 10 μm

Therefore, length of SM = 100 X 0.01

= 1 mm = 1000 μm

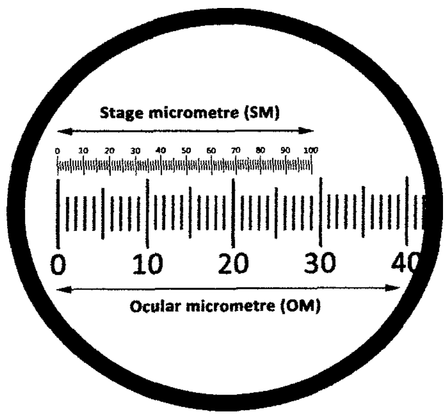
Calibration for 4X objective (Figure 2.2)

100 units of SM = 29 units of OM

= 1000 μm = 29 units of OM

Therefore, 1 unit of OM = 1000 / 29

= 34.48 μm



Microscopic view (4X)

Figure 2.2. Schematic representation of ocular and stage micrometer

2.7.6. Regression analysis

Regression analysis was performed using standardized monthly weight data to evaluate the correlation between total catch, target catch, commercial bycatch and discarded bycatch.

2.7.7. Cluster analysis

Cluster analysis is a statistical technique used to assign objects or data into groups (clusters) those exhibit natural groupings and differs from one another. The present study primarily employed two routines of Plymouth Routines In Multivariate Ecological Research (PRIMER-6) version 6.1.10 software (Clarke and Gorley, 2006) namely dendrogram plotting and non-metric Multi-Dimensional Scaling (nMDS; Bray and Curtis, 1957) to assess the faunal associations within the demersal community and to create trophic guilds of predatory finfishes and subsequent graphical representation. The significance of the cluster groups ($p < 0.05$) was tested by similarity profile (SIMPROF) analysis. Additionally, two more routines of the same package namely similarity percentage (SIMPER) and BVSTEP routine were employed to observe differences in predatory fish assemblages, and to determine the influential prey groups for predatory fin fishes. BVSTEP is one of the algorithms of BEST analysis of primer software which selects environmental variables or species "best explaining" the community pattern, by maximizing a rank correlation between their respective resemblance matrices. In this, a stepwise search over the trial variables is tried. In the present study it is applied between predatory finfishes and their prey groups to observe important or influential prey groups for predatory finfishes based on Spearman's rank correlation.

2.7.8. Principal Component Analysis (PCA)

A correlation-based Principal Component Analysis (PCA) using STATISTICA software version 12 (StatSoft.Inc., 2014) was employed to assess the correlation or relationships between species abundance and environmental parameters (seasonal) and between prey categories and mouth parts. The principal components were identified on the basis of eigen-values (> 1.00). Species or prey categories representing significantly to principal components were identified according to their PCA scores (> ± 0.70).

Chapter 3 -

Demersal faunal community structure off Goa

3.1. Introduction

Coastal ecosystems support wide array of species and their complexity in terms of interactions are much emphasized in the tropical seas (Venkataraman and Wafar, 2005). In the demersal environment, high diversity leads to the formation of myriad assemblages, which interact among themselves forming larger communities. The community structure concept focuses on the interactions among the species and their habitats including the trophic networks (Pianka, 1973) enabling better understanding of the species and the associated biological processes (trophic dynamics, reproduction and migration patterns) those regulate the community. These community studies involve qualitative analyses comprising of species composition and their ecological categorization, as well as quantitative analyses consisting of enumeration, faunal abundance, diversity estimation and their spatio-temporal variations.

Published literature on demersal marine fish communities indicates extensive studies from the major bay-estuarine and coastal ecosystems of the world (Elliot *et al.*, 2007). The literature also suggests that the environmental anomalies play a vital role in the composition of biotic communities (Loneragan *et al.*, 1989; Martin *et al.*, 1995; Kuo *et al.*, 2001; Ansari *et al.*, 2003; Lugendo *et al.*, 2007; Haicheng and Weiwei, 2009; Aschan *et al.*, 2013). Other studies have highlighted the role of physico-chemical factors such as salinity, temperature and depth in structuring the demersal faunal species assemblages (Prista *et al.*, 2003; Akin *et al.*, 2005; Selleslagh and Amara, 2008). Similarly, biological factors such as food availability, reproduction and migration patterns also influence the fish community structure (Allen, 1982; Súarez and Petrere-Júnior, 2007; Aschan *et al.*, 2013). Apart from these, the anthropogenic activities such as effluent and sewage discharge, pollution and fishing activities, particularly the bottom trawling, are widely known to influence the fish communities either through habitat alteration and destruction or water quality deterioration (Jennings and Kaiser, 1998; Turner *et al.*, 1999; Blaber *et al.*, 2000; Myers and Worm, 2003; Wilson *et al.*, 2010).

Previous studies pertaining to the demersal fauna of the estuarine and shelf waters of Goa were mainly focused on commercial fish species (Rao and Dorairaj, 1968; Talwar, 1972; Prabhu and Dhawan, 1974; George, 1980; Parulekar *et al.*, 1980; Ansari *et al.*, 1995). Recently, more extensive studies carried out by Padate (2010) and Hegde (2013) reported 204 and 184 species, respectively, including both commercial and non-commercial fauna from the nearshore coastal waters of Goa. Apart from these, few studies (Ansari *et al.*, 1995, 2003; Padate, 2010; Hegde, 2013; Sreekanth *et al.*, 2015, 2016) have addressed the issues pertaining to fish community structure such as spatial and temporal variations, environmental influences, etc. However, the effects of continuous removal and mortality of non-targeted fauna and juveniles of targeted fauna as by-catch on the demersal faunal community structure have not been assessed from this region.

In view of above and the ever-increasing impact of anthropogenic activities on the coastal waters, it is necessary to establish a comprehensive database of the demersal marine fauna in order to provide a platform towards an improved understanding of the coastal biodiversity of Goa and underlying biological processes that sustain fishery resources. Therefore, the present study primarily attempts to provide the baseline information on the species composition of coastal macrofauna including commercial as well as non-commercial and the rare fauna from the nearshore coastal waters of Goa through exhaustive trawl surveys. Further, the study also makes an attempt to explain the spatio-temporal variations in the occurrence of demersal fauna along the Goa coast.

3.2. Results and Discussion

3.2.1. Total trawl catch

3.2.1a. Species composition and new records

The nearshore coastal waters of Goa are well known for its habitat heterogeneity and productivity. The extensive trawl surveys carried out during the present study revealed altogether 196 taxa (Table 3.1) from the nearshore coastal waters of Goa belonging to seven faunal groups (Figure 3.1). Among these faunal groups, the teleosts were represented by the highest number of taxa (126) followed by crustaceans (36), molluscs (20), elasmobranchs (07) and miscellaneous faunal groups (07). The miscellaneous group comprised of echinoderms (04), reptiles / sea snakes (02) and the cnidarians (01 taxa).

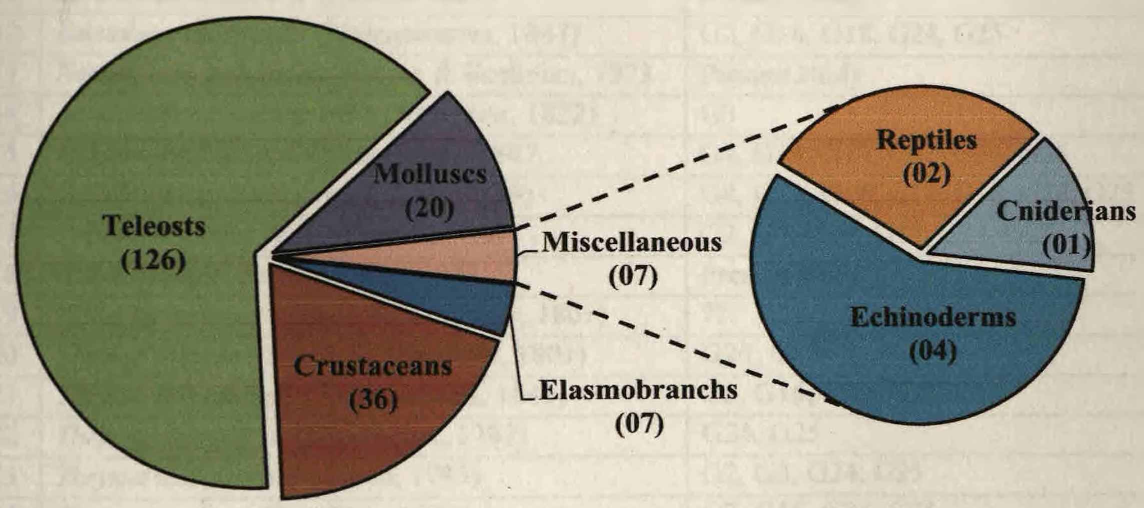


Figure 3.1. Species composition of demersal faunal groups

Higher species diversity in this region is an indicative of stable ecosystem and is primarily attributed to its higher productivity and the habitat heterogeneity (Wafar *et al.*, 1997; Krishna Kumari *et al.*, 2002) thus making the region a good nursery ground for variety of resident and transient fauna (Ansari *et al.*, 1995).

Out of the 196 taxa reported, nineteen taxa are new to the Goan coast (Table 3.2). Among these, one brachyuran crab species namely *Hexapus bidentatus* is described as new to science (Velip and Rivonker, 2015a), two teleosts namely *Callionymus sublaevis* and

Table 3.1. List of demersal marine taxa observed during the present study

Sr. No.	Name of species	Reports from Goa coast
A.	**Elasmobranchs**	
1	*Himantura gerrardi* (Gray, 1851)	G24, G25
2	*Himantura walga* (Müller & Henle, 1841)	G24, G25
3	*Himantura uarnak* (Gmelin, 1789)	G22, G16, G25
4	*Aetobatus flagellum* (Bloch & Schneider, 1801)	G24, G25
5	*Glaucostegus granulatus* (Cuvier, 1829)	G22, G16, G24, G25
6	*Chiloscyllium griseum* Müller & Henle, 1838	G2, G24, G25
7	*Scoliodon laticaudus* Müller & Henle, 1838	G2, G4, G14, G17, G22, G16, G24, G25
B.	**Teleosts**	
8	*Sardinella longiceps* Valenciennes, 1847	G2, G16, G22, G18, G24, G25
9	*Sardinella brachysoma* Bleeker, 1852	G23, G24, G25
10	*Sardinella gibbosa* (Bleeker, 1849)	G2, G23, G25
11	*Sardinella melanura* (Cuvier, 1829)	Present study
12	*Escualosa thoracata* (Valenciennes, 1847)	G2, G16, G18, G24, G25
13	*Nematalosa galatheae* Nelson & Rothman, 1973	Present study
14	*Anodontostoma chacunda* (Hamilton, 1822)	G3
15	*Dussumieria acuta* Valenciennes, 1847	G4, G14, G17, G22, G24, G25
16	*Opisthopterus tardoore* (Cuvier, 1829)	G4, G14, G16, G17, G18, G24, G25
17	*Pellona ditchela* Valenciennes, 1847	G2, G4, G14, G17, G24, G25
18	*Ilisha sirishai* Seshagiri Rao, 1975	Present study
19	*Ilisha melastoma* (Bloch & Schneider, 1801)	??
20	*Thryssa mystax* (Bloch & Schneider, 1801)	G24, G25
21	*Thryssa dussumieri* (Valenciennes, 1848)	G2, G16, G24, G25
22	*Thryssa setirostris* (Broussonet, 1782)	G24, G25
23	*Thryssa malabarica* (Bloch, 1795)	G2, G3, G24, G25
24	*Thryssa purava* (Hamilton, 1822)	G2, G16, G24, G25
25	*Stolephorus commersonnii* Lacepède, 1803	G16, G21, G25
26	*Mugil cephalus* Linnaeus, 1758	G18, G24, G25
27	*Siganus canaliculatus* (Park, 1797)	G2, G16, G24, G25
28	*Ambassis gymnocephalus* (Lacepède, 1802)	G2, G3, G16, G24, G25
29	*Ostorhinchus fasciatus* (White, 1790)	G24,
30	*Archamia bleekeri* (Günther, 1859)	G24, G25
31	*Alectis indica* (Rüppell, 1830)	G2, G22, G24, G25
32	*Alepes djedaba* (Forsskål, 1775)	G2, G22, G24, G25
33	*Atropus atropos* (Bloch & Schneider, 1801)	G2, G14, G17, G22, G24, G25
34	*Caranx sexfasciatus* Quoy & Gaimard, 1825	G2, G23, G25
35	*Decapterus russelli* (Rüppell, 1830)	G22, G24, G25
36	*Seriolina nigrofasciata* (Rüppell, 1829)	G2
37	*Megalaspis cordyla* (Linnaeus, 1758)	G2, G14, G16, G17, G22, G24, G25
38	*Parastromateus niger* (Bloch, 1795)	G2, G4, G16, G22, G24, G25

39	*Scomberoides tol* (Cuvier, 1832)	G2, G23, G25
40	*Trachinotus mookalee* Cuvier, 1832	G25
41	*Rachycentron canadum* (Linnaeus, 1766)	G2, G3, G16, G24
42	*Drepane longimana* (Bloch & Schneider, 1801)	G24, G25
43	*Drepane punctata* (Linnaeus, 1758)	G2, G16, G22, G24, G25
44	*Platax teira* (Forsskål, 1775)	G31
45	*Gerres filamentosus* Cuvier, 1829	G2, G16, G24, G25
46	*Gerres limbatus* Cuvier, 1830	G16, G24, G25
47	*Lactarius lactarius* (Bloch & Schneider, 1801)	G1, G2, G4, G14, G17, G22, G24, G25
48	*Gazza minuta* (Bloch, 1795)	G24, G25
49	*Photopectoralis bindus* (Valenciennes, 1835)	G4, G14, G17, G22, G24, G25
50	*Nuchequula blochii* (Valenciennes, 1835)	G2, G16, G24, G25
51	*Karalla daura* (Cuvier, 1829)	G2, G16, G24, G25
52	*Leiognathus equulus* (Forsskål, 1775)	Present study
53	*Leiognathus brevirostris* (Valenciennes, 1835)	G24, G25
54	*Eubleekeria splendens* (Cuvier, 1829)	G2, G4, G14, G17, G24, G25
55	*Secutor ruconius* (Hamilton, 1822)	G2, G25
56	*Secutor insidiator* (Bloch, 1787)	G2, G4, G16, G22, G24, G25
57	*Mene maculata* (Bloch & Schneider, 1801)	G24,
58	*Nemipterus japonicus* (Bloch, 1791)	G2, G16, G18, G22, G24, G25
59	*Nemipterus bipunctatus* (Valenciennes, 1830)	G25
60	*Parascolopsis townsendi* Boulenger, 1901	G24,
61	*Pempheris molucca* Cuvier, 1829	G24, G25
62	*Filimanus heptadactyla* (Cuvier, 1829)	G2, G16, G22, G24, G25
63	*Dendrophysa russelii* (Cuvier, 1829)	G24, G25
64	*Johnius borneensis* (Bleeker, 1851)	G2, G14, G16, G25
65	*Johnius dussumieri* (Cuvier, 1830)	G2, G25
66	*Johnius coitor* (Hamilton, 1822)	G25
67	*Johnius elongatus* Lal Mohan, 1976	G2, G14, G16, G25
68	*Johnius belangerii* (Cuvier, 1830)	G2, G3, G25
69	*Johnius macropterus* (Bleeker, 1853)	G2
70	*Johnius amblycephalus* (Bleeker, 1855)	G25
71	*Otolithes cuvieri* Trewavas, 1974	G2, G14, G16, G18, G25
72	*Otolithes ruber* (Bloch & Schneider, 1801)	G2, G4, G14, G17, G18, G24, G25
73	*Pennahia anea* (Bloch, 1793)	G2, G14, G17, G24, G25
74	*Pennahia macrophthalmus* (Bleeker, 1849)	G14, G17
75	*Kathala axillaris* (Cuvier, 1830)	G2, G25
76	*Protonibea diacanthus* (Lacepède, 1802)	G14, G17
77	*Paranibea semiluctuosa* (Cuvier, 1830)	G23, G26
78	*Epinephelus diacanthus* (Valenciennes, 1828)	G2, G22,G16, G24, G25
79	*Sillago sihama* (Forsskål, 1775)	G2, G14, G17, G18, G16, G25
80	*Pomadasys maculatus* (Bloch, 1793)	G2, G22, G16, G24, G25
81	*Plectorhinchus gibbosus* (Lacepède, 1802)	G24, G25
82	*Terapon jarbua* (Forsskål, 1775)	G2, G16, G22, G24, G25
83	*Terapon theraps* Cuvier, 1829	G2, G16, G24, G25

84	*Terapon puta* Cuvier, 1829	G2, G16, G24, G25
85	*Pelates quadrilineatus* (Bloch, 1790)	??
86	*Scomberomorus guttatus* (Bloch & Schneider, 1801)	G2, G16, G22, G24, G25
87	*Rastrelliger kanagurta* (Cuvier, 1816)	G2, G16, G18, G22, G24, G25
88	*Trichiurus lepturus* Linnaeus, 1758	G2, G14, G17, G22, G24, G25
89	*Sphyraena putnamae* Jordan & Seale, 1905	G22, G24, G25
90	*Sphyraena obtusata* Cuvier, 1829	G16, G22, G24, G25
91	*Pampus argenteus* (Euphrasen, 1788)	G2, G4, G14, G16, G17, G24, G25
92	*Pampus chinensis* (Euphrasen, 1788)	G2, G4, G14, G16, G17, G24, G25
93	*Trypauchen vagina* (Bloch & Schneider, 1801)	G2, G16, G24
94	*Odontamblyopus rubicundus* (Hamilton, 1822)	G2, G24, G25
95	*Yongeichthys criniger* (Valenciennes, 1837)	G24, G25
96	*Parachaeturichthys polynema* (Bleeker, 1853)	G24, G25
97	*Oxyurichthys paulae* Pezold, 1998	G24
98	*Callionymus sagitta* Pallas, 1770	G24, G25
99	*Callionymus sublaevis* McCulloch, 1926	Present study
100	*Grammoplites scaber* (Linnaeus, 1758)	G2, G16, G24, G25
101	*Thysanophrys armata* (Fowler, 1938)	Present study
102	*Platycephalus indicus* (Linnaeus, 1758)	G14, G17
103	*Minous monodactylus* (Bloch & Schneider, 1801)	G2, G25
104	*Trachicephalus uranoscopus* (Bloch & Schneider, 1801)	G9, G16, G24
105	*Cynoglossus macrostomus* Norman, 1928	G2, G14, G17, G24, G25
106	*Cynoglossus puncticeps* (Richardson, 1846)	G2, G24, G25
107	*Cynoglossus dispar* Day, 1877	Present study
108	*Cynoglossus lida* (Bleeker, 1851)	G2
109	*Synaptura commersonnii* (Lacepède, 1802)	G4, G16, G24, G25
110	*Synaptura albomaculata* Kaup, 1858	G24, G25
111	*Solea ovata* Richardson, 1846	G2, G16, G24, G25
112	*Pseudorhombus triocellatus* (Bloch & Schneider, 1801)	G2, G16, G24, G25
113	*Pseudorhombus arsius* (Hamilton, 1822)	G2, G14, G17, G24, G25
114	*Triacanthus biaculeatus* (Bloch, 1786)	G24, G25
115	*Lagocephalus spadiceus* (Richardson, 1845)	G2, G24, G25
116	*Arothron immaculatus* (Bloch & Schneider, 1801)	G24
117	*Chelonodon patoca* (Hamilton, 1822)	G2, G24, G25
118	*Aluterus monoceros* (Linnaeus, 1758)	??
119	*Colletteichthys dussumieri* (Valenciennes, 1837)	G2, G24
120	*Bregmaceros mcclellandi* Thompson, 1840	G16, G24, G25
121	*Dactyloptena gilberti* Snyder, 1909	??
122	*Arius maculatus* (Thunberg, 1792)	G2, G14, G17, G24, G25
123	*Arius arius* (Hamilton, 1822)	G2
124	*Plicofollis nella* (Valenciennes, 1840)	??
125	*Plotosus lineatus* (Thunberg, 1787)	G14, G16, G17, G24, G25
126	*Netuma bilineata* (Valenciennes, 1840)	Present study

127	*Pisodonophis cancrivorus* (Richardson, 1848)	G2, G24, G25
128	*Muraenesox cinereus* (Forsskål, 1775)	G2, G22, G24, G25
129	*Gymnothorax dorsalis* Seale, 1917	Present study
130	*Gymnothorax thyrsoideus* (Richardson, 1845)	G25
131	*Saurida tumbil* (Bloch, 1795)	G2, G14, G16, G17, G24, G25
132	*Synodus myops* (Forster, 1801)	G24, G25
133	*Harpadon nehereus* (Hamilton, 1822)	G2
C.	**Crustaceans**	
134	*Penaeus monodon* Fabricius, 1798	G4, G5, G16, G21, G24, G25
135	*Fenneropenaeus indicus* (H. Milne-Edwards, 1837)	G4, G5, G21, G16, G24, G25
136	*Fenneropenaeus merguiensis* (De Man, 1888)	G5, G22, G23, G24
137	*Marsupenaeus japonicus* (Bate, 1888)	G11, G21, G24, G25
138	*Metapenaeus dobsoni* (Miers, 1878)	G4, G5, G9, G16, G21, G24, G25
139	*Metapenaeus affinis* (H. Milne-Edwards, 1837)	G4, G5, G9, G16, G21, G24, G25
140	*Metapenaeus moyebi* (Kishinouye, 1896)	G22, G24
141	*Parapenaeopsis stylifera* (Milne-Edwards, 1837)	G4, G5, G16, G21,G9, G24, G25
142	*Exhippolysmata ensirostris* (Kemp, 1914)	G16, G24, G25
143	*Alpheus euphrosyne* De Man, 1897	G6, G24, G25
144	*Neocallichirus audax* (de Man, 1911)	Present study
145	Mysis larvae	??
146	*Diogenes miles* (Fabricius, 1787)	G24, G25
147	*Schizophrys aspera (H. Milne Edwards, 1834)*	Present study, G25
148	*Dorippe astuta* (Fabricius, 1793)	G13, G6, G24, G25
149	*Calappa lophos* (Herbst, 1785)	G24, G25
150	*Ashtoret lunaris* (Forsskål, 1775)	G13, G6, G24, G25
151	*Leucosia pubescens* Miers, 1877	G13, G24
152	*Etisus anaglyptus* H. Milne Edwards, 1834	Present study
153	*Doclea rissonii* Leach, 1815	G13, G24
154	*Portunus sanguinolentus* (Herbst, 1783)	G6, G13, G16, G22, G24, G25
155	*Portunus pelagicus* (Linnaeus, 1758)	G6, G13, G16, G22, G24, G25
156	*Scylla serrata* (Forsskål, 1775)	G13, G16, G24, G25
157	*Charybdis lucifera* (Fabricius, 1798)	G13, G24, G25
158	*Charybdis feriatus* (Linnaeus, 1758)	G13, G22, G24, G25
159	*Charybdis variegata* (Fabricius, 1798)	G24, G25
160	*Charybdis goaensis* (Padate, Rivonker, Anil, Sawant & Krishnamurthy 2010)	G24
161	*Charybdis vadorum* Alcock, 1899	G13, G24, G25
162	*Hexapus bidentatus* (Velip & Rivonker, 2015)	Present study
163	*Hexapus estuarinus* Sankarankutty, 1975	Present study
164	*Trissoplax dentata* (Stimpson, 1858)	Present study
165	*Albunea symmysta* (Linnaeus, 1758)	Present study
166	*Raphidopus indicus* Henderson, 1893	Present study
167	*Miyakella nepa* (Latreille, 1828)	G24, G25
168	*Harpiosquilla raphidea* (Fabricus, 1798)	Present study

169	*Lysiosquilla tredecimdentata* Holthuis, 1941	Present study
D.	**Molluscs**	
170	*Perna viridis* (Linnaeus, 1758)	G27, G28
171	*Crassostrea madrasensis* unspecified	G29, G30
172	*Tegillarca granosa* (Linnaeus, 1764)	G18, G24
173	*Turritella duplicata* (Linnaeus, 1758)	G15, G24, G25
174	*Turritella turritella* (Lamarck, 1822)	G15, G25
175	*Turritella* sp.	??
176	*Bufonaria spinosa* Schumacher, 1817	G24, G25
177	*Gyrineum natator* (Röding, 1798)	G8, G24, G25
178	*Murex trapa* Röding, 1798	??
179	*Murex* sp.	??
180	*Babylonia spirata* (Linnaeus, 1758)	G15, G24, G25
181	*Babylonia* sp.	??
182	*Oliva* sp.	??
183	*Natica picta* Récluz, 1844	G15, G24
184	*Tibia curta* (G.B. Sowerby II, 1842)	G15, G24, G25
185	*Antalis* sp.	??
186	*Uroteuthis duvaucelii* (D'Orbigny, 1835)	G22, G16, G24, G25
187	*Sepiella inermis* (Van Hasselt, 1835)	G24, G25
188	*Cistopus indicus* (Rapp, 1835)	G24, G25
189	*Octopus* sp.	??
E.	**Echinoderms**	
190	*Astropecten indicus* Döderlein, 1888	G6, G24, G25
191	*Temnopleurus toreumaticus* (Leske, 1778)	G6, G24, G25
192	*Temnopleurus decipiens* (de Meijere, 1904)	G25
193	Brittle star	??
D.	**Sea snakes**	
194	*Enhydrina schistosa* Daudin, 1803	G19, G20, G24, G25
195	*Lapemis curtus* (Shaw, 1802)	G19, G20, G24, G25
D.	**Cnidaria**	
196	*Aurelia aurita* (Linnaeus, 1758)	G24, G25

G1– Rao and Dorairaj (1968) G2 – Talwar (1973) G3 – Tilak (1973)

G4 – Prabhu and Dhawan (1974) G5 – George (1980) G6 – Parulekar *et al.* (1980)

G7 – Poss (1986) G8 – Mookherjee (1985)

G9 – Achuthankutty and Parulekar (1986) G10 – Rao *et al.* (1992)

G11– Achuthankutty and Nair (1993) G12– Rao and Rao (1993) G13 – Chatterji (1994)

G14 – Ansari *et al.* (1995) G15 – Apte (1998) G16 – Alvares (2002)

G17 – Ansari *et al.* (2003) G18 – Ansari (2004) G19 – Lobo *et al.* (2004)
G20 – Lobo (2005) G21– Ansari *et al.* (2006) G22 – Ansari (2008)
G23 – Froese and Pauly (2015) G24 – Padate *et al.* (2010) G25 – Hegde (2013)
G26 – Krishnan and Mishra (2004) G27 – Rivonler *et al.* (1993) G28 – Parulekar *et al.* (1982) G29 – Parulekar *et al.* (1983) G30 – Nagi *et al.* (2011)
G31 – Neuparth (1913) ?? – Literature not available

Table 3.2. New records of demersal marine species along Goa coast

Sr. No.	Name of species	Habitat
1	*Sardinella melanura* (Cuvier, 1829)	Pelagic/Euryhaline
2	*Nematalosa galatheae* Nelson & Rothman, 1973	Pelagic-Neritic
3	*Ilisha sirishai* Seshagiri Rao, 1975	Pelagic/Euryhaline
4	*Leiognathus equulus* (Forsskål, 1775)	Pelagic, Muddy bottom
5	*Callionymus sublaevis* McCulloch, 1926	Rocky/Coral reef
6	*Thysanophrys armata* (Fowler, 1938)	Sandy/Silt
7	*Cynoglossus dispar* Day, 1877	Muddy bottom
8	*Netuma bilineata* (Valenciennes, 1840)	Muddy bottom
9	*Gymnothorax dorsalis* Seale, 1917	Demersal
10	*Neocallichirus audax* (de Man, 1911)	Benthic/Mangroves
11	*Schizophrys aspera (H. Milne Edwards, 1834)*	Rocky
12	*Etisus anaglyptus* H. Milne Edwards, 1834	Rocky/Crevices, Benthic
13	*Hexapus bidentatus* (Velip & Rivonker, 2015)	Muddy/Clay
14	*Hexapus estuarinus* Sankarankutty, 1975	Muddy/Clay
15	*Trissoplax dentata* (Stimpson, 1858)	Benthic/Sandy
16	*Albunea symmysta* (Linnaeus, 1758)	Sandy bottom
17	*Raphidopus indicus* Henderson, 1893	Soft muddy/Sandy
18	*Harpiosquilla raphidea* (Fabricus, 1798)	Sandy/Soft clay
19	*Lysiosquilla tredecimdentata* Holthuis, 1941	Sandy/Mudflats

Thysanophrys armata are new to the entire Indian coast and one anomuran crab (*Raphidopus indicus*) is new to west coast of India. In addition, one anomuran crab (*Albunea symmysta*), four brachyuran crabs (*Schizophrys aspera, Etisus anaglyptus, Hexapus estuarinus* and *Trissoplax dentata*), two stomatopods (*Harpiosquilla raphidea* and *Lysiosquilla tredecimdentata*), one ghost shrimp (*Neocallichirus audax*) and seven teleosts (*Sardinella melanura, Nematalosa galatheae, Ilisha sirishai, Leiognathus equulus, Cynoglossus dispar, Netuma bilineata* and *Gymnothorax dorsalis*) were new records for

Goa coast. Several authors in the past have attempted to document the demersal marine fauna of the region. Rao and Dorairaj (1968) reported four genera and one species of commercial species. Talwar (1972) reported 168 finfish species from littoral waters; Tilak (1973) reported 51 finfish species from riverine and estuarine waters. Prabhu and Dhawan (1974) reported 47 commercially important species of demersal marine fauna. George (1980) provided brief taxonomic descriptions of 17 species of penaeid prawns. Parulekar *et al.* (1980) reported 78 epifaunal marine taxa. Ansari *et al.* (1995, 2003) reported altogether 59 species from Mandovi - Zuari estuarine complex and the adjacent bays. Lobo (2005) reported eight species of sea snakes. Recently, Padate (2010) and Hegde (2013) updated the information on demersal marine fauna off Goa coast with 204 species (including 55 new reports) and 184 species (including 16 new records), respectively from the region.

3.2.1b. Quantitative analysis

The quantitative analysis of total trawl catch revealed a dominance of crustaceans fauna (45%) in terms of abundance (Figure 3.2) followed by teleosts (28%), echinoderms (17%) and molluscs

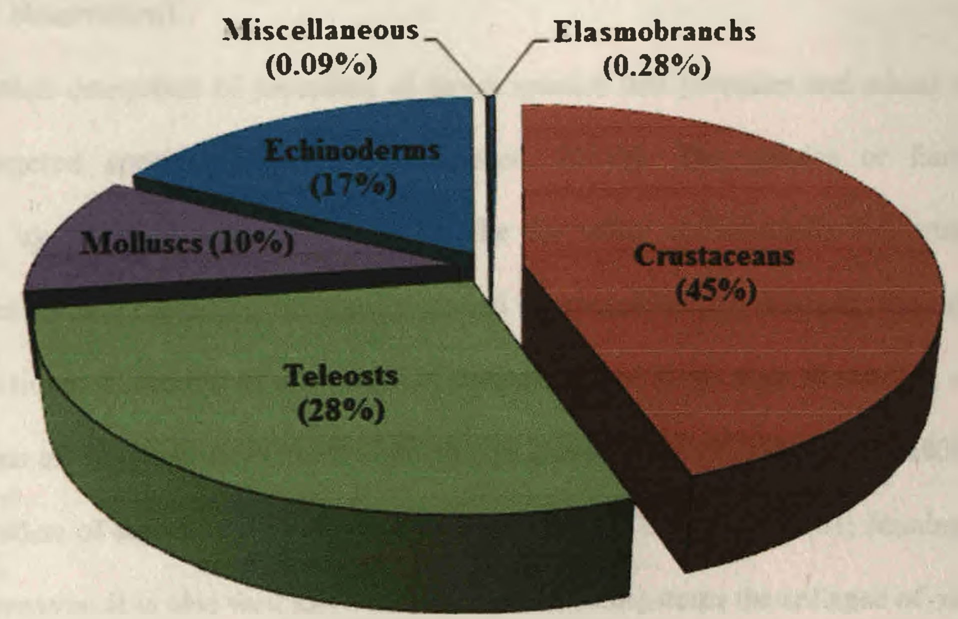


Figure 3.2. Group-wise proportions of faunal abundance

(10%). The elasmobranchs, sea snakes and cnidarians constituted only 0.4 % to the total trawl catch in terms of their abundance (Figure 3.2). The bottom trawlers primarily target prawns of all sizes due to use of reduced mesh size, hence the dominance of crustacean fauna in trawl catch. Earlier studies (Padate, 2010; Hegde, 2013) also reported the predominance of crustacean fauna in terms of abundance in the trawl catches along the region. Although prawns are the target catch of the trawl net, they constitute only 30.12 % of the total trawl catches in terms of their abundance. These results are also in concurrence with the global assessment of demersal fish catches using bottom trawls provided by Watson *et al.* (2006). The rest of the catch (finfishes, other crustaceans, molluscs, echinoderms, etc.) is incidental. The non-selective nature of trawl net has also been studied by Bijukumar and Deepthi (2006). The commercially important fauna in the incidental catch, for example crabs, squids, sole fishes, sciaenids, etc. are sometimes also considered as target catch of bottom trawlers subjected to their size range and utility from the region (Velip and Rivonker, 2015b). The remaining fauna is regarded as by-catch, and is sometimes brought back to the fishing jetty (Dineshbabu *et al.*, 2013) or discarded back to the sea (personal observation).

The by-catch comprises of juveniles of target species and juveniles and adults of trash or non-targeted species (Velip and Rivonker, 2015b). The species or fauna representing the by-catch are equally important like the other commercially important species in structuring and balancing the marine faunal communities (for example, through food web interactions; Schindler *et al.*, 2002). Continuous and large scale discarding of non-targeted fauna as by-catch may lead to reduction in species diversity (Hall *et al.*, 2000) resulting in alteration of demersal fish community structure (Jackson *et al.*, 2001; Jennings *et al.*, 2005). Moreover, it is also well known that in marine ecosystems the collapse of one fishery may trigger or suppress the proliferation of others which might result in cascading ecological changes (Springer *et al.*, 2003). The International Union for Conservation of

Nature (IUCN) has enlisted most of the demersal finfish species in their Red List and prioritized their conservation due to increasing threats from by-catch of bottom trawlers to diversity of demersal fauna (IUCN, 2014).

3.2.1c. Temporal variations – faunal abundance

An analysis of temporal variations of total faunal abundance ($No.h^{-1}$) during the present study revealed an overall increase in faunal abundance towards the end of the study period i.e. during the year 2012 – 2013 (third fishing season) as compared to the year 2010 – 2011 and 2011 – 2012 (first and second fishing season; Figure 3.3). During first and the second fishing season (2010 – 2012) the abundance did not show much of the variations. However, it was slightly higher during second fishing season compared to the first fishing season. During the third fishing season (October, 2012 to May, 2013) the abundance showed a distinct increase toward the end of the fishing season. The observed increase in total faunal abundance is due to the increase in crustacean, echinoderm and to some extent, teleostean faunal abundance. Abundance patterns of the respective faunal groups (crustaceans, echinoderms and teleosts) are discussed in detail below in the respective sections. The highest abundance was observed during the month of April, 2013 (165.43×10^2) owing to the exceptionally high recruits of echinoderms which further is subsidized by low predation pressure (Hereu *et al.*, 2012); whereas the lowest abundance was observed during the month of September, 2011 (8.267×10^2). The lower abundance during September, 2011 may be because of sampling constraints owing to rough weather conditions prevailing in the sea.

3.2.2. Crustaceans

3.2.2a. Species composition and faunal proportions

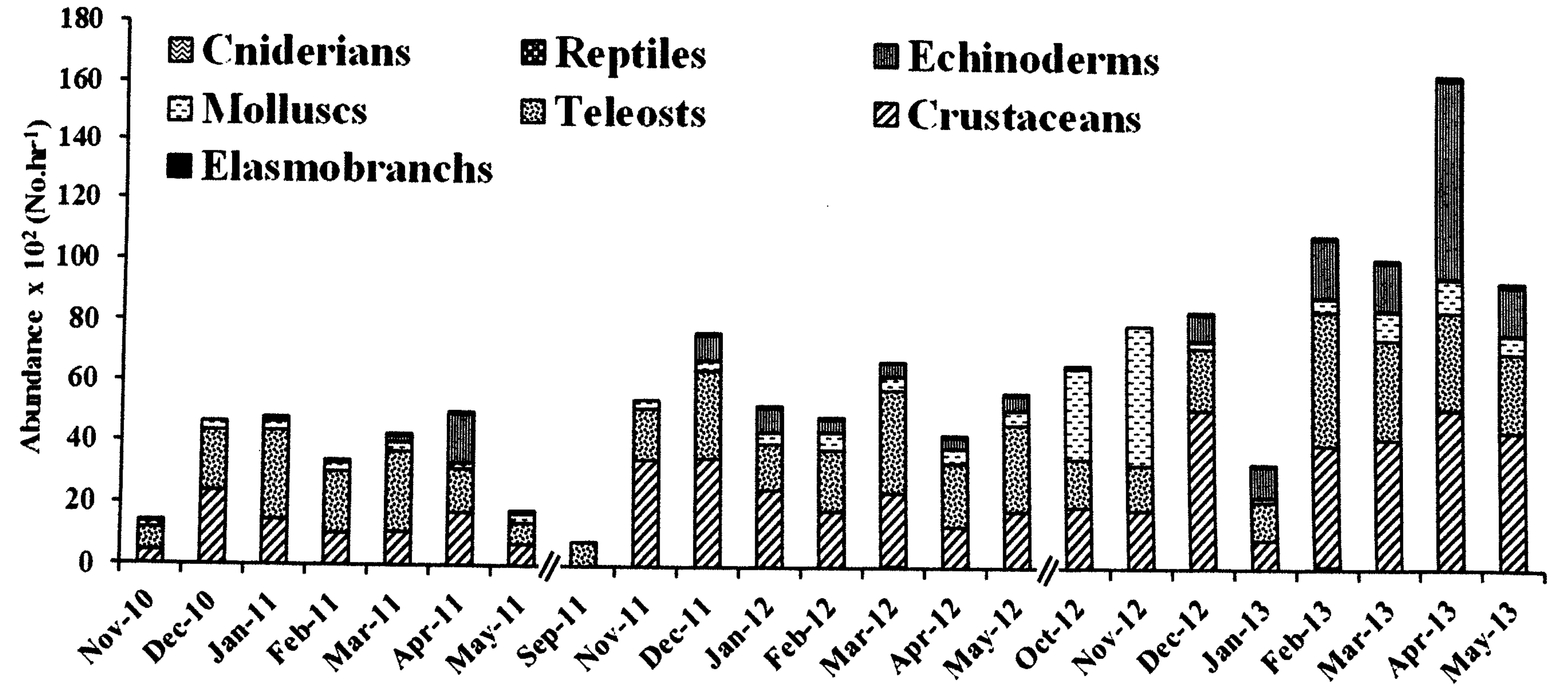


Figure 3.3. Month-wise variations in total faunal abundance

The crustaceans were the most abundant faunal group observed during the present study. Earlier studies (Padate, 2010; Hegde, 2013) also reported high abundance and species diversity of crustacean fauna along the nearshore coastal waters of Goa. During the present study a total of 36 species of crustaceans were recorded and were sub-divided into three sub-groups namely, stomatopods, prawns and crabs. Among these sub-groups, crabs were represented by maximum number of taxa (21; Figure 3.4a) and accounted for 16 % of the crustacean abundance (Figure 3.4b). The prawns were represented by 12 taxa and accounted for major bulk of crustacean abundance (66 %). The stomatopods contributed 18 % to the crustacean abundance and were represented by just three species.

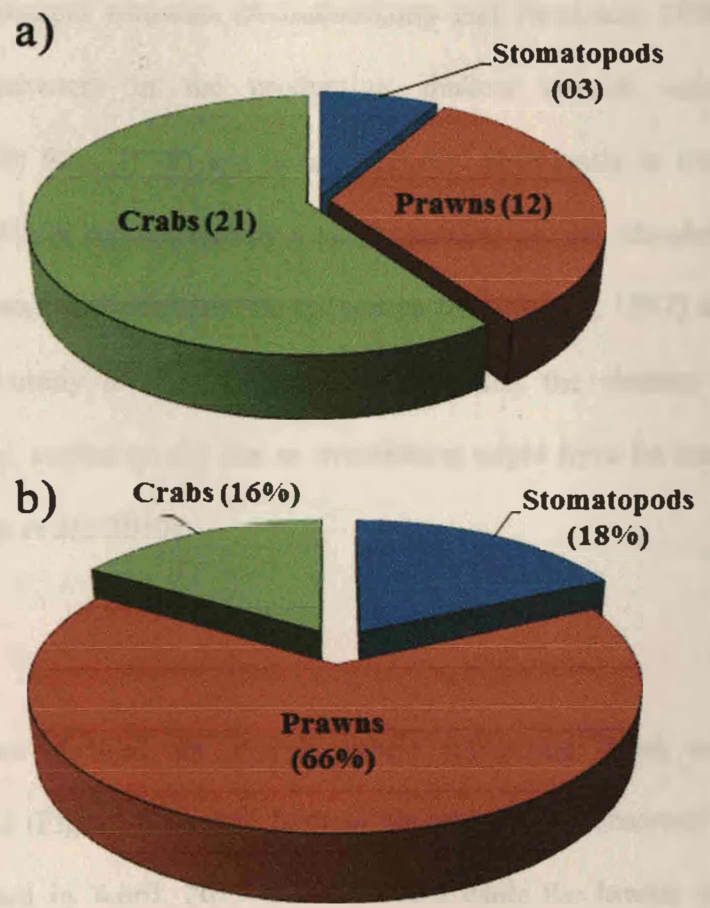


Figure 3.4. Crustaceans: a) number of species representing faunal groups b) percentage contribution of faunal groups in terms of abundance

Among the crabs, *Charybdis vadorum*, *Portunus sanguinolentus*, *C. lucifera* and *C. feriatus* were the most abundant species. *Portunus sanguinolentus* and *C. feriatus* were known to spawn from December to February (Sukumaran and Neelakantan, 1998) and November to May (Pillai and Nair, 1971) along the region and the subsequent recruitment may be responsible for their increased abundance. The higher occurrences of *C. vadorum* and *C. lucifera* may be attributed to their spawning activity as evidenced by the occurrence of juvenile crabs in the sub-samples. The prawn abundance was dominated by three abundant species namely, *Parapenaeopsis stylifera*, *Metapenaeus dobsoni* and *M. affinis*. All the three species are residents of nearshore coastal waters of Goa and their juveniles are known to migrate into the adjacent estuaries (Achuthankutty and Parulekar, 1986). Further, they are perennial spawners in the productive shallow coastal waters (Shaikhmahmud and Tembe, 1960; Rao, 1978) and hence occurred abundantly in trawl catches. The stomatopods were chiefly represented by a single species i.e. the *Miyakella nepa*. The species is known to spawn in nearshore coastal waters (Sukumaran, 1987) and feed at diverse trophic levels (Antony *et al*., 2010). Apart from this, the absence of potential predators (elasmobranchs, cephalopods) due to overfishing might have favoured to their higher abundances (Antony *et al*., 2010).

3.2.2b. Temporal variations

The crustacean abundance showed an overall yearly increasing trend with maximum abundance during 2013 (Figure 3.5). The highest abundance was observed in December, 2012 (50.98×10^2) and in April, 2013 (52.06×10^2) while the lowest was recorded during September, 2011 (0.8×10^2). An analysis of temporal variations of abundance of crustacean faunal sub-groups revealed that the prawns showed a year-wise increase in abundance mainly due to their higher recruitment. Additionally, the harvesting of large amount of prawn juveniles in recent years as envisaged by occurrence of smaller sized prawns in trawl catches (Velip and Rivonker, 2015b) owing to reduction in mesh size have further subsidized their abundance in trawl catches. The other two groups i.e. the crabs and stomatopods did not show any significant changes in abundance (Figure 3.5). Average crustacean abundance observed during the present study was $8.00 \pm 9.34 \times 10^2$.

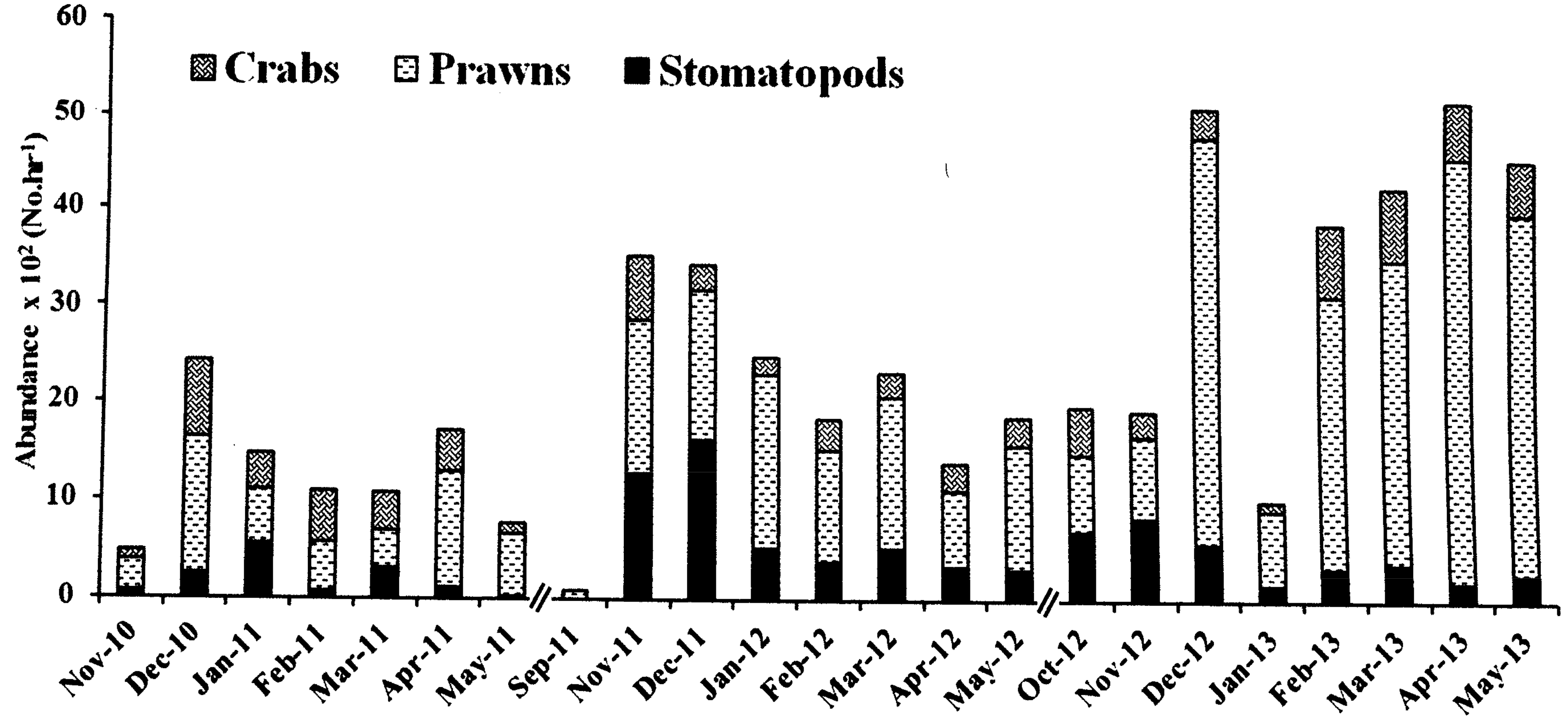


Figure 3.5. Month-wise variations in abundance of crustacean faunal groups

3.2.3. Elasmobranchs

3.2.3a. Species composition and faunal proportions

The elasmobranchs were represented by very few taxa (07; Figure 3.6a) and were sub-divided into three sub-groups namely, sharks (02 taxa), guitarfishes (01 taxa) and rays (04 taxa). They are highly predatory finfishes and usually occur in lower abundances largely owing to their biological traits such as slow growth rate and lower fecundity (Jennings *et al.*, 1998; Ebert *et al.*, 2008). Among the elasmobranch sub-groups, the sharks contributed 55 % to the total elasmobranch abundance followed by rays (45 %) and guitarfish (0.22 %; Figure 3.6b). Two shark species namely, *Scoliodon laticaudus* and *Chiloscyllium griseum* and one ray species namely, *Himantura walga* were the commonly occurring elasmobranch species along the region.

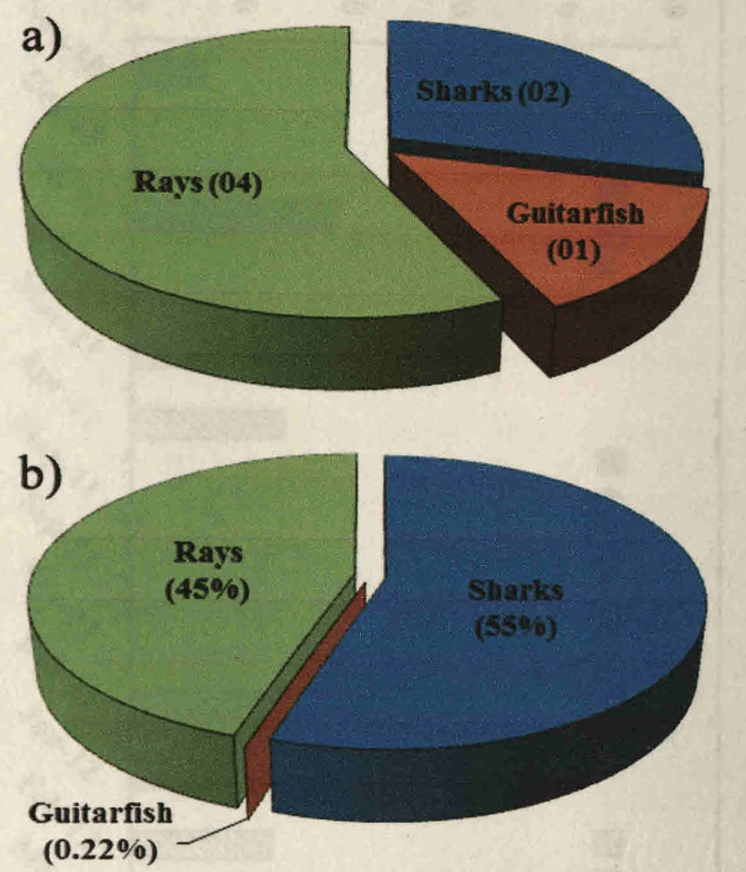


Figure 3.6. Elasmobranchs: a) number of species representing faunal groups b) percentage contribution of faunal groups in terms of abundance

3.2.3b. Temporal variations

Month-wise variations of elasmobranch faunal abundance did not show any significant pattern (Figure 3.7) owing to their irregular occurrence and lower abundance.

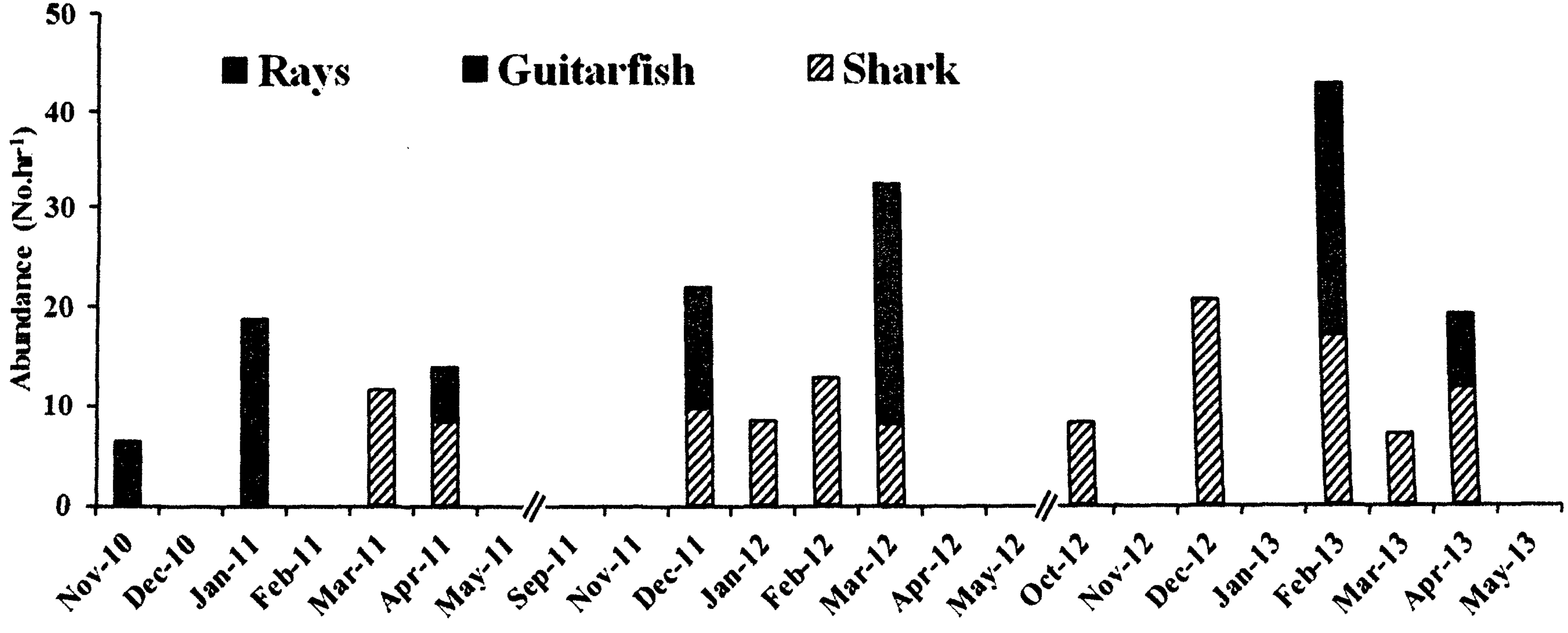


Figure 3.7. Month-wise variations in abundance of elasmobranch faunal groups

The maximum abundance was observed in the month of February, 2013 (43) while the lowest was observed in November, 2010 (06). Large scale fishing mortality of elasmobranchs (juveniles) especially due to bottom trawlers as by-catch has led to the reduction in their abundance (Stevens *et al.*, 2000; Hegde *et al.*, 2014).

3.2.4. Teleosts

3.2.4a. Species composition and faunal proportions

Teleosts are the second largest and most speciose faunal group observed during the present study incorporating a total of 126 taxa. Although this faunal group was represented by highest number of taxa their abundance was low as compared to crustaceans as the latter are perennial spawners in the nearshore coastal waters (Achuthankutty and Parulekar, 1986). Moreover, the teleostean fauna undertake estuarine or marine migration mostly related to spawning and feeding (Ansari *et al.*, 1995) and their active swimming capability enables them to escape from the trawl net (Hargreaves, 1980; Eayrs, 2012). This group is sub-divided into 16 sub-groups namely, clupeoids (18 taxa), eels (04), catfishes (04), lizardfishes (03), flatheads (03), grunters (04), carangids (10), pony fishes (09), silver-biddies (02), sciaenids (15), barracudas (02), threadfin breams (02), gobies (05), flatfishes (09), puffer fishes (02) and other teleosts (34; Figure 3.8a). Among these sub-groups, the clupeoids contributed maximum to the teleostean fauna (21 %) followed by other teleosts (18 %), sciaenids (15 %), ponyfishes (12 %) and flatfishes (12 %; Figure 3.8b). The contribution of rest of the faunal groups was very low.

Among the clupeoids caught in trawl catches due to less sampling depth, *Sardinella longiceps*, *Opisthopterus tardoore*, *Stolephorus commersonii*, *Thryssa mystax* and *T. dussumieri* were the most abundant species. These species spawn mostly during monsoon season (Nair, 1959; Deshmukh *et al.*, 2010; Fishbase, 2015) which is characterized by intense upwelling associated with south-west monsoon and the subsequent higher primary productivity (Madhupratap *et al.*, 2001) supports higher abundance of these planktivorous

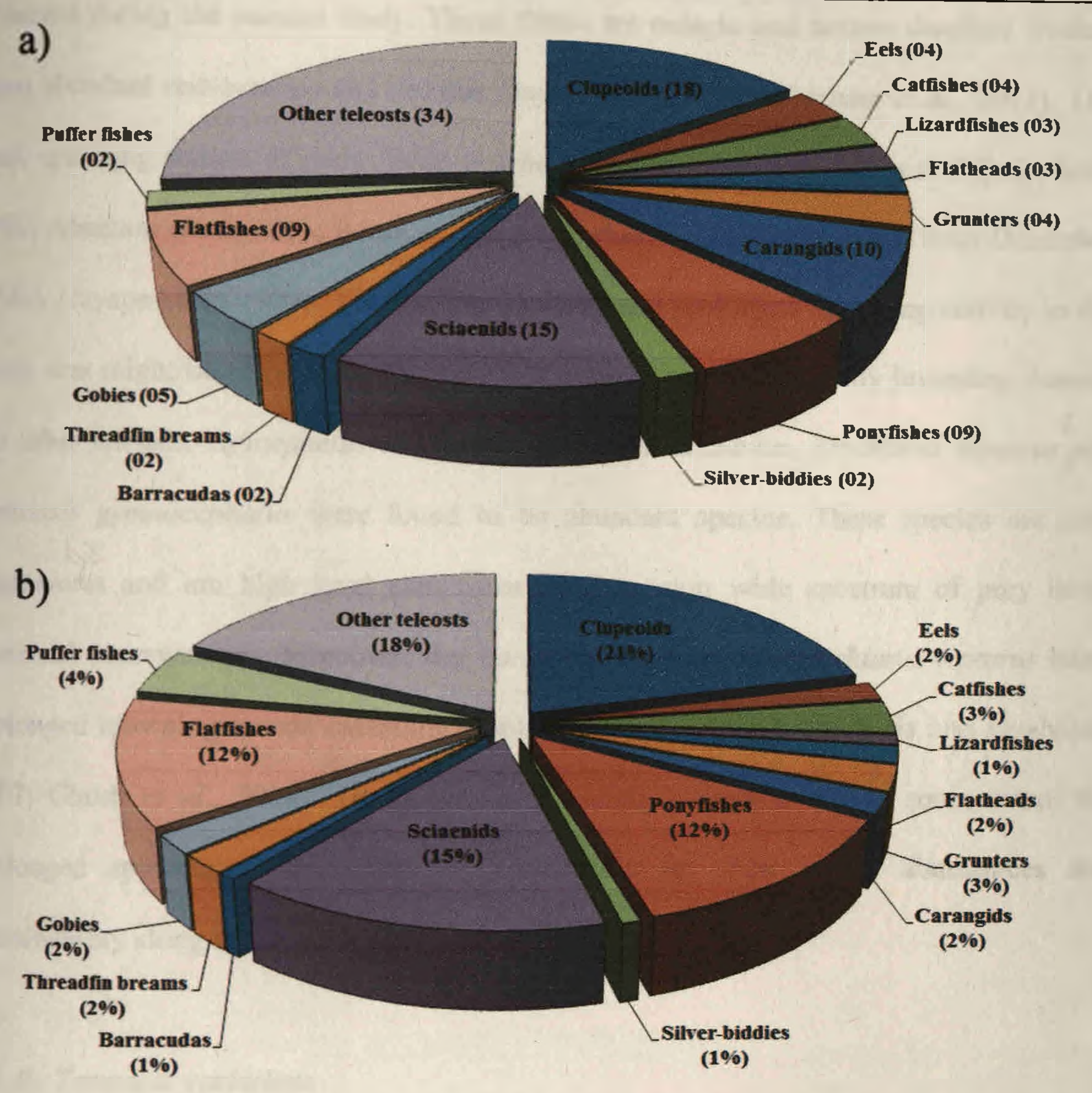


Figure 3.8. Teleosts: a) number of species representing faunal groups b) percentage contribution of faunal groups in terms of abundance

species. *Johnius borneensis*, *J. coitor*, *Otolithes cuvieri* and *O. ruber* were the abundant species among sciaenids. The sciaenids represent an important component of the demersal fishery of the region forming around 10 % of the total demersal fish catches (CMFRI, 2012). The biological traits of these fishes especially the feeding behavior (omnivory as well as carnivory; personal observations) along with higher reproductive potential might have supported to their higher abundances along the region. Similarly, among ponyfishes and flatfishes, *Photopectoralis bindus*, *Eubleekeria splendens* and *Secutor ruconius* and *Cynoglossus macrostomus* and *C. puncticeps*, respectively were the most abundant species observed during the present study. These fishes are pelagic and bottom dwellers feeding upon abundant zoo-benthos and detritus (Jayaprakash, 2000; Abraham *et al.*, 2011). The peak spawning season of pony fishes is from October – January (James and Badrudeen, 1986; Abraham *et al.*, 2011; Borah *et al.*, 2016) while the flatfishes spawn from December – May (Jayaprakash, 1999). The feeding diversity and prolonged spawning activity in the study area might be responsible for their higher abundances, especially juveniles. Among the other teleosts, *Epinephelus diacanthus*, *Lactarius lactarius*, *Trichiurus lepturus* and *Ambassis gymnocephalus* were found to be abundant species. These species are zoo-benthivores and are high level carnivores feeding upon wide spectrum of prey items (personal observations). Moreover, the *Lactarius lactarius* and *Trichiurus lepturus* bears prolonged spawning season extending from November – March (Zacharia and Jayabalan, 2007; Ghosh *et al.*, 2014). The generalized feeding behaviour and to some extent the prolonged spawning season may be responsible for their higher abundances and sustainability along this region.

3.2.4b. Temporal variations

Monthly abundance of teleostean fauna did not show much variation however, it increased slightly from first to the third fishing season (Figure 3.9). The maximum abundance was observed during the month of February, 2013 (45.34×10^2) while the minimum was observed during May, 2011 (6.63×10^2). The average teleostean abundance observed during the present study was $1.89 \pm 2.19 \times 10^2$ h^{-1}. Overall, higher teleostean abundance was observed during pre-monsoon as compared to post-monsoon period. The pre-monsoon period is characterized by relatively calm and stable hydrographic conditions

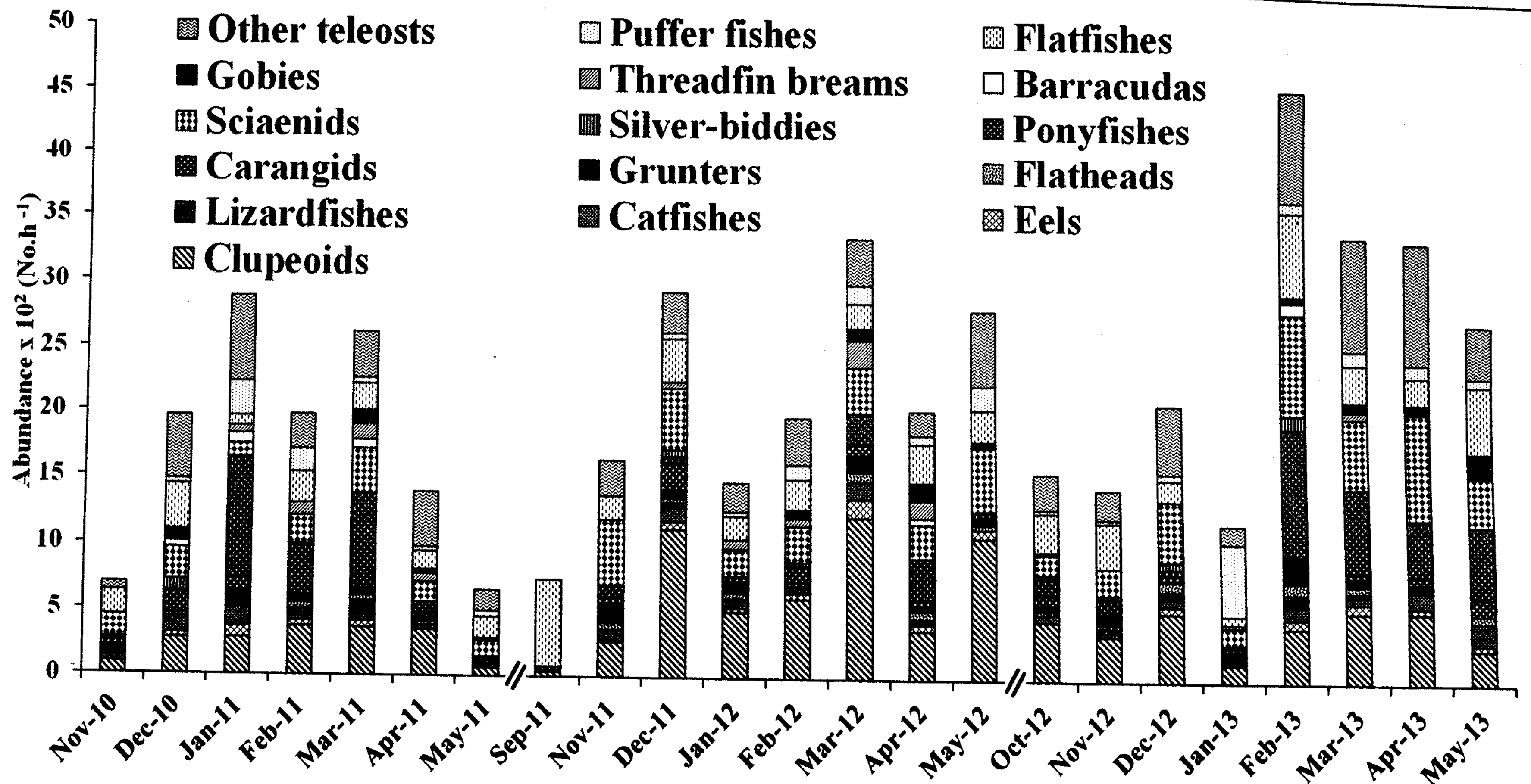


Figure 3.9. Month-wise variations in abundance of teleostean faunal groups

(salinity, temperature, etc.) with elevated primary productivity thus favouring the finfish abundance, especially the juveniles. Moreover, most of the teleostean species are reported to spawn during late post-monsoon to pre-monsoon season (James and Badrudeen, 1986; Jayaprakash, 1999; Zacharia and Jayabalan, 2007; Abraham *et al.*, 2011; Ghosh *et al.*, 2014; Borah *et al.*, 2016) and the juveniles of some teleostean species from adjacent waters migrate to coastal waters (potential nurseries) for feeding, thus contributing to higher teleostean abundance during pre-monsoon season. This was also corroborated by increased occurrence of juveniles of finfishes in the trawl net (Velip and Rivonker, 2015b). The higher abundance of flatheads, sciaenids and other teleosts towards the end of the study period could be attributed to favourable environmental conditions, prolonged spawning seasons leading to higher reproductive success and wide diet spectrum. On the other hand, the decreased abundance of barracudas and threadfin breams towards the end of the study period may be attributed to increased fishing pressure as fishing activities are reported to cause decline in fish populations (Myers *et al.*, 1997). The remaining sub-groups did not show any noteworthy variations.

3.2.5. Molluscs

3.2.5a. Species composition and faunal proportions

The molluscan group was represented by 20 taxa, sub-divided into three sub-groups namely, bivalves (02 taxa), cephalopods (04 taxa) and gastropods (14 taxa; Figure, 3.10a). Padate (2010) and Hegde (2013) reported 24 and 22 species of molluscan fauna, respectively from the nearshore coastal waters of Goa. This group was largely dominated by bivalves (54 %) in terms of their abundance followed by gastropods (31 %) and cephalopods (15 %; Figure, 3.10b). The bivalves were represented by a single species, *Anadara granosa*. Its higher abundance can be attributed to increased recruitment owing to favourable environmental conditions (Suwanjarat *et al.*, 2009). The cephalopods were represented by two species, *Uroteuthis duvaucelii* and *Sepiella inermis*. These species are highly carnivorous and exhibit a prolonged spawning season ranging from January to March and May to October (Silas *et al.*, 1982). These characteristics might have favoured to higher cephalopod abundances. Among gastropods, the abundant species were *Gyrineum natator* and *Turritella* sp. The lack of potential predators of gastropods such as predatory finfishes and crabs (Palmer, 1979) might be responsible for their higher abundances along the study area as these are removed by continuous fishing activities.

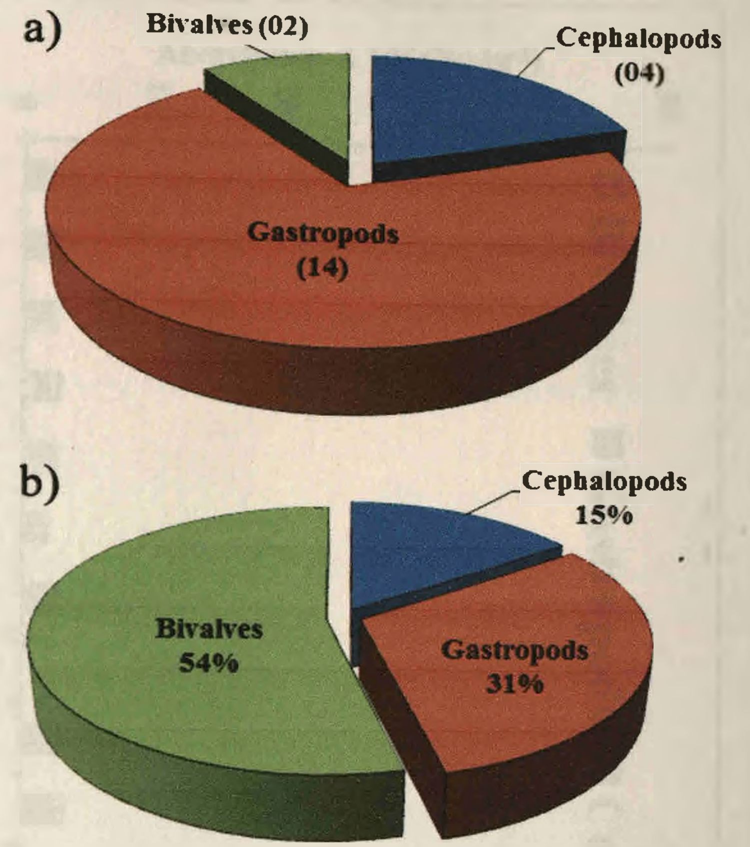


Figure 3.10. Molluscs: a) number of species representing faunal groups b) percentage contribution of faunal groups in terms of abundance

3.2.5b. Temporal variations

Monthly abundance data of molluscan fauna revealed a slight increase in their abundance towards the end of study period (Figure 3.11). However, they showed exceptionally higher abundance during the months of October and November, 2012 owing to the predominance of *Anadara granosa*. The maximum molluscan abundance was observed during the month of November, 2012 (46.50×10^2) while the minimum was

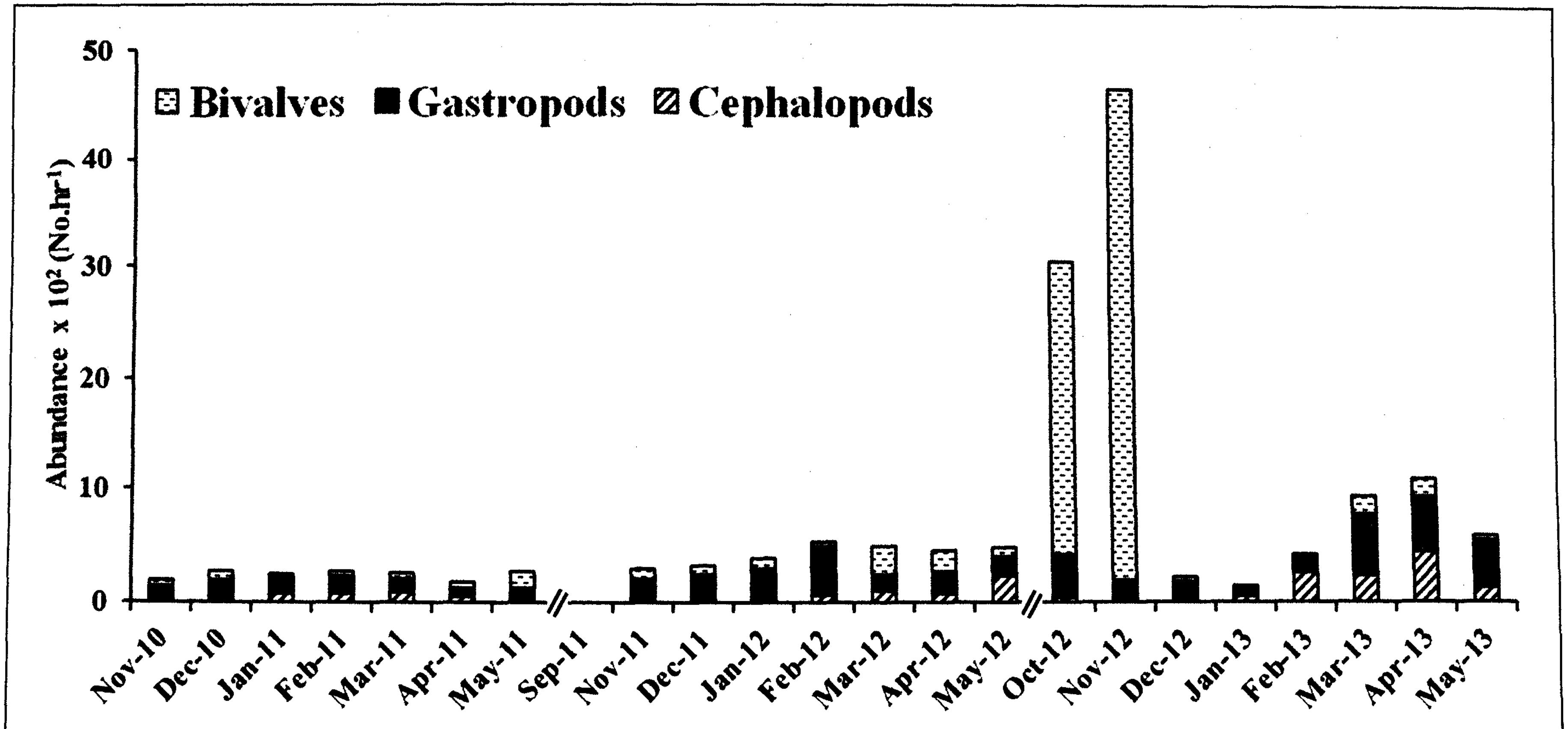


Figure 3.11.Month-wise variations in abundance of molluscan faunal groups

recorded in January, 2013 (1.64 x 10^2). The average molluscan abundance observed during the present study was 2.61 ± 6.34 x 10^2. The gastropods and cephalopods showed slightly increasing trend in their abundance towards the end of the study period while the bivalves did not show much of the variations; however they showed exceptionally higher values during October and November, 2012. The period coincides with the active spawning period of *A. granosa* (Suwanjarat *et al.*, 2009). The recruitment of large number of juveniles coupled with trawl operation in same habitat might have contributed to their increased abundance.

3.2.6. Echinoderms

3.2.6a. Species composition and faunal proportions

The echinoderms were represented by only four species but they constituted 17 % of the total faunal abundance. This faunal group was sub-divided into three sub-groups namely, sea urchins (02 taxa), sea stars (01 taxa) and brittle stars (01 taxa; Figure 3.12a). This faunal group consisted mostly of sea urchins (52 %) and sea stars (48 %). The contribution of brittle star was meager

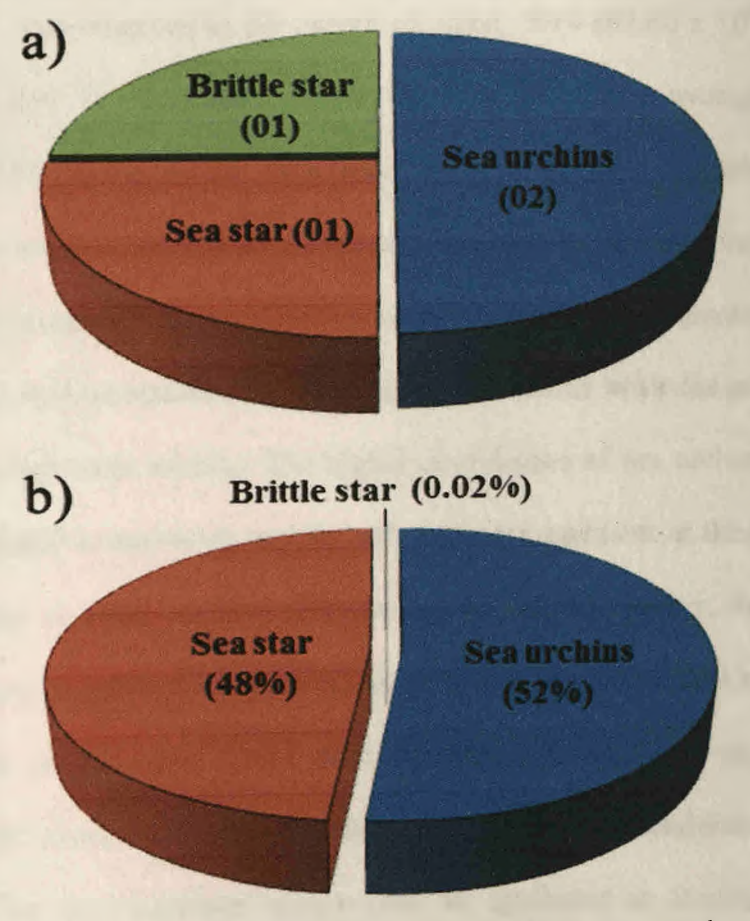


Figure 3.12. Echinoderms: a) number of species representing faunal groups b) percentage contribution of faunal groups in terms of abundance

(0.02 %; Figure 3.12b). Earlier studies (Padate, 2010; Hegde, 2013) reported minor contribution of echinoderm fauna (1.86 % and 3 %, respectively) in terms of their abundance along the region. In contrast, present study reported 17 % of echinoderm faunal contribution to the total trawl abundance. The observations made at this time from the region suggest that there could have been time-related changes or shift in demersal faunal community structure possibly due to higher recruitment, better survival due to favourable environmental conditions and reduced predation.

3.2.6b. Temporal variations

The abundance pattern of echinoderms showed a distinct temporal variation with an increased abundance towards the end of the study period i.e. during the year 2013 (Figure 3.13). The maximum abundance was observed in the month of April, 2013 (67.60 x 10^2) while the minimum was recorded in November, 2010 (0.23 x 10^2). The average echinoderm abundance observed during the present study was 5.75 ± 10.24 x 10^2. The sub-groups namely, sea stars and sea urchins showed an increased abundance towards the end of the study period. They were dominated by *Temnopleurus toreumaticus* and *Astropecten indicus*, respectively. Sea urchins were abundant during pre-monsoon months while the sea stars were abundant during post-monsoon months. The higher abundances of sea urchins during pre-monsoon can be attributed to spawning and the subsequent recruitment as these are known to spawn from spring to early summer (Rahman *et al.*, 2014). Further, the reduced predation pressure owing to continuous removal of potential predators such as groupers, triggerfishes, lobsters, mussels etc. might have facilitated the survival and proliferation of sea urchins (Hereu *et al.*, 2012). On the other hand, the higher abundances of sea star, *A. indicus* during the post-monsoon season may be attributed to feeding aggregations coinciding with higher abundances of gastropods and bivalves. This species is

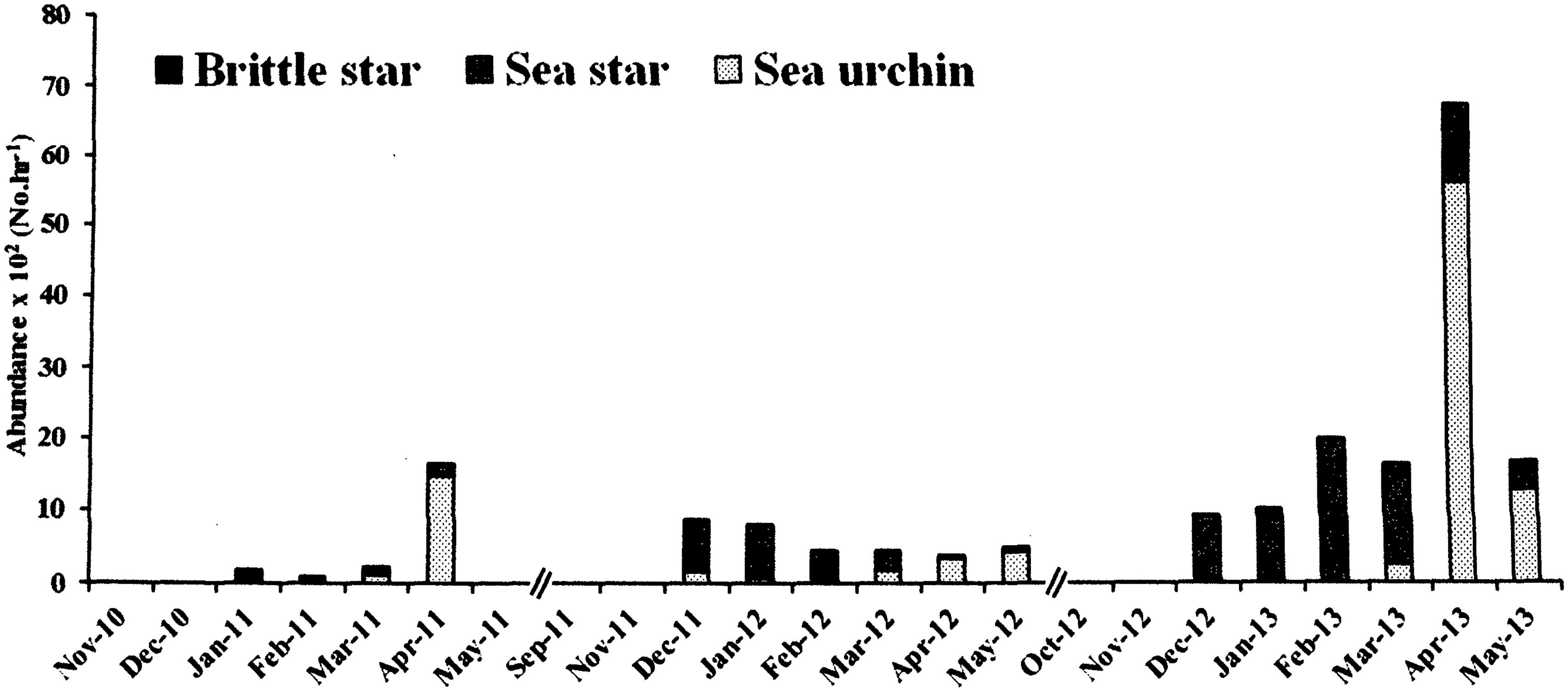


Figure 3.13. Month-wise variations in abundance of echinoderm faunal groups

a generalist carnivore and is known to prey upon gastropods and bivalves (Loh and Todd, 2011).

3.2.7. Spatial (depth-wise) variations of faunal abundance

The analysis of depth-wise variations in faunal abundance revealed a clear decrease in total faunal abundance with increasing depth (Figure 3.14), validated through ANOVA

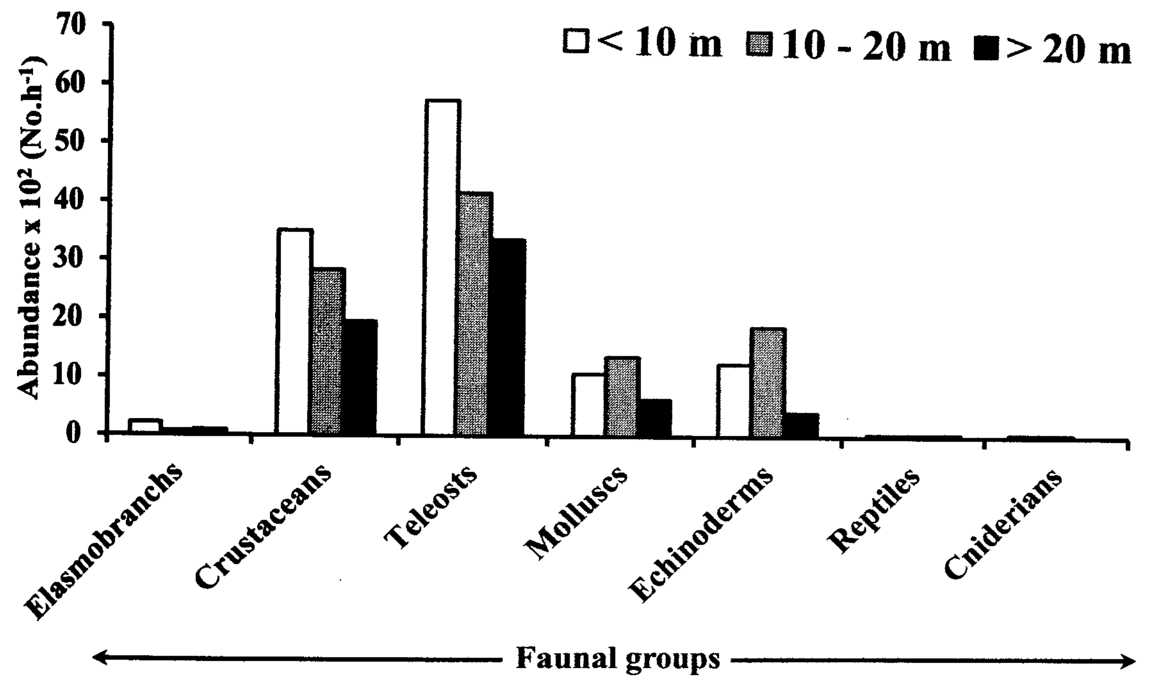


Figure 3.14. Depth-wise variations of faunal abundance

Table 3.3. Depth-wise variations in faunal abundance using two way ANOVA (P = 0.001)

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	49945708	6	8324285	29.97865	1.5E-06	8.378814
Columns	2217140	2	1108570	3.992347	0.046871	12.97367
Error	3332085	12	277673.7			
Total	55494933	20				

(*P* = < *0.001*; Table 3.3). Published literature (Rao and Dorairaj, 1968; Prabhu and Dhawan, 1974) also reported the depth-wise variations in faunal abundance along the study area. The crustacean and teleostean fauna showed a distinct decrease with increasing depth. The decrease in teleostean abundance may be attributed to decrease in plankton abundance which served as primary food for most of the teleostean juveniles. Prabhu and Dhawan (1974) also observed the decrease in crustacean and teleostean faunal abundance at 40 m depth zone compared to 20 m depth zone. On the other hand, the molluscs and echinoderms showed higher abundance in 10 – 20 m depth zone compared to < 10 m and > 20 m depth zone. The molluscan fauna (gastropods and bivalves) prefer to live in continuous submergence usually below the lowest low tide level (Parulekar, 1973) to overcome the problem of desiccation. The sea stars largely predate upon these molluscan fauna under continuous submergence (Loh and Todd, 2011). Moreover, much of the trawling activity is carried out in 15 – 20 m depth and due to trawling activity the hidden fauna gets exposed and the conditions become favourable for sea stars to predate upon molluscs. Apart from sea stars, the sea urchins are also found in higher abundance in this depth zone which actively feed upon submerged algae (Sauchyn and Scheibling, 2009).

3.2.8. Species diversity indices – temporal variations

An assessment of Shannon-Wiener's diversity index (H') revealed values ranging from 0.76 (September, 2011) to 3.85 (March, 2012; Figure 3.15). It showed slightly higher values in pre-monsoon months (3.44 ± 0.37) compared to post-monsoon months (2.75 ± 0.76). Margalef's species richness (SR) also showed higher values during pre-monsoon months (6.50 ± 1.41) as compared to post-monsoon months (4.88 ± 1.73; Figure 3.15). The values of SR ranged from 0.56 (September, 2011) to 9.20 (February, 2012). Similarly, the values of Dominance (D) were ranged from 0.03 (February, 2011) to 0.66 (September, 2011) and were inversely proportional to species richness and H' (Figure 3.15). It showed higher values in post-monsoon months (0.17 ± 0.18) compared to pre-monsoon months

(0.06 ± 0.04). Assessment of diversity indices and species composition suggests that the region supports multispecies fishery with rich faunal diversity (Ansari *et al.*, 1995; Hegde *et al.*, 2013). The prevalence of higher values of H' and SR during the pre-monsoon months can be attributed to increased spawning activity and the subsequent recruitment. Moreover, migration of juveniles from the adjacent areas to coastal waters for feeding purpose as the region is known to serve as potential nursery area due to its higher productivity (Ansari *et al.*, 1995) also contributes to higher H' and SR. On the other hand, the higher values of dominance during September, 2011 and October – November, 2012 was due to the predominance of tongue sole *Cynoglossus macrostomus* and *Anadara granosa*, respectively; attributed to their higher juvenile recruitment (Jayaprakash, 1999; Suwanjarat *et al.*, 2009).

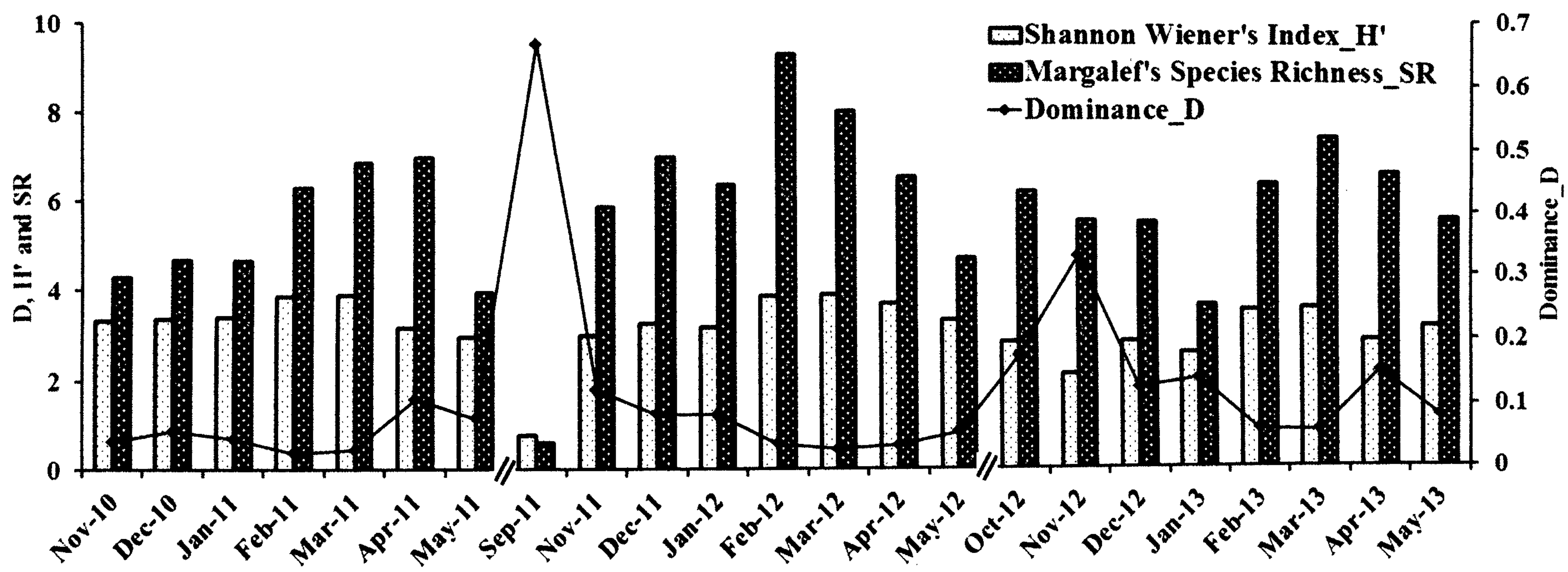


Figure 3.15. Monthly variations in dominance (D), Shannon Wiener's diversity index (H') and Margalef's species richness (SR)

Chapter 4 -

Description of *Hexapus bidentatus*, new species

4.1. Introduction

The near shore coastal waters (up to 25 m depth) off Goa, west coast of India supports a wide array of demersal fauna (Ansari *et al.*, 1995; Padate *et al.*, 2010a, b; Hegde and Rivonker 2013; Hegde *et al.*, 2013). Intensive bottom trawling surveys to assess the diversity and community structure of demersal fauna carried out during the present study revealed three specimens of hitherto unidentified hexapodid crabs.

The family Hexapodidae (Miers, 1886) can be easily distinguished from other brachyuran families by their seven exposed sternites (instead of eight in other Brachyura) and a strongly reduced or vestigial last pair of pereiopods (P5) (Guinot *et al.*, 2013). The other distinguishing characters include sub-parallel and similarly developed sternites 5–7, in contrast to an extremely reduced sternite 8, which is partially concealed under the carapace and abdomen, except for a small triangular portion visible dorsally (Angeli *et al.*, 2010; Guinot *et al.*, 2013); sternite 4 laterally extended forming a marked process on each side in extant as well as fossil hexapodids (Guinot 1979; Guinot *et al.*, 2010). This family is represented by 21 valid species belonging to 13 genera (Ng *et al.*, 2008).

A review of taxonomic literature revealed extensive work on the taxonomy of these shallow water crabs. Fabricius (1798) described *Cancer sexpes* from the south-eastern coast of India. De Haan (1833) described *Hexapus sexpes* (valid nomenclature *Hexapinus latipes* (De Haan, 1833)) in the family Pinnotheridea from Japan. Subsequently, Miers (1886) established the subfamily Hexapodinae under the family Pinnotheridae. However, Alcock (1900) cited affinities between Hexapodinae and Goneplacidae and recognized it as a sub-family of the latter. Contrary to the above, Manning and Holthuis (1981) opined that the suppression of the last pair of pereiopods was a fundamental character that warranted the recognition of the Hexapodinae as a distinct family, Hexapodidae following Guinot

(1978), who first created the super-family Hexapodoidea with a single family Hexapodidae.

This chapter deals with the description of new species of hexapodid crab, *Hexapus bidentatus*. In addition, an attempt is made to re-describe some of the salient morphological characters of its closest congener, *Hexapus estuarinus* Sankarankutty, 1975. Further, the new species is compared with all the existing congeners and an identification key to all the five valid species of the genus *Hexapus*, including the new species, is provided.

4.2. Methodology

The following abbreviations are used in the chapter: Ch, cheliped length; CL, carapace length; CW, extreme width of carapace; FOW, width of fronto-orbital margin of carapace; FW, width of frontal margin of carapace (Figure 4.1A); PD, Depth of propodus of cheliped; PL, Length of propodus of cheliped (Figure 4.1B); G1, male gonopod/first pleopod.

Terminology used in the morphological description of the new species follows Manning and Holthuis (1981) and Sankarankutty

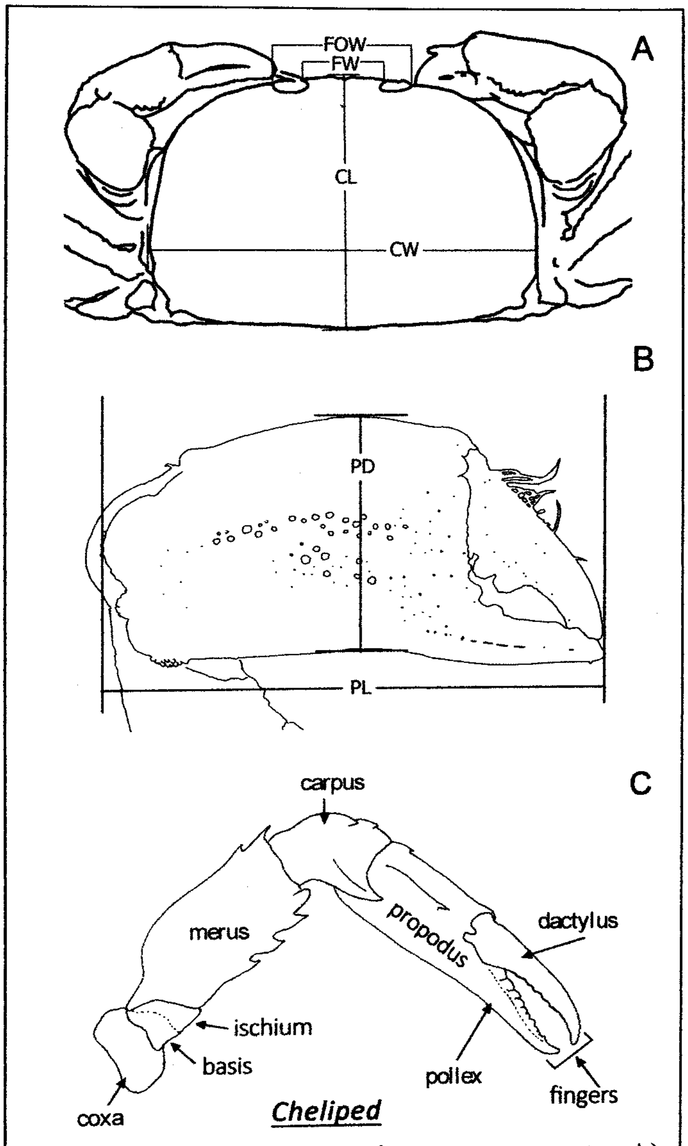


Figure 4.1. Morphometric measurements A) Dorsal surface of carapace, B) Outer surface of chela and C) Inner view of cheliped

(1975). In addition, the terminology describing G1 follows Wee and Ng (1995).

The morphological characteristics of the crabs were photographed with a stereo-zoom microscope (Olympus SZX–16). Morphometric parameters were measured using vernier calipers with an accuracy of 0.01 mm. In the case of chelipeds, the four distal segments (dactylus, propodus, carpus and merus) were separately measured. Subsequently, a detailed line diagram of the gonopod of the holotype male of the new species was drawn to ascertain the identity and distinctiveness of the species. Additionally, line diagram of G1 of *H. estuarinus* was drawn to elucidate its structure. Further validation of the identity of the congeneric species was done by detailed examination of chelipeds and G1 of its type specimens (Indian Museum Reg. no. 1263/2 and 1264/2).

Generic level identification was based on morphological characters described by Manning and Holthuis (1981). Morphological characters such as transverse sternal grooves of sterno-abdominal cavities of male, frontal width of carapace, dentition on base of dactylus of major cheliped and ornamentation on G1 were used as criteria to differentiate the new species from its congeners. The type specimens were stored in 5 % buffered formalin (buffered with hexamethylenetetramine to prevent fragmenting of appendages) solution in pre-labelled transparent plastic bottles. These are deposited in the Crustacea section of Indian Museum, Kolkata [Indian Museum Registration Number (IMRN): C6144/2 (Holotype) C6145/2 (Paratype I), C6146/2 (Paratype II)].

4.2.1. Comparative material examined

Hexapus estuarinus: Indian Museum Reg. no. 1263/2, Male: CL 7.60 mm, CW 11.00 mm, holotype, Thevara, Cochin, Southwest India, stake net collection; Indian Museum Reg. no. 1264/2, Male: CL 4.8 mm, CW 7.00 mm, paratype, same station data as holotype; GUMSMB 4, Male: CL 7.25 mm, CW 11.13 mm, off Goa, west coast of India, between 15°30'59.5" N, 73°43'26.7" E and 15°35'53.4" N, 73°40'46.6" E, depth 16–18 m, bottom trawl, 5th November 2012.

4.3. Taxonomy

4.3.1. Family Hexapodidae Miers, 1886

Hexapodinae Miers, 1886: 275. Type genus *Hexapus* De Haan, 1833.

4.3.1a. Diagnosis

Carapace much broader than its length, antero-lateral corners cut away and rounded off. Front narrow, antennules folds transversely. Orbits, eyes and antennae are small. Buccal cavern with the sides slightly convergent anteriorly or not, nearly closed by the third maxillipeds. Merus of third maxillipeds either quadrate or with the antero-external angles rounded off. Only three pairs of ambulatory legs visible, P5 being absent or rudimentary (Guinot and Bauchard, 1998).

4.3.2. Genus ***Hexapus*** De Haan, 1833

Hexapus De Haan, 1833: 35. Type species *Cancer sexpes* (Fabricius, 1798).

4.3.2a. Diagnosis

Short and stout eyes, cornea is not broader than stalk. Third maxilliped is with broad ischium and merus, mesial margin of ischium distally straight or sinuous; carpus, propodus and dactylus slender, sub-cylindrical; dactylus longer than propodus; exopod with flagellum. Pereiopods 2 – 4 are short; merus of third pereiopod shorter than carapace. Male abdomen with third to fifth somites fused, terminal somites rounded, not trilobed. G1 not concealed under abdomen, lying in deep, oblique grooves on anterior part of sternum, apices setose, directed antero-laterally. Female abdomen is with seven unfused segments (Manning and Holthuis, 1981).

4.3.2b. Distribution

Indo-West Pacific regions – South Africa (Barnard, 1947), Persian Gulf (Stephensen, 1946), India (Fabricius, 1798; Sankarankutty, 1975; Manning, 1982), Thailand (Rathbun, 1909; Serène and Soh, 1976), and Indonesia (Tesch, 1918).

4.3.2c. Remarks

The genus *Hexapus* De Haan, 1833 is represented by four valid species namely *Hexapus sexpes* (Fabricius, 1798), *Hexapus anfractus* (Rathbun, 1909), *Hexapus estuarinus* Sankarankutty, 1975 and *Hexapus edwardsi* Serène and Soh, 1976. Ng *et al.* (2008) listed five species including *Hexapus stebbingi* Barnard, 1947. However, this species was assigned to the genus *Tritoplax* due to the distinct trilobed form of the terminal segment of the male abdomen (it is broadly rounded in *Hexapus*) (Manning and Holthuis 1981). Another species whose taxonomic status is ambiguous is *H. estuarinus*, which was described by Sankarankutty (1975). Holthuis and Manning (1981) speculated that *H. estuarinus* is a junior synonym of *H. sexpes*. Manning (1982) formally considered it as a junior synonym of *H. sexpes*. However, Ng *et al.* (2008) listed *H. estuarinus* as a valid species.

In addition to the extant species, there are four fossil species namely *Hexapus decapodus* (Morris and Collins, 1991), *Hexapus granuliformis* Karasawa and Kato, 2008, *Hexapus nakajimai* Imaizumi, 1959 and *Hexapus pinfoldi* Collins and Morris, 1978 (Angeli *et al.*, 2010), whereas *H. anfractus* has been reported as both fossil and extant (Angeli *et al.*, 2010).

4.3.3. Key to the species of genus Hexapus De Haan, 1833

1a. Transverse sternal sutures (3/4) extend forward almost up to the base of third maxillipeds.. *H. anfractus.*

1b. Transverse sternal grooves not extending forward up to the base of third maxillipeds.. 2.

2a. FW approximately 0.50 times CL.. *H. edwardsi.*

2b. FW approximately 0.25 times CL.. 3.

3a. Fingers (dactylus and pollex) of major cheliped without distinct basal teeth; fingers of minor cheliped crossed, without gaping.. *H. sexpes.*

3b. Fingers of major cheliped with distinct basal teeth; fingers of minor cheliped meet at the tips, with prominent gaping in between.. 4.

4a. Cutting edge of dactylus of major cheliped with one large and one basal small tooth, pollex with one small basal tooth; fingers of minor cheliped curved and leave a rounded gaping in between them; G1 with six sub-distal evenly spaced spines on outer border.. *H. estuarinus.*

4b. Cutting edge of dactylus of major cheliped with two large basal teeth, pollex with two small basal teeth; fingers of minor cheliped more or less straight and leave a triangular gaping in between them; G1 with pair of spines on distal tip giving it a bifid appearance, followed by three sub-distal spines in zigzag position and four more in a straight row on outer border...***H. bidentatus* sp. nov.**

4.3.4. Hexapus bidentatus sp. nov.

4.3.4a. Material examined

Holotype (A holotype is the single specimen upon which a new nominal species-group taxon is based in the original publication): IMRN – C6144/2, male, CL 6.12 mm, CW 9.54 mm, off Goa, west coast of India, between 15°32'52.8" N, 73°44'26.8" E and 15°31'26.8" N, 73°44'44.1" E, depth 9–10 m, bottom trawl, 10 February 2012.

Paratypes (When an author designates a holotype, then the other specimens of the type series are called paratypes): IMRN – C6145/2, male, CL 5.65 mm, CW 8.72 mm, IMRN – C6146/2, male, CL 4.62 mm, CW 7.0 mm, Goa, west coast of India, between 15°30'59.5" N, 73°43'26.7" E and 15°35'53.4" N, 73°40'46.6" E, depth 16–18 m, bottom trawl, 5 November 2012.

4.3.4b. Diagnosis

Carapace quadrilateral, broader than long, rounded off at antero-lateral margins; dorsal surface pitted, except on gastric and cardiac regions. Fingers of major cheliped with sub-distal interlocking mechanism; dactylus basally armed with two equally large blunt teeth; pollex bears two small teeth basally; propodus 1.89 ± 0.07 times longer than depth, outer surface with two patches of granules separated from each other by an upwardly curved smooth patch. Fingers of minor cheliped with triangular gap in between, cutting edges irregularly toothed; propodus 2.18±0.10 times longer than depth. G1 tip with two spines giving it a bifid appearance; three sub-distal spines arranged in a zigzag position followed by four spines in a single row.

4.3.4c. Description

Carapace quadrilateral, broader than long (CW/CL = 1.54±0.02), with pitted (except gastric and cardiac regions) dorsal surface (Figure 4.2A). Dorsal surface

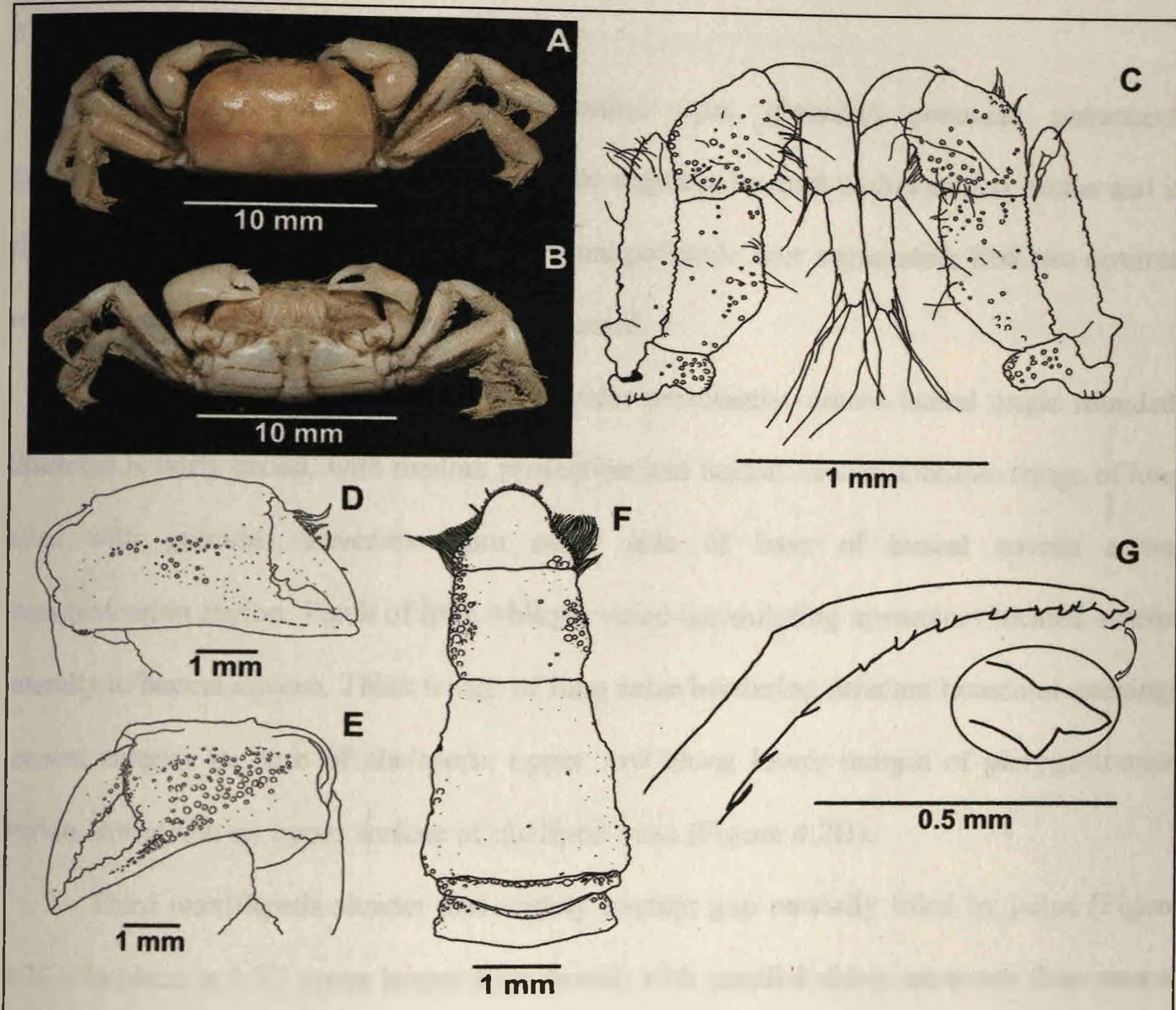


Figure 4.2. *Hexapus bidentatus* sp. nov. – A) Dorsal surface of carapace (photograph); B) Ventral surface of carapace (photograph); C) Third maxillipeds; D) Outer surface of major cheliped; E) Outer surface of minor cheliped; F) Abdomen of male; G) Tip of first pleopod or gonopod (G1); inset – tip of G1

longitudinally convex, transversely flat and with drooping lateral margins. Shallow grooves separate gastric and cardiac regions. Front narrow (FW/CW = 0.17±0.02) bilobed, pubescent, granulated at margins, deflexed ventrally and pitted dorsally, with ventrally directed and tapering median part separating antennulary fossa of either side (a transverse septum). Antennules are long, cylindrical, fold transversely in antennulary fossae; tuft of long setae ventrally at junction of antennular segments. Antennular flagellum is with tuft of four filaments distally. Antero-lateral margins of carapace rounded, granular and pubescent. Postero-lateral margins of carapace with few granules, distinct knob at postero-lateral angles. Posterior margin of carapace is broad, more or less straight with slight median convexity.

Orbits partially open intero-ventrally, eyes globular; peduncle pubescent, granulated, as long as cornea. Basal antennal segment located within orbital hiatus and is slightly in advance of frontal margin. Antennal peduncle four segmented; first two covered with setae; antennal flagellum long, 9-segmented.

Buccal cavern broader than long, wider posteriorly, antero-lateral angle rounded. Epistome is fairly broad, with median projection into buccal cavern. Oblique fringe of long setae with granules traverses from outer side of base of buccal cavern across pterygostomian region. Patch of long oblique striae (stridulating apparatus) located antero-laterally to buccal cavern. Thick fringe of long setae bordering inhalant branchial openings located anterior to base of chelipeds, upper row along lower margin of pterygostomian region, lower row on upper surface of cheliped coxa (Figure 4.2B).

Third maxillipeds slender and widely gaping; gap partially filled by palps (Figure 4.2C). Ischium is 1.77 times longer than broad, with parallel sides, narrower than merus; inner surface serrated, pubescent. Merus roughly pentagonal and as long as broad; outer and inner margins serrated at mid length, completely pubescent (pubescence longer along inner margin). Palp sub-equal to ischio-merus, cylindrical, covered with long setae. Dactylus is digitate, as long as merus, longer than propodus and shorter than ischium. Exopod long, cylindrical, flagellate; flagellum distally pubescent; lateral margins highly serrated; outer margin with outwardly pointing stout spine at proximal end.

Thoracic sternum broad, pitted [eight sternite (S8) reduced compared to seventh sternite (S7)], trilobate anteriorly; sternal sutures, lateral margins of sterno-abdominal cavity granulated. Transverse sternal sutures of sterno-abdominal cavity short, not extending beyond bases of third maxillipeds. Sternal sutures (3/4) lodging distal tip of G1. Setose patch of granules extends laterally from anterior margin of each transverse groove and meets granular patch at base of third maxillipeds of same side (Figure 4.2B).

Chelipeds heterochelous, heterodonts, ChL slightly less than three times CL. Dactylus (movable finger) of larger cheliped glossy, thickened, slightly curved with blunt tip; inner surface marked with series of transverse striations; cutting edge smooth, basally armed with two equally large blunt teeth; basal fringe of long setae on upper surface. Pollex slightly curved, thick, terminates with blunt tip, inner surface devoid of striations. Pollex is with two small teeth basally; shallow longitudinal groove on outer surface interrupted. Both fingers possess alternating sub-distal projections and recessions that forming interlocking mechanism. Fingers are gaping at mid-length (Figure 4.2D). Propodus glossy, pitted, PL/PD = 1.89±0.07, outer surface bears two patches of tubercles separated by upwardly curved smooth patch (Figure 4.2D); proximal hinge granular on outer surface; dorsal margin granular proximally, with row of seven granules followed by two teeth on a higher plane; another median row of five tubercles on inner surface lies parallel to it. Carpus glossy, pitted, granular on inner margin, granules on inner angle large, granules decrease in size anteriorly and posteriorly. Merus glossy, granulated on dorsal and ventral margins, with short pubescence on dorsal margin, inner surface with granulated ridges adjacent to ischial joint. Ischio-basis medially granulated on outer margin. Coxal margins granulated, pubescent.

Minor cheliped less massive, fingers thin, slightly curved, with blunt tips and sub-distal interlocking mechanism. Fingers leave triangular gap in between from base to 3/4 distance distally, cutting edges irregularly toothed (Figure 4.2E). Dactylus marked with a series of transverse striations on inner surface, dorsal margin irregularly granulated and pubescent. Pollex is with shallow longitudinal, interrupted groove and a granular patch proximally on outer surface. Propodus glossy, randomly pitted, PL/PD = 2.18±0.10; distal margin and ventral surface of proximal hinge granulated; outer surface with triangular patch of tubercles extending anteriorly to base of pollex (Figure 4.2E); dorsal margin with 4–5 large granules on proximal half, with small granules in their interstices; another medial row of 6 tubercles on inner surface lies parallel to it. Structures and ornamentations of carpus, merus, ischio-basis and coxa are similar to that of major cheliped.

Pereiopod 3 longest, length less than three times CL; pereiopods 2 and 4 sub-equal, dorso-ventrally flattened and with pitted glossy surfaces. Three distal-most segments (dactylus, propodus and carpus) are densely pubescent on anterior and posterior margins. Dactylus acutely pointed, with smooth margins, other two segments conspicuously granulated on anterior and posterior margins. Meri of second and third pereiopods is with shallow longitudinal grooves on dorsal and ventral surfaces. Merus of fourth pereiopod slightly curved. Granulations and pubescence grow denser from second to fourth pereiopod.

Male abdomen narrow, seven segmented including telson. Lateral margins of segments granulated. First segment is shorter and narrower than second. Segments 3 - 5 fused, each segment distinguished by narrowing of lateral margins at distal end. Surface of fused segments pitted. Sixth segment as long as broad, and with slightly bulging lateral margins; surface slightly pitted, semi-circular patches of granules on lateral margins. Seventh or distal-most segment is pyriform and with pubescent margins. Lateral bulges with tufts of long setae cover lateral extensions of sterno-abdominal cavity (Figure 4.2F).

G1 placed sterno-abdominally, bent outwards, tapers distally, with two lateral bends, proximal one at mid length, second at four-fifths distance from its base; inner border flared at distal bent portion. Long setae cover G1 from base to distal bend, denser at proximal bend (Figure 4.2G). Ornamentation comprises two distal and seven sub-distal spines on outer border. Distal two spines give tip bifid appearance. Sub-distal spines arranged as three spines in zigzag position followed by four in single row (Figure 4.2G).

4.3.4d. Colour

Carapace of fresh specimens is light greyish brown dorsally and pearly white ventrally. Dactyli and propodi of chelipeds, all pereiopodal (2 – 4) segments off white; carpi and meri of chelipeds light brown. Formalin-preserved specimens appear light brown (Figure 4.2A).

4.3.4e. Distribution

Hexapus bidentatus is currently known only from the type locality Goa, west coast of India.

4.3.4f. Etymology

The species name, *Hexapus bidentatus* is derived from the two equally large basal teeth ("bi" is the Latin prefix for two and "dentatus" is the Latin word for toothed) of the dactylus of the major cheliped, a character unique to this species.

4.3.4g. Comparison with congeneric species

Hexapus bidentatus sp. nov. differs from *Hexapus anfractus* in having shorter transverse sternal grooves of male that do not extend forward up to the bases of third maxillipeds. The new species differs from *Hexapus edwardsi* in narrower frontal margin of carapace, which is less than 0.25 times CL.

Hexapus bidentatus sp. nov. is morphologically more similar to *Hexapus estuarinus* and *Hexapus sexpes* in the narrow frontal margin of carapace (Table 4.1). Further, both *H.*

bidentatus and *H. estuarinus* possess "basal teeth on dactylus and pollex of major cheliped" as compared to lack of teeth in *H. sexpes*. Another morphological character that deserves mention is the gaping of the fingers of the minor cheliped. The re-description of *H. sexpes* by Manning (1982) states "Minor chelipeds with fingers not gaping". The illustration of *H. sexpes* (Manning 1982: Fig. 1D, minor chela, Pg. 158) also indicates crossed fingers. In contrast, fingers of the minor cheliped of both *H. bidentatus* and *H. estuarinus* meet at the tips with a conspicuous gap in between them. Other differences include "absence of tubercles on sternum" and "presence of basal setae on fixed finger of major cheliped" in *H. sexpes* as compared to "sternal sutures tuberculate" and "absence of

Table 4.1. Comparative analysis of morphometric characteristics of three closely related congeners namely *Hexapus bidentatus* sp. nov., *Hexapus estuarinus* and *Hexapus sexpes*

Morphological Character	***Hexapus bidentatus* sp. nov. (n=3)**	***Hexapus estuarinus* (n=3)**	***Hexapus sexpes*† (based on Manning (1982))**
Morphometric Ratios			
CW/CL	1.54±0.02	1.48±0.05#	1.53*
FW/CW	0.17±0.02	0.21±0.03#	0.20*
PL/PD (Major cheliped or pereiopod 1)	1.89± 0.07	1.63±0.05#	NA
PL/PD (Minor cheliped or pereiopod 1)	2.18±0.10	1.99±0.02#	NA
Basal antennal segment	Long, extends slightly beyond frontal margin	Short, does not extend beyond level of frontal margin	NA
Sternum (male)	Surface smooth, sternal sutures tuberculate	Surface smooth, sternal sutures tuberculate	Surface smooth, non-tuberculate
Ornamentation on inner surfaces of dactyli of both	Single series of transverse striations along entire length of	Single series of transverse striations along entire length of	NA

chelipeds	dactyli	dactyli	
Basal setae on pollex of major cheliped	Absent	Absent	Present
Dentition on cutting edge of fingers of major cheliped	Both fingers smooth along cutting edges; dactylus with two large basal teeth, pollex with two small basal teeth	Both fingers smooth along cutting edges; dactylus with one large and one small basal tooth, pollex with one small basal tooth	Both fingers toothed, both lack large basal teeth
Dentition on cutting edge of fingers of minor cheliped	Alternate large and small teeth along entire cutting edge	Randomly placed irregular teeth along entire cutting edge	Teeth present
Sub-distal interlocking mechanism on fingers of major cheliped	Present	Present	NA
Form of fingers and gaping in minor cheliped	Fingers more or less straight, not crossing, with triangular gaping between them	Fingers distinctly curved, not crossing, with rounded gaping between them	Fingers curved, crossed, not gaping
Ornamentation on outer surface of propodus of major cheliped	Two patches of tubercles separated by a upwardly curved smooth patch	Randomly scattered tubercles	Granules separated by smooth area
Ornamentation on outer surface of propodus of minor cheliped	Elongated triangular patch of granules on lower half of propodus	Elongated triangular patch of granules on lower half of propodus	Granulated areas separated by smooth area
Dactyli of pereiopods 2–4	Pubescent, length of dactyli of pereiopods 2 and 3 shorter than propodal length, those of pereiopod 4 equal to propodal length	Pubescent, length of dactyli of pereiopods 2 and 3 shorter than propodal length, those of pereiopod 4 equal to propodal length	Naked, their length equal to propodal length
Meri of pereiopods	Tuberculate and setose	Tuberculate and setose	Tuberculate

2-4	on both anterior and posterior margins; dorsal surfaces of meri of pereiopods 2 and 3 pubescent, those of pereiopod 4 naked	on both anterior and posterior margins; dorsal surfaces of meri of pereiopods 2 and 3 pubescent, those of pereiopod 4 naked	dorsally, setose ventrally
G1 shape	Two lateral bends, the proximal one at mid length, second at four-fifths distance from base; inner border flared at distal bend	Two lateral bends, the proximal one at mid length, second at four-fifths distance from base; inner border flared at distal bend	Bent laterally near mid length?
Pubescence on G1	Long setae cover G1 from base to distal bend, denser at proximal bend	Long setae cover G1 from base to distal bend, denser at proximal bend	NA
Distal spines on tip of G1	Two distal spines present on tip of G1, giving it a bifid appearance	Absent	NA
Sub-distal spines on tip of G1	Seven sub-distal spines arranged as three in zigzag position followed by single row of four on outer border	Evenly spaced six sub-distal spines on outer border	NA

† Data obtained from Manning (1982) NA – Data not available

* Ratios derived from values provided by Manning (1982)

\# Data obtained from Indian Museum type specimens (02) and Goan specimen (01)

basal setae on fixed finger of major cheliped" in *H. bidentatus* sp. nov. and *H. estuarinus*. Further morphological comparison between *H. bidentatus* sp. nov. and *H. estuarinus* revealed the following differences.

1. *Hexapus bidentatus* sp. nov. possesses "two equally large basal teeth on cutting edge of dactylus" and "two small basal teeth on cutting edge of pollex" of major cheliped as compared to "one large and one small basal tooth" on dactylus and "one small basal tooth" on pollex of *H. estuarinus* (Table 4.1).

2. Ornamentation on the distal portion of G1 of *H. bidentatus* sp. nov. comprises a pair of spines at distal tip giving it a bifid appearance, followed by three spines in zigzag position and four more in a straight row. On the other hand, ornamentation on the G1 of *H. estuarinus* comprises evenly spaced six sub-distal spines on outer border (Table 4.1).

*4.3.5. **Hexapus estuarinus** Sankarankutty, 1975*

Hexapus estuarinus Sankarankutty, 1975: 1–6, figures 1–2 (type locality: Thevara, Cochin, southwest India)

4.3.5a. Diagnosis

Carapace quadrilateral, broader than long, rounded off at antero-lateral margins (Figure 4.3A). Antennules fold transversely. Basal antennal segment short, not extending beyond level of frontal margin. Margins of thoracic sternites are tuberculated. Dactylus of major cheliped with one large basal tooth followed by smaller tooth; pollex with one small basal tooth, sub-distal interlocking mechanism on fingers; propodus 1.63±0.05 times longer than depth, outer surface bears randomly scattered tubercles. Fingers of minor cheliped are with random irregular teeth on cutting edges; propodus 1.99 ± 0.02 times longer than depth. Dactyli of chelipeds is with single series of transverse striations traversing their entire length on inner surface. G1 bent proximally at mid-length and distally at 4/5 distance from base, inner border flared at distal bend, long setae cover G1 from base to distal bend, denser at proximal bend; distal tip lacks spines, sub-distal ornamentation consists of evenly spaced six sub-distal spines on outer border.

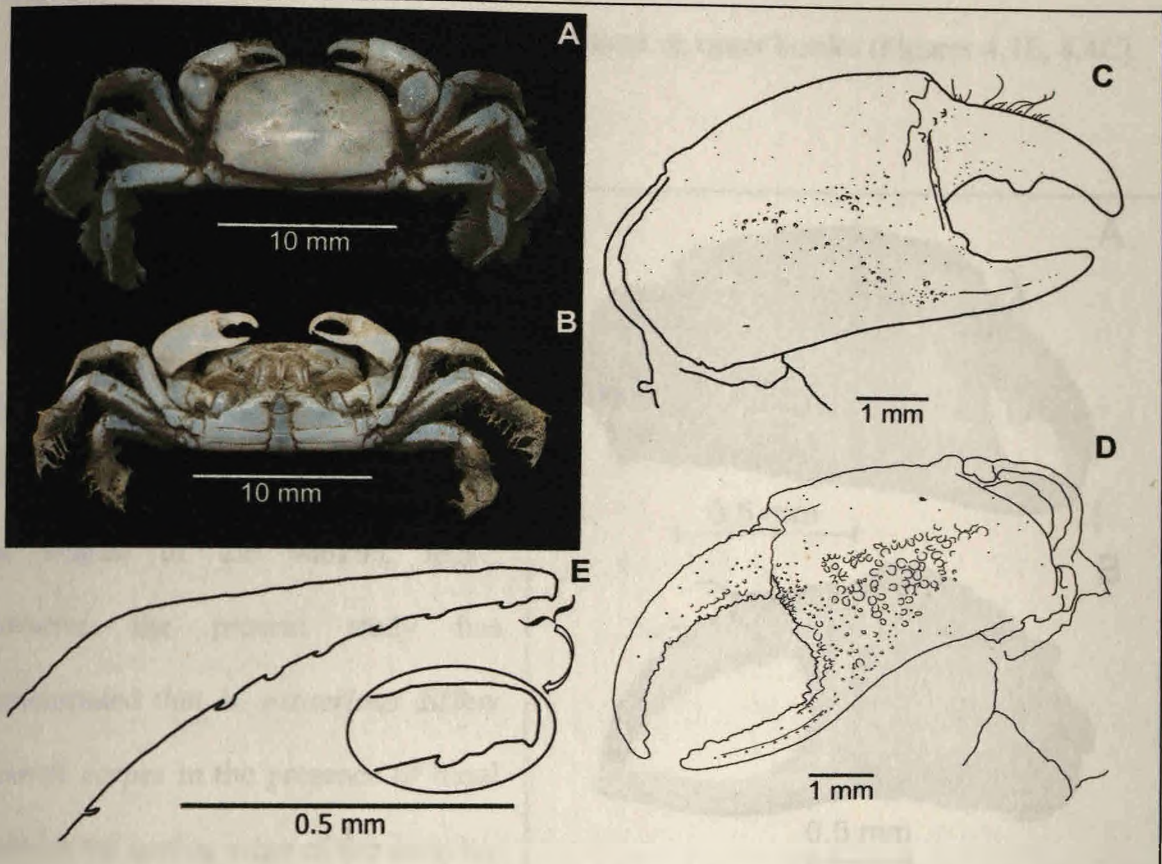


Figure 4.3. *Hexapus estuarinus* – A) Dorsal surface of carapace (photograph); B) Ventral surface of carapace (photograph); C) Outer surface of major cheliped; D) Outer surface of minor cheliped; E) Tip of first pleopod or gonopod (G1); inset – tip of G1

Some of the additional salient morphological characters mentioned above (based on the Goan specimen and re-examination of Sankarankutty's type specimens deposited at the Indian Museum (Figure 4.4A – C)), that were not included in the original description (Sankarankutty, 1975) are as follows.

1. Antennules fold transversely.
2. Basal antennal segment short, not extending beyond level of frontal margin.
3. Margins of thoracic sternites tuberculated (Figure 4.3B).
4. Single series of transverse striations on inner surface along entire length of cheliped dactyli.

5. Few randomly scattered tubercles on outer surface of propodus of major cheliped (Figure 4.3C).
6. G1 with six sub-distal evenly spaced spines on outer border (Figures 4.3E, 4.4C).

4.3.5b. Taxonomic status

Manning (1982) believed that *Hexapus estuarinus* was a junior synonym of *Hexapus sexpes* based on "chelae are unequal" and "second leg is the longest of the walking legs". However, the present study has demonstrated that *H. estuarinus* differs from *H. sexpes* in the presence of basal teeth on the cutting edge of the dactylus and pollex of major cheliped (Figure 4.3C, 4.4A), prominent rounded gap between the fingers of the smaller cheliped (Figure 4.3D, 4.4B). Other differences include presence of tubercles on sternal sutures and absence of basal setae on fixed finger of major cheliped. These differences warrant the recognition of *H. estuarinus* as a separate species.

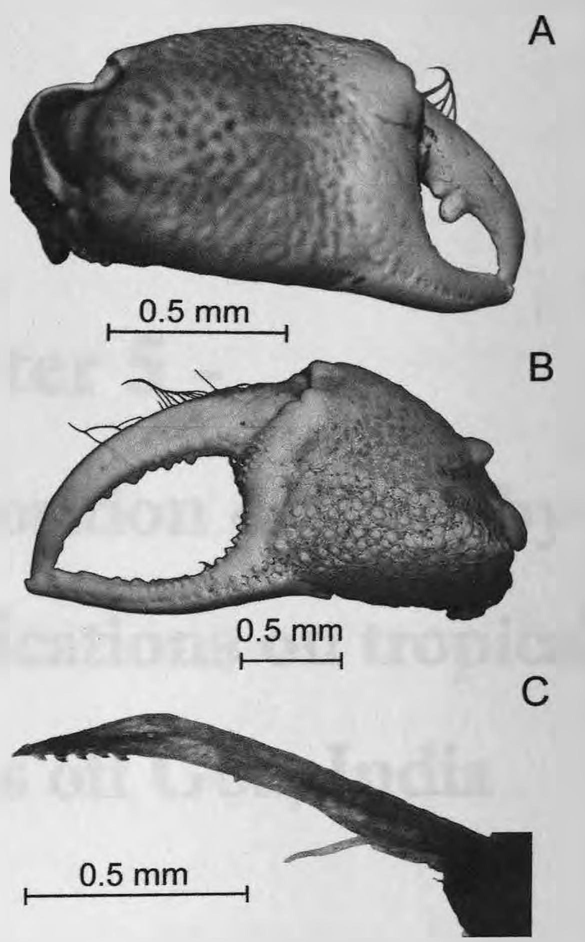


Figure 4.4. *Hexapus estuarinus* (Holotype) – A) Outer surface of major cheliped (photograph); B) Outer surface of minor cheliped (photograph); C) First pleopod or gonopod (G1) (photograph)

Chapter 5 -

Trends and composition of trawl by-catch and its implications on tropical fishing grounds off Goa, India

5.1. Introduction

The exploitation of coastal demersal resources by trawl gear has led to indiscriminate removal of target as well as non-target species, affecting diversity (Davies *et al.*, 2009; Thurston and Roberts, 2010). One of the most adverse problems faced is associated with shrimp by-catch (Clucas, 1997) affecting rare and endangered species (Wallace, 1996), habitat through hypoxia (Naqvi *et al.*, 2010) and food web through trophic displacement (Murawski, 1995). Published literature (Bijukumar and Deepthi, 2006; Davies *et al.*, 2009) suggests that the by-catch is perceived contrarily in different parts of the world, and varies according to geographical region, fishing depth and fishing gear. This problem is more severe in tropical coastal waters where the shrimp trawlers arbitrarily target diverse faunal assemblages and eventually destroy vital benthic habitats (Rao *et al.*, 2013).

Although it is well-accepted that by-catch is an unavoidable component of trawl net, increased utilization for economic purposes has led to reduction in discarded by-catch (Dineshbabu *et al.*, 2013). The issue of discarded by-catch is particularly severe along the Indian coastal region due to multispecies fishery. Species composition of multispecies fishery trawl catch suggests that the enormity of by-catch resulting from such fishing operations is inevitable, causing loss of species and physical damage to the ecosystem (Sabu, 2008; Gibinkumar *et al.*, 2012).

The concept of by-catch that has been put forth in this chapter, and the terminology used, follow Alverson *et al.* (1994), with minor modifications in view of species composition and its utilization from the region. The "Target catch" refers to the catch of a species or species assemblage that is primarily sought in a fishery (shrimp, soles, sciaenids, squids and crabs); "Incidental Catch" or "Commercial By-catch" – Retained catch of non-target species; "Discarded by-catch" or "Trash fishes" is that portion of the catch that is returned to the sea as a result of economic, legal, or personal considerations; "By-catch" or "Non-target catch" is the incidental, plus discarded catch.

In view of the above, the present study attempts to emphasize seasonal changes in by-catch composition and species associations in respect of its application along the coast of Goa. Further, the occurrence of different groups of associated benthic fauna at different times has been assessed and discussed. The study also involves the assessment of species specific response to environmental parameters and the fate of by-catch along Goa coast.

5.2. Methodology

5.2.1. Data analysis

The total trawl catch was segregated into 'target catch' and 'by-catch' based on economic use. Further, the by-catch was grouped as 'commercial by-catch' and 'discarded by-catch'. The discarded by-catch comprised mainly of juveniles of target species and a majority of non-edible fishes. Biomass of trawl catch was assessed by dividing the entire study period into six seasons, Post-monsoon 2010 (Oct 2010 – Jan 2011; PostM 10); Pre-monsoon 2011 (Feb – May 2011; PreM 11); Post-monsoon 2011 (Oct 2011 – Jan 2012; PostM 11); Pre-monsoon 2012 (Feb – May 2012; PreM 12); Post-monsoon 2012 (Oct 2012 – Jan 2013; PostM 12) and Pre-monsoon 2013 (Feb – May 2013; PreM 13).

5.2.2. Cluster analysis

The entire duration of study was divided into two seasons i.e. pre-monsoon (February to May) and post-monsoon season (October to January) and the taxa contributing more than 0.5 % to a monthly aggregate abundance data were selected for cluster analysis to filter out rare and uncommon species. Abundance data were normalized using the square root transformation function, converted into a lower triangular matrix using the Bray-Curtis Similarity Coefficient (Bray and Curtis, 1957) and dendrogram plots were constructed using the group average function of PRIMER statistical software (Clarke and Gorley, 2006). The significance of the cluster groups ($p < 0.05$) was tested by similarity profile (SIMPROF) analysis. Abbreviations used to represent species are given in Appendix 5.1.

5.2.3. Principal Component Analysis (PCA)

Relationships between species abundance and environmental parameters (seasonal) were analyzed by correlation-based Principal Component Analysis (PCA). Species that accounted for more than 0.5 % of discarded by-catch abundance were selected for this analysis. Additionally, three environmental variables (temperature, dissolved oxygen and salinity) were subjected to PCA to extract the components that explained maximum environmental variation.

5.3. Results and Discussion

5.3.1. Species composition

Trawl by-catch comprises of a variety of fauna including juveniles and adults of non-target species as well as juveniles of target species (Sabu, 2008). The present observation revealed that the non-target species of by-catch included some of the commercially important as well as trash species. The use of non-selective fishing gear with reduced mesh size to exploit demersal fish in recent times has led to excessive amount of by-catch. Although the mortality on-board may not be instant, 80 - 90 % of the mortality occurs during the course of sorting and eventually dead fauna are discarded into the sea (personal observation).

The present investigation on the catch composition of shrimp trawl revealed that 89 % of the species contributed to the trawl by-catch (174 species) as compared to only 11 % (22 species) target species (shrimps, soles, crabs, squids and sciaenids; Figure 5.1). Among

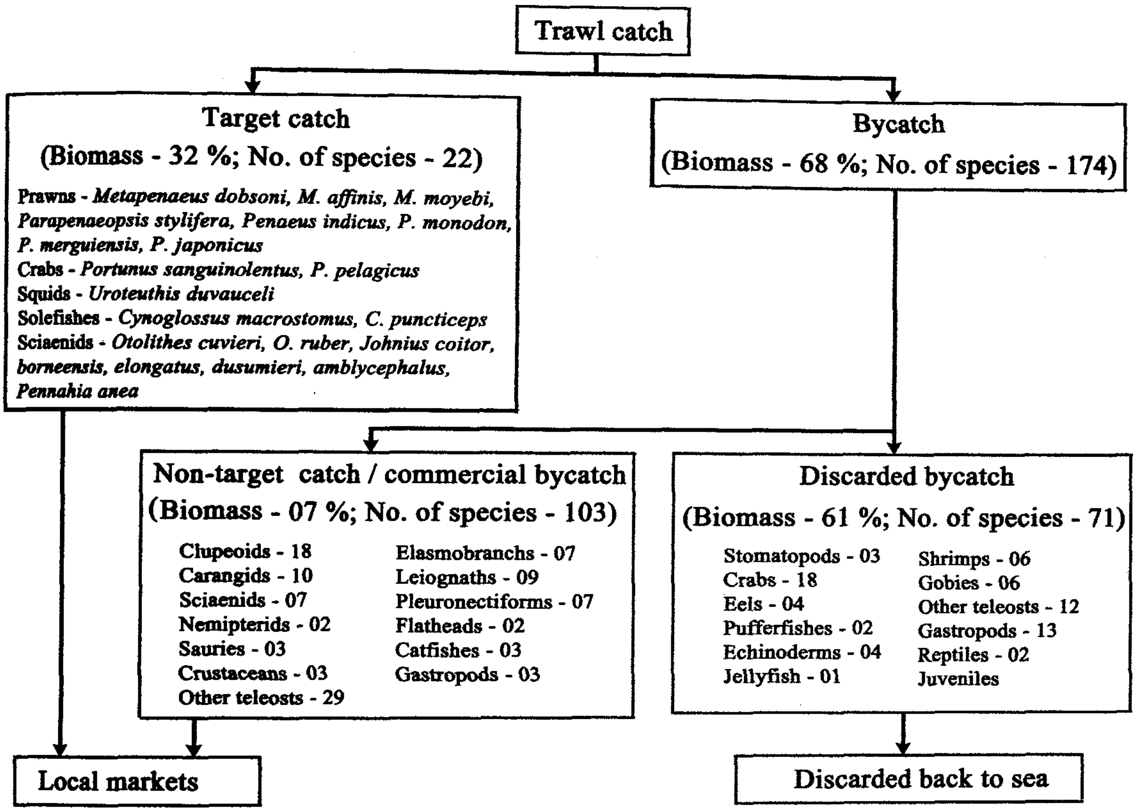


Figure 5.1. Flow chart showing different sections of trawl catch based on its utility along with species composition

the by-catch species, 36 % (71 species) were always discarded into the sea irrespective of size, owing to lack of commercial value (non-edible fishes). The remaining 53 % (103 species) were brought to landing sites depending on their size (Figure 5.1). In view of the above, the by-catch was categorized as commercial by-catch (elasmobranchs (07 species), teleosts (90), crustaceans (03) and molluscs (03)) and discarded by-catch (teleosts (24 species), crustaceans (27), molluscs (13), echinoderms (04), reptiles (02) and cnidarian (01)) (Figure 5.1). Within the discarded by-catch, most abundant species were *Astropecten indicus* (12.30 %), *Miyakella nepa* (11.94 %), *Temnopleurus toreumaticus* (8.34 %) and *Anadara* spp. (7.64 %; Table 5.1).

Table 5.1. Percentage contribution of major species in discarded by-catch (> 0.1 % of abundance)

Sr. No.	Species name	N	%	TL	Sr. No.	Species name	N	%	TL
Economically important species (Commercial)									
1.	*Scoliodon laticaudus*	4	0.12	4.0 [2]	26.	*Grammoplites scaber*	6	0.17	3.8 [1]
2.	*Dasyatis walga*	5	0.15	3.58 [2]	27.	*Epinephelus diacanthus*	32	0.96	3.8 [1]
3.	*Parapenaeopsis stylifera*	264	8.02	2.0–2.5 [2]	28.	*Terapon theraps*	10	0.30	3.49 [5]
4.	*Metapenaeus affinis*	48	1.45	2.0–2.5 [2]	29.	*Terapon puta*	4	0.12	3.12 [5]
5.	*Metapenaeus dobsoni*	94	2.85	2.0–2.5 [2]	30.	*Lactarius lactarius*	46	1.39	4.0 [1]
6.	*Metapenaeus moyebi*	10	0.29	2.0–2.5 [2]	31.	*Leiognathus brevirostris*	5	0.14	2.96 [5]
7.	*Penaeus semisulcatus*	7	0.21	2.0 [6]	32.	*Photopectoralis bindus*	21	0.62	2.5 [1]
8.	*Exhippolysmata ensirostris*	16	0.49	2.0–2.5 [2]	33.	*Eubleekeria splendens*	72	2.20	2.9 [1]
9.	*Portunus sanguinolentus*	32	0.96	2.5–3.0 [2]	34.	*Secutor ruconius*	7	0.21	3.4 [1]
10.	*Portunus pelagicus*	11	0.34	2.5–3.0 [2]	35.	*Pennahia anea*	5	0.15	3.99 [5]
11.	*Charybdis feriata*	31	0.93	2.5–3.0 [2]	36.	*Otolithes cuvieri*	17	0.50	3.87 [5]
12.	*Charybdis lucifera*	19	0.59	2.5–3.0 [2]	37.	*Otolithes ruber*	13	0.40	3.60 [5]
13.	Small un. red prawns	245	7.46	2.0–2.5 [2]	38.	*Johnius borneensis*	49	1.50	3.69 [5]
14.	Small un. white prawns	13	0.40	2.0–2.5 [2]	39.	*Johnius dussumieri*	6	0.18	4.09 [5]
15.	Mysis	28	0.84	2.0 [2]	40.	*Johnius coitor*	5	0.15	3.3 [1]
16.	*Sardinella longiceps*	13	0.39	2.5 [2]	41.	*Trichiurus lepturus*	57	1.73	4.4 [1]
17.	*Ilisha sirishai*	4	0.12	2.5–3.0 [1]	42.	*Nemipterus japonicus*	13	0.40	3.8 [1]
18.	*Opisthopterus tardoore*	125	3.81	3.4 [1]	43.	*Pomadasys maculatus*	5	0.15	4.04 [1]
19.	*Stolephorus commersonnii*	32	0.97	3.05 [5]	44.	*Solea ovata*	5	0.15	3.5 [1]
20.	*Thryssa mystax*	28	0.84	3.6 [1]	45.	*Cynoglossus macrostomus*	35	1.05	3.28 [1]
21.	*Thryssa dussumieri*	24	0.73	2.82 [5]	46.	*Cynoglossus puncticeps*	4	0.12	3.3 [1]
22.	*Thryssa setirostris*	9	0.27	3.3 [1]	47.	*Ambassis gymnocephalous*	23	0.69	3.91 [5]
23.	*Thryssa purava*	6	0.18	3.55 [5]	48.	*Apogon fasciatus*	6	0.18	3.5 [1]
24.	*Arius maculatus*	38	1.17	3.36 [5]	49.	*Uroteuthis duvaucelii*	27	0.84	3.7 [2]
25.	*Bregmaceros mcclellandi*	6	0.17	3.3 [1]	50.	*Sepiella inermis*	24	0.73	3.83 [6]

(Non-commercial / trash fauna)									
1.	*Miyakella nepa*	393	11.94	3.10 [3]	11.	*Lagocephalus spadiceus*	68	2.07	3.5–4 [2]
2.	*Charybdis variegata*	4	0.11	2.7 [2]	12.	*Gyrenium natator*	9	0.26	2.5 [2]
3.	*Charybdis vadorum*	60	1.82	2.7 [2]	13.	*Teritella* sp.	24	0.44	2.5 [2]
4.	*Philyra globosa*	5	0.14	2.7 [2]	14.	Other gastropods	61	2.17	2.5 [2]
5.	*Doclea gracilipes*	9	0.27	2.7 [2]	15.	*Antalis* spp	9	0.27	2.5 [2]
6.	*Diogenes miles*	8	0.24	2.7 [2]	16.	Bivalve	251	7.64	2.0 [4]
7.	*Trypauchen vagina*	5	0.14	3.5 [1]	17.	*Temnopleurus toreumaticus*	274	8.34	2.2 [4]
8.	*Muraenesox cinereus*	20	0.61	4.0 [1]	18.	*Astropecten indicus*	404	12.30	2.5 [4]
9.	*Yongeichthys criniger*	5	0.15	3.36 [1]	19.	Sea cucumber	7	0.21	2.3 [4]
10.	*Parachaeturichthys polynema*	5	0.16	3.1 [1]					

TL – Total Length
1. Bijukumar and Deepthi, 2009
2. Vivekanandan *et al.*, 2009;
3. Padate, 2010
4. Okey *et al.*, 2004
5. Froese and Pauly, 2014
6. Sealifebase; 2014

5.3.2. Seasonal trends of abundance

Astropecten indicus was found to be abundant from December to May coinciding with higher abundance of gastropods and bivalves. Published literature (Loh and Todd, 2011) suggests that *A. indicus* is a generalist carnivorous feeder that preys upon gastropods and bivalves under continuous submergence in a sub-tidal ecotope. Much of the trawling activity is carried out at a depth beyond 15 - 20 m where the conditions are favourable for predation of prey exposed due to trawling (gastropods / bivalves) resulting in high abundance (Chícharo *et al.*, 2002). The lack of information on abundance pattern, spawning and reproduction of starfish from this region is one of the constraints to elucidate its impact on the ecosystem function.

Miyakella nepa was observed in high abundance throughout the fishing season (October to May). This species is known to spawn in nearshore waters from December to October, with peak during February to April and September to October (Sukumaran, 1987). The continuous occurrence of *M. nepa* in trawl discards suggested intermittent recruitment and reduced level of predation (Antony and Madhsoodana, 2010; Antony *et al.*, 2010). Further, the present set of data and published reports from this region (Hegde *et al.*, 2014) reveal a marginal reduction in the abundance of potential predators (elasmobranchs and cephalopods) due to unselective removal by trawl gear. On the other hand, the stomatopod population (*Miyakella nepa, Harpiosquilla raphidea* and *Lysiosquilla tredecimdentata*) is quite diverse and known to feed at different trophic levels (Antony *et al.*, 2010) which probably favour enhanced abundance and continuous occurrence.

Temnopleurus toreumaticus was observed to be abundant during April and May. Similar observations have also been made by Hegde and Rivonker (2013) along south Goa coast. Sea urchins are known to spawn from spring to early summer (Rahman *et al.*, 2014) and the differences in their density is primarily caused due to variance in recruitment (Hereu *et al.*, 2012). Sea urchin abundance is also determined by upwelling, water temperature, sedimentation, wave action, floods and harvesting (Andrew *et al.*, 2002; Walker, 2007). However, no published literature exists on echinoid reproduction from Indian waters. The increased abundance of sea urchins during pre-monsoon may be related to the spawning activity and recruitment as evidenced by the occurrence of juvenile urchins (0.5 to 2.0 cm test diameter). Spawning may be enhanced by higher water temperatures during summer months as reduced temperature is known to affect spawning activity (Barnes *et al.*, 2002). Further, due to intensive fishing, reduced fish abundance might also facilitate their survival and proliferation (Hereu *et al.*, 2012).

The bivalves (*Anadara* spp.) were found in greater abundance in October and November, 2012. The period coincided with active spawning (August to December and May to July) for these species (Suwanjarat *et al.*, 2009). Recruitment of a large number of juveniles, as evident from the sample size (shell height: 0.5 to 1.5 cm), coupled with high phytoplankton biomass in the coastal waters (Gosling, 2003) might have supported the increased abundance of bivalves in this region.

In addition to the above, juveniles of a few target species such as prawns, crabs, squids, soles and sciaenids contributed to discarded by-catch. Among prawns, juveniles of *Parapenaeopsis stylifera* were the most abundant (8.02 %), followed by *Metapenaeus dobsoni* (2.85 %), and *Metapenaeus affinis* (1.45 %; Table 5.1). The juveniles of *P. stylifera* were highly abundant in the months of December and March to May; *M. dobsoni* in December, March and *M. affinis* in April - May. Morphometric measurements of the above three species indicated that prawns up to 6 cm total length (TL) were also observed in discarded by-catch. The occurrence of such large sized prawns in the discarded by-catch could be attributed to hasty sorting by the fishing crew. High abundance of their juveniles in the discards coincided with spawning and recruitment periods. Published literature (Achuthankutty and Parulekar, 1986) suggests that these species generally breed during October to August with certain peaks highly specific to respective species. *P. stylifera* being exclusively marine and sensitive to reduced salinity (Rao, 1968) restricts itself to nearshore coastal waters causing an increased abundance of juveniles in trawl discards as compared to the other two species. Further, this region is found to be highly productive due to habitat heterogeneity resulting in increased food availability supporting the juvenile population (Wafar *et al.*, 1997).

Apart from prawns, juveniles of two targeted teleost species, i.e. *Johnius borneensis* (1.50 %) and *Cynoglossus macrostomus* (1.05 %; Table 5.1), showed higher

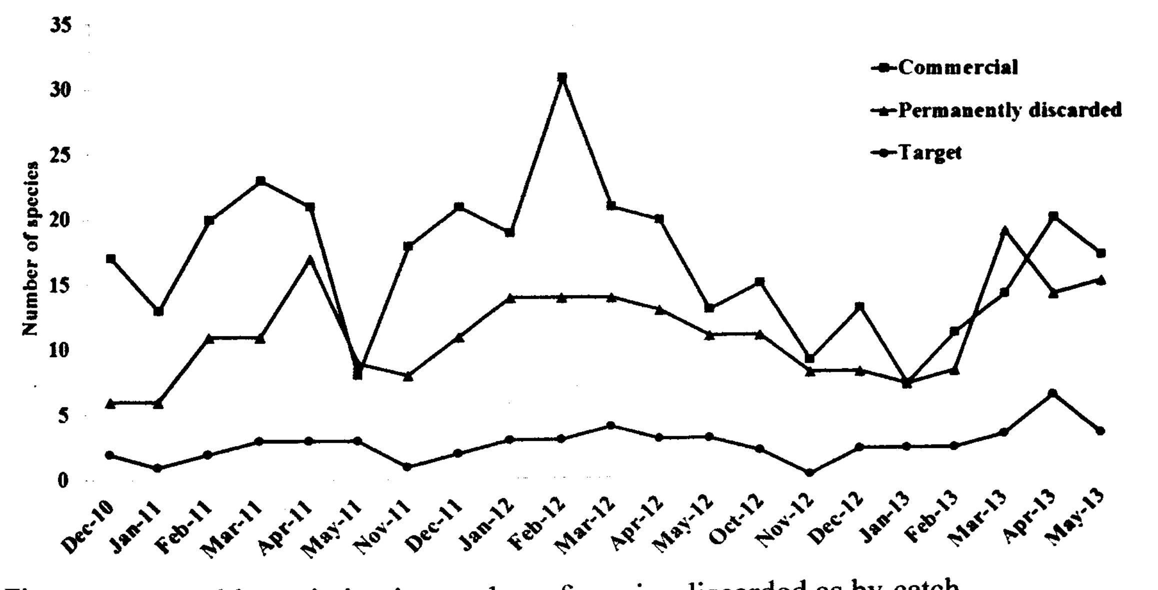


Figure 5.2. Monthly variation in number of species discarded as by-catch

abundance in trawl discard. Average discarded sizes for these species were 6.0 cm and 7.0 cm, respectively. Higher abundance of these species from December to May coincided with the spawning and recruitment period (Jayaprakash, 1999). The recruitment of juveniles during this period has contributed to the increased abundance as witnessed by discarded size. Among the discarded species, a sizeable portion was formed by commercially important species as compared to trash / discarded catch species (Figure

5.2). During pre-monsoon, the juveniles of commercially important species share a significant portion in discarded by-catch in terms of their abundance. Among these, juvenile stages of prawns also formed a noticeable component (18.32 %) in terms of their abundance (Table 5.1).

Published literature on the spawning biology of coastal fishes along the region suggests that, most of the fishes breed during late post-monsoon to pre-monsoon season (Ansari *et al.*, 1995). The present observation reveals increased abundance of juveniles in trawl net as the cod end mesh size used is very small i.e. 9 mm (Hegde *et al.*, 2013). Existence of high species diversity is one of the major reasons which contribute to the high rate of species discards in tropical waters (EJF, 2003). A major portion of trash fish occurring along this coast is discarded mainly due to low or lack of commercial value, non-edibility and lack of on-board storage facility.

Despite the fact that trawl net is basically operated to target prawns, non-target species make a significant contribution to the total catch in terms of their number and biomass as elucidated in the present investigation. Similar trends have been reported from other parts of the country (Bijukumar and Deepthi, 2006; Pillai *et al.*, 2014). The present study indicates clearly that continuous discarding of juveniles of commercially important and target species will definitely have long-term implications affecting the local recruitment pattern. The observations made in the present study suggest that the fate of other demersal fishery resources such as soles, squids, crabs, sciaenids, etc. is changing due to increased demand for consumption in local markets especially when prawn catches are low.

5.3.3. Seasonal trends of biomass

An analysis of trawl catch biomass indicated greater contribution of by-catch to trawl catch with consistently higher values (68 %) irrespective of season (Figure 5.3a). Within this, discarded by-catch was the major component (61 %) followed by commercial

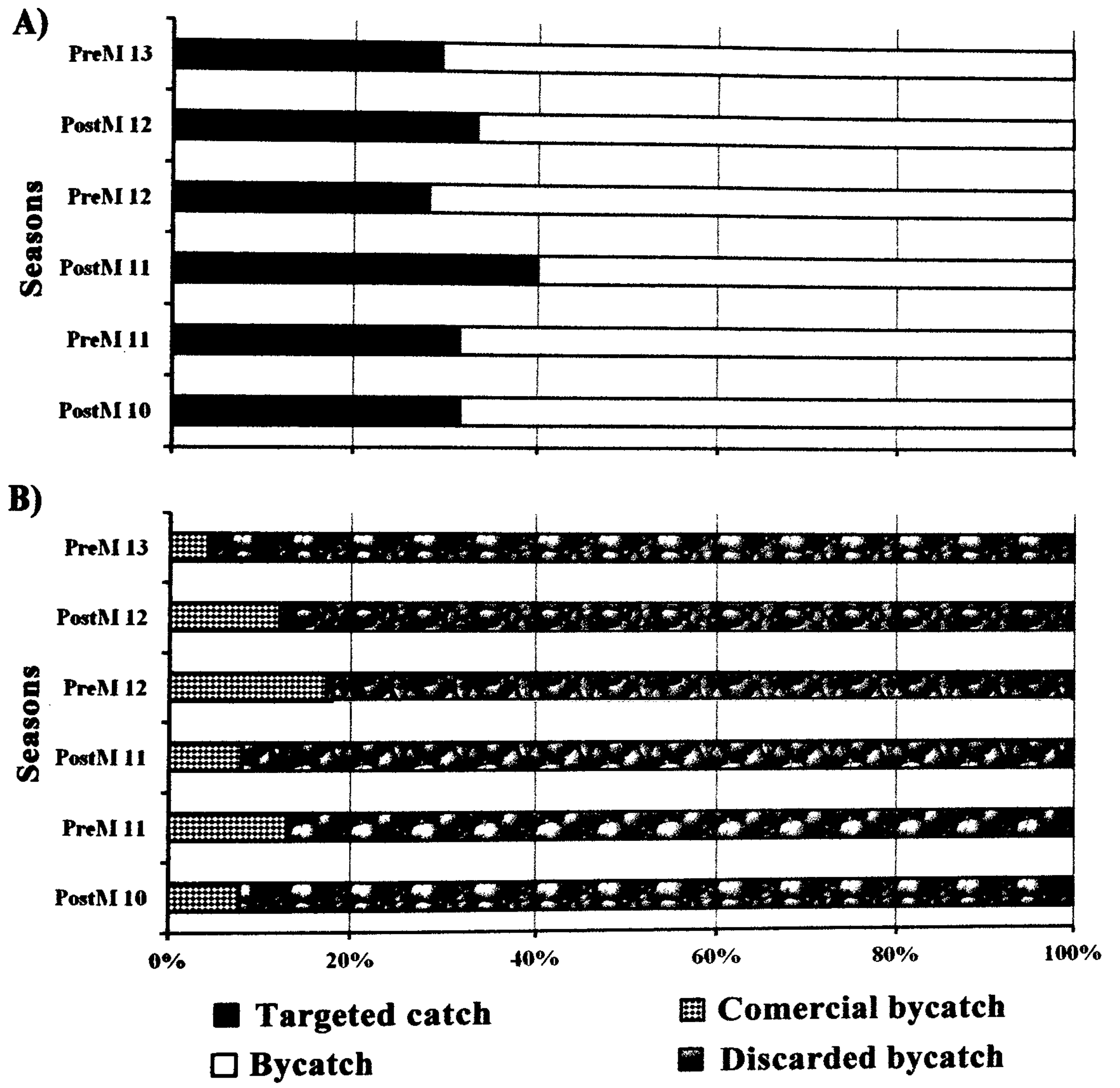


Figure 5.3. Seasonal variation in biomass (weight) of (a) target catch and by-catch; (b) commercial and discarded by-catch

by-catch (07 %; Figure 5.3b). Regression analysis revealed a significant linear relationship between total catch and by-catch ($R^2 = 0.89$), and a weak relationship between total catch and target catch ($R^2 = 0.63$). This suggests that by-catch constituted bulk of the total trawl catch. Similarly, regression analysis between by-catch and discarded catch revealed a strong linear relationship ($R^2 = 0.94$) suggesting most of the by-catch was discarded into the sea; a very weak relationship was observed between by-catch and commercial catch (R^2 = 0.08). The preponderance of non-commercial species and juveniles in the trawl catches is attributed to intensive use of non-selective fishing gear with cod end mesh size (9 mm) to regulate the population through recruitment in biologically rich habitats that serve as potential nursery grounds for most marine organisms (Ansari *et al.*, 1995).

5.3.4. Season-wise species associations

Cluster analysis of discarded by-catch revealed three and four major clusters in pre-monsoon and in post-monsoon season (Figure 5.4), respectively. In the pre-monsoon

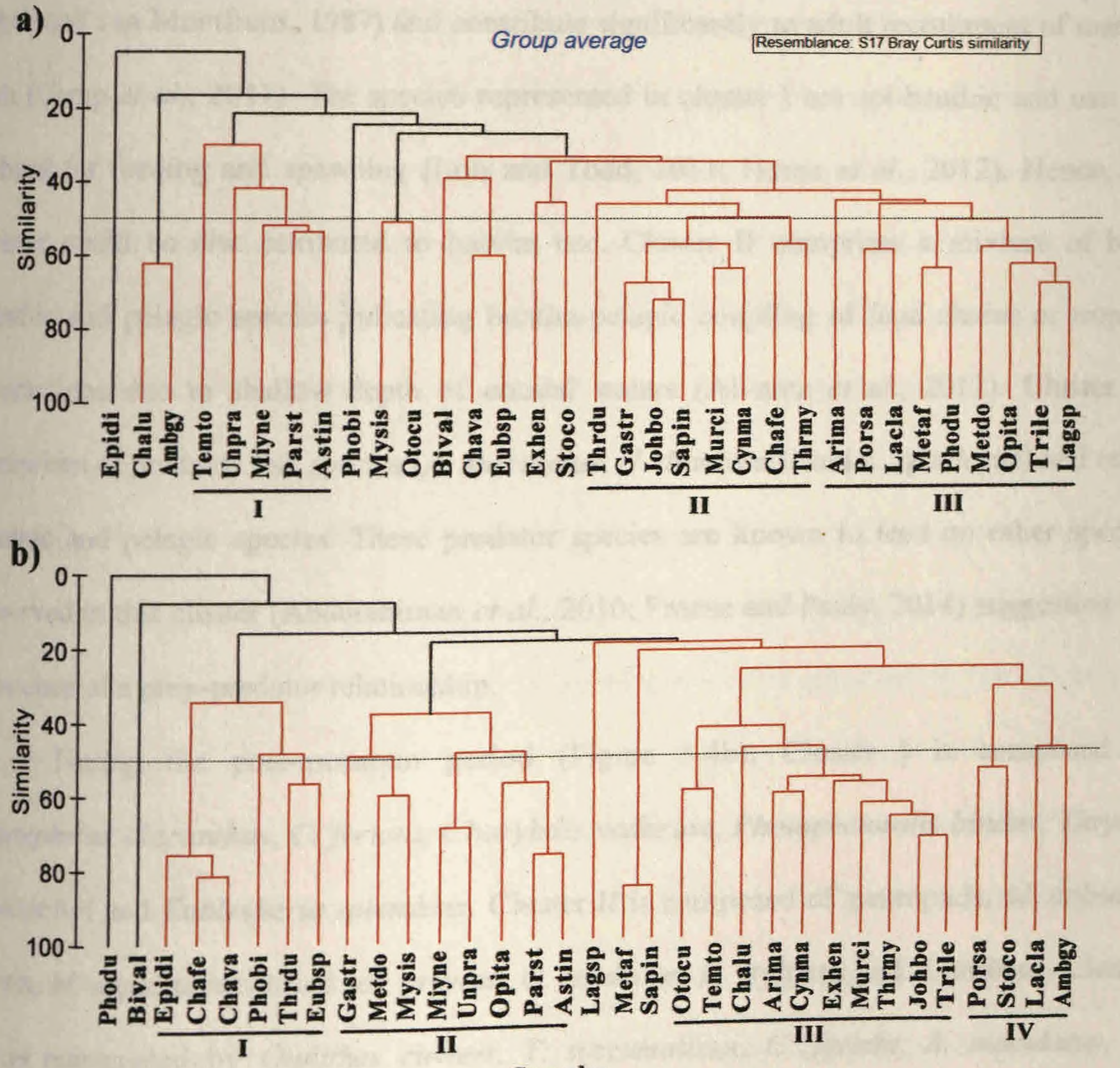


Figure 5.4. Dendrogram showing clustering of species in (a) pre-monsoon season (b) post- monsoon season

season (Figure 5.4a), Cluster I comprised of *T. toreumaticus*, an unidentified red prawn, *M. nepa*, *P. stylifera* and *A. indicus*. Cluster II comprised of *Thryssa dussumieri*, gastropods, *J. borneensis*, *Sepiella inermis*, *Muraenesox cinereus*, *C. macrostomus*, *Charybdis feriata*, and *Thryssa mystax*. Cluster III comprised of *Arius maculatus*, *Portunus sanguinolentus*, *Lactarius lactarius*, *M. affinis*, *Uroteuthis duvaucelii*, *M. dobsoni*, *Opisthopterus tardoore*, *Trichiurus lepturus* and *Lagocephalus spadiceus* (Figure 5.4a). During pre-monsoon, species associations could be attributed to feeding aggregations as observed by the dominance of juveniles in the discarded by-catch. Coastal waters serve as nurseries for a variety of marine species (Sheaves *et al.*, 2014). They support a high density of juveniles (Orth and van Montfrans, 1987) and contribute significantly to adult recruitment of marine fish (Camp *et al.*, 2011). The species represented in cluster I are epi-benthic and use the habitat for feeding and spawning (Loh and Todd, 2011; Hereu *et al.*, 2012). Hence, the cluster could be also attributed to habitat use. Cluster II comprises a mixture of both benthic and pelagic species indicating bentho-pelagic coupling of food chains or trophic interactions due to shallow depth of coastal waters (Alvarez *et al.*, 2012). Cluster III comprises of predator fish species (*A. maculatus*, *U. duvaucelii* and *L. spadiceus*) and other benthic and pelagic species. These predator species are known to feed on other species observed in this cluster (Abdurahiman *et al.*, 2010; Froese and Pauly, 2014) suggesting the existence of a prey-predator relationship.

During the post-monsoon period (Figure 5.4b), Cluster I is composed of *Epinephelus diacanthus*, *C. feriata*, *Charybdis vadorum*, *Photopectoralis bindus*, *Thryssa dussumieri* and *Eubleekeria splendens*. Cluster II is composed of gastropods, *M. dobsoni*, mysis, *M. nepa*, unidentified red prawns, *O. tardoore*, *P. stylifera* and *A. indicus*. Cluster III is represented by *Otolithes cuvieri*, *T. toreumaticus*, *C. feriata*, *A. maculatus*, *C. macrostomus*, *Exhippolysmata ensirostris*, *M. cinereus*, *T. mystax*, *J. borneensis* and *T.*

lepturus. Cluster IV comprises of *P. sanguinolentus*, *Stolephorus commersonii*, *L. lactarius* and *Ambassis gymnocephalus* (Figure 5.4b). In Cluster I, *E. diacanthus*, *C. feriata* and *C. vadorum* exhibit a prey-predator relationship as *E. diacanthus* is known to feed on *C. feriata* and *C. vadorum* (Abdurahiman, 2006). The latter three species in this cluster are pelagic planktivores (Froese and Pauly, 2014) and hence their presence could be attributed to feeding association. Cluster II comprised of epi-benthic species except *O. tardoore* suggesting sharing of habitat. Two species, namely *P. stylifera* and *A. indicus*, exhibited highest similarity in abundance due to increased sensitivity to reduced salinity and preference to higher salinities (Rao, 1968; Kinne, 1971). This cluster also revealed a prey-predator relationship to some extent as *O. tardoore* feeds on mysis and shrimps (Froese and Pauly, 2014) and *A. indicus* actively feeds on gastropods (Loh and Todd, 2011). Cluster III comprised of carnivores and planktivorous species, and their association suggested a prey-predator relationship (Froese and Pauly, 2014). Cluster IV comprised of zoo-planktivores and zoo-benthivores (Froese and Pauly, 2014) and hence the cluster may be attributed to feeding aggregation while the presence of *P. sanguinolentus* was due to preferred habitat.

The trawl by-catch was represented by juveniles of all species and adults of trash species. The variability in cluster formations during pre-monsoon and post-monsoon season is primarily due to differential recruitment patterns as observed by the occurrence of a large number of juvenile species, leading to changes in their abundance. Cluster formation is also influenced by species-specific response or preference to environmental conditions as it varied between seasons, habitat preferences and feeding associations and trophic dynamics. Another reason may be the shallow depth of coastal waters which favours bentho-pelagic coupling of the food chain that determines species associations.

An analysis of temporal variations of four major faunal groups (teleosts, crustaceans, echinoderms and molluscs) in the discarded by-catch revealed that during pre-monsoon, echinoderms, crustaceans and teleosts were most abundant whereas, during the post-monsoon season molluscs, crustaceans, teleosts and echinoderms were dominant (Figure 5.5). The species-wise seasonal variations are explained with the help of PCA analysis.

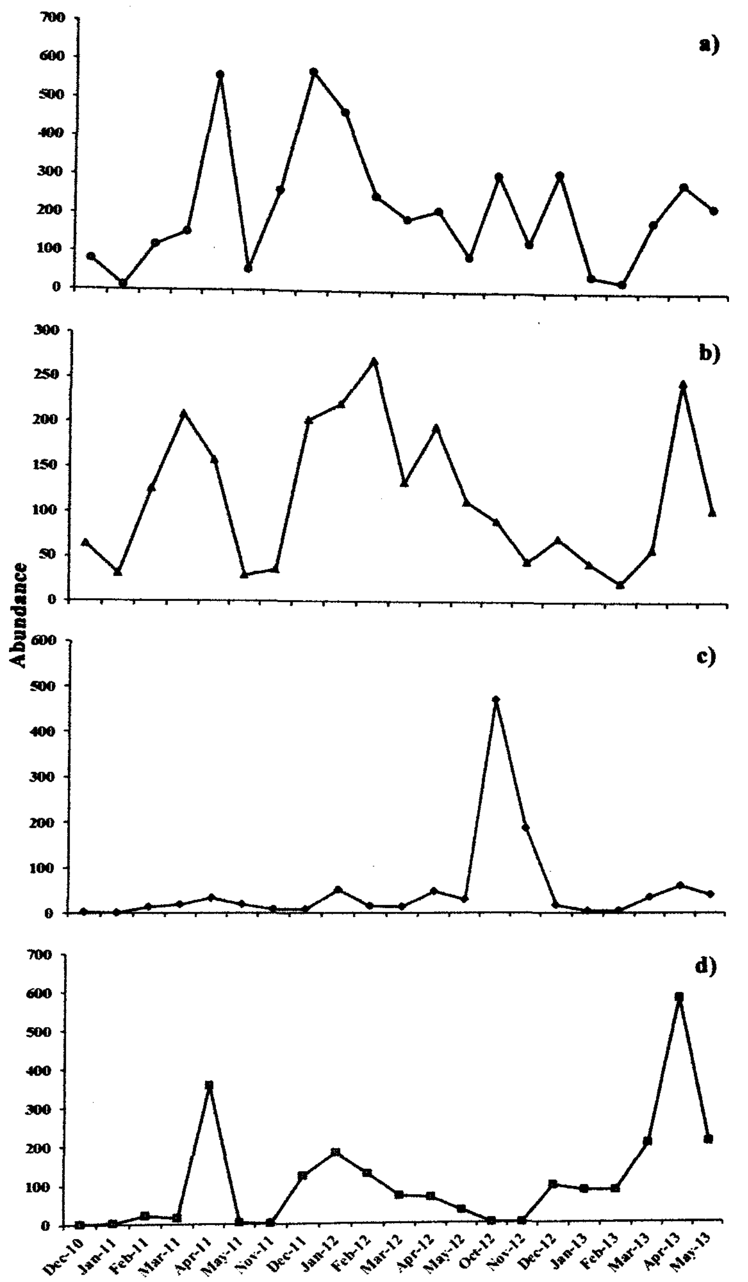


Figure 5.5. Monthly variations in abundance of discarded by-catch faunal groups (a) crustaceans, (b) teleosts, (c) molluscs and (d) echinoderms

5.3.5. Environmental influence on species

Principal component analysis was carried out to identify significantly correlated species and to explain the inherent variation in the data during pre-monsoon and post-monsoon. PCA evaluation demonstrated seven principal components (PCs) on the basis of eigenvalues in pre-monsoon and six in post-monsoon season with dissimilar species composition. The first five components in pre-monsoon and first four in post-monsoon explained 84 and 86 % of the variation in faunal abundance (Table 5.2 and 5.3).

Table 5.2. Species contribution to principal components during pre-monsoon season based on PCA scores

PC1 (24.90)	**PC2 (17.43)**	**PC3 (15.90)**
Miyakella nepa	Un. Red prawns	Mysis
Metapenaeus affinis	*Opisthopterus tardoore*	*Thryssa mystax*
Parapenaeopsis stylifera	*Otolithes cuvieri*	*Uroteuthis duvacellii*
Arius maculatus	*Lagocephalus spadiceus*	
Temnopleurus toreumaticus		
Portunus sanguinolentus		
Muraenesox cinereus	**PC5 (11.28)**	**PC6 (8.46)**
Lactarius lactarius	*Stolephorus commersonnii*	*Thryssa dussumieri*
Johnius borneensis	*Epinephelus diacanthus*	Gastropods
	Eubleekeria splendens	
	Photopectoralis bindus	
PC4 (14.89)		**PC7 (7.10)**
Charybdis feriata		*Cynoglossus macrostomus*
Trichiurus lepturus		

Table 5.3. Species contribution to principal components during post-monsoon season based on PCA scores

PC1 (40.64)	**PC2 (19.79)**	**PC3 (13.67)**
Charybdis feriata	Un. Red prawns	*Metapenaeus affinis*
Charybdis vadorum	*Lagocephalus spadiceus*	*Sepiella inermis*
Parapenaeopsis stylifera	*Uroteuthis duvaucelii*	
Exhippolysmata ensirostris		
Mysis		
Epinephelus diacanthus	**PC4 (11.86)**	**PC5 (8.65)**
Photopectoralis bindus	Gastropods	*Charybdis lucifera*
Opisthopterus tardoore		
Muraenesox cinereus		
Arius maculatus	**PC6 (5.35)**	
Lactarius lactarius	*Stolephorus commersonii*	
Johnius borneensis		
Trichiurus lepturus		
Astropecten indicus		
Bivalves		

During the pre-monsoon season, *P. sanguinolentus, L. lactarius, J. borneensis, T. toreumaticus* and *A. maculatus* (positive loadings) and *M. nepa*, and *M. cinereus* (negative loadings) explained 25 % of the total variance along the first principal axis (Figure 5.6a). These species showed weak positive or weak negative correlation with environmental parameters (temperature, salinity and dissolved oxygen) owing to little variation in these parameters during the pre-monsoon season.

During the post-monsoon season, *C. vadorum*, *C. feriata*, *E. diacanthus*, *P. bindus* and bivalves

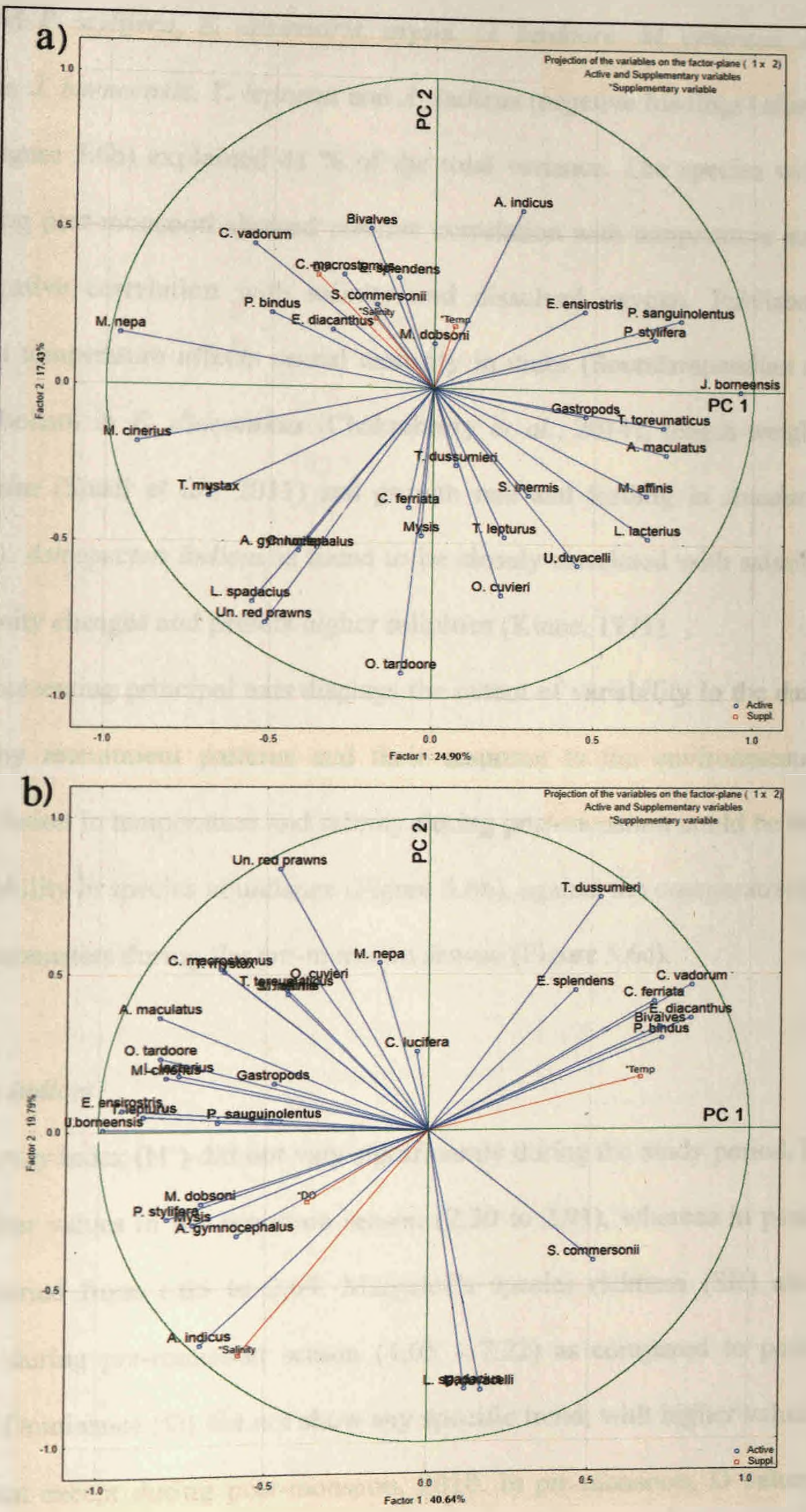


Figure 5.6. Principal component analysis (correlation-based PCA) of by-catch species abundance and environmental parameters during (a) pre-monsoon season; (b) post- monsoon season

(positive loadings) and *P. stylifera, E. ensirostris*, mysis, *O. tardoore, M. cinereus, A. maculatus, L. lactarius, J. borneensis, T. lepturus* and *A. indicus* (negative loadings) along first principal axis (Figure 5.6b) explained 41 % of the total variance. The species with positive loadings during post-monsoon showed positive correlation with temperature and weak positive or negative correlation with salinity and dissolved oxygen. Published literature suggests that temperature affects sexual maturity in crabs (Soundarapandian *et al.*, 2013), lipid metabolism in *E. diacanthus* (Chakraborty *et al.*, 2014), length-weight relationship in *P. bindus* (Shadi *et al.*, 2011) and growth rate and feeding in *Anadara* species (Broom, 1982). *Astropecten indicus* is found to be closely correlated with salinity as it is sensitive to salinity changes and prefers higher salinities (Kinne, 1971).

The species representing principal axis displays the extent of variability in the data which is influenced by recruitment patterns and their response to the environmental parameters. Higher variation in temperature and salinity during post-monsoon could be the reason for greater variability in species abundance (Figure 5.6b), against the comparatively stable environmental parameters during the pre-monsoon season (Figure 5.6a).

5.3.6. Species diversity indices

Shannon's diversity index (H') did not vary significantly during the study period. It showed noticeably higher values in pre-monsoon season (2.30 to 2.91), whereas in post-monsoon the values varied from 1.65 to 2.69. Margalef's species richness (SR) also showed higher values during pre-monsoon season (4.05 - 7.22) as compared to post-monsoon (2.71 - 5.12). Dominance (D) did not show any specific trend; with higher values during the post-monsoon except during post-monsoon, 2010. In pre-monsoon, D values were consistently low except in the month of February, 2013 (Figure 5.7).

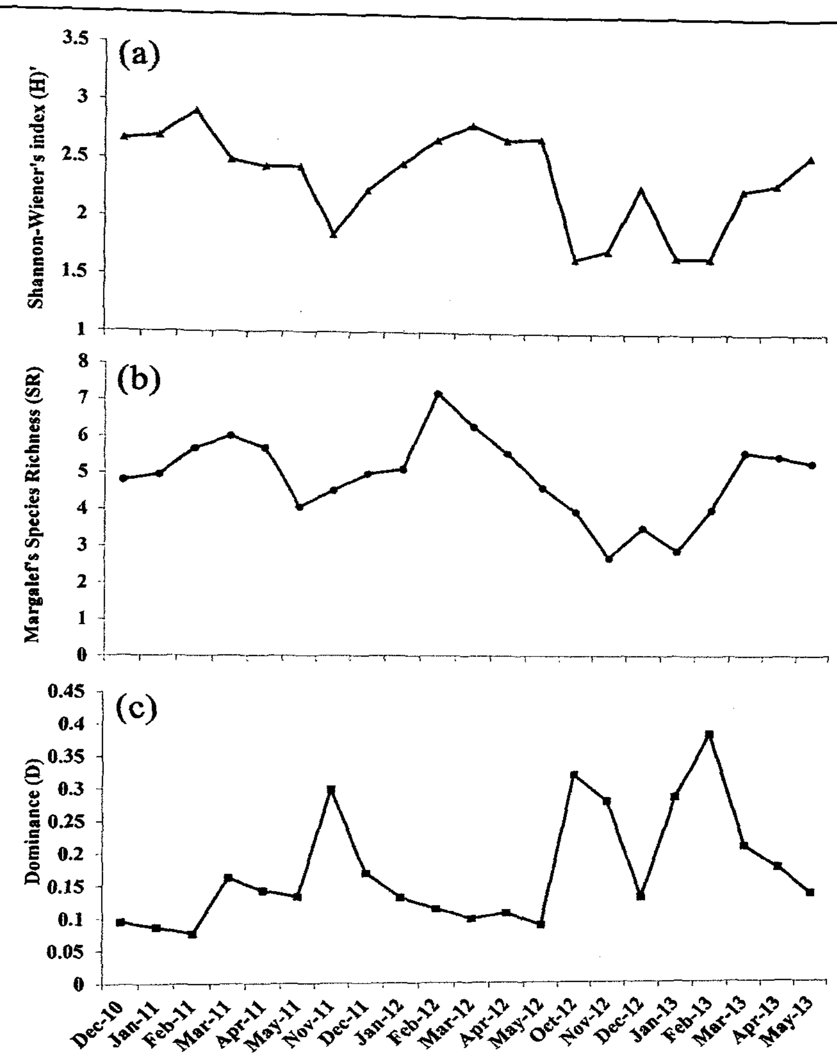


Figure 5.7. Monthly variations in (a) Shannon-Wiener's diversity index – H', (b) species richness – SR and (c) dominance – D of discarded by-catch

It is obvious from the species composition and diversity indices of by-catch that the region supports a multispecies fishery with high diversity. Previous studies have also reported the existence of high diversity values along the region (Ansari *et al.*, 1995; Velip and Rivonker, 2015b). The discards are usually considered as trash from a commercial perspective and therefore discarded directly back into the sea. However, from an ecological point of view they are equally important as target species. They also play an important role in structuring and balancing the faunal communities through trophic dynamics and associated interactions (Schindler *et al.*, 2002). It is well known that in marine ecosystems the collapse of one fishery may trigger or suppress the proliferation of others and may result in cascading ecological changes (Springer *et al.*, 2003). Continuous large scale discarding of by-catch may lead to reduction in species diversity (Hall *et al.*, 2000) and changes in demersal community structure (Jackson *et al.*, 2001; Jennings *et al.*, 2005). IUCN has enlisted most species in their Red List and prioritized their conservation due to increasing threats from by-catch and discarding practices of bottom trawlers to diversity of demersal fauna (IUCN, 2014).

5.3.7. Trophic level

An examination of trophic level of species representing discarded by-catch (> 0.1% abundance) revealed that low trophic level species (2.0 – 3.0) are discarded back to the sea. These include planktivores, zoo-benthivores, detritivores, omnivores and grazers. Species belonging to these trophic levels play a vital role in the ecosystem functioning through breakdown of dead animal and algal matter (Astor, 2014), enhancing microbial growth and nutrient cycling through mixing of sub-surface sediments (Covich *et al.*, 1999), and structuring marine benthic communities as predators, grazers and prey (Pearse, 2006). Each species has the potential to perform an essential role in the persistence of the community and the ecosystem (Ehrlich and Walker, 1998) and hence the presence or absence of a single species could dramatically alter ecological processes (Covich *et al.*, 1999). For example, removal of large quantities of by-catch species such as stomatopods by bottom trawling might result in potential trophic cascades leading to proliferation of their bentho-pelagic prey species as they compete for food resources and predate upon bentho-pelagic fishes.

In view of the results found in the present study, it is essential to develop a comprehensive fisheries database to enable evaluation of the impacts of by-catch on the fisheries and biodiversity of the region. Further, the use of By-catch Reduction Devices (BRDs) should be made mandatory to reduce the amount of by-catch and subsequent mortality. Apart from this, the existing mesh size regulations need to be strictly enforced and monitored properly to regulate the violation of fishing rules and regulations (Goa, Daman and Diu, Marine Fishing Regulation Act, 1980) along with application of time and area closures in areas with reports of high rate of discards. Moreover, the reduction in towing time and priority to return live by-catch species during on-board sorting may also help in survival of fauna. Promulgation and implementation of management policies, or guidelines, solely, will not help in mitigating the by-catch problem. It should be reinforced with appropriate fisheries education and awareness programme for the local fishing community. Additionally, while designing or planning any by-catch mitigation measures, the policy makers must ensure fisher community participation to avoid conflicts.

Chapter 6 -

Trophic dynamics of few selected nearshore coastal finfishes with emphasis on prawns as prey item

6.1. Introduction

Tropical coastal waters are biologically productive environments, which support large, complex food webs (Pimm and Kitching, 1987) and serve as potential nurseries for a wide variety of coastal and marine species (Beck *et al.*, 2003; Kostecki *et al.*, 2010). These organisms are involved in complex ecological relationships those include trophic interactions (Pascual and Dunne, 2006) as one of the vital component that determines ecosystem function. Tropical demersal food webs are far more complex than the pelagic webs owing to high numbers of species and diverse communities (Abdurahiman *et al.*, 2010). However, in shallow coastal waters, there is no clear distinction between the benthic and pelagic food webs and, bentho-pelagic coupling of food chains is more prominent.

Trophic dynamics determine the sustenance of fish populations, which in turn regulate the fishery in an ecosystem. Moreover, the downfall of a single fishery may result either in increase or decrease of other trophically-related species, widely known as trophic cascades (Heath *et al.*, 2014). Therefore, it is essential to know the diet preferences of predatory fishes and food partitioning among them. Diet preferences of fishes vary according to prey availability and ontogeny-related morphological variations especially of mouth parts such as gape width or height, gill raker density, teeth structure, etc. (Gerking, 1994; Lukoschek and McCormick, 2001). Additionally, the awareness of the effects of fishing mortality on trophic ecology especially through generation of by-catch, and ontogenetic diet changes is critical for effective management of fishery resources (Bijukumar and Deepthi, 2006).

Although trophic interactions and food webs in coastal habitats are known to support coastal fisheries (Abrantes *et al.*, 2015), earlier studies from the Indian region mostly dealt with the qualitative aspects of trophic ecology (Rao, 1964). Subsequent studies attempted to provide detailed information on the feeding ecology of single species or particular groups (Pati, 1978, Rao, 1981; Sivakami, 1995; Manojkumar, 2008; Hegde *et al.*, 2014). Qasim (1972) employed the 'trophic guilds' concept to categorize Indian marine fishes into broad trophic groups, and the 'food chain model' concept to explain the trophic dynamics of these fishes. However, the methodological approach and statistical tests applied to analyze results of diet analysis are seen to be inconsistent. The traditional diet measurements included measurements of counts, weight or volume and frequency of occurrence. These measurements on individual scale such as 'count measurement' will give biased results in the case of very small (plankton) and relatively larger (prawns, teleosts) prey items in terms of their frequency of occurrence in stomachs and subsequently influence their relative importance in the total diet. The animal/fish can feed upon larger number of smaller prey items however; it may feed upon few individuals of larger prey. Further, frequency of occurrence only provides the information of how often a prey is consumed but provides no indication of relative importance of that particular prey to overall diet. To overcome such limitations of individual diet measurements and to promote consistency in estimation of relative importance of each prey an integrated index of number/counts, volume/weight and frequency of occurrence (Index of Relative Importance - IRI) given by Pinkas *et al.* (1971) is used to facilitate comparison of diets between different predators and within different size groups of each predator (Abdurahiman *et al.*, 2007, 2010).

Recently, Abdurahiman *et al.* (2010) made a comprehensive attempt to elucidate the trophic ecology of commercially exploited demersal finfishes from the south-eastern Arabian Sea, with emphasis on trophic organization and prey-predator interactions. However, along the west coast of India, very few studies have attempted to elucidate trophic dynamics of finfishes using both qualitative and quantitative analyses (Kuthalingam, 1965; Suseelan and Nair, 1969; Manojkumar and Acharya, 1990;

Thangavelu *et al.*, 2012; Rohit *et al.*, 2015). In light of the above, an attempt is made to provide an in-depth analysis of the diet and feeding attributes of selected finfishes including the importance of prawns as a prey resource, and the influence of mouth parts in the prey selection.

6.2. Methodology

6.2.1. Data analysis

Fish specimens from selected species groups (based on higher abundance and continuous occurrence in trawl catches; e.g. sciaenids, groupers, threadfin breams, etc.) were segregated according to size and maturity, and divided into three size categories viz. small, medium and large to study the possible ontogenic shift in diet (Table 6.1).

6.2.2. Cluster analysis

Trophic guilds were created using multivariate methods provided by Primer-6 version 6.1.10 software (Clarke and Gorley, 2006). For classification purpose, % IRI values of each predator fish group were subjected to cluster analysis using the Bray-Curtis Similarity Coefficient (Bray and Curtis, 1957). For analysis and interpretation of diet data, the pre-identified prey items were categorized into 11 prey categories (Appendix 6.1). Trophic guilds were determined at 50% similarity level. Apart from this, Multi-dimensional scaling (MDS) plots were created using the same package for graphical representation of trophic guilds. The prey groups which accounted for the observed differences in predator assemblages were identified using similarity percentage (SIMPER) routine in Primer-6. Additionally, the BVSTEP routine was used to determine which prey groups were most influential for the predatory finfishes. Abbreviations used to represent predatory finfish groups are provided in Appendix 6.1.

6.2.3. Principal Component Analysis (PCA)

Relationships between prey categories and mouth parts were analyzed by correlation-based PCA using STATISTICA software version 12 (StatSoft.Inc, 2014). The input data consisting of % IRI values of 11 prey categories, gape height, numbers of gill arches with rakers, and numbers of gill rakers on first gill arch, were subjected to PCA to extract the components (axes). The principal components were identified on the basis of eigen-values (> 1.00). Prey categories identified by the principal components were selected on the basis of PCA scores (Table 6.4). Abbreviations used to represent prey categories and mouth parts are provided in Appendix 6.1.

6.3. Results and Discussion

6.3.1. General dietary features

The importance of the biological productivity, faunal diversity and fishery potential of the coastal waters of Goa has been emphasized earlier by Rao and Dorairaj (1968), Prabhu and Dhawan (1974), Ansari *et al.* (1995), and Goswami and Padmavati (1996). However, only one previous study has dealt with the quantitative dietary aspects of demersal finfishes (Hegde *et al.,* 2014). During the present study, altogether, 1742 teleostean stomachs belonging to 19 size groups of 24 taxa were analyzed (Table 6.1). Preliminary examination of stomachs revealed a high Vacuity Index (43.23 %). Published reports (Abdurahiman *et al.*, 2007; Hajisamae, 2009) have attributed the occurrence of empty stomachs in finfishes largely to spawning activity and food scarcity, whereas in the case of piscivores, low daily intake is attributed to a high calorific value of ingested food (Longhurst, 1957; Abdurahiman *et al.*, 2007).

A total of 84 prey taxa were identified from the stomach contents, grouped into 11 different prey categories to facilitate analysis and interpretation. Among the prey

Table 6.1. Finfish groups with number (N), size range, trophic level (TrL), diet breadth (B) and major prey items with percentage Index of Relative Importance (% IRI)

Sr. No.	Finfish groups	Finfish species name	N	Size range (mm)	Avg. length (mm)	TrL	B	Major prey items with %IRI
1	Small Groupers	*Epinephelus diacanthus*	87	< 150	119.39	3.94	0.05	Prawns (49.93), Phytoplankton (25.06), Teleosts (12.62)
2	Medium Groupers		42	> 150	151.67	4.08	0.44	Prawns (59.84), Teleosts (15.75), Zooplankton (7.72)
3	Small Flatheads	*Grammoplites scaber*	35	< 150	115.67	3.65	0.43	Teleosts (38.99), Prawns (22.08), Zooplankton (14.96)
4	Medium Flatheads		29	150 - 200	160.56	3.82	0.29	Teleosts (61.48), Stomatopods (16.91), Prawns (9.03)
5	Large Flatheads		27	> 200	212.14	3.90	0.82	Prawns (61.03), Teleosts (19.53), Stomatopods (11.81)
6	Small Clupeoids	*Thryssa mystax* *Thryssa purava* *Thryssa setirostris* *Thryssa dussumieri* *Opisthopterus tardoore*	40	< 100	121.75	3.25	0.15	Zooplankton (98.40), Phytoplankton (1.12)
7	Medium Clupeoids		76	100 - 150	143.68	3.40	0.15	Zooplankton (97.73), Prawns (1.08)
8	Large Clupeoids		58	> 150	169.48	3.70	0.13	Zooplankton (93.02), Algae (3.85)
9	Small Grunters	*Terapon puta* *Terapon theraps* *Terapon jarbua*	19	< 100	87.11	2.81	0.32	Zooplankton (45.60), Phytoplankton (34.02), Prawns (8.41)
10	Medium Grunters		23	100 - 150	129.23	3.28	0.08	Phytoplankton (55.95), Teleosts (35.23), Prawns (3.81)
11	Small Sciaenids	*Johnius borneensis*	94	< 100	83.01	3.50	0.19	Zooplankton (86.62), Prawns (6.70), Teleosts (3.59)

12	Medium Sciaenids	*Johnius dussumieri* *Johnius coitor* *Johnius elongatus* *Johnius amblycephalus* *Johnius belangerii* *Pennahia macrophthalmus* *Otolithus ruber* *Otolithus cuvieri*	185	100 - 150	120.16	3.63	0.10	Zooplankton (42.65), Teleosts (22.20), Phytoplankton (16.54), Prawns (15.42)
13	Large Sciaenids		89	> 150	164.55	3.80	0.24	Teleosts (43.37), Zooplankton (25.70), Prawns (18.58)
14	Small Threadfin breams	*Nemipterus japonicus*	27	< 100	91.43	3.47	0.49	Zooplankton (58.22), Phytoplankton (15.27), Stomatopods (11.18), Prawns (9.85)
15	Medium Threadfin breams		36	100 - 200	114.33	3.65	0.33	Zooplankton (66.99), Teleosts (17.49), Stomatopods (6.93)
16	Medium False trevally	*Lactarius lactarius*	34	100 - 150	135.00	3.50	0.60	Prawns (77.35), Zooplankton (16.76), Phytoplankton (3.21)
17	Medium Lizardfish	*Saurida tumbil*	37	150 - 300	173.78	4.60	0.53	Teleosts (88.51), Prawns (6.05), Phytoplankton (3.06)
18	Medium Pufferfish	*Lagocephalus spadiceus*	28	100 - 150	114.44	3.89	0.64	Semi-digested matter (60.93), Teleosts (18.63), Prawns (9.87)
19	Medium Hairtails	*Trichurus lepturus*	23	300 - 600	396.88	4.33	0.83	Teleosts (54.53), Zooplankton (37.41), Prawns (7.56)

categories, teleosts were represented by the highest number of taxa (23), followed by phytoplankton (20), crustaceans (20), and zooplankton (19). The observed higher prey diversity from the stomach contents validated the earlier reports (Abdurahiman *et al.*, 2010) that the diet of Indian marine fishes consists of highly diverse prey. The % IRI values revealed that zooplankton (34.74) were the most important prey resource for the finfishes, followed by crustaceans (24.09), phytoplankton (19.80), teleosts (18.62) and miscellaneous (2.74) organisms. The miscellaneous group comprised of molluscs, echinoderms, benthos, algae and digested matter. Several earlier studies along the Indian coast have also highlighted the importance of these prey organisms (Rao, 1964; Qasim, 1972; Vivekanandan, 2001; Abdurahiman *et al.*, 2010; Hegde *et al.*, 2014).

Among the zooplankton, mysis (29.78 % IRI) was the single-most important prey item. The phytoplankton prey category comprised of three most abundant prey items namely *Ornithocircus magnificus* (8.32 % IRI), *Coscinodiscus* spp. (5.18), and *Prorocentrum* spp. (2.74). The crustacean diet component was dominated by a single penaeid prawn namely *Metapenaeus dobsoni* (19.34 % IRI) while unidentified teleosts accounted for 15.99 % IRI in the teleost category. The frequent occurrences of large proportions of mysis (prawn larvae; 17.54 % FO, 29.78 % IRI) in the stomach contents of finfishes was due to the perennial occurrence of larval prawns in the nearshore waters of Goa (Goswami and Goswami, 1993). Similarly, the recurrent occurrences of large numbers of phytoplankton (21.51 % FO; 19.80 % IRI) in the stomach contents of piscivores could be attributed either to accidental intake of phytoplankton, or due to the consumption of planktivorous fishes (Renones *et al.*, 2002). A detailed analysis of the stomach contents of *Epinephelus diacanthus* and *Saurida tumbil* revealed high abundances of phytoplankton, attributed to predation on planktivorous sardines.

6.3.2. Trophic level (TrL) and diet breadth (B)

The trophic level and diet breadth of a fish is determined by the composition, numbers and proportion of prey items in its diet. Both these parameters vary with ontogeny (Winemiller, 1989; Abdurahiman *et al.*, 2010). The observed variations in the trophic level and diet breadth of fish groups may be attributed to prey availability, prey preferences, and ontogenic variations in mouth part morphology (Table 6.1). The mean trophic level and mean diet breadth values for all the examined species were 3.70 ± 0.40 and 0.36 ± 0.24, respectively. Differences in trophic level and diet breadth between small (3.44 ± 0.38; 0.27 ± 0.17), medium (3.64 ± 0.29; 0.23 ± 0.14) and large (3.80 ± 0.10; 0.40 ± 0.37) predators indicated distinct ontogenic changes. Four finfish groups namely false trevally, lizardfish, pufferfish and hairtails were not included in the above analyses owing to the occurrence of only medium size-class individuals.

The mean TrL value obtained during the present study suggested that the species in question were mostly high-level carnivores and top predators (Vivekanandan *et al.*, 2009). On the other hand the finfish groups namely, small and medium-sized clupeoids, medium-sized grunters, small-sized sciaenids, small-sized threadfin breams, and medium-sized false trevallies exhibited a lower trophic level owing to the low numbers of prey and dominance of plankton and prawns in their diets (Abdurahiman *et al.*, 2007). These observations do not concur with published values (3.14) of mean TrL for the entire southwest coastal zone of India (Vivekanandan *et al.*, 2005), as the present study was mostly restricted to high trophic level species. On the other hand, the values provided by Vivekanandan *et al.* (2005) were based on the analysis of all the commercial fish groups ranging from herbivores / detritivores to top predators. Moreover, a recent study by Abdurahiman *et al.* (2010) reported a similar mean TrL value (3.7 ± 0.7) from the southwest coastal zone of India, largely owing to the predominance of high trophic level fishes in the study. An overall low diet breadth observed during the present study indicated the availability of abundant and diverse prey (Hajisamae *et al.*, 2003).

6.3.3. Trophic guilds and guild attributes

Cluster analysis of prey categories (% IRI values) during the present study revealed three major trophic guilds namely 'teleost feeders', 'prawn feeders' and the 'zooplankton feeders' (Figure 6.1) on the basis of similarity in feeding preferences. The guild 'zooplankton feeders' was identified as the largest trophic guild (Figure 6.1). The three major guilds further comprised a total of seven sub-guilds. Additionally, there were two minor guilds namely 'phytoplankton and teleost feeders' and 'zooplankton and teleost feeders' (Figure 6.1). The results of cluster analysis were also validated by an MDS plot, which showed clear separation between these fish groups (Figure 6.2). Diet overlap between the major guilds was low (42.29 % between 'teleost feeders' and 'prawn feeders'; 41.77 % between 'prawn feeders' and 'zooplankton feeders'; 29.06 % between 'teleost feeders' and 'zooplankton feeders') suggesting a low level of competition for the prey resources.

6.3.3a Teleost feeders

The guild 'teleost feeders' consisting of large sciaenids, small and medium flatheads, medium lizardfish, and medium hairtails, clustered at 60 % similarity level (Figure 6.1). SIMPER analysis showed an average diet similarity of 65.18 % in this guild with the highest contribution from teleosts (70.05 %), followed by prawns (12.81 %) and zooplankton (11.86 %; Table 6.2). This guild was further sub-divided into two sub-guilds. The sub-guild 'true piscivores' comprising of medium flatheads and medium lizardfish, showed an average diet similarity of 70.98 %, with teleosts alone contributing to 86.61%

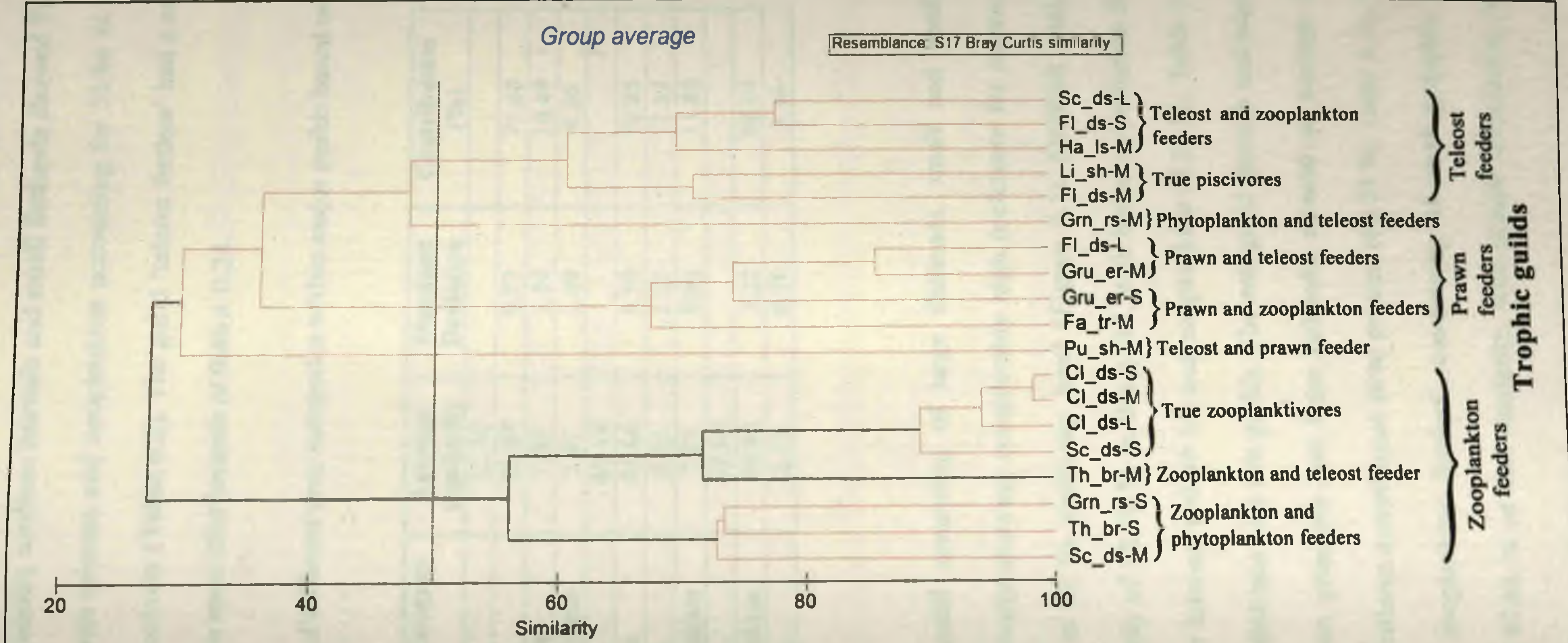


Figure 6.1. Dendrogram showing categorization of different trophic guilds

of diet similarity (Table 6.2). The other sub-guild namely 'teleosts and zooplankton feeders' comprising of large sciaenids, medium hairtails and small flatheads showed 72.29 % of average diet similarity, with teleosts and zooplankton accounting for 55.96 % and 25.65 % of diet similarity, respectively (Table 6.2). The guild 'teleost feeders' had a mean trophic level of 4.06 ± 0.42 and a mean diet breadth of 0.46 ± 0.24.

Table 6.2. Relative similarities of different prey categories within major guilds based on SIMPER analysis.

Trophic guilds	Prey category	Average similarity	Standard Deviation	Contribution (%)
Prawn feeders		72.78		
	Prawns	55.09	9.73	75.68
	Teleosts	7.63	1.14	10.49
	Zooplankton	5.97	2.49	8.20
Teleost feeders		65.18		
	Teleosts	45.66	5.59	70.05
	Prawns	8.35	2.21	12.81
	Zooplankton	7.73	0.91	11.86
Zooplankton feeders		67.94		
	Zooplankton	59.82	3.22	88.04
	Prawns	2.35	0.78	3.46

6.3.3b. Prawn feeders

The 'prawn feeders' guild consisting of large flatheads, small and medium groupers, and medium false trevally showing considerably high preference for prawns as their primary prey, clustered at 67 % similarity level (Figure 6.1). SIMPER analysis showed an average diet similarity of 72.78 % in this guild, with higher contribution from prawns (75.68 %), followed by teleosts (10.49 %) and zooplankton (8.20 %; Table 6.2). This guild was further sub-divided into two sub-guilds. The sub-guild 'prawns and teleosts feeders,' comprising of medium groupers and large fatheads, showed an average diet similarity of 85.82 %, with significant contribution from prawns (69.73 %; Table 6.2). The other sub-guild 'prawns and zooplankton feeders', comprising of small groupers and medium false trevally showed 63.68 % of diet similarity, with notable contribution from prawns (78.41 %; Table 6.2). The guild 'prawn feeders' had a mean trophic level of 3.86 ± 0.25 and a diet breadth of 0.48 ± 0.32.

6.3.3c. Zooplankton feeders

The 'zooplankton feeders' guild was the largest feeding guild identified during the present study that consisted of eight groups namely small, medium and large clupeoids, small and medium sciaenids, small and medium threadfin breams, and small grunters, showing high preference for zooplankton as their primary prey, clustered at 56 % similarity level (Figure 6.1). SIMPER analysis showed an average diet similarity of 67.94 %, with very high contribution from zooplankton (88.04 %; Table 6.2). This guild was further sub-divided into three sub-guilds. All the size groups of clupeoids and small sciaenids formed a distinct sub-guild, 'true zooplanktivores' with an average diet similarity of 92.52 %, absolutely dominated by zooplankton (97.93 %; Table 6.2). The next sub-guild was formed by small grunters and threadfin breams and medium sciaenids as 'zooplankton and phytoplankton feeders' with an average diet similarity of 73.03 %, supported by highest contribution from zooplankton (59.74 %), followed by phytoplankton (21.49 %; Table 6.2). The medium-sized threadfin breams alone represented the third sub-guild namely 'zooplankton and teleost feeders', which preferred zooplankton (% IRI = 66.99) as primary diet followed by teleosts (% IRI = 17.49; Table 6.1). The guild 'zooplankton feeders' had a mean trophic level of 3.43 ± 0.29 and a diet breadth of 0.23 ± 0.13.

Along the Indian coast, George *et al.* (1968) and Qasim (1972) had initiated the groupings of marine fishes based on feeding preferences and identified three and nine broad guilds, respectively. Recently, Abdurahiman *et al.* (2010) identified four trophic guilds based on feeding similarity of commercially exploited demersal finfishes. The observations made during the present study revealed that the species representing the major trophic guilds showed strong preference towards teleosts, prawns and zooplankton as their principal prey items and this was also corroborated by the SIMPER analysis. In addition, members of 'teleost feeders' and 'prawn feeders' guilds also preferred secondary prey in smaller proportions owing to the plasticity in their feeding behaviour and easy availability of diverse prey items (Pérez-Matus *et al.*, 2012). Moreover, the finfishes representing the guilds teleost feeders and prawn feeders are opportunistic feeders (Leadbitter, 1992; Bittar *et al.*, 2012; Willis *et al.*, 2015) and hence may feed upon secondary prey items. On the other hand, high average diet similarity among the members of the individual guilds suggested that the species-groups representing respective guild obtained food from a common pool of prey resources.

6.3.4. Ontogenic variations in diet

The size-wise segregation of finfishes revealed marked ontogenic variations in composition and abundance of prey items in some of the predatory finfish groups (Table 6.1). Small and medium-sized groupers fed mostly on prawns (49.93 % and 59.83 % IRI, respectively). However, their secondary preference shifted ontogenically from phytoplankton (25.06 % IRI) to teleosts (15.75 % IRI). In the case of flatheads, the small-sized individuals fed on mixed proportions of teleosts (38.99 % IRI), prawns (22.08 %) and zooplankton (14.96 %). The % IRI values of prey categories for medium and large-sized individuals showed major ontogenic shift with respect to primary (medium: teleosts – 61.48 %; large: prawns – 61.03 %) and secondary (medium: stomatopods – 16.91 %; large: teleosts – 19.53 %) prey categories. In the case of clupeoids, zooplankton remained the most preferred prey in all three size categories (small – 98.40 %, medium – 97.73 % and large – 93.02 % IRI). The small-sized individuals of grunters fed on a mixed diet of zooplankton (45.60 % IRI) and phytoplankton (34.02 %), whereas medium-sized individuals fed upon phytoplankton (55.95 % IRI) and teleosts (35.23 %) indicating a clear ontogenic shift in the diet. The assessment of % IRI values in three size classes of sciaenids revealed a distinctive ontogenic shift. The percentage IRI of zooplankton (small – 86.62 %; medium – 42.65 %; large – 25.70 %) decreased considerably, whereas teleost prey showed a reverse (increasing) trend (small – 3.59 %; medium – 22.20 %; large – 43.37 %). On the other hand, there was a minor increase in percentage IRI of prawns (6.70 %, 15.42 % and 18.58 %, respectively). In the case of threadfin breams, zooplankton remained the most preferred prey category in small (58.22 % IRI) and medium (66.99 %) size groups. However, the secondary prey preference changed from phytoplankton (15.27 % IRI) to teleosts (17.49 %).

The shift in dietary preferences with ontogeny may be attributed to changes in the predator size (Winemiller, 1989), morphology, mouth part anatomy (Lukoschek and McCormick, 2001), metabolism (Jackson *et al.*, 2004), and prey size (Barros *et al.*, 2011). The sciaenids exhibited a distinct dietary shift from zooplanktivory to ichthyophagy, with an increasing size which could be attributed to ontogeny-related increase in mouth gape height (Scharf *et al.*, 2000). On the other hand, the flatheads shifted from ichthyophagy (medium-sized) to a prawn-dominated diet. Jackson *et al.* (2004) demonstrated that in the case of benthic 'sit-and-wait' predators, prey selection maximized energy intake rates prior to and after the diet shift.

Minor differences in the mean trophic levels of the small, medium and large size groups of predatory finfishes were as a result of minor changes in the proportion of prey categories with ontogeny. On the other hand, a distinct ontogenic increase in diet breadth indicated that small-sized fishes fed upon narrow range of prey due to anatomical constraints, whereas medium and large-sized fishes were capable of hunting wide array of prey species. Abdurahiman *et al.* (2010), however, reported increase in both the trophic level and diet breadth of medium and large-sized fishes owing to prey availability and corresponding diet preferences associated with life cycle.

6.3.5. Significant prey items

Although the predatory finfishes were observed to consume 84 different prey items, the BVSTEP analysis of prey categories and predator size groups, revealed four variables which highly influence predatory fish groups namely *Metapenaeus dobsoni,* teleosts, mysis larvae and digested matter (R^2 = 0.964). If digested matter is excluded, it may be concluded that *M. dobsoni,* teleosts, and mysis larvae were the most influential prey items for the predatory finfishes (Table 6.3) in nearshore coastal waters and are subjected to high predation. Moreover, these prey items served as major trophic links to sustain respective trophic guilds.

Table 6.3. Significant prey groups based on BVSTP analysis

No. of Variables	$\mathbf{R^2}$	**Prey groups with highest variability**
4	0.964	*M. dobsoni*, teleosts, mysis, digested matter
4	0.951	*M. dobsoni*, teleosts, mysis, diatoms

6.3.6. Importance of prawns as prey item

An examination of stomach contents revealed that prawns formed an important component of the diets of finfishes (21.71 % IRI; Figure 6.2). Altogether, five species of prawns were identified from the stomach contents of finfishes namely *Metapenaeus dobsoni, Parapenaeopsis stylifera, Acetes indicus, Exhippolysmata ensirostris* and *Alpheus euphrosyne*. *Metapenaeus dobsoni* was the major prey species (19.34 % IRI), whereas other prawns contributed meagrely (2.37 % IRI). The MDS plot (Figure 6.2) revealed that prawns accounted for the major part of the diet of medium-sized false trevally, small and medium groupers, and large flatheads. On the other hand, their contribution to the diets of other 15 groups was comparatively low (Figure 6.2). The varying proportions of prawns in

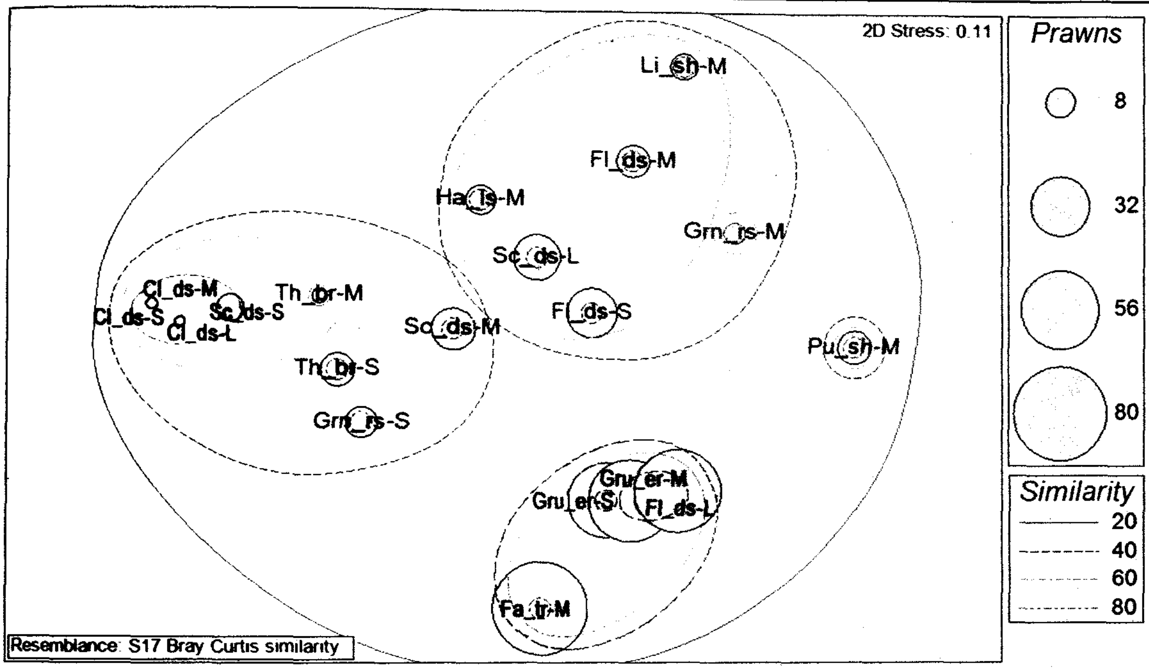


Figure 6.2. Multi-dimensional scaling (MDS) ordination of finfish groups into guilds based on similarities and contribution of prawns in the diet of each predator size groups

the diets of all the observed size classes suggested that they served as a major or secondary prey throughout the life span of the predatory fishes. Their frequent occurrences in the fish diets are probably suggestive of their vulnerability to predation due to their sluggish nature. Their importance in the diet of predatory finfishes has been emphasized by several studies (Vivekanandan, 2001; Abdurahiman *et al.*, 2010; Thangvelu *et al.*, 2012). On the other hand, penaeid prawns constituted the most important 'target catch' of the bottom trawlers that are 'primarily sought in a fishery' (Velip and Rivonker, 2015b) along the region. It is also noteworthy to mention here that, long-term fishing has resulted in a gradual decrease in penaeid prawn catches after 1990 along the Goan coast (Figure 6.3; CMFRI, 2015b) and hence need to be managed properly.

6.3.7. Influence of mouth parts on prey selection

The ability of finfishes to feed upon specific prey or preferred prey items is highly influenced by their mouth structure, size and mouth parts (Fugi *et al.*, 2001; Sudheesan *et al.*, 2009). The present study attempted to correlate oral morphometric (gape height) and meristics (numbers of gill rakers and gill arches with rakers) of predatory finfishes with prey categories (% IRI values) using of Principal Component Analysis (PCA) to understand the influence of mouth parts in prey selection and feeding. The analysis revealed five principal components based on eigenvalues (Table 6.4). Digested matter, molluscs, benthos and crabs (positive loadings) explained 30.76 % of the total variance along the first principal axis (Figure 6.4).

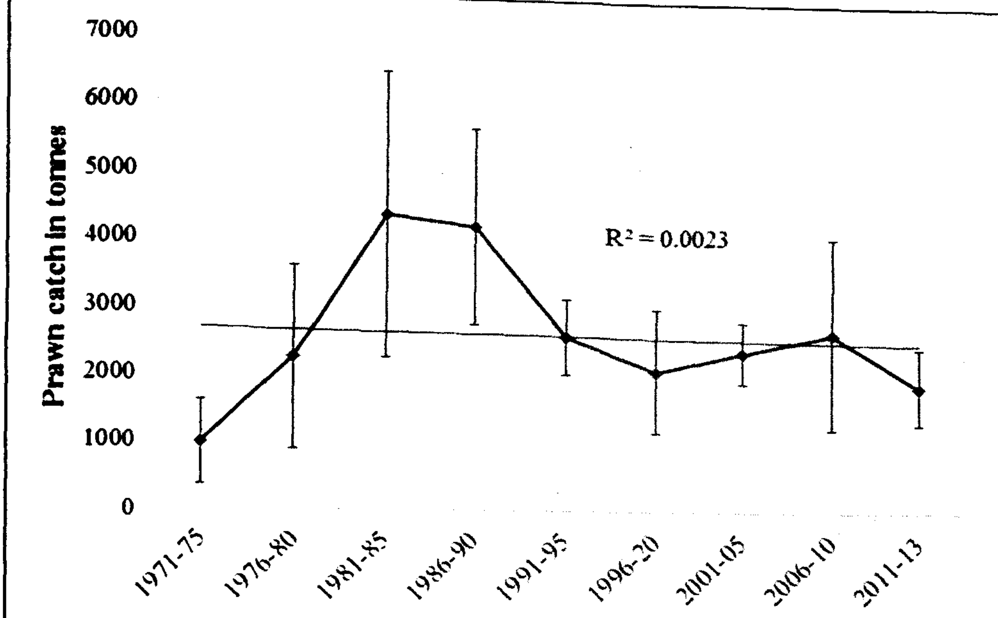


Figure 6.3. Prawn landing data along Goa coast from 1970 to 2013

Table 6.4. Contribution of prey categories to principal components

PC1 (30.76)	PC2 (18.84)	PC3 (15.63)	PC4 (12.29)	PC5 (9.92)
Di_ma (Digested matter)	Zo_on (Zooplankton)	Pr_ns (Prawns)	Ph_on (Phytoplankton)	St_ds (Stomatopods)
Mo_cs (Molluscs)	Te_ts (Teleosts)		Al_ae (Algae)	
Be_os (Benthos)	Ec_ms (Echinoderms)			
Cr_bs (Crabs)	*Gi_ra (No. of gill rakers on 1st arch)			
	*Ga_he (Gape height)			
	*Gi_ar (No. of gill arches with rakers)			

The prey items representing the first principal component showed either weak or no correlation with mouth parts examined. Zooplankton (positive loading), teleosts and echinoderms (negative loadings) explained 18.84 % of the total variance along the second principal axis. Zooplankton showed a strong positive correlation with density / numbers of gill rakers on first gill arch, and a positive correlation with the numbers of gill arches

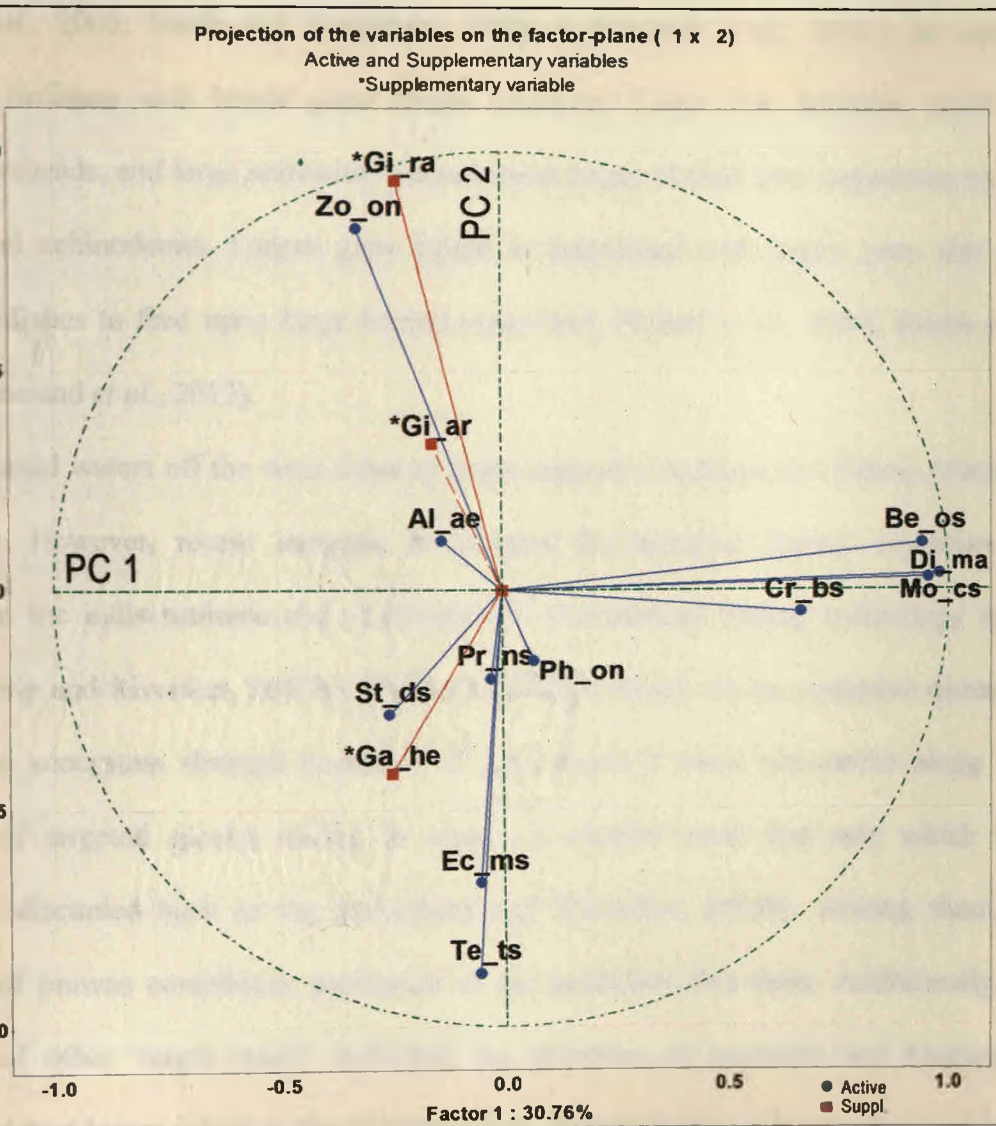


Figure 6.4. Principal Component Analysis (correlation-based PCA) of prey item abundance and mouth parts

bearing rakers; while it did not show any correlation with gape height. The prey items namely teleosts and echinoderms showed a positive correlation with gape height and did not show any correlation with numbers of gill rakers and numbers of gill arches bearing gill rakers (Figure 6.4).

The results of PCA suggested that the zooplanktivory is associated with the density of gill rakers on gill arches and the numbers of gill arches bearing gill rakers. High density of gill rakers in all the size groups of clupeoids, small-sized sciaenids, as well as small and medium threadfin breams, small grunters and medium sciaenids enabled zooplanktivory. The long, dense gill rakers enable 'sieving' of the zooplankton from the water column (Budy *et al.*, 2005; Smith and Sanderson, 2008; Kahilainen *et al.*, 2011). In contrast, predatory finfishes with larger gape height (medium lizard fish, hairtails, small and medium flatheads, and large sciaenids) preyed upon larger bodied prey organisms such as teleosts and echinoderms. Larger gape height is associated with larger prey size as it enables finfishes to feed upon large-bodied organisms (Scharf *et al.*, 2000; Russo *et al.*, 2009; Ronnestad *et al.*, 2013).

Coastal waters off the west coast of India support a multispecies fishery (Ansari *et al.*, 1995). However, recent increase in demand for lucrative fishery resources has encouraged the indiscriminate use of destructive mechanized fishing technology in the region (Velip and Rivonker, 2015b). Bottom trawling activity causes extensive damage to the marine ecosystem through mortality of non-targeted fauna (by-catch) along with juveniles of targeted species owing to usage of smaller mesh size nets which were eventually discarded back to the sea (Velip and Rivonker, 2015b). Among these, the juveniles of prawns contributes maximum to the predatory fish diets. Additionally, the juveniles of other 'target catch' including the juveniles of sciaenids and tonguesoles contributed to a lesser extent to the predator diets. The remaining teleosts observed in the stomach contents of the predatory fishes include a wide array of juvenile fishes (catfishes, clupeoids, flatheads, ambassids, false trevallies, lizardfishes, cods and puffers), which constitute the 'discarded by-catch' of the bottom trawlers. The by-catch species play a vital role in structuring and balancing the marine faunal communities in terms of trophic dynamics (Dayton *et al.*, 1995). Trawling-related loss of prey biomass could cause large scale alterations in the marine food web with adverse implications for the ecology and the fishery of the region (Suvapepun, 1991).

Trophic dynamic studies entailing qualitative and quantitative assessments of fish diets are vital to implement effective fisheries management, therefore necessitate thorough consideration to accomplish the same. Moreover, it is crucial to examine the long-term impacts of mechanized fishing and the resulting by-catch on trophic dynamics (Frank *et al.*, 2011). Until now, most of the efforts have been concentrated towards the study of commercially important species. Every species has the potential to perform an essential role in the persistence of the community and the ecosystem (Ehrlich and Walker, 1998). Therefore, trophic dynamic studies should adopt a holistic approach including commercial as well as non-commercial species towards a better understanding of ecological processes for sustainable fisheries management.

Chapter 7 -

Abundance and reproductive biology of selected sciaenid species

7.1. Introduction

The coastal waters off Goa inhabit variety of vertebrate and invertebrate fauna (Prabhu and Dhawan, 1974; Ansari *et al.*, 1995; Padate *et al.*, 2010). Among these, the sciaenids are one of the most diverse and commonly occurring teleostean faunal group contributing to around 10 % of the total demersal catches of Goa (CMFRI, 2012). Published literature from this region (Ansari *et al.,* 1995) revealed that, these constituted 18 % and 23 % of the demersal fish assemblages of Marmugao and Aguada bay, respectively in terms of their abundance.

Reproduction is a species-specific biological process crucial for the continued existence and proliferation. Studies pertaining to reproductive biology and spawning behavior are essential for complete understanding of population dynamics (Nikolsky, 1969; Hilborn and Walters, 1992; Hunter *et al.*, 1992). Moreover, reproductive rate determines the resilience capacity and sustainability of a species in response to environmental and anthropogenic changes. Therefore, the knowledge of reproductive biology of finfishes is necessary for sustainable exploitation and subsequent management of these resources (King, 1995; Mayol *et al.,* 2000).

Published literature suggests extensive research on the reproductive biology of sciaenids from the Indian waters (Pantulu and Jones, 1951; Rao, 1967; Devadoss, 1969; Bhusari, 1975; Baragi and James, 1980; Pillai, 1983; Rao, 1985; Vivekanandan, 1985; Nimbalkar, 1991; Telvekar *et al.*, 2006; Ghosh *et al.*, 2009; Manojkumar, 2011; Kumar *et al.*, 2013; Kumar *et al.*, 2014). However, no work has been carried out on reproductive biology of sciaenids from the coastal waters of Goa. In view of the continued importance of sciaenids to the commercial fishery of Goa, a comprehensive assessment of sciaenid population along with reproductive biology of two common species has been carried out and presented.

7.2. Methodology:

7.2.1. Species selection

The species (*Johnius borneensis* and *Otolithes ruber*) were selected on the basis of their higher abundance and continuous occurrence in the trawl catches.

7.2.2. Sample processing and preservation

Prior to dissection, the fish samples were thoroughly washed and identified to the species level using conventional taxonomic keys (Lal Mohan, 1981; Talwar and Kacker, 1984; Froese and Pauly, 2015). Thereafter, the specimens were weighed to nearest 0.1 g using an electronic balance and their total lengths were measured using a scale to nearest 0.1 cm. Subsequently, the specimens were dissected and the gonads were examined visually following Devadoss (1969) and Bhusari (1975; Table 7.1) and the maturity stages were recorded. Thereafter, the gonads were weighed using an electronic balance to nearest 0.001 g and preserved in Gilson's fluid (Bagenal, 1978).

7.2.2a. Description of Ovary (Devadoss, 1969; Bhusari, 1975)

1) **Immature:** Ovary transparent, reddish or pale creamy in colour, extends to about 1/3 or to ½ of the body cavity.

2) **Mature:** Ovary reddish-yellow in colour, blood vessels prominent, and ova granular and visible to naked eye. Ovary swollen and extends to 3/4 or to entire length of body cavity.

3) **Fully mature/ Ripe:** Ovary fully swollen, reddish in colour, occupying entire body cavity. Ova are transparent and seen from ovarian wall.

4) **Spent:** Ovary flaccid, blood-shot, shrunk and wrinkled; extends to ½ of the body cavity or more.

7.2.3. Fecundity and ova diameter studies

The preserved gonads were washed thoroughly in 70 % alcohol (Bagenal, 1978) with intense care, dried with blotting paper and weighed to obtain total weight of eggs. The fecundity was then analyzed by weighing and counting 0.01 g of dried eggs under the compound microscope using counting chamber in triplicate to obtain the average number of eggs in the gonads. The absolute fecundity was then calculated using formula given by Bagenal (1967). The egg diameter of 150 random ova was measured from each ovary using ocular micrometer.

7.3. Results and Discussion

7.3.1. General species composition and abundance

The family Sciaenidae is one among the most speciose and dominant demersal fish families occurring along the region (Prabhu and Dhawan, 1974; Ansari *et al.*, 1995) contributing to around 10 % of the total demersal fish production of Goa (CMFRI, 2012). During the present study, it consisted of 07 genera and 15 species, which contributed 2.97 % of the total trawl catch and 10.33 % of the teleostean fauna, respectively in terms of their abundance. Among these species, *Johnius borneensis* was observed to be the most abundant species (46%) followed by *Otolithes cuvieri* (14%), *O. ruber* (11%), *J. coitor* (7%), *J. elongatus* (5%), *Pennahia macropthalmus, J. belangerii, J. amblycephalus* (4% each), *J. dussumieri* (3%) and others (3%; Figure 7.1). However, published literature (Hegde *et al.*, 2016) along the southern coastal waters of Goa reported *O. ruber* as the most abundant species. These observations suggest the existence of spatial variability in the abundance and dominance of sciaenid species, attributed to habitat heterogeneity and depth (Araujo *et al.*, 2006) along the Goan coast. The depth-wise variations in the sciaenid

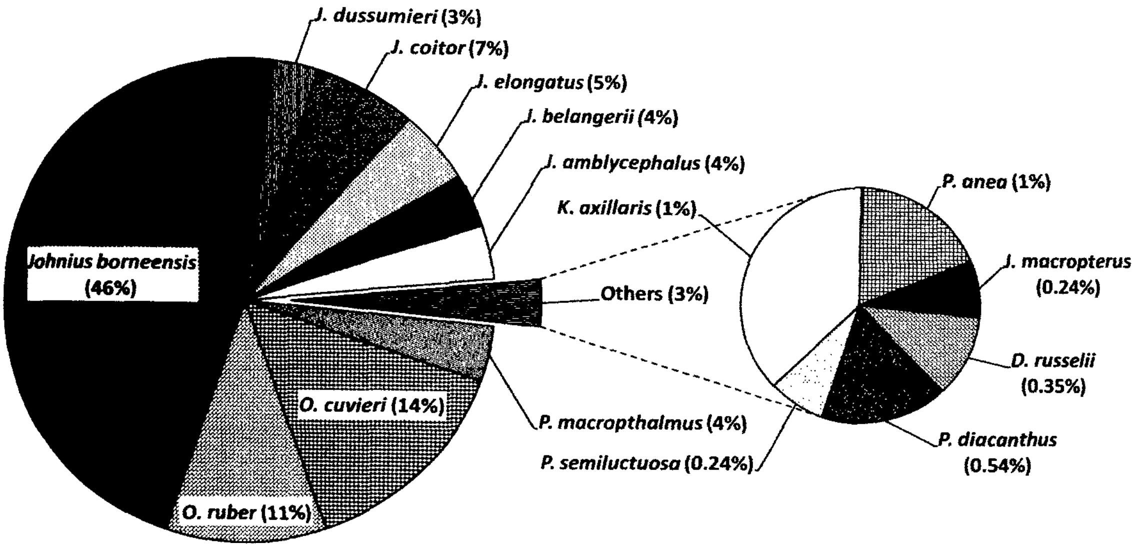


Figure 7.1. Species composition and percentage contribution of family Sciaenidae occuring along the region

abundance have also been validated by one way ANOVA ($P \leq 0.001$). Among the fifteen species observed during the present study, only two species namely, the sharpnose hammer croaker (*Johnius borneensis* Bleeker, 1851) and tiger tooth croaker (*Otolithes ruber* Bloch and Schneider, 1801) were studied in detail owing to their continuous occurrence during the period of study.

7.3.2. Species-specific abundance

Johnius borneensis is one of the most commonly occurring and abundant sciaenid species which influences the abundance pattern of total sciaenid population along the region. Analysis of monthly abundance showed an inverse pattern between *J. borneensis* and *O. ruber* with an overall increasing trend in the case of former species (Figure 7.2a) and an overall decreasing trend in case of latter species (Figure 7.2b). The observations suggest a clear dominance of *J. borneensis* over the other sciaenid species occurring along the region, and can be attributed to their higher survival rate and species-specific resilience to fishing pressure (Chao *et al.*, 2015). It showed higher abundance during the months of December and May. Further, its abundance was consistently high during February to May,

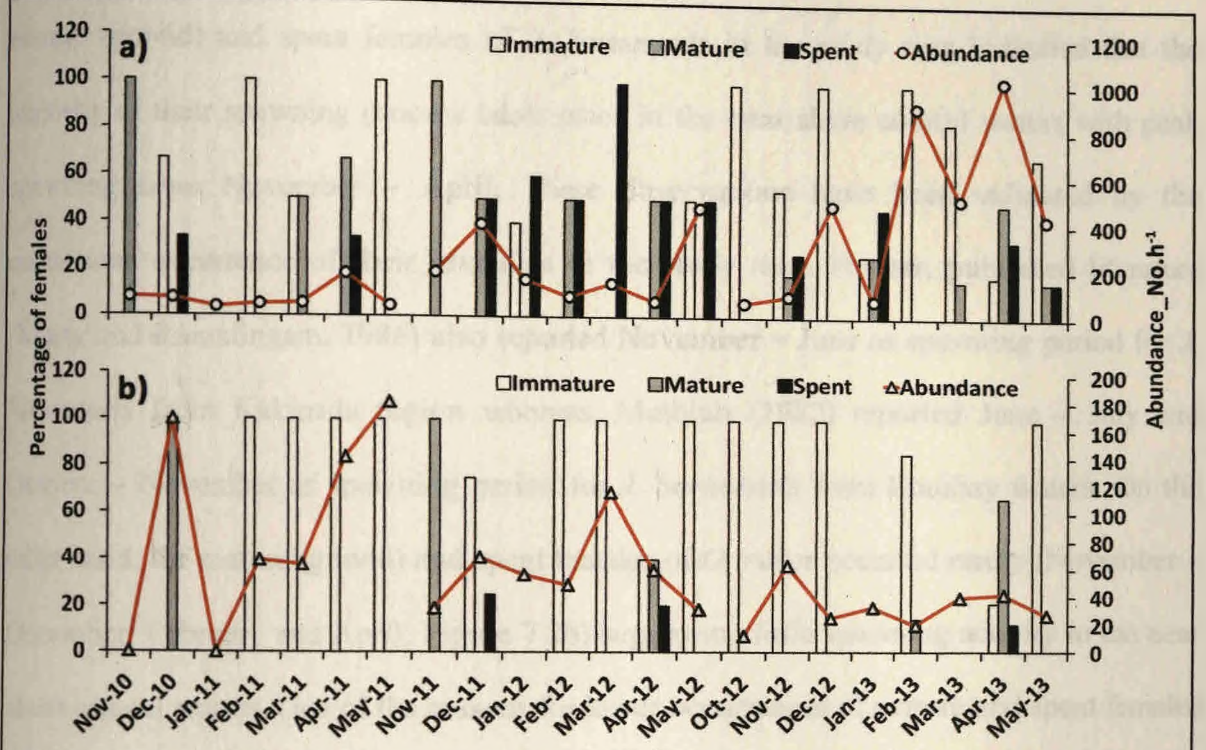


Figure 7.2. Monthly variation in abundance (h^{-1}) and percentage of immature; mature and spent females of a) *Johnius borneensis* and b) *Otolithes ruber*

2013. On the other hand, the *O. ruber* was found to be abundant during the months of December and March to May. The mean abundance ($No.h^{-1}$) observed for *J. borneensis* and *O. ruber* during the present study was 255 ± 281and 64 ± 48, respectively. The higher abundance of sciaenids during this period (December – May) can be attributed to recruitment of new juveniles as evidenced by predominance of their juveniles in the sub-samples (Velip and Rivonker, 2015b). Similar observations on abundance of sciaenids have been reported by Muthiah (1982) and Joseph and Jayaprakash (2002) and attributed to recruitment patterns.

7.3.3. Occurrence of immature, mature and spent females

Females of *J. borneensis* and *O. ruber* were found throughout the study period (Figure 7.2a, 7.2b). The juveniles / immature females of both the species were found abundantly during the months of October – December and February to May suggesting a prolonged / perennial spawning activity. The continuous and abundant occurrence of mature (gravid) and spent females of *J. borneensis* in the study area indicated that the majority of their spawning process takes place in the near shore coastal waters with peak spawning from November – April. These observations have been validated by the continuous occurrence of their juveniles in the study area. Further, published literature (Murty and Ramalingam, 1986) also reported November – June as spawning period for *J. borneensis* from Kakinada region whereas, Muthiah (1982) reported June – July and October – November as spawning period for *J. borneensis* from Bombay waters. On the other hand, the mature (gravid) and spent females of *O. ruber* occurred rarely (November – December, February and April; Figure 7.2b) suggesting little spawning activity in the near shore coastal waters. One of the reasons for lower occurrences of mature and spent females of *O. ruber* could be attributed to its spawning season which extends from June – October (Devadoss, 1969; Nair, 1979) along the west coast of India, whereas the present sampling period did not corresponds to the reported spawning months. The reported spawning period coincided with the monsoon fishing ban along the study area (Goa, Daman and Diu Marine Fishing Regulation Rules, 1981) and hence sampling could not be done. Secondly, there is also a possibility of migration of gravid females of *O. ruber* to the deeper offshore waters or some other potential spawning grounds for spawning as reported in other finfishes (Goldsmith *et al*., 2015; Hislop *et al*., 2015) and hence the lower occurrences of gravid females in the study area. Further, the migration of their juveniles back to the coastal waters might be responsible for the continuous occurrence of juveniles of *O. ruber* in the study area as the coastal waters along the study area are well known to serve as potential nurseries (Ansari *et al*., 1995, 2003).

7.3.4. Fecundity

The fecundity in sciaenids is species-specific; varying from few thousands to 2 – 3 lakhs and sometimes even up to 6 lakhs in large species (Rao *et al.*, 1992). In *J. borneensis* (N = 21), the fecundity ranged from 9.54 x 10^3 (TL = 11 cm) to 130.08 x 10^3 (TL = 16.2 cm) with an average of 66.67 x 10^3 ± 27.43 x 10^3; while in the case of *O. ruber* (N = 26), it ranged from 12.18 x 10^3 (TL = 16 cm) to 226.85 x 10^3 (TL = 18.6 cm) with an average of 106.41 x 10^3± 43.92 x 10^3(Table 7.1). Published literature (Devadoss, 1969; Pillai, 1983; Rao *et al.*, 1992) also reported fecundity ranging from 43810 – 179659 numbers of eggs for *O. ruber* and 9253 – 151697 numbers of eggs for *J. borneensis* (Bhusari, 1975; Dukhande, 1991; Telvekar *et al.*, 2006; Manojkumar, 2011; Kumar *et al.*, 2014). Moreover, Muthiah (1982) and Rao (1986) have reported fecundity ranging from 26028 – 581298 numbers of eggs for *J. borneensis*. The fully mature / ripe females were observed to bear higher fecundity followed by mature and spent females. Among these two species, *O. ruber* exhibited the maximum average fecundity (106.41 x 10^3± 43.92 x 10^3) compared to *J. borneensis* (66.67 x 10^3 ± 27.43 x 10^3). Fecundity was also seen to vary significantly in fishes of same length and of same species owing to variability in gonadal state (immature, mature, and spent). Similar observations on fecundity of finfishes have been reported earlier by Bhusari (1975), Muthiah (1982) and Manojkumar (2011).

7.3.5. Ova diameter and distribution patterns

Ova diameter (OD) in *J. borneensis* ranged from 0.14 mm (TL = 11.5 cm) to 0.66 mm (TL = 16.2 cm) with an average of 0.33 ± 0.09 while in case of *O. ruber* it ranged from 0.17 mm (TL = 18.5, 21, 23.7 cm) to 0.76 mm (TL = 18.1 cm) with an average OD of 0.38 ± 0.11 mm (Table 7.1). The average OD also varied among mature, fully mature and spent females of both the species viz. 0.32 ± 0.05, 0.37 ± 0.11 and 0.29 ± 0.06 in *J.*

Table 7.1. Maturity stage-wise average total length, weight of fish, weight of gonad, fecundity, ova diameter and gonado-somatic index (GSI) of *Johnius borneensis* and *Otolithes ruber*

Maturity stage	Total length (cm)	Weight of fish (gm)	Weight of gonad (gm)	Fecundity	Ova diameter (mm)	GSI
***Johnius borneensis* (N = 21)**						
Mature	14.69 ± 1.49	39.84 ± 10.35	1.19 ± 0.37	$63.38 \times 10^3 \pm 24.66 \times 10^3$	0.32 ± 0.05	2.98 ± 0.42
Fully Mature	15.13 ± 1.05	42.60 ± 10.59	2.11 ± 0.85	$80.04 \times 10^3 \pm 27.75 \times 10^3$	0.37 ± 0.11	4.96 ± 1.44
Spent	13.78 ± 2.16	30.58 ± 12.15	0.71 ± 0.27	$43.17 \times 10^3 \pm 15.59 \times 10^3$	0.29 ± 0.06	2.33 ± 0.40
Overall	14.70 ± 1.47	39.26 ± 11.17	1.49 ± 0.83	$66.67 \times 10^3 \pm 27.43 \times 10^3$	0.33 ± 0.09	3.70 ± 1.49
***Otolithes ruber* (N = 26)**						
Mature	18.25 ± 2.58	62.43 ± 25.93	2.19 ± 0.53	$105.11 \times 10^3 \pm 17.07 \times 10^3$	0.33 ± 0.04	3.74 ± 0.87
Fully Mature	19.44 ± 1.85	78.07 ± 25.30	3.35 ± 1.06	$123.88 \times 10^3 \pm 51.81 \times 10^3$	0.44 ± 0.13	4.34 ± 0.80
Spent	16.98 ± 0.87	46.80 ± 04.88	1.11 ± 0.61	$57.23 \times 10^3 \pm 30.09 \times 10^3$	0.32 ± 0.04	2.35 ± 1.30
Overall	18.60 ± 2.19	67.24 ± 25.67	2.56 ± 1.15	$106.41 \times 10^3 \pm 43.92 \times 10^3$	0.38 ± 0.11	3.81 ± 1.11

borneensis, and 0.33 ± 0.04, 0.44 ± 0.13, and 0.32 ± 0.04 mm in *O. ruber*, respectively owing to maturity stage of ova. Further, the ova distribution patterns studied in mature, fully mature and spent females of *J. borneensis* and *O. ruber* (Figure 7.3) revealed unimodal distribution of ova in mature and spent females (Figure 7.3a, c, d, and f) with a mode at 0.30 – 0.35 mm and a distinct bimodal distribution was observed in fully mature / ripe females (Figure 7.3b and e) with primary mode at 0.30 – 0.35 mm in both species and secondary mode at 0.50 – 0.55 mm and 0.55 – 0.60 mm in *J. borneensis* and *O. ruber*, respectively.

Published literature (Pillai, 1983) reported ova diameter ranging from 0.063 – 0.693 mm from mature ovaries of *O. ruber* with single mode at 0.39 – 0.44 mm. In contrast, a distinct bimodal distribution of ova was observed in fully mature / ripe females of *O. ruber* in the present study; showing distinct separation between immature and mature stock owing to asynchronous development of ova. Similarly, Dadzie (2007) observed a

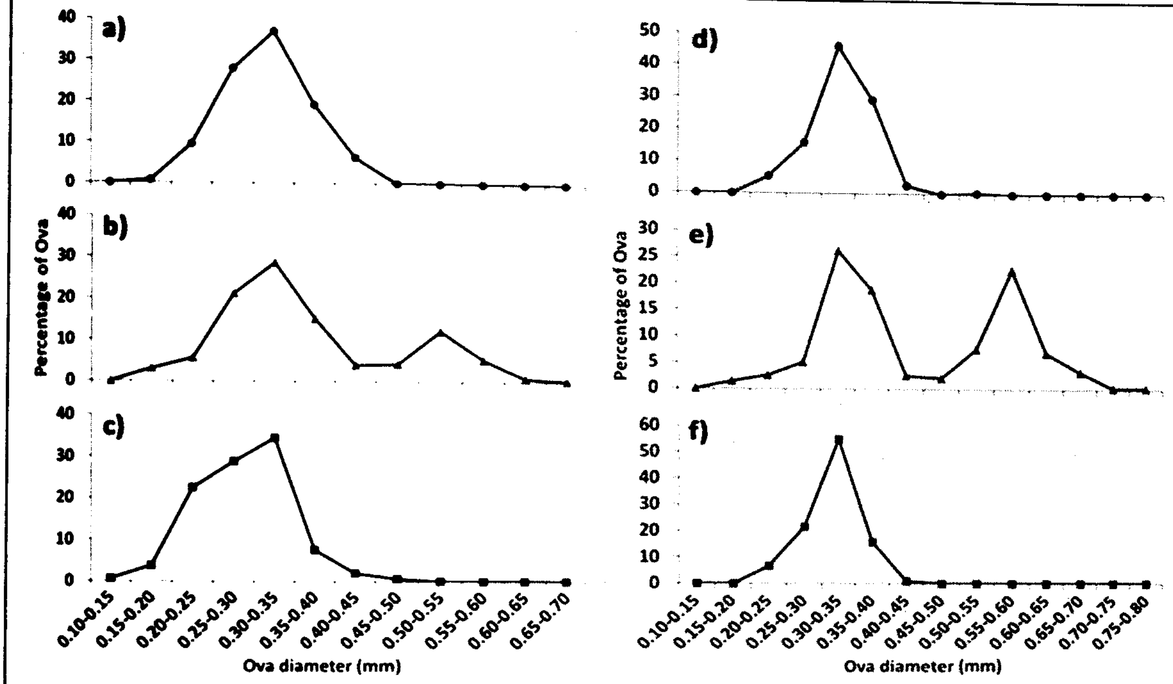


Figure 7.3. Percentage ova distribution plot of *Johnius borneensis* – a) mature, b) fully mature c) spent females and *Otolithes ruber* – d) mature, e) fully mature f) spent females

multimodal distribution in *O. ruber* based on oocyte diameter frequency. Similarly, *J. borneensis* also exhibited a bimodal distribution of ova in fully mature / ripe females. Published literature also reported a bimodal or multimodal distribution of ova in *J. borneensis* at maturity stages IV to VI (Muthiah, 1982; Rao, 1986). In these species (*J. borneensis* and *O. ruber*), once the ova has been ovulated from the ready batch (0.45 – 0.80 / 0.45 – 70 mm), the ova from the intermediate or smaller size class (0.30 – 0.45/ 0.20 – 0.40 mm) transforms into a new ready batch for spawning as a result of asynchronous development of ova. This sequential event continues till the last batch of eggs shed-off indicating a multiple/ intermittent spawning process and this has also been reported in many other teleostean species (Bagenal and Braum, 1971; Jones, 1978; Conover, 1985; Hunter *et al.*, 1992; Almatar *et al.*, 2004; Dadzie, 2007).

It is noteworthy to mention here that, being continuous / multiple spawner and having higher fecundity compared to *J. borneensis*, *O. ruber* showed lower abundance during the present study. This can be attributed to productivity of spawning grounds, mortality during drifting / migration, and resilience to fishing pressure. The species *O. ruber* spawns away from the coastal waters may be in less productive offshore waters as evidenced by rare occurrence of mature and spent females in study area. Subsequently, the juveniles of *O. ruber* migrate to the productive coastal water which serves as potential nurseries (Ansari *et al.*, 1995) and during this process there might be some mortality of larvae and juveniles due to starvation and predation (Hunter, 1981; Bailey and Haude, 1989) and hence low survival rate leading to reduced species abundance. On the other hand, *J. borneensis* spawns in productive coastal waters which also serve as good nurseries (Sheaves *et al.*, 2014). Therefore, leading to high survival rate of juveniles and this might be responsible for its increased abundance compared to *O. ruber*. Moreover, the higher dietary breadth in *J. borneensis* (0.34) might have favoured their increased abundance (Offem *et al.*, 2009; Murphy *et al.*, 2012) as compared to *O. ruber* (0.21). In addition to these, the species-specific resilience to fishing pressure might have also contributed to the abundance patterns of these sciaenid species (Chao *et al.*, 2015).

The sciaenid landings along the Goa coast displayed an overall decreasing trend (R^2 = 0.677; Figure 7.4; Fish trails, 2014, 2015), attributed to the combined effect of elevated exploitation and resultant by-catch generation and coastal anoxia. In recent years, high demand for fish and consequent intensification in fishing efforts for elevated yields / catch along with the resultant by-catch have made the sciaenid fishery of Goa highly vulnerable to sustained fishing pressure. A sizeable portion of sciaenid population (2.99 % of trawl catch) mainly comprising the juveniles, are being removed and wasted as trawl discards. Apart from this, the seasonal anoxia occurring over the western Indian continental shelf

(Naqvi *et al.*, 2009) may result in mortality of fish larvae and juveniles of sciaenids (Breitburg *et al.*, 2009) as the anoxic period coincides with the spawning period of

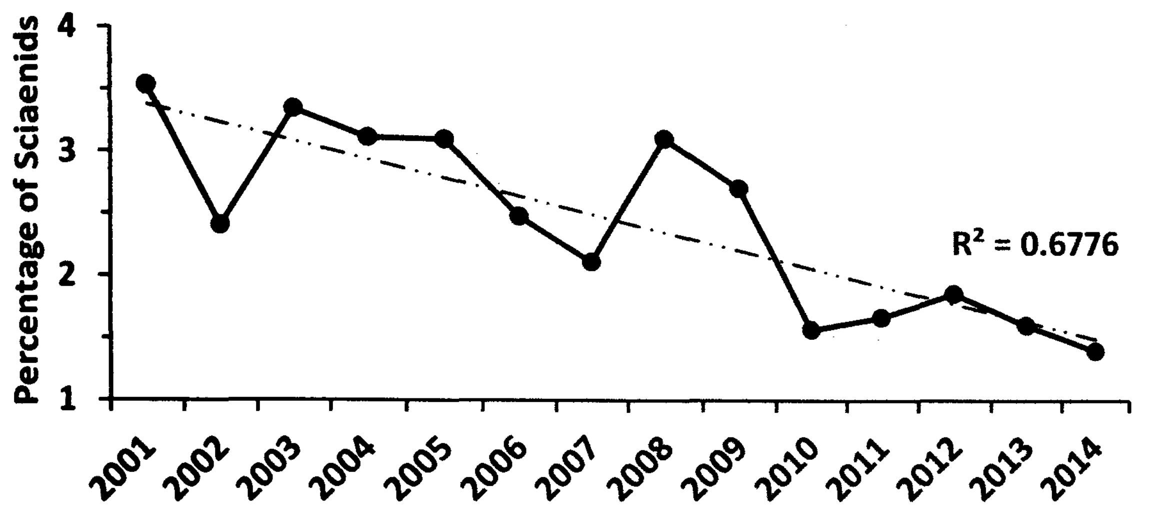


Figure 7.4. Percentage landings of sciaenids along Goa coast from 2001 - 2014

** Source: Fish trails, 2014 & 2015, Directorate of Fisheries, Govt. of Goa,

sciaenids (Joseph and Jayaprakash, 2002) and may also compel some of the sciaenid species to migrate to other places (Allen *et al.*, 2006). In view of above, necessitates continuous monitoring of trawl catches along with by-catch to enable complete understanding of biological and ecological aspects of sciaenids for sustainable exploitation and management of sciaenid fishery along the Goa coast.

Chapter 8 -

Summary and recommendations

The present study attempts to provide comprehensive information to elucidate the demersal fish community structure based on the data collected from the trawl gear along the nearshore coastal waters of Goa (up to 30 m depth), central west coast of India.

1. The demersal fish community is comprised of a total of 196 taxa, categorized into seven faunal groups namely, elasmobranchs, crustaceans, teleosts, molluscs, echinoderms, reptiles and cnidarians. Nineteen taxa were new records from the study area including one new to science, two new to entire Indian coast, and one new to west coast of India. Quantitative analysis of trawl catch revealed the dominance of crustaceans in terms of abundance owing to reduced mesh size. Detailed analysis of demersal faunal groups revealed a conspicuous increase in the abundance of echinoderm fauna attributed to recruitment, favourable environmental conditions and absence of potential predators. The abundance and diversity indices decreased with depth owing to reduced food availability. Higher abundances of molluscs and echinoderms at 10 – 20 m depth zone can be attributed to their preference for sub-tidal habitat to overcome desiccation and form feeding aggregations.

2. *Hexapus bidentatus* (Family Hexapodidae), a brachyuran crab new to science is described in detail and compared with its closest congener, *H. estuarinus*. In addition, an updated description of *H. estuarinus* and a taxonomic key to all the five valid congeners is provided.

3. The trawl by-catch representing 174 species accounted for 68 % of the total catches in terms of biomass. Discarded by-catch consisting of juveniles of targeted catch and the trash fauna, constituted 89 % of the total faunal species. The environmental parameters such as temperature, salinity and dissolved oxygen were found to influence the by-catch species occurrence and abundance. Species assemblages were determined by the recruitment patterns and ecological relationships.

4. Altogether, 84 taxa were identified from stomach contents of finfishes, of which prawns were observed to be a significant component. In addition, cluster analysis of predatory fish groups revealed three trophic guilds namely teleost, prawn and zooplankton feeders. The trophic dynamic study revealed *Metapenaeus dobsoni*, mysis, teleosts and diatoms as important entities to establish trophic links for the coastal finfishes. Gill raker density played an important role in zooplanktivory by finfishes. Distinct ontogenic changes observed in the diets of sciaenids and flatheads were primarily due to increase in the mouth gape height.

5. Analysis of temporal trends of sciaenid fishes from the trawl catches revealed an inverse trend in the abundances of *Johnius borneensis* and *Otolithes ruber* during the later phase of study period. *J. borneensis* was observed to be a perennial spawner in the coastal waters as evidenced by occurrence of gravid females and their juveniles, while the absence of gravid females of *O. ruber* suggested that the species spawns away from the coast. Moreover, the higher dietary breadth of *J. borneensis* might have favoured their increased abundance. The ova distribution pattern suggested multiple spawning activities in both the species, with comparatively higher fecundity in *O. ruber*.

Based on the observations made in the present study, the following recommendations are made for the effective management of fishery resources along the region

1. The generation of high proportion of by-catch, comprising rare species as well as juveniles of commercially important species, is a major problem associated with bottom trawling along this coast. The mitigation of this problem requires strict enforcement of fisheries laws (Goa, Daman and Diu Marine Fishing Regulation Act, 1980) relating to bycatch reduction including the use of recommended mesh size, by-catch reduction devices, and limitations on site and duration of harvest.

2. The discarding of by-catch directly into the sea is a common practice along the Goa coast. The subsequent decomposition of carcasses results in hypoxic conditions at the sea bottom, thereby endangering demersal or benthic marine fauna. In view of this, it is recommended to retain the bycatch to be subsequently utilized for the production of fish meal or fertilizer.

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Appendix

Appendix 3.1.

Sr. No.	Name of species	Common name
A.	**Elasmobranchs**	
1	*Himantura gerrardi* (Gray, 1851)	Sharpnose stingray
2	*Himantura walga* (Müller & Henle, 1841)	Dwarf whipray
3	*Himantura uarnak* (Gmelin, 1789)	Honeycomb stingray
4	*Aetobatus flagellum* (Bloch & Schneider, 1801)	Longheaded eagle ray
5	*Glaucostegus granulatus* (Cuvier, 1829)	Granulated guitarfish
6	*Chiloscyllium griseum* Müller & Henle, 1838	Grey bambooshark
7	*Scoliodon laticaudus* Müller & Henle, 1838	Spadenose shark
B.	**Teleosts**	
8	*Sardinella longiceps* Valenciennes, 1847	Indian oil sardine
9	*Sardinella brachysoma* Bleeker, 1852	Deepbody sardinella
10	*Sardinella gibbosa* (Bleeker, 1849)	Goldstripe sardinella
11	*Sardinella melanura* (Cuvier, 1829)	Blacktip sardinella
12	*Escualosa thoracata* (Valenciennes, 1847)	White sardine
13	*Nematalosa galatheae* Nelson & Rothman, 1973	Galathea gizzard shad
14	*Anodontostoma chacunda* (Hamilton, 1822)	Chacunda gizzard shad
15	*Dussumieria acuta* Valenciennes, 1847	Rainbow sardine
16	*Opisthopterus tardoore* (Cuvier, 1829)	Tardoore
17	*Pellona ditchela* Valenciennes, 1847	Indian pellona
18	*Ilisha sirishai* Seshagiri Rao, 1975	Lobejaw ilisha
19	*Ilisha melastoma* (Bloch & Schneider, 1801)	Indian ilisha
20	*Thryssa mystax* (Bloch & Schneider, 1801)	Moustached thryssa
21	*Thryssa dussumieri* (Valenciennes, 1848)	Dussumier's thryssa
22	*Thryssa setirostris* (Broussonet, 1782)	Longjaw thryssa
23	*Thryssa malabarica* (Bloch, 1795)	Malabar thryssa
24	*Thryssa purava* (Hamilton, 1822)	Oblique-jaw thryssa
25	*Stolephorus commersonnii* Lacepède, 1803	Commerson's anchovy
26	*Mugil cephalus* Linnaeus, 1758	Flathead grey mullet
27	*Siganus canaliculatus* (Park, 1797)	White-spotted spinefoot
28	*Ambassis gymnocephalus* (Lacepède, 1802)	Bald glassy
29	*Ostorhinchus fasciatus* (White, 1790)	Broadbanded cardinalfish
30	*Archamia bleekeri* (Günther, 1859)	Gon's cardinalfish
31	*Alectis indica* (Rüppell, 1830)	Indian threadfish
32	*Alepes djedaba* (Forsskål, 1775)	Shrimp scad
33	*Atropus atropos* (Bloch & Schneider, 1801)	Cleftbelly trevally
34	*Caranx sexfasciatus* Quoy & Gaimard, 1825	Bigeye trevally
35	*Decapterus russelli* (Rüppell, 1830)	Indian scad
36	*Seriolina nigrofasciata* (Rüppell, 1829)	Blackbanded trevally

37	*Megalaspis cordyla* (Linnaeus, 1758)	Torpedo scad
38	*Parastromateus niger* (Bloch, 1795)	Black pomfret
39	*Scomberoides tol* (Cuvier, 1832)	Needlescaled queenfish
40	*Trachinotus mookalee* Cuvier, 1832	Indian pompano
41	*Rachycentron canadum* (Linnaeus, 1766)	Cobia
42	*Drepane longimana* (Bloch & Schneider, 1801)	Concertina fish
43	*Drepane punctata* (Linnaeus, 1758)	Spotted sicklefish
44	*Platax teira* (Forsskål, 1775)	Longfin batfish
45	*Gerres filamentosus* Cuvier, 1829	Whipfin silver-biddy
46	*Gerres limbatus* Cuvier, 1830	Saddleback silver-biddy
47	*Lactarius lactarius* (Bloch & Schneider, 1801)	False trevally
48	*Gazza minuta* (Bloch, 1795)	Toothed Ponyfish
49	*Photopectoralis bindus* (Valenciennes, 1835)	Orangefin ponyfish
50	*Nuchequula blochii* (Valenciennes, 1835)	Twoblotch ponyfish
51	*Karalla daura* (Cuvier, 1829)	Goldstripe ponyfish
52	*Leiognathus equulus* (Forsskål, 1775)	Common ponyfish
53	*Leiognathus brevirostris* (Valenciennes, 1835)	Shortnose ponyfish
54	*Eubleekeria splendens* (Cuvier, 1829)	Splendid ponyfish
55	*Secutor ruconius* (Hamilton, 1822)	Deep pugnose ponyfish
56	*Secutor insidiator* (Bloch, 1787)	Pugnose ponyfish
57	*Mene maculata* (Bloch & Schneider, 1801)	Moonfish
58	*Nemipterus japonicus* (Bloch, 1791)	Japanese threadfin bream
59	*Nemipterus bipunctatus* (Valenciennes, 1830)	Delagoa threadfin bream
60	*Parascolopsis townsendi* Boulenger, 1901	Scaly dwarf monocle bream
61	*Pempheris molucca* Cuvier, 1829	Black-edged sweeper
62	*Filimanus heptadactyla* (Cuvier, 1829)	Sevenfinger threadfin
63	*Dendrophysa russelii* (Cuvier, 1829)	Goatee croaker
64	*Johnius borneensis* (Bleeker, 1851)	Sharpnose hammer croaker
65	*Johnius dussumieri* (Cuvier, 1830)	Sin croaker
66	*Johnius coitor* (Hamilton, 1822)	Coitor croaker
67	*Johnius elongatus* Lal Mohan, 1976	Spindle croaker
68	*Johnius belangerii* (Cuvier, 1830)	Belanger's croaker
69	*Johnius macropterus* (Bleeker, 1853)	Largefin croaker
70	*Johnius amblycephalus* (Bleeker, 1855)	Bearded croaker
71	*Otolithes cuvieri* Trewavas, 1974	Lesser tigertooth croaker
72	*Otolithes ruber* (Bloch & Schneider, 1801)	Tigertooth croaker
73	*Pennahia anea* (Bloch, 1793)	Donkey croaker
74	*Pennahia macrophthalmus* (Bleeker, 1849)	Bighead croaker
75	*Kathala axillaris* (Cuvier, 1830)	Kathala croaker
76	*Protonibea diacanthus* (Lacepède, 1802)	Blackspotted croaker
77	*Paranibea semiluctuosa* (Cuvier, 1830)	Half-mourning croaker
78	*Epinephelus diacanthus* (Valenciennes, 1828)	Spinycheek grouper
79	*Sillago sihama* (Forsskål, 1775)	Silver sillago

80	*Pomadasys maculatus* (Bloch, 1793)	Saddle grunt
81	*Plectorhinchus gibbosus* (Lacepède, 1802)	Harry hotlips
82	*Terapon jarbua* (Forsskål, 1775)	Crescent Grunter
83	*Terapon theraps* Cuvier, 1829	Largescaled terapon
84	*Terapon puta* Cuvier, 1829	Small-scaled terapon
85	*Pelates quadrilineatus* (Bloch, 1790)	Fourlined terapon
86	*Scomberomorus guttatus* (Bloch & Schneider, 1801)	Indo-Pacific king mackerel
87	*Rastrelliger kanagurta* (Cuvier, 1816)	Indian mackerel
88	*Trichiurus lepturus* Linnaeus, 1758	Largehead hairtail
89	*Sphyraena putnamae* Jordan & Seale, 1905	Sawtooth barracuda
90	*Sphyraena obtusata* Cuvier, 1829	Obtuse barracuda
91	*Pampus argenteus* (Euphrasen, 1788)	Silver pomfret
92	*Pampus chinensis* (Euphrasen, 1788)	Chinese silver pomfret
93	*Trypauchen vagina* (Bloch & Schneider, 1801)	Burrowing goby
94	*Odontamblyopus rubicundus* (Hamilton, 1822)	Rubicusdus eelgoby
95	*Yongeichthys criniger* (Valenciennes, 1837)	Horny Goby
96	*Parachaeturichthys polynema* (Bleeker, 1853)	Taileyed goby
97	*Oxyurichthys paulae* Pezold, 1998	Jester goby
98	*Callionymus sagitta* Pallas, 1770	Arrow dragonet
99	*Callionymus sublaevis* McCulloch, 1926	Australian filamentous dragonet
100	*Grammoplites scaber* (Linnaeus, 1758)	Rough flathead
101	*Thysanophrys armata* (Fowler, 1938)	N.A.
102	*Platycephalus indicus* (Linnaeus, 1758)	Bartail flathead
103	*Minous monodactylus* (Bloch & Schneider, 1801)	Grey stingfish
104	*Trachicephalus uranoscopus* (Bloch & Schneider, 1801)	Stargazing stonefish
105	*Cynoglossus macrostomus* Norman, 1928	Malabar tonguesole
106	*Cynoglossus puncticeps* (Richardson, 1846)	Speckled tonguesole
107	*Cynoglossus dispar* Day, 1877	Roundhead toungesole
108	*Cynoglossus lida* (Bleeker, 1851)	Roughscale tonguesole
109	*Synaptura commersonnii* (Lacepède, 1802)	Commerson's sole
110	*Synaptura albomaculata* Kaup, 1858	Kaup's sole
111	*Solea ovata* Richardson, 1846	Ovate sole
112	*Pseudorhombus triocellatus* (Bloch & Schneider, 1801)	Three spotted flounders
113	*Pseudorhombus arsius* (Hamilton, 1822)	Largetooth flounder
114	*Triacanthus biaculeatus* (Bloch, 1786)	Short-nosed tripodfish
115	*Lagocephalus spadiceus* (Richardson, 1845)	Half-smooth golden pufferfish
116	*Arothron immaculatus* (Bloch & Schneider, 1801)	Immaculate puffer
117	*Chelonodon patoca* (Hamilton, 1822)	Milkspotted puffer
118	*Aluterus monoceros* (Linnaeus, 1758)	Unicorn leatherjacket filefish
119	*Colletteichthys dussumieri* (Valenciennes, 1837)	Flat toadfish

120	*Bregmaceros mcclellandi* Thompson, 1840	Unicorn cod
121	*Dactyloptena gilberti* Snyder, 1909	Flathead Helmet Gurnard/ Flying Gurnard
122	*Arius maculatus* (Thunberg, 1792)	Spotted catfish
123	*Arius arius* (Hamilton, 1822)	Threadfin sea catfish
124	*Plicofollis nella* (Valenciennes, 1840)	Smooth-headed catfish
125	*Plotosus lineatus* (Thunberg, 1787)	Striped eel catfish
126	*Netuma bilineata* (Valenciennes, 1840)	Bronze catfish
127	*Pisodonophis cancrivorus* (Richardson, 1848)	Longfin snake-eel
128	*Muraenesox cinereus* (Forsskål, 1775)	Daggertooth pike conger
129	*Gymnothorax dorsalis* Seale, 1917	N.A.
130	*Gymnothorax thyrsoideus* (Richardson, 1845)	Greyface moray
131	*Saurida tumbil* (Bloch, 1795)	Greater lizardfish
132	*Synodus myops* (Forster, 1801)	Snakefish
133	*Harpadon nehereus* (Hamilton, 1822)	Bombay-duck
C.	**Crustaceans**	
134	*Penaeus monodon* Fabricius, 1798	Giant tiger prawn
135	*Fenneropenaeus indicus* (H. Milne-Edwards, 1837)	Indian white prawn
136	*Fenneropenaeus merguiensis* (De Man, 1888)	Banana prawn
137	*Marsupenaeus japonicus* (Bate, 1888)	Kuruma prawn
138	*Metapenaeus dobsoni* (Miers, 1878)	Kadal shrimp/ Flowertail shrimp
139	*Metapenaeus affinis* (H. Milne-Edwards, 1837)	Jinga shrimp
140	*Metapenaeus moyebi* (Kishinouye, 1896)	Moyebi shrimp
141	*Parapenaeopsis stylifera* (Milne-Edwards, 1837)	Kiddi shrimp
142	*Exhippolysmata ensirostris* (Kemp, 1914)	Hunter Shrimp
143	*Alpheus euphrosyne* De Man, 1897	Nymph Snapping Shrimp
144	*Neocallichirus audax* (de Man, 1911)	N.A.
145	Mysis larvae	N.A.
146	*Diogenes miles* (Fabricius, 1787)	N.A.
147	*Schizophrys aspera (H. Milne Edwards, 1834)*	Common Decorator Crab
148	*Dorippe astuta* (Fabricius, 1793)	N.A.
149	*Calappa lophos* (Herbst, 1785)	Common box crab
150	*Ashtoret lunaris* (Forsskål, 1775)	Yellow moon crab
151	*Leucosia pubescens* Miers, 1877	Olive Purse Crab
152	*Etisus anaglyptus* H. Milne Edwards, 1834	Togari-hizumegani [Japanese]
153	*Doclea rissonii* Leach, 1815	Red-legged spider crab
154	*Portunus sanguinolentus* (Herbst, 1783)	Three-spot swimming crab
155	*Portunus pelagicus* (Linnaeus, 1758)	Flower crab
156	*Scylla serrata* (Forsskål, 1775)	Giant Mud Crab
157	*Charybdis lucifera* (Fabricius, 1798)	Yellowish brown crab
158	*Charybdis feriatus* (Linnaeus, 1758)	Crucifix crab

159	*Charybdis variegata* (Fabricius, 1798)	Kawari-íshigani [Japanese]
160	*Charybdis goaensis* (Padate, Rivonker, Anil, Sawant & Krishnamurthy 2010)	N.A.
161	*Charybdis vadorum* Alcock, 1899	N.A.
162	*Hexapus bidentatus* (Velip & Rivonker, 2015)	N.A.
163	*Hexapus estuarinus* Sankarankutty, 1975	N.A.
164	*Trissoplax dentata* (Stimpson, 1858)	N.A.
165	*Albunea symmysta* (Linnaeus, 1758)	N.A.
166	*Raphidopus indicus* Henderson, 1893	N.A.
167	*Miyakella nepa* (Latreille, 1828)	Smalleyed Squillid/ Mantis Shrimp
168	*Harpiosquilla raphidea* (Fabricus, 1798)	Giant harpiosquillid mantis shrimp
169	*Lysiosquilla tredecimdentata* Holthuis, 1941	Golden mantis shrimp
D.	**Molluscs**	
170	*Perna viridis* (Linnaeus, 1758)	Asian green mussel
171	*Crassostrea madrasensis* unspecified	Indian backwater oyster
172	*Anadara* (*Tegillarca*) *granosa* (Linnaeus, 1764)	Cockle (blood clam)
173	*Turritella duplicata* (Linnaeus, 1758)	Duplicate turret
174	*Turritella turritella* (Lamarck, 1822)	N.A.
175	*Turritella* sp.	-
176	*Bufonaria spinosa* Schumacher, 1817	N.A.
177	*Gyrineum natator* (Röding, 1798)	Tuberculara gyre triton
178	*Murex trapa* Röding, 1798	Rarespined murex
179	*Murex* sp.	-
180	*Babylonia spirata* (Linnaeus, 1758)	Spiral Babylon
181	*Babylonia* sp.	-
182	*Oliva* sp.	-
183	*Natica picta* Récluz, 1844	Beautifully-banded moon snail
184	*Tibia curta* (G.B. Sowerby II, 1842)	N.A.
185	*Antalis* sp.	-
186	*Uroteuthis duvaucelii* (D'Orbigny, 1835)	Indian squid
187	*Sepiella inermis* (Van Hasselt, 1835)	Spineless cuttlefish
188	*Cistopus indicus* (Rapp, 1835)	Old woman octopus
189	*Octopus* sp.	-
E.	**Echinoderms**	
190	*Astropecten indicus* Döderlein, 1888	Fringed star fish
191	*Temnopleurus toreumaticus* (Leske, 1778)	Striped spine sea urchin
192	*Temnopleurus decipiens* (de Meijere, 1904)	N.A.
193	Brittle star	-
D.	**Sea snakes**	
194	*Enhydrina schistosa* Daudin, 1803	Beaked sea snake

195	*Lapemis curtus* (Shaw, 1802)	Hardwicke's spine-bellied sea snake
D.	**Cnidaria**	
196	*Aurelia aurita* (Linnaeus, 1758)	Moon jelly

Appendix 5.1.

Species name	**Abbreviation**	**Species name**	**Abbreviation**
Miyakella nepa	Miyne	*Lactarius lactarius*	Lacla
Parapenaeopsis stylifera	Parst	*Photopectoralis bindus*	Phobi
Metapenaeus affinis	Metdo	*Eubleekeria splendens*	Eubsp
Metapenaeus dobsoni	Metaf	*Otolithes cuvieri*	Otocu
Exhippolysmata ensirostris	Exhen	*Johnius borneensis*	Johbo
Portunus sanguinolentus	Porsa	*Trichiurus lepturus*	Trile
Charybdis feriata	Chafe	*Cynoglossus macrostomus*	Cynma
Charybdis lucifera	Chalu	*Ambassis gymnocephalus*	Ambgy
Charybdis vadorum	Chava	*Uroteuthis duvaucelii*	Phodu
Unidentified red prawns	Unpra	*Sepiella inermis*	Sepin
Mysis	Mysis	*Muraenesox cinereus*	Murci
Opisthopterus tardoore	Opita	*Lagocephalus spadiceus*	Lagsp
Stolephorus commersonnii	Stoco	*Temnopleurus toreumaticus*	Temto
Thryssa mystax	Thrmy	*Astropecten indicus*	Astin
Thryssa dussumieri	Thrdu	Bivalve	Bival
Arius maculatus	Arima	Gastropods	Gastr
Epinephelus diacanthus	Epidi		

Appendix 6.1.

Abbreviations used for predatory finfish groups (Cluster analysis)			
Finfish group	**Abbreviation**	**Finfish group**	**Abbreviation**
Small Groupers	Gru_er-S	Small Sciaenids	Sc_ds-S
Medium Groupers	Gru_er-M	Medium Sciaenids	Sc_ds-M
Small Flatheads	Fl_ds-S	Large Sciaenids	Sc_ds-L
Medium Flatheads	Fl_ds-M	Small Threadfin breams	Th_br-S
Large Flatheads	Fl_ds-L	Medium Threadfin breams	Th_br-M
Small Clupeoids	Cl_ds-S	Medium False trevally	Fa_ly-M
Medium Clupeoids	Cl_ds -M	Medium Lizard fish	Li_sh-M
Large Clupeoids	Cl_ds -L	Medium Puffer fish	Pu_sh-M
Small Grunters	Grn_rs-S	Medium Hairtails	Ha_ls-M
Medium Grunters	Grn_rs-M		
Abbreviations used for prey items (PCA analysis – active variables)			
Prey items	**Abbreviation**	**Prey items**	**Abbreviation**
Prawns	Pr_ns	Benthos	Be_os
Crabs	Cr_bs	Zooplankton	Zo_on
Stomatopods	St_ds	Phytoplankton	Ph_on
Teleosts	Te_ts	Algae	Al_ae
Molluscs	Mo_cs	Digested matter	Di_ma
Echinoderms	Ec_ms		

Published articles

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Velip D.T. and Rivonker C.U. (2015a) *Hexapus bidentatus* (Crustacea: Decapoda: Brachyura: Hexapodidae), new species from Goa, west coast of India. *Marine Biology Research* **11**(1): 97 – 105.

Velip D.T. and Rivonker C.U. (2015b) Trends and composition of trawl bycatch and its implications on tropical fishing grounds off Goa, India. *Regional Studies in Marine Science*, **2**: 65 – 75.

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An updated inventory of new records of coastal macrofauna along Goa, west coast of India

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An assessment of demersal macrofauna for 7 years (2005-2011) through continuous survey (250 trawls, 4 beach seines) with total effort of 424 hours along the bay estuarine and nearshore waters of Goa, yielded 84 new records for the region. Among these, *Charybdis (Charybdis) goaensis* was new to science. In addition, two species (*Thysanophrys armata* and *Callionymus sublaevis*) were found to be first records for the Indian waters, seven were new to the West coast of India and 74 others were new reports for this region.

[**Keywords:** New records, Macrofauna, Diverse habitat, Goa, West coast]

Introduction

Studies pertaining to the diversity of coastal macrofauna from the estuarine and shelf waters of Goa[1,2,3,4,5,6] were focussed on reporting commercial species, thereby creating lacunae on occurrence and distribution of rare and non-commercial species from this region. Hence, the establishment of a comprehensive database on the demersal marine fauna was pertinent in order to provide a platform towards improved understanding of the coastal biodiversity of Goa. Present study primarily attempts to provide baseline information on the species composition of coastal macrofauna through intensive sampling and subsequent creation of an inventory of all the components of the demersal community.

Materials and Methods

Present study area (Fig. 1) comprised two coastal regions namely (1) Nearshore fishing grounds (sand-silt substratum) up to 25 m depth. Regions of Mandovi-Zuari estuaries (15°32'N – 15°28'N latitudes and 73°45'E – 73°57'E longitudes with clayey substratum) and adjacent Aguada - Mormugao bays with mixed substratum interspersed with submerged rocky patches. (2) Nearshore fishing grounds down upto 25 m depth located off the mouth of the Sal estuary (15°00'N – 15°16'N latitudes and 73°41'N – 74°00'E longitudes). Coastal bathymetry along the northern side of the estuary is primarily silt, whereas towards the south it is marked with submerged rock outcrops.

The nearshore trawl operations were carried out on a fortnightly basis during February 2006 – November 2008 and November 2010 – February 2012 off North Goa, and January 2009 – January 2012 off South Goa with exception of the South-west monsoon season.

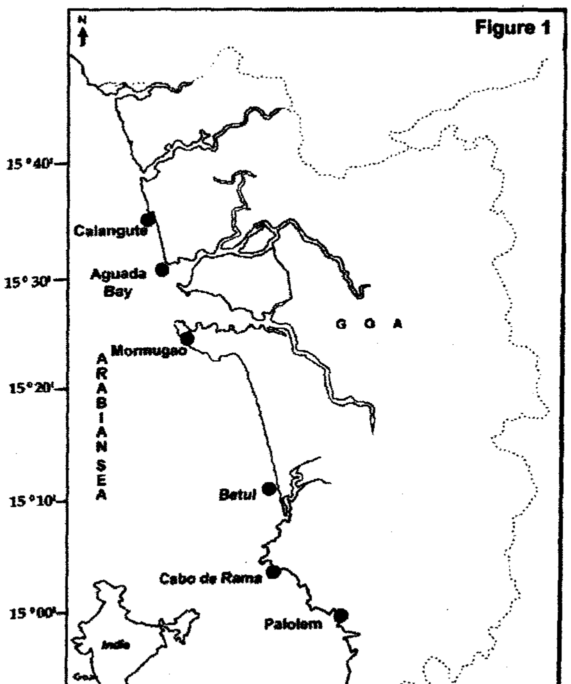

Fig. 1—Map showing sampling locations

In addition, trawling was carried out occasionally in estuaries owing to irregular bottom topography. Trawl nets with mesh sizes of 15 mm (mouth end) and 9 mm (cod end) were towed at a speed of about 2 knots (4 kmh^{-1}). Altogether, 250 trawl hauls were obtained with an effort of 420 hours. The trawl catch obtained was thoroughly examined for species composition and uncommon (or rare) specimens were separately sorted and temporarily preserved in ice. In addition, four beach seines were operated (one at Betim during December 2005, three in the vicinity of the Mormugao Port Trust during May and December 2005 and September 2006) with a total effort of four hours in estuarine embayment inaccessible to bottom trawling. Fish samples were also collected from local fishermen operating gill nets near the mouth of the Mandovi estuary in December 2005. Mud crabs were obtained from the estuarine embayment using crab traps (one each at the Port and Betim in May 2005 and December 2005, respectively) and also obtained from fishing jetties.

Subsequently, the samples were identified using conventional taxonomic methods involving phenotypic analyses (morphology, colour, texture patterns, meristic counts) and morphological measurements aided by published taxonomic literature for the respective faunal groups: fin fishes[7], penaeid prawns[8], non-penaeid shrimps[9,10], stomatopods[11], brachyura[12,13,14], anomura[15,16,17], molluscs[18,19,20], echinoderms[21].

Results

The present study revealed a total of 84 new records of coastal macrofauna for the Goan coasts. These include six elasmobranchs, 57 teleosts, 15 crustaceans, five molluscs and one echinoderm.

Highlights of the study are *Charybdis* (*Charybdis*) *goaensis*, a crab new to science[22], *Thysanophrys armata* and *Callionymus sublaevis* (both demersal fishes), which are new records for Indian waters.

A total of seven species were recorded for the first time for west coast of India (Table 1), which includes red bellied yellow tail reef fusilier *Caesio cuning*[23] recorded for the first time from outside its known geographical range. In addition, a mud crab *Scylla olivacea*[24] has been reported for the first time from west coast of India. Apart from these, 74 more species were recorded for the first time from Goa coast (Table 1) which includes a muricid gastropod, *Morula anaxares*[25].

Among the 84 new records, 52 species were found to be inhabitants of sandy and muddy habitat, 20 were coral reef inhabitants, five species were known to occur around mangroves, four were rocky and hard bottom inhabitants, two were exclusively estuarine residents and one species was found to occur along the sea grass beds (Table 1). This observation suggests the occurance of complex and diversified habitats in this region.

Discussion

Published literature[1,2,3,4,5,6] provides scanty and unorganised information on demersal benthic macrofauna along the Goa coast. Moreover, much of the earlier studies were oriented towards the economically important and commonly occurring species in the trawl catch. It was obvious that not much attention was paid to the rare species as these constituted trash fish on the commercial trawlers. Present study attempted to develop a more strengthened scientific database on the occurrence of macrofauna from the region through continuous monitoring of various habitats through different sampling devices.

The present study envisages a total of 84 new records of fishes and benthic invertebrates from the Goan coast (105 km). It is pertinent that the present reporting of new records from this region would definitely reinforce the existing information on diversity of benthic population from this region. A significant result of this exercise led to the description of one species new to science, *Charybdis* (*Charybdis*) *goaensis*[22] from this region. Secondly, was red bellied yellow tail reef fusilier *Caesio cuning* recorded for the first time from outside its known geographical array[23], suggesting the productive nature and importance of the region with respect to diversity.

Further, an attempt was made to have a closer look at the mud crab diversity and our observations revealed that there exists two species of *Scylla* along this region. A comparative analysis of external characters resulted in description of *Scylla olivacea*, a new record for the entire west coast of India[24]. In an attempt to study gastropod diversity, a new record of *Morula anaxares* along with its radula was described for the first time from this region[25].

This updated information and a more strengthened inventory of new records of coastal macrofauna documented was mainly due to the sustained,

Table 1—New records along with their habitats from Goa, West coast of India (*Contd.*)

Sr. No.	Species	Habitat
1	***Charybdis (Charybdis) goaensis*** Padate *et al.*, 2010[1,*]	Sandy
2	***Callionymus sublaevis*** McCulloch, 1926[5,δ]	Rocky/Coral reef
3	***Thysanophrys armata*** (Fowler, 1938)[5,δ]	Sandy/Silt
4	***Hydatina velum*** (Gmelin, 1791)[5,†]	Sandy/Rocky
5	***Raphidopus indicus*** Henderson, 1893[5,†]	Soft muddy/Sandy
6	***Scylla olivacea*** (Herbst, 1796)[3,†]	Mangrove/Muddy
7	***Charybdis (Charybdis) variegata*** (Fabricius, 1798)[5,†]	Sandy
8	***Hexapus estuarinus*** *Sankaran kutty, 1975*	Sandy bottom
9	***Caesio cuning*** (Bloch, 1791)[2,†]	Coral reef
10	***Stomopneustes variolaris*** (Lamarck, 1816)[5,†]	Rocky
11	***Haustellum (Vokesimurex) malabaricus*** (Smith, 1894)[5,‡]	Sandy bottom
12	***Morula anaxeres*** (Kiener, L.C., 1835)[4‡]	Sandy/Rocky
13	***Trigonostoma scalarifomis*** (Lamarck, 1822)[5,‡]	Sandy bottom
14	***Cistopus indicus*** (Orbigny, 1840)[5,‡]	Muddy bottom
15	***Parapenaeopsis maxillipedo*** Alcock, 1905[5,‡]	Muddy/Mangrove
16	***Macrobrachium equidens*** (Dana, 1852)[5,‡]	Sandy/Estuary
17	***Thalassina anomala*** (Herbst, 1804)[5,‡]	Muddy/Mangrove
18	***Diogenes miles*** (Fabricius, 1787)[5,‡]	Muddy Bottom
19	***Clibanarius infraspinatus*** Hilgendorf, 1869[5,‡]	Sandy/Soft silt
20	***Diogenes alias*** McLaughlin and Holthuis, 2001[5,‡]	Sandy/Muddy/Coral reef
21	***Albunea symmysta*** (Linnaeus, 1758)[5,‡]	Sandy bottom
22	***Harpiosquilla raphidea*** (Fabricius, 1798)[5,‡]	Sandy/Soft clay
23	***Philyra globus*** (Fabricius, 1775)[5,‡]	Sand/silt
24	***Schizophrys aspera*** (H. Milne Edwards, 1834)[5,‡]	Rocky
25	***Himantura walga*** (Müller & Henle, 1841)[5,‡]	Sandy bottom
26	***Himantura gerrardi*** (Gmelin, 1789)[5,‡]	Sandy/Rocky/Coral reef
27	***Himantura marginata*** (Blyth, 1860)[5,‡]	Sandy reef
28	***Neotrygon kuhlii*** (Müller & Henle, 1841)[5,‡]	Sandy/Rocky/Coral
29	***Aetobatus flagellum*** (Bloch & Schneider, 1801)[5,‡]	Sandy/Rocky
30	***Rhinobatos obtusus*** Müller & Henle, 1841[5,‡]	Sandy/Muddy
31	***Ilisha sirishai*** (Rao, 1975)[5,‡]	Pelagic/Euryhaline
32	***Thryssa setirostris*** (Broussonet, 1782)[5,‡]	Sandy/Rocky/Sea grass
33	***Thryssa mystax***(Bloch & Schneider, 1801)[5,‡]	Sandy/Rocky/Coral
34	***Hyporhampus limbatus*** (Valenciennes, 1847)[5,‡]	Muddy/Mangrove/Estuary
35	***Hippocampus kuda*** Bleeker, 1852[5,‡]	Mangrove/Rocky/Estuary
36	***Apogon fasciatus*** (White, 1870)[5,‡]	Sandy/Muddy bottom
37	***Archamia bleekeri*** (Günther, 1859)[5,‡]	Muddy/Clay
38	***Scomberoides commersonnianus*** (Lacepede, 1801)[5,‡]	Pelagic coral
39	***Trachinotus mookalee*** (Cuvier 1832)[5,‡]	Coral reef
40	***Heniochus acuminatus*** (Linnaeus, 1758)[5,‡]	Rocky/Coral
41	***Drepane longimana*** (Linnaeus, 1758)[5,‡]	Sandy/Rocky/Coral
42	***Platax teira*** (Forsskål, 1775)[5,‡]	Coral reef
43	***Gerres erythrourus*** (Bloch, 1791)[5,‡]	Sandy
44	***Gerres longirostris*** (Lacepede, 1801)[5,‡]	Estuary/Mangrove
45	***Gazza minuta*** (Bloch, 1795)[5,‡]	Sandy/Silt
46	***Leiognathus brevirostris*** (Valenciennes, 1835)[5,‡]	Sandy/Rocky
47	***Monodactylus argenteus*** (Linnaeus, 1758)[5,‡]	Estuary/Mangrove
48	***Upeneus tragula*** Richardson 1846[5,‡]	Coral reef
49	***Nemipterus bipunctatus*** (Valenciennes, 1830)[5,‡]	Rocky/Coral reef
50	***Parascolopsis townsendi*** Boulenger, 1901[5,‡]	Sandy/Soft bottom

(*Contd.*)

Table 1—New records along with their habitats from Goa, West coast of India

Sr. No.	Species	Habitat
51	*Pempheris molucca* Cuvier, 1829[5,‡]	Coral reef/Rocky
52	*Dendrophysa russelii* (Cuvier, 1829)[5,‡]	Rocky
53	*Johnius amblycephalus* (Bleeker, 1855)[5,‡]	Muddy soft bottom
54	*Johnius carutta* Bloch, 1793[5,‡]	Muddy/Estuary
55	*Johnius coitor* (Hamilton, 1822)[5,‡]	Muddy/Estuary
56	*Epinephelus coioides* (Hamilton, 1822)[5,‡]	Coral/Sandy/Mangrove
57	*Epinephelus erythrurus* (Valenciennes, 1828)[5,‡]	Rocky/Coral reef
58	*Sparidentex hasta* (Valenciennes, 1830)[5,‡]	Rocky/Coral reef
59	*Pomadasys furcatus* (Bloch & Schneider, 1801)[5,‡]	Soft bottom/Coral reef
60	*Plectorhinchus gibbosus* (Lacepede, 1802)[5,‡]	Rocky/Coral reef
61	*Plectorhinchus schotaf* (Forsskal, 1775)[5,‡]	Rocky/Coral reef
62	*Yongeichthys criniger* (Valenciennes, 1837)[5,‡]	Muddy/Coral reef
63	*Parachaeturichthys polynema* (Bleeker, 1853)[5,‡]	Muddy/Coral reef
64	*Oxyurichthys paulae* Pezold, 1998[5,‡]	Muddy coral reef
65	*Callionymus japonicus* Houttuyn, 1782[5,‡]	Sandy/coral reef
66	*Callionymus sagitta* Pallas, 1770[5,‡]	Muddy/Mangrove/Estuary
67	*Eurycephalus carbunculus* (Valenciennes, 1833)[5,‡]	Muddy bottom
68	*Cynoglossus dispar* Day, 1877[5,‡]	Muddy bottom
69	*Synaptura albomaculata* Kaup, 1858[5,‡]	Muddy bottom
70	*Brachirus orientalis* (Bloch & Schneider, 1801[5,‡]	Coral reef/Sandy bottom
71	*Acreichthys hajam* (Bleeker, 1851)[5,‡]	Coral reef
72	*Odonus niger* (Rüppell, 1836)[5,‡]	Coral reef
73	*Diodon hystrix* Linnaeus, 1758[5,‡]	Coral reef
74	*Lactoria cornuta* Linnaeus, 1758[5,‡]	Rocky/Coral/ Sea grass
75	*Triacanthus nieuhofii* Bleeker, 1852[5,‡]	Sandy bottom
76	*Takifugu oblongus* (Bloch, 1786)[5,‡]	Estuary/Coral reef
77	*Arothron immaculatus* (Bloch and Schneider, 1801)[5,‡]	Sea grass
78	*Tetraodon fluviatilis* fluviatilis (Hamilton, 1822)[5,‡]	Estuary/Muddy bottom
79	*Arius subrostratus* Valenciennes, 1840[5,‡]	Muddy bottom
80	*Nemapteryx caelata* (Valenciennes, 1840)[5,‡]	Muddy bottom
81	*Netuma bilineata* Valenciennes, 1840[5,‡]	Muddy bottom
82	*Muraenesox bagio* (Hamilton, 1822)[5,‡]	Estuary/Mangrove
83	*Gymnothorax pseudothyrsoideus* (Bleeker 1853)[5,‡]	Coral reef/Muddy bottom
84	*Trachinocephalus myops* (Forster, 1801)[5,‡]	Sandy bottom/coral reef

Padate *et al.* 2010a, [2] Padate *et al.* 2010b, [3]Padate *et al.* 2012, [4]Kumbhar and Rivonker, 2012 [5]Present study, *New to science, New to Indian waters, †New to west coast of India, ‡New to Goa coast

intensive sampling effort (424 hrs) and a focused approach to look at the rare species that enabled to uncover large number of species. Present study conducted sampling along diverse habitats such as bay–estuarine (mangrove dominated) and nearshore waters marked with various substrata (silt, sand, clay, submerged rocks). Further, published reports[26] suggest the existence of coral reef in vicinity of fishing grounds of Goa. Observations made in the present study also revealed coral reef inhabitant species (n = 20) in the nearshore trawl catches. In addition, the occurrence of red bellied yellow tail reef fusilier *Caesio cuning* in the nearshore trawl catches suggested the existence of coral reef patches in the vicinity of fishing grounds. Further, presence of artificial structures such as the grounded vessel *MV River Princess* enabled habitation by a wide array of demersal reef fish through provision of niches in the form of platform and crevices[23] probably might have played marked role in augmentation of diversity of coastal waters.

It is imperative from the data collected during the above period that sizable information coupled with reporting of new records has enabled to create a stronger database from this region. Hence, it appears mandatory that continuous monitoring of these coastal habitats needs to be carried out to generate a much better inventory in recent times.

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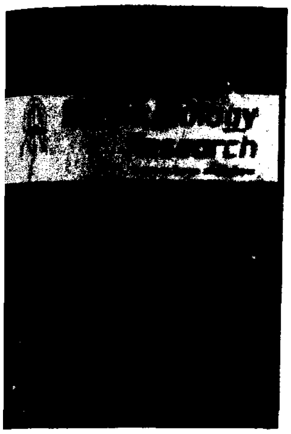

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Hexapus bidentatus sp. nov. (Crustacea: Decapoda: Brachyura: Hexapodidae), a new species from Goa, west coast of India

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ORIGINAL ARTICLE

Hexapus bidentatus sp. nov. (Crustacea: Decapoda: Brachyura: Hexapodidae), a new species from Goa, west coast of India

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Abstract
A new species of hexapodid crab, *Hexapus bidentatus* sp. nov. is described from Goa, west coast of India. The new species differs from its closest congener, *H. estuarinus* in possessing more slender chelipeds, two large basal teeth on the dactylus and two small basal teeth on the pollex of the larger cheliped, a smaller cheliped with more or less straight fingers with a triangular gap between them, and the tip of the gonopod (G1) with nine spines on the outer border. Additionally, an updated description of *H. estuarinus* based on an examination of the holotype and another specimen collected from Goa is provided. A comparative analysis of *H. sexpes*, *H. estuarinus* and the new species is made. A key to all the five valid species of the genus *Hexapus*, including the new species, is provided.

Key words: *Brachyura, Hexapodidae,* Hexapus, *new species, taxonomy*

Introduction

The near-shore waters (down to 25 m depth) off Goa, west coast of India support a wide array of demersal fauna (Ansari et al. 1995; Padate et al. 2010a, 2010b; Hegde & Rivonker 2013). Intensive bottom trawling surveys to assess the diversity and community structure of the demersal fauna from November 2010 to January 2013 revealed three specimens of hexapodid crabs that could not be identified to species level.

The family Hexapodidae (Miers, 1886) comprises crabs that are easily distinguished from other brachyuran families by their seven exposed sternites (instead of eight in other Brachyura) and a strongly reduced or vestigial last pair of pereiopods (P5) (Guinot et al. 2013). The other distinguishing characters include sub-parallel and similarly developed sternites 5–7, in contrast to an extremely reduced sternite 8, which is partially concealed under the carapace and partially under the abdomen, except for a small triangular portion visible dorsally (De Angeli et al. 2010; Guinot et al. 2013); sternite 4 laterally extended, forming a marked process on each side in extant as well as fossil hexapodids (Guinot 1979; Guinot et al. 2010). This family is represented by 21 species belonging to 13 genera (Ng et al. 2008).

A new species of hexapodid crab, *Hexapus bidentatus* sp. nov. is described here. In addition, an attempt is made to re-describe some of the salient morphological characters of its closest congener, *Hexapus estuarinus* Sankarankutty, 1975. Furthermore, the new species is compared with all the existing congeners and an identification key to all the five valid species of the genus *Hexapus*, including the new species, is provided.

Materials and methods

The following abbreviations are used: CL, carapace length; CW, extreme width of carapace; FOW, width of fronto-orbital margin of carapace; FW, width of frontal margin of carapace (Figure 1A); PD, depth of propodus of cheliped; PL, length of propodus of cheliped (Figure 1B); G1, male gonopod/first pleopod.

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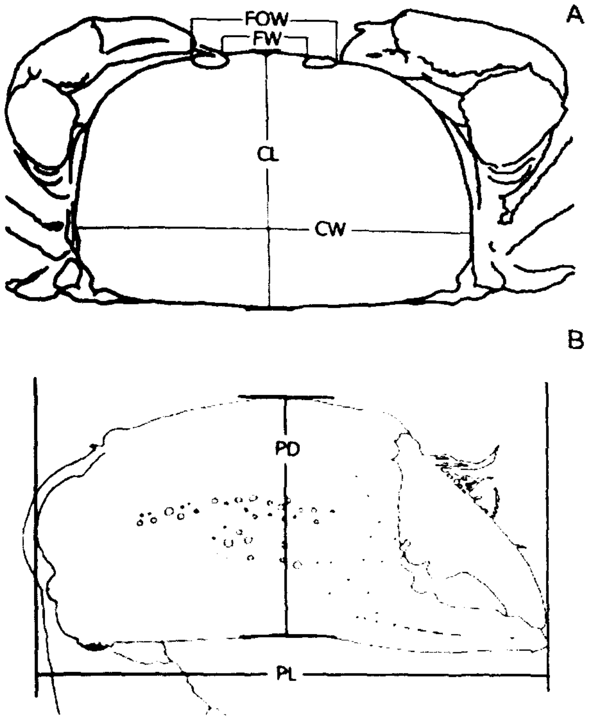

Figure 1. Morphometric measurements of (A) dorsal surface of carapace; (B) outer surface of cheliped.

Terminology used in the morphological description of the new species follows Manning & Holthuis (1981) and Sankarankutty (1975). In addition, terminology describing G1 follows Wee & Ng (1995).

Bottom trawlers operating trawl nets with mesh sizes of 15 mm (mouth end) and 9 mm (cod end) at 2 knots speed for a duration of up to 3 hours were employed to collect demersal faunal specimens from the near-shore fishing grounds (down to 25 m depth) off Goa, west coast of India between 15°27′41.8″N and 15°35′53.4″N latitudes and 73°38′10.5″E and 73°46′03.1″E longitudes (Figure 2). The sampling was carried out from November 2010 to January 2013. Demersal faunal specimens were picked out, temporarily preserved in ice and brought to the laboratory for detailed examination.

At the laboratory, morphological characteristics of the crabs were photographed with a stereo-zoom microscope (Olympus SZX-16). Morphometric parameters were measured using vernier calipers to an accuracy of 0.01 mm. In the case of chelipeds, the four distal segments (dactylus, propodus, carpus and merus) were measured separately. Subsequently, a detailed line diagram of the gonopod of the holotype male of the new species was drawn to ascertain the identity and distinctiveness of the species. Additionally, a line diagram of G1 of the other congeneric species was drawn to elucidate its structure. Further validation of the identity of *Hexapus estuarinus* was done by detailed examination of the chelipeds and G1 of its type specimens (Indian Museum Reg. no. 1263/2 and 1264/2).

Generic level identification was based on morphological characters described by Manning & Holthuis (1981). Morphological characters such as transverse sternal grooves of the sterno-abdominal cavities of males, frontal width of carapace, dentition on base of dactylus of the major cheliped and ornamentation on G1 were used as criteria to differentiate the new species from its congeners. The type specimens were stored in 5% buffered formalin (buffered with hexamethylene tetramine to prevent fragmenting of appendages) solution in pre-labelled transparent plastic bottles. These are deposited at the Marine Biology Laboratory, Department of Marine Sciences, Goa University, Goa (GUMSMB).

Comparative material examined

Hexapus estuarinus: Indian Museum reg. no. 1263/2, holotype: CL 7.60 mm, CW 11.00 mm, male, Thevara, Cochin, Southwest India, stake net collection; Indian Museum reg. no. 1264/2, paratype: CL 4.8 mm, CW 7.00 mm, male, same station data as holotype; GUMSMB 4, Male: CL 7.25 mm, CW 11.13 mm, off Goa, west coast of India, between 15°30′59.5″N, 73°43′26.7″E and 15°35′53.4″N, 73°40′46.6″E, depth 16–18 m, bottom trawl, 5 November 2012.

Taxonomy

Family Hexapodidae Miers, 1886
Genus *Hexapus* De Haan, 1833

Hexapus De Haan, 1833: 35. Type species *Cancer sexpes* (Fabricius, 1798).

Distribution

Indo-West Pacific regions to South Africa (Barnard 1947), Persian Gulf (Stephensen 1946), India (Fabricius 1798; Sankarankutty 1975; Manning 1982), Thailand (Rathbun 1909; Serène & Soh 1976), Indonesia (Tesch 1918).

Remarks

The genus *Hexapus* De Haan, 1835 contains four valid species, namely *Hexapus sexpes* (Fabricius, 1798), *H. anfractus* (Rathbun, 1909), *H. estuarinus* Sankarankutty, 1975 and *H. edwardsi* Serène & Soh, 1976. Ng et al. (2008) listed five species, including *Hexapus stebbingi* Barnard, 1947. However, this species was assigned to the genus *Tritoplax* due to the distinct trilobed form of the terminal segment of

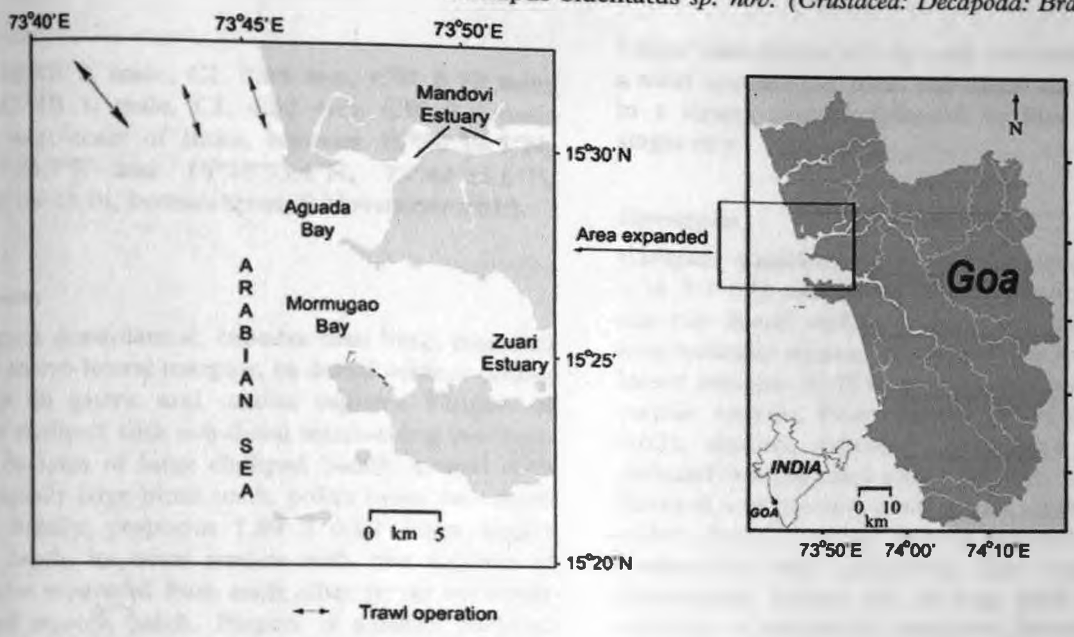

Figure 2. Map of the study area indicating the sampling sites.

the male abdomen (it is broadly rounded in *Hexapus*) (Manning & Holthuis 1981). Another species whose taxonomic status is ambiguous is *H. estuarinus*, which was described by Sankarankutty (1975). Manning & Holthuis (1981) suspected that *H. estuarinus* is a junior synonym of *H. sexpes*. Manning (1982) formally considered it as a junior synonym of *H. sexpes*. However, Ng et al. (2008) listed *H. estuarinus* as a valid species.

In addition to the extant species, there are four fossil species, namely *Hexapus decapodus* (Morris & Collins, 1991), *H. granuliformis* Karasawa & Kato, 2008, *H. nakajimai* Imaizumi, 1959 and *H. pinfoldi* Collins & Morris, 1978 (De Angeli et al. 2010), whereas *H. anfractus* has been reported as both fossil and extant (De Angeli et al. 2010).

Key to the species of genus *Hexapus* De Haan, 1833

1a. Transverse sternal sutures (3/4) extend forward almost to the base of third maxillipeds .... *H. anfractus*

1b. Transverse sternal grooves do not extend forward to the base of third maxillipeds 2

2a. FW approximately 0.50 times CL .... *H. edwardsi*

2b. FW approximately 0.25 times CL 3

3a. Fingers (dactylus and pollex) of major cheliped without distinct basal teeth; fingers of minor cheliped crossed, without gaping .... *H. sexpes*

3b. Fingers of major cheliped with distinct basal teeth; fingers of minor cheliped meet at the tips, with prominent gaping in between 4

4a. Cutting edge of dactylus of major cheliped with one large and one small basal tooth, pollex with one small basal tooth; fingers of minor cheliped curved and leave a rounded gaping in between them; G1 with six sub-distal, evenly spaced spines on outer border .... *H. estuarinus*

4b. Cutting edge of dactylus of major cheliped with two large basal teeth, pollex with two small basal teeth; fingers of minor cheliped more or less straight and leave a triangular gaping in between them; G1 with pair of spines on distal tip, giving it a bifid appearance, followed by three sub-distal spines in zigzag position and four more in a straight row on outer border .... *H. bidentatus* sp. nov.

Hexapus bidentatus sp. nov.

Holotype

GUMSMB 1, male, CL 6.12 mm, CW 9.54 mm, off Goa, west coast of India, between 15°32′52.8″ N, 73°44′26.8″E and 15°31′26.8″N, 73°44′44.1″ E, depth 9–10 m, bottom trawl, 10 February 2012.

Paratypes

GUMSMB 2, male, CL 5.65 mm, CW 8.72 mm; GUMSMB 3, male, CL 4.62 mm, CW 7.0 mm: Goa, west coast of India, between 15°30′59.5″N, 73°43′26.7″E and 15°35′53.4″N, 73°40′46.6″E, depth 16–18 m, bottom trawl, 5 November 2012.

Diagnosis

Carapace quadrilateral, broader than long, rounded off at antero-lateral margins; its dorsal surface pitted, except on gastric and cardiac regions. Fingers of major cheliped with sub-distal interlocking mechanism; dactylus of large cheliped basally armed with two equally large blunt teeth; pollex bears two small teeth basally; propodus 1.89 ± 0.07 times longer than depth, its outer surface with two patches of granules separated from each other by an upwardly curved smooth patch. Fingers of smaller cheliped have triangular gap in between, their cutting edges irregularly toothed; propodus 2.18 ± 0.10 times longer than depth. G1 tip with two spines, giving it a bifid appearance; three sub-distal spines arranged in a zigzag position followed by four spines in a single row.

Description

Carapace quadrilateral, broader than long (CW/CL = 1.54 ± 0.02), with pitted (except gastric and cardiac regions) dorsal surface (Figure 3A). Dorsal surface longitudinally convex, transversely flat with drooping lateral margins. Shallow grooves separate gastric and cardiac regions. Front narrow (FW/CW = 0.17 ± 0.02), bilobed, pubescent, granulated at margins, deflexed ventrally and pitted dorsally, with ventrally directed and tapering median part separating antennulary fossa of either side (a transverse septum). Antennules long, cylindrical, fold transversely in antennulary fossae; tuft of long hairs ventrally at junction of antennular segments. Antennular flagellum with tuft of four filaments distally. Antero-lateral margins of carapace rounded, granular and pubescent.

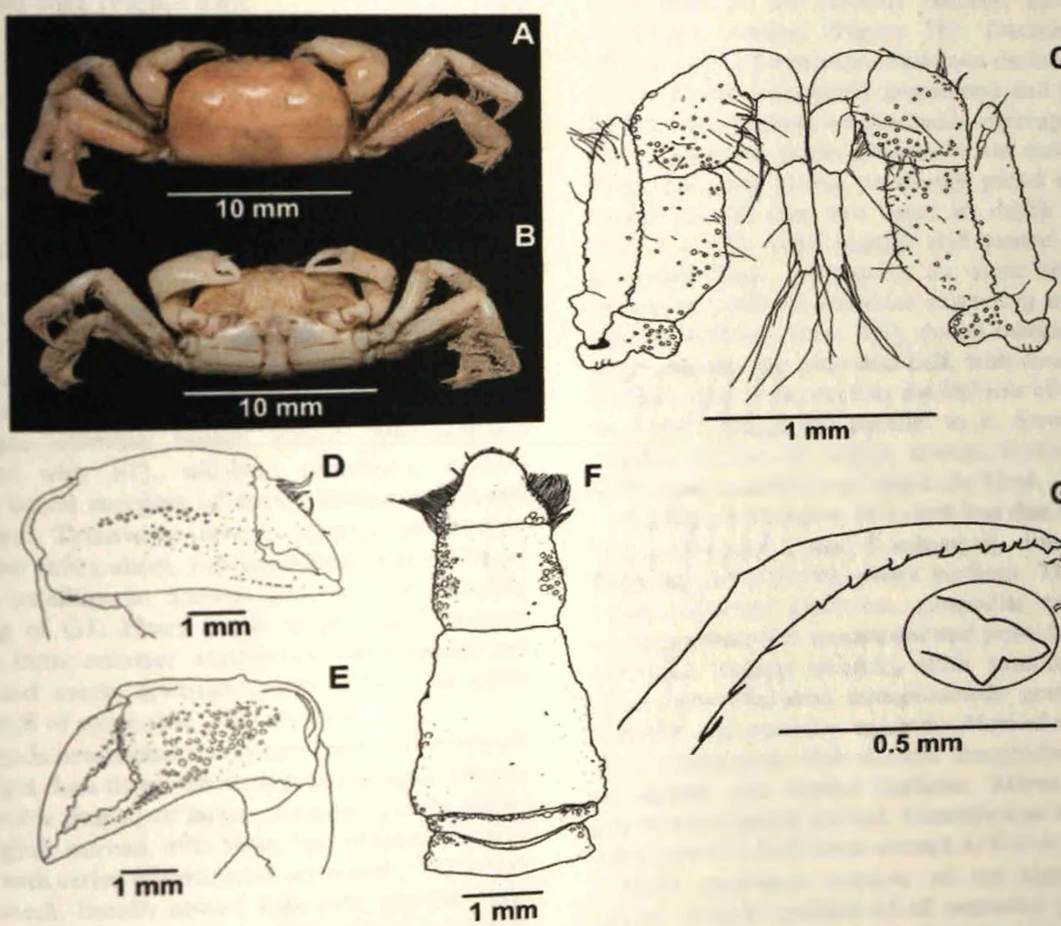

Figure 3. *Hexapus bidentatus* sp. nov. – (A) dorsal surface of carapace (photograph); (B) ventral surface of carapace (photograph); (C) third maxillipeds; (D) outer surface of major cheliped; (E) outer surface of minor cheliped; (F) abdomen of male; (G) tip of first pleopod or gonopod (G1); inset – tip of G1.

Postero-lateral margins of carapace with few granules, with distinct knob at postero-lateral angles. Posterior margin of carapace broad, more or less straight with slight median convexity.

Orbits partially open intero-ventrally, eyes globular; peduncle pubescent, granulated, as long as cornea. Basal antennal segment located within orbital hiatus. It is slightly in advance of frontal margin. Antennal peduncle of four segments; first two covered with setae; antennal flagellum long, 9-segmented.

Buccal cavern broader than long, wider posteriorly, antero-lateral angle rounded. Epistome fairly broad, with median projection into buccal cavern. Oblique fringe of long setae with granules traverses from outer side of base of buccal cavern across pterygostomian region. Patch of long oblique striae (stridulating apparatus) located antero-laterally to buccal cavern. Thick fringe of long hairs bordering inhalant branchial openings located anterior to base of chelipeds, upper row along lower margin of pterygostomian region, lower row on upper surface of cheliped coxa (Figure 3B).

Third maxillipeds slender, widely gaping, gap partially filled by palps (Figure 3C). Ischium 1.77 times longer than broad, with parallel sides, narrower than merus; inner surface serrated, pubescent. Merus roughly pentagonal, as long as broad; outer and inner margins serrated at mid-length, completely pubescent (pubescence longer along inner margin). Palp sub-equal to ischio-merus, cylindrical, covered with long setae. Dactylus digitate, as long as merus, longer than propodus, shorter than ischium. Exopod long, cylindrical, flagellate; flagellum distally pubescent; lateral margins highly serrated; outer margin with outwardly pointing stout spine at proximal end.

Thoracic sternum broad, pitted (S8 reduced compared with S7), trilobate anteriorly; sternal sutures, lateral margins of sterno-abdominal cavity granulated. Transverse sternal sutures of sterno-abdominal cavity short, not extending beyond bases of third maxillipeds. Sternal sutures (3/4) lodging distal tip of G1. Hairy patch of granules extends laterally from anterior margin of each transverse groove and meets granular patch at base of third maxillipeds of same side (Figure 3B).

Chelipeds heterochelous, heterodonts, their length slightly less than three times carapace length. Dactylus (movable finger) of larger cheliped glossy, thickened, slightly curved, with blunt tip; its inner surface marked with series of transverse striations; its cutting edge smooth, basally armed with two equally large blunt teeth; with basal fringe of long hairs on upper surface. Pollex slightly curved, thick, terminates with blunt tip, inner surface devoid of striations. It bears two small teeth basally. Shallow longitudinal groove on outer surface of pollex interrupted. Both fingers possess alternating sub-distal projections and recessions that form an interlocking mechanism. Fingers gaping at mid-length (Figure 3D). Propodus glossy, pitted, its length less than two times its depth (PL/PD = 1.89 ± 0.07); outer surface bears two patches of tubercles separated by upwardly curved smooth patch (Figure 3D); proximal hinge granular on outer surface; dorsal margin granular proximally, with row of seven granules followed by two teeth on a higher plane; another median row of five tubercles on inner surface lies parallel to it. Carpus glossy, pitted, granular on inner margin, granules on inner angle large, granules decrease in size anteriorly and posteriorly. Merus glossy, granulated on dorsal and ventral margins, with short pubescence on dorsal margin, inner surface with granulated ridges adjacent to ischial joint. Ischio-basis medially granulated on outer margin. Coxal margins granulated, pubescent.

Smaller cheliped less massive, fingers thin, slightly curved, with blunt tips and sub-distal interlocking mechanism. Fingers leave triangular gap in between from base to 3/4 distance distally, cutting edges irregularly toothed (Figure 3E). Dactylus marked with a series of transverse striations on inner surface, dorsal margin irregularly granulated and pubescent. Pollex with shallow, longitudinal, interrupted groove and a granular patch proximally on outer surface. Propodus with glossy, randomly pitted surface, its length greater than two times its depth (PL/PD = 2.18 ± 0.10); distal margin and ventral surface of proximal hinge granulated; its outer surface with triangular patch of tubercles extending anteriorly to base of pollex (Figure 3E); dorsal margin with 4–5 large granules on proximal half, with small granules in their interstices; another medial row of 6 tubercles on inner surface lies parallel to it. Structures and ornamentations of carpus, merus, ischio-basis and coxa similar to those of major cheliped.

Pereiopod 3 longest, its length less than three times CL; pereiopods 2 and 4 sub-equal, dorso-ventrally flattened, with pitted, glossy surfaces. Three distal-most segments (dactylus, propodus and carpus) densely pubescent on anterior and posterior margins. Dactylus acutely pointed, with smooth margins, other two segments conspicuously granulated on anterior and posterior margins. Meri of second and third pereiopods with shallow longitudinal grooves on dorsal and ventral surfaces. Merus of fourth pereiopod slightly curved. Granulations and pubescence grow denser from second to fourth pereiopod.

Male abdomen narrow, of six segments and telson. Lateral margins of all segments granulated. First segment shorter and narrower than second. Segments 3–5 fused, each segment distinguished by narrowing of lateral margins at distal end. Surface of fused segments pitted. Sixth segment as long as broad, with slightly bulging lateral margins; its surface slightly pitted, semi-circular patches of granules on lateral margins. Seventh or distal-most segment pyriform, with pubescent margins. Lateral bulges with tufts of long hair cover lateral extensions of sterno-abdominal cavity (Figure 3F).

G1 placed sterno-abdominally, bent outwards, tapers distally, with two lateral bends, proximal one at mid-length, second at four-fifths distance from its base; inner border flared at distal, bent portion. Long hairs cover G1 from base to distal bend, denser at proximal bend (Figure 3G). Ornamentation comprises two distal and seven sub-distal spines on outer border. Distal two spines give tip bifid appearance. Sub-distal spines arranged as three spines in zigzag arrangement followed by four in single row (Figure 3G).

Colour

Carapace of fresh specimens light greyish brown dorsally, pearly white ventrally. Dactyli and propodi of chelipeds, all pereiopodal (2–4) segments off-white; carpi and meri of chelipeds light brown. Formalin-preserved specimens appear light brown (Figure 3A).

Distribution

Hexapus bidentatus is currently known only from the type locality Goa, west coast of India.

Etymology

The species name, *Hexapus bidentatus* is derived from the two equally large basal teeth ('bi' is the Latin prefix for two and 'dentatus' is the Latin word for toothed) of the dactylus of the major cheliped, a character unique to this species.

Comparison with congeneric species

Hexapus bidentatus sp. nov. differs from *Hexapus anfractus* in having shorter transverse sternal grooves in the male that do not extend forward to the bases of third maxillipeds. The new species differs from *Hexapus edwardsi* in having a narrower frontal margin of the carapace, which is less than 0.25 times CL.

Hexapus bidentatus sp. nov. is morphologically more similar to *Hexapus estuarinus* and *Hexapus sexpes* in the narrow frontal margin of the carapace (Table I). Furthermore, both *H. bidentatus* and *H. estuarinus* possess 'basal teeth on dactylus and pollex of major cheliped', as compared with the lack of teeth in *H. sexpes*. Another morphological character that deserves mention is the gaping of the fingers of the minor cheliped. The re-description of *H. sexpes* by Manning (1982) states: 'Minor chelipeds with fingers not gaping'. The illustration of *H. sexpes* (Manning 1982: Fig. 1D, minor chela, page 158) also indicates crossed fingers. In contrast, fingers of the minor cheliped of both *H. bidentatus* and *H. estuarinus* meet at the tips, with a conspicuous gap in between them. Other differences include 'absence of tubercles on sternum' and 'presence of basal setae on fixed finger of major cheliped' in *H. sexpes*, as compared with 'sternal sutures tuberculate' and 'absence of basal setae on fixed finger of major cheliped' in *H. bidentatus* sp. nov. and *H. estuarinus*.

Further morphological comparison between *H. bidentatus* sp. nov. and *H. estuarinus* revealed the following differences:

(1) *Hexapus bidentatus* sp. nov. possesses 'two equally large basal teeth on cutting edge of dactylus' and 'two small basal teeth on cutting edge of pollex' of the major cheliped, as compared with 'one large and one small basal tooth' on the dactylus and 'one small basal tooth' on the pollex of *H. estuarinus* (Table I).

(2) Ornamentation on the distal portion of G1 in *H. bidentatus* sp. nov. comprises a pair of spines at the distal tip, giving it a bifid appearance, followed by three spines in a zigzag arrangement and four more in a straight row. On the other hand, ornamentation on the G1 of *H. estuarinus* comprises six evenly spaced, sub-distal spines on the outer border (Table I).

Hexapus estuarinus Sankarankutty, 1975

Hexapus estuarinus Sankarankutty, 1975: 1–6, figures 1–2 (type locality: Thevara, Cochin, southwest India).

Diagnosis

Carapace quadrilateral, broader than long, rounded off at antero-lateral margins (Figure 4A). Antennules fold transversely. Basal antennal segment short, not extending beyond level of frontal margin. Margins of thoracic sternites tuberculated. Dactyl of major cheliped with one large basal tooth followed by smaller tooth; pollex with one small basal tooth; sub-distal interlocking mechanism on fingers; propodus 1.63 ± 0.05 times longer than depth, outer surface bears randomly scattered tubercles. Fingers of minor cheliped with random irregular teeth on cutting edges; propodus 1.99 ± 0.02 times longer than depth. Dactyli of both chelipeds with single series of transverse striations traversing their entire

Table I. Comparative analysis of morphometric characteristics of three closely related congeners, namely *Hexapus bidentatus* sp. nov., *Hexapus estuarinus* and *Hexapus sexpes*.

Morphological character	*Hexapus bidentatus* sp. nov. (n = 3)	*Hexapus estuarinus* (n = 3)	*Hexapus sexpes*[a]
CW/CL	1.54 ± 0.02	1.48 ± 0.05[b]	1.53[c]
FW/CW	0.17 ± 0.02	0.21 ± 0.03[b]	0.20[c]
PL/PD (Major cheliped or pereiopod 1)	1.89 ± 0.07	1.63 ± 0.05[b]	NA
PL/PD (Minor cheliped or pereiopod 1)	2.18 ± 0.10	1.99 ± 0.02[b]	NA
Basal antennal segment	Long, extends slightly ahead of frontal margin	Short, does not extend beyond level of frontal margin	NA
Sternum (male)	Surface smooth, sternal sutures tuberculate	Surface smooth, sternal sutures tuberculate	Surface smooth, non-tuberculate
Ornamentation on inner surfaces of dactyli of both chelipeds	Single series of transverse striations along entire length of dactyli	Single series of transverse striations along entire length of dactyli	NA
Basal setae on pollex of major cheliped	Absent	Absent	Present
Dentition on cutting edge of fingers of major cheliped	Both fingers smooth along cutting edges; dactylus with two large basal teeth, pollex with two small basal teeth	Both fingers smooth along cutting edges; dactylus with one large and one small basal tooth, pollex with one small basal tooth	Both fingers toothed, both lack large basal teeth
Dentition on cutting edge of fingers of minor cheliped	Alternate large and small teeth along entire cutting edge	Randomly placed irregular teeth along entire cutting edge	Teeth present
Sub-distal interlocking mechanism on fingers of major cheliped	Present	Present	NA
Form of fingers and gaping in minor cheliped	Fingers more or less straight, not crossing, with triangular gaping between them	Fingers distinctly curved, not crossing, with rounded gaping between them	Fingers curved, crossed, not gaping
Ornamentation on outer surface of propodus of major cheliped	Two patches of tubercles separated by a upwardly curved smooth patch	Randomly scattered tubercles	Granules separated by smooth area
Ornamentation on outer surface of propodus of minor cheliped	Elongated triangular patch of granules on lower half of propodus	Elongated triangular patch of granules on lower half of propodus	Granulated areas separated by smooth area
Dactyli of pereiopods 2–4	Pubescent, length of dactyli of pereiopods 2 and 3 shorter than propodal length, those of pereiopod 4 equal to propodal length	Pubescent, length of dactyli of pereiopods 2 and 3 shorter than propodal length, those of pereiopod 4 equal to propodal length	Naked, their length equal to propodal length
Meri of pereiopods 2–4	Tuberculate and setose on both anterior and posterior margins; dorsal surfaces of meri of pereiopods 2 and 3 pubescent, those of pereiopod 4 naked	Tuberculate and setose on both anterior and posterior margins; dorsal surfaces of meri of pereiopods 2 and 3 pubescent, those of pereiopod 4 naked	Tuberculate dorsally, setose ventrally
G1 shape	Two lateral bends, the proximal one at mid-length, second at four-fifths distance from base; inner border flared at distal bend	Two lateral bends, the proximal one at mid-length, second at four-fifths distance from base; inner border flared at distal bend	Bent laterally near mid-length?
Pubescence on G1	Long hairs cover G1 from base to distal bend, denser at proximal bend	Long hairs cover G1 from base to distal bend, denser at proximal bend	NA
Distal spines on tip of G1	Two distal spines present on tip of G1, giving it a bifid appearance	Absent	NA
Sub-distal spines on tip of G1	Seven sub-distal spines arranged as three in zigzag position followed by single row of four on outer border	Six evenly spaced, sub-distal spines on outer border	

NA, data not available.
[a]Data derived from Manning (1982).
[b]Data obtained from Indian Museum type specimens (2) and Goan specimen.
[c]Ratios derived from values provided by Manning (1982).

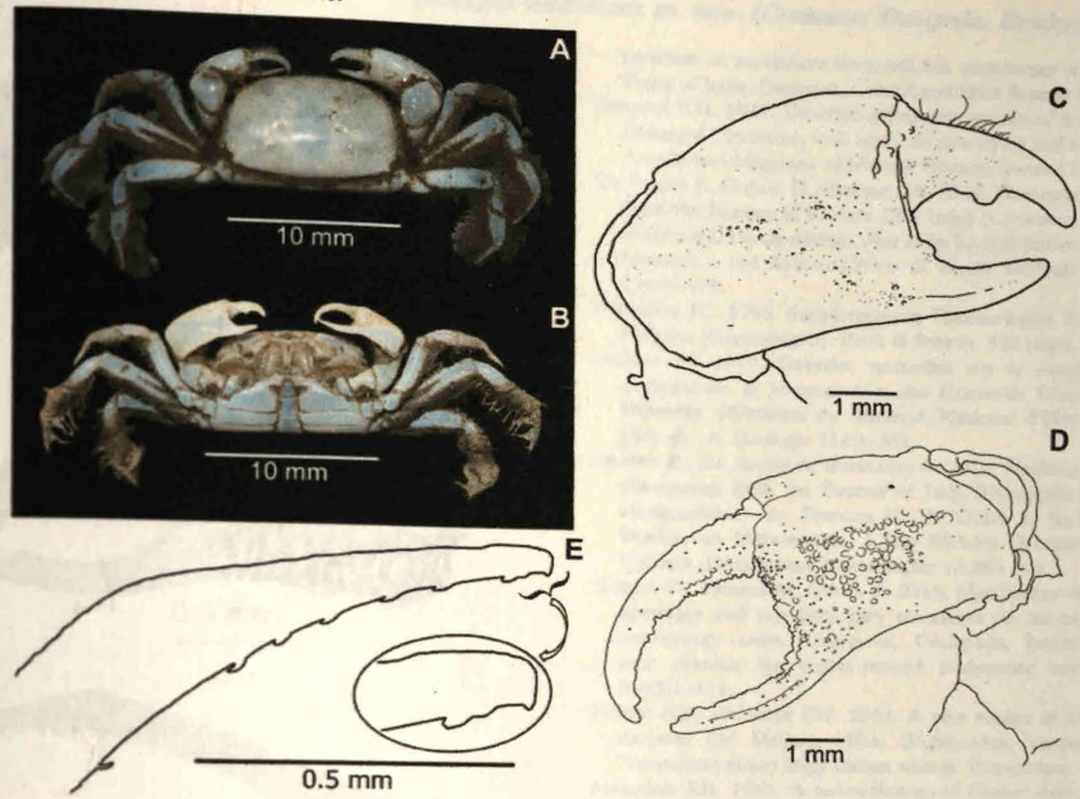

Figure 4. *Hexapus estuarinus* – (A) dorsal surface of carapace (photograph); (B) ventral surface of carapace (photograph); (C) outer surface of major cheliped; (D) outer surface of minor cheliped; (E) tip of first pleopod or gonopod (G1); inset – tip of G1.

length on inner surface. G1 bent proximally at mid-length and distally at 4/5 distance from base, inner border flared at distal bend; long hairs cover G1 from base to distal bend, denser at proximal bend; distal tip lacks spines, sub-distal ornamentation consists of six evenly spaced, sub-distal spines on outer border.

Some of the additional salient morphological characters mentioned above (based on Goan specimen and re-examination of the type specimens deposited at the Indian Museum (Figure 5A–C)), that were not included in the original description (Sankarankutty 1975), are as follows:

(1) Antennules fold transversely.
(2) Basal antennal segment short, not extending beyond level of frontal margin.
(3) Margins of thoracic sternites tuberculated (Figure 4B).
(4) Single series of transverse striations on inner surface along entire length of cheliped dactyli.
(5) Few randomly scattered tubercles on outer surface of propodus of major cheliped (Figure 4C).
(6) G1 with six sub-distal, evenly spaced spines on outer border (Figure 4E, 5C).

Taxonomic status

Manning (1982) believed that *Hexapus estuarinus* was a junior synonym of *Hexapus sexpes* based on 'chelae are unequal' and 'second leg is the longest of the walking legs'. However, the present study has demonstrated that *H. estuarinus* differs from *H. sexpes* in the presence of basal teeth on the cutting edge of the dactylus and pollex of the major cheliped (Figure 4C, 5A) and the prominent rounded gap between the fingers of the smaller cheliped (Figure 4D, 5B). Other differences include the presence of tubercles on the sternal sutures and the absence of basal setae on the fixed finger of the major cheliped. These differences warrant the recognition of *H. estuarinus* as a separate species.

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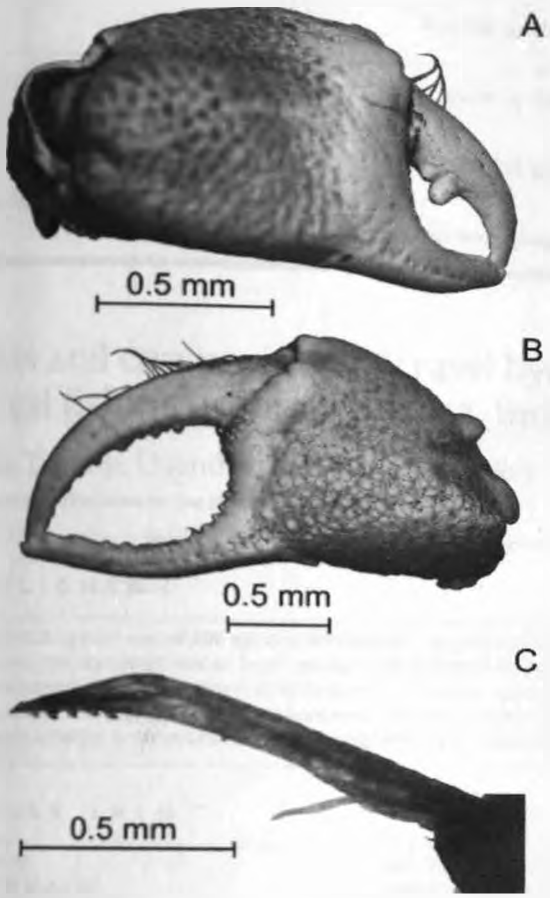

Figure 5. *Hexapus estuarinus* (holotype) – (A) outer surface of major cheliped (photograph); (B) outer surface of minor cheliped (photograph); (C) first pleopod or gonopod (G1) (photograph).

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Trends and composition of trawl bycatch and its implications on tropical fishing grounds off Goa, India

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HIGHLIGHTS

- 174 bycatch species out of 196 species account for significantly high biomass (68%).
- Discarded species comprised of trash species and juveniles of target species (89%).
- Species assemblages determined by recruitment patterns and ecological relationships.
- Temperature and salinity influenced seasonal trends of species abundance.
- Strong correlation between total catch and bycatch; bycatch and discarded.

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ABSTRACT

Trawl bycatch is a globally recognized issue with intensified effects in tropical waters affecting both the ecosystem function and biodiversity, as well as causing physical damage and habitat loss. The present study envisages temporal variations of bycatch with regard to the species and their biological interactions based on data obtained from commercial single-day bottom trawlers operating off Goa, west coast of India. The data revealed that bycatch constituted about 68% of the trawl catch, the remaining being target species (shrimp, flat fishes, sciaenids, squids and crabs). Approximately 89% of the species discarded into the sea comprised of juveniles of target and trash species, suggesting a major share of non-target species, leading to species loss. Out of 196 taxa observed in the trawl catch, 174 constituted bycatch with a significantly high percentage of biomass. Abundance of discarded bycatch species (crustaceans, echinoderms, teleosts) displayed distinct peaks during pre-monsoon whereas molluscs, crustaceans and teleosts dominated during post-monsoon. A conspicuous increase in abundance of molluscs during post-monsoon (October, 2012) and echinoderms during pre-monsoon (April, 2011 and April, 2013) is largely attributed to the recruitment process. Cluster analysis identified different clusters during pre-monsoon and post-monsoon season corresponding to their recruitment patterns and diverse species assemblages. Principal Component Analysis performed using three environmental parameters accounted for 84% (five components) and 86% (four components) of variance during pre-monsoon and post-monsoon, respectively. Regression analysis indicated a significant linear relationship between total catch and bycatch ($R^2 = 0.89$), and between bycatch and discarded catch ($R^2 = 0.94$).

1. Introduction

The exploitation of coastal demersal resources by trawl gear has led to indiscriminate removal of target as well as non-target species, affecting diversity (Davies et al., 2009; Thurston and Roberts, 2010). One of the most adverse problems faced is associated with shrimp bycatch (Clucas, 1997) affecting rare and endangered species (Wallace, 1996), habitat through hypoxia (Naqvi et al., 2010) and food web through trophic displacement (Murawski, 1995). Published literature (Bijukumar and Deepthi, 2006; Davies et al., 2009) suggests that the bycatch is perceived contrarily in different parts of the world, and varies according to geographical region, fishing depth and fishing gear. This problem is more severe in tropical coastal waters where the shrimp trawlers arbitrarily target diverse faunal assemblages and eventually destroy vital benthic habitats (Rao et al., 2013).

Although it is well-accepted that bycatch is an unavoidable component of trawl net, increased utilization for economic purposes has led to reduction in discarded bycatch (Dineshbabu et al., 2013). The issue of discarded bycatch is particularly severe along

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the Indian coastal region due to multispecies fishery. Species composition of multispecies fishery trawl catch suggests that the enormity of bycatch resulting from such fishing operations is inevitable, causing loss of species and physical damage to the ecosystem (Bijukumar and Deepthi, 2006; Gibinkumar et al., 2012).

The concept of bycatch that has been put forth in the present paper, and the terminology used, follow Alverson et al. (1994), with minor modifications in view of species composition and its utilization from this region. The "Target catch" refers to the catch of a species or species assemblage that is primarily sought in a fishery (shrimp, soles, sciaenids, squids and crabs); "Incidental Catch" or "Commercial Bycatch"—Retained catch of non-target species; "Discarded bycatch" or "Trash fishes" is that portion of the catch that is returned to the sea as a result of economic, legal, or personal considerations; "Bycatch" or "Non-target catch" is the incidental, plus discarded catch.

In view of the above, the present study attempts to envisage seasonal changes in bycatch composition and species associations in respect of its application along the coast of Goa. Further, the occurrence of different groups of associated benthic fauna at different times has been assessed and discussed. The study also involves the assessment of species specific response to environmental parameters and the status of utility of bycatch along Goa coast.

2. Materials and methods

2.1. Study area

Goa, with a coastline of about 105 km along NW–SE (Lat: 14°53′54″N–15°48′00″N, Long: 73°40′33″E–74°20′13″E), facing the Arabian Sea, supports diversified ecological features and forms an integral part of the central west coast of India. It has a continental shelf of about 1 million hectares and active fishing area of 20,000 km^2 (Subramanian et al., 2014). The proposed study area (Fig. 1) covers the potential fishing grounds along the near-shore shelf waters off Goa coast. The near-shore waters are characterized by the presence of patchy reefs, submerged rocks, sandy silt substratum and an artificial habitat created by the sunken ship 'River Princess' (Ingole et al., 2006). The coastal waters are influenced by riverine discharge from the adjacent mangrove-fringed Mandovi–Zuari estuarine complex (Ansari et al., 1995).

2.2. Sampling

Sampling consisted of 100 trawl hauls on-board a 15 m long commercial shrimp trawler during day-time at fortnightly intervals. The sampling period extended from November 2010 to May 2013 with an exception of the monsoonal ban during June to September. Geographical position of sampling stations was recorded with 12-channel GPS and the corresponding depth was obtained from Naval Hydrographic Chart no. 2022. A trawl net with 20 m head and foot rope lengths and mesh sizes of 25 mm at mouth, 15 mm in the middle and 9 mm at cod end was towed at a speed of about 2–3 knots. Once the haul was taken on board, five random sub-samples of approximately 1 kg each were collected prior to sorting to assess total species composition. Subsequently, trash fauna were also sub-sampled after sorting. Quantitative assessment i.e. weight measurements of different target and commercial bycatch faunal groups and discarded bycatch (trash fauna) was done on-board the fishing trawler. All the samples were temporarily preserved in ice and brought to the laboratory. In the laboratory the abundance of representative species was quantified after sorting and identifying the mixed catch. The length of discarded species was obtained from discarded by-catch samples.

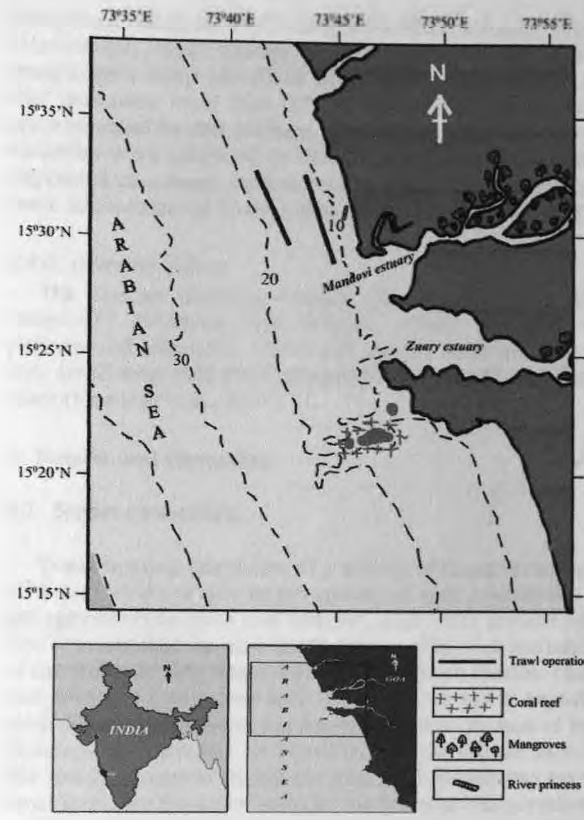

Fig. 1. Map showing study area.

In addition to these, water samples were collected to study environmental parameters (temperature, dissolved oxygen (D.O.) and salinity) at the start of trawl haul. The temperature was recorded on-board using mercury thermometer. Water samples for salinity were collected in 200 ml plastic bottles, and those for D.O. in 125 ml borosil glass stoppered bottles. Water samples for D.O. estimation were fixed on-board using Winkler's reagent and brought to the laboratory. In laboratory, salinity was estimated using Mohr–Knudsen titration method and D.O. using Winkler's method (Strickland and Parsons, 1968).

2.3. Species identification

Fauna were identified using conventional taxonomic methods involving phenotypic analysis and morphological measurements to the lowest possible taxonomic level aided by published taxonomic literature (Chhapgar, 1957; Froese and Pauly, 2014).

2.4. Data analysis

The total trawl catch was segregated into 'target' and 'bycatch' based on economic use. Further, the bycatch was grouped as 'commercial' and 'discarded'. The discarded bycatch comprised mainly of juveniles of target species and a majority of non-edible fishes.

2.4.1. Species abundance

Abundance data of discarded bycatch species from five sub-samples of each trawl haul was standardized to per hour (number h^{-1}). Subsequently, standardized abundance data obtained from two fortnightly surveys was averaged to obtain

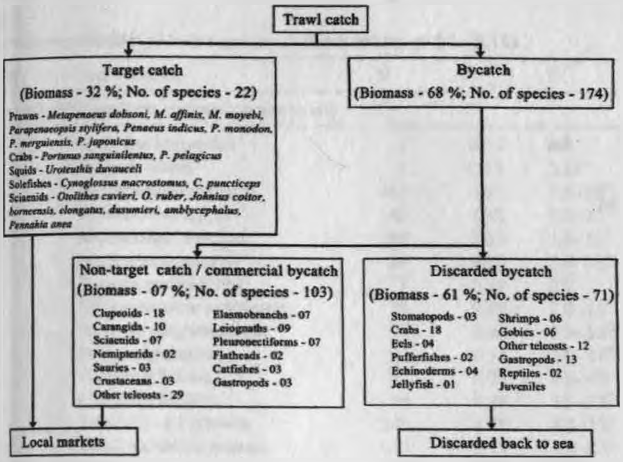

Fig. 2. Flow chart showing different sections of trawl catch based on its utility along with species composition.

monthly abundance data. Abundance and corresponding percentage of each bycatch species was extrapolated from monthly abundance data for the entire study period and the abundance of major faunal groups (crustaceans, teleosts, molluscs and echinoderms) was determined.

2.4.2. *Biomass (weight)*

Biomass of trawl catch was assessed by dividing the entire study period into six seasons, namely Post-monsoon 2010 (Oct–Jan; PostM 10); Pre-monsoon 2011 (Feb–May; PreM 11); Post-monsoon 2011 (PostM 11); Pre-monsoon 2012 (PreM 12); Post-monsoon 2012 (PostM 12) and Pre-monsoon 2013 (PreM 13). Once the trawl haul was fully sorted out into different faunal groups based on economic value, weight of each group was recorded and categorized as target catch commercial bycatch and discarded bycatch. The weight data was standardized to per hour (weight h^{-1}) and then averaged to obtain monthly weight data. Subsequently, the monthly average weight data was converted to percentages to evaluate the seasonal variations in target catch, commercial bycatch and discarded bycatch.

2.4.3. *Regression analysis*

Regression analysis was performed using standardized monthly weight data to evaluate the correlation between total catch, target catch, commercial bycatch and discarded bycatch.

2.4.4. *Cluster analysis*

The entire duration of study was divided into two seasons i.e. pre-monsoon (February–May) and post-monsoon (October–January) and taxa (those which contributed more than 0.5% to a monthly aggregate abundance) data were selected for cluster analysis. Abundance data were normalized using the square root transformation function, converted into a lower triangular matrix using the Bray–Curtis Similarity Coefficient (Bray and Curtis, 1957) and dendrogram plots were constructed using the group average function Plymouth Routines In Multivariate Ecological Research (PRIMER) v.6 computer program (Clarke and Gorley, 2006). The significance of the cluster groups ($p < 0.05$) was tested by similarity profile (SIMPROF) analysis. Abbreviations used to represent species are given in the Appendix.

2.4.5. *Principle Component Analysis (PCA)*

Relationships between species abundance and environmental parameters (seasonal) was analysed by correlation-based Principle Component Analysis (PCA) using STATISTICA software version 12 (StatSoft Inc, 2014). Species representing significant to principle components were identified according to PCA scores. Species that contained more than 0.5% of discarded bycatch abundance were selected for this analysis. Additionally, three environmental variables were subjected to PCA to extract the components that explained maximum environmental variation. The components were selected based on the value of eigen vector ($> \pm 0.70$).

2.4.6. *Diversity indices*

The species diversity indices (Shannon–Weiner's diversity index—H′) (Shannon and Wiener, 1963); Margalef species richness—SR (Margalef, 1968) and species dominance—D (Simpson, 1949) were calculated using PAST version 2.07 statistical software (Hammer et al., 2001).

3. Results and discussion

3.1. *Species composition*

Trawl bycatch comprises of a variety of fauna including juveniles and adults of non-target species as well as juveniles of target species (Bijukumar and Deepthi, 2006). The present observation revealed that the non-target species of bycatch included some of the commercially important as well as trash species. The use of non-selective fishing gear with reduced mesh size to exploit demersal fish in recent times has led to excessive amount of bycatch. Although the mortality on-board may not be instant, 80%–90% of the mortality occurs during the course of sorting and eventually dead fauna are discarded into the sea (personal observation).

The present investigation on the catch composition of shrimp trawl revealed that 89% of the catch formed bycatch (174 species) as compared to only 11% (22 species) target species (shrimps, soles, crabs, squids and sciaenids) (Fig. 2). Among the bycatch species, 36% (71 species) were always discarded into the sea irrespective of size, owing to lack of commercial value or non-edibility. The remaining 53% (103 species) were brought to landing sites depending on their large size (Fig. 2). In view of the above, the bycatch was categorized as commercial bycatch (elasmobranchs (07 species), teleosts (90), crustaceans (03) and molluscs (03)) and discarded bycatch (teleosts (24 species), crustaceans (27), molluscs (13), echinoderms (04), reptiles (02) and cnidarian (01)) (Fig. 2). Among the discarded bycatch, most abundant species were *Astropecten indicus* (12.30%), *Miyakella nepa* (11.94%), *Temnopleurus toreumaticus* (8.34%) and Bivalves—*Anadara* spp. (7.64%; Table 1).

3.2. *Seasonal trends of abundance*

Astropecten indicus was found to be abundant from December to May coinciding with higher abundance of gastropod and bivalve. Published literature (Loh and Todd, 2011) suggests that *A. indicus* is a generalist carnivorous feeder that preys upon gastropods and bivalves under continuous submergence in a sub-tidal ecotope. Much of the trawling activity is carried out at a depth beyond 15–20 m where the conditions are favourable for predation of prey exposed due to trawling (gastropods/bivalves) resulting in high abundance (Chícharo et al., 2002). The lack of information on abundance pattern, spawning and reproduction of starfish from this region is one of the constraints to elucidate its impact on the ecosystem function.

Miyakella nepa was observed in high abundance throughout the fishing season (October to May). This species is known to spawn in nearshore waters from December to October, with peak during February to April and September to October (Sukumaran, 1987).

Table 1
Percentage contribution of major species in discarded bycatch (>0.1%).

Sr. No.	Species name	N	%	TL*	Sr. No.	Species name	N	%	TL*
Economically important species (commercial)									
1.	*Scoliodon laticaudus*	4	0.12	4.0[b]	26.	*Grammoplites scaber*	6	0.17	3.8[a]
2.	*Dasyatis walga*	5	0.15	3.58[b]	27.	*Epinephelus diacanthus*	32	0.96	3.8[a]
3.	*Parapeneopsis stylifera*	264	8.02	2.0–2.5[b]	28.	*Terapon theraps*	10	0.30	3.49[e]
4.	*Metapenaeus affinis*	48	1.45	2.0–2.5[b]	29.	*Teraopn puta*	4	0.12	3.12[e]
5.	*Metapenaeus dobsoni*	94	2.85	2.0–2.5[b]	30.	*Lactarius lactarius*	46	1.39	4.0[a]
6.	*Metapenaeus moyebi*	10	0.29	2.0–2.5[b]	31.	*Leiognathus brevirostris*	5	0.14	2.96[e]
7.	*Penaeus semisulcatus*	7	0.21	2.0[f]	32.	*Photopectoralis bindus*	21	0.62	2.5[a]
8.	*Exhippolysmata ensirostris*	16	0.49	2.0–2.5[b]	33.	*Eubleekeria splendens*	72	2.20	2.9[a]
9.	*Portunus sanguinolentus*	32	0.96	2.5–3.0[b]	34.	*Secutor ruconius*	7	0.21	3.4[a]
10.	*Portunus pelagicus*	11	0.34	2.5–3.0[b]	35.	*Pennahia anea*	5	0.15	3.99[e]
11.	*Charybdis feriata*	31	0.93	2.5–3.0[b]	36.	*Otolithes cuvieri*	17	0.50	3.87[e]
12.	*Charybdis lucifera*	19	0.59	2.5–3.0[b]	37.	*Otolithes ruber*	13	0.40	3.60[e]
13.	Small un. red prawns	245	7.46	2.0–2.5[b]	38.	*Johnius borneensis*	49	1.50	3.69[e]
14.	Small un. white prawns	13	0.40	2.0–2.5[b]	39.	*Johnius dussumieri*	6	0.18	4.09[e]
15.	Mysis	28	0.84	2.0[b]	40.	*Johnius coitor*	5	0.15	3.3[a]
16.	*Sardinella longiceps*	13	0.39	2.5[b]	41.	*Trichiurus lepturus*	57	1.73	4.4[a]
17.	*Ilisha sirishai*	4	0.12	2.5–3.0[a]	42.	*Nemipterus japonicus*	13	0.40	3.8[a]
18.	*Opisthopterus tardoore*	125	3.81	3.4[a]	43.	*Pomadasys maculatus*	5	0.15	4.04[a]
19.	*Stolephorus commersonnii*	32	0.97	3.05[c]	44.	*Solea ovata*	5	0.15	3.5[a]
20.	*Thryssa mystax*	28	0.84	3.6[a]	45.	*Cynoglossus macrostomus*	35	1.05	3.28[a]
21.	*Thryssa dussumieri*	24	0.73	2.82[e]	46.	*Cynoglossus puncticeps*	4	0.12	3.3[a]
22.	*Thryssa setirostris*	9	0.27	3.3[a]	47.	*Ambassis gymnocephalous*	23	0.69	3.91[e]
23.	*Thryssa purava*	6	0.18	3.55[e]	48.	*Apogon fasciatus*	6	0.18	3.5[a]
24.	*Arius maculatus*	38	1.17	3.36[c]	49.	*Uroteuthis duvauceli*	27	0.84	3.7[b]
25.	*Bregmaceros mcclellandi*	6	0.17	3.3[a]	50.	*Sepiella inermis*	24	0.73	3.83[f]
(Non-commercial)									
1.	*Miyakella nepa*	393	11.9	3.10[c]	11.	*Lagocephalus spadiceus*	68	2.07	3.5–4[b]
2.	*Charybdis variegata*	4	0.11	2.7[b]	12.	*Gyrenium natator*	9	0.26	2.5[b]
3.	*Charybdis vadorum*	60	1.82	2.7[b]	13.	*Teritella* sp.	24	0.44	2.5[b]
4.	*Philyra globosa*	5	0.14	2.7[b]	14.	Other gastropods	61	2.17	2.5[b]
5.	*Doclea gracilipes*	9	0.27	2.7[b]	15.	*Antalis* spp	9	0.27	2.5[b]
6.	*Diogenes miles*	8	0.24	2.7[b]	16.	Bivalve	251	7.64	2.0[d]
7.	*Trypauchen vagina*	5	0.14	3.5[a]	17.	*Temnopleurus toreumaticus*	274	8.34	2.2[d]
8.	*Muraenesox cinereus*	20	0.61	4.0[a]	18.	*Astropecten indicus*	404	12.30	2.5[d]
9.	*Yongeichthys criniger*	5	0.15	3.36[a]	19.	Sea cucumber	7	0.21	2.3[d]
10.	*Parachaeturichthys polynema*	5	0.16	3.1[a]					

* TL–Total length.
[a] BijuKumar and Deepthi (2009).
[b] Vivekanandan et al. (2009).
[c] Bhathal and Pauly (2008).
[d] Okey et al. (2004).
[e] Froese and Pauly (2014).
[f] Sealifebase; 2014.

The continuous occurrence of *M. nepa* in trawl discards suggested intermittent recruitment and reduced level of predation (Antony and Madhsoodana, 2010; Antony et al., 2010). Further, the present set of data and published reports from this region (Hegde et al., 2014) reveal a marginal reduction in the abundance of potential predators (elasmobranchs and cephalopods) due to overfishing and unselective removal by trawl gear. On the other hand, the stomatopod population (*Miyakella nepa*, *Harpiosquilla raphidea* and *Lysiosquilla tredecimdentata*) is quite diverse and known to feed at different trophic levels (Antony et al., 2010) which probably favour enhanced abundance and continuous occurrence.

Temnopleurus toreumaticus was observed to be abundant during April and May. Similar observations have also been made by Hegde and Rivonker (2013) along south Goa coast. Sea urchins are known to spawn from spring to early summer (Rahman et al., 2014) and the differences in their density is primarily caused due to variance in recruitment (Hereu et al., 2012). Sea urchin abundance is also determined by upwelling, water temperature, sedimentation, wave action, floods and harvesting (Andrew et al., 2002; Walker, 2007). However, no published literature exists on echinoid reproduction from Indian waters. The increased abundance of sea urchins during pre-monsoon may be related to the spawning activity and recruitment as evidenced by the occurrence of juvenile urchins (0.5–2.0 cm test diameter). Spawning may be enhanced by higher water temperatures during summer months as reduced temperature is known to affect spawning activity (Barnes et al., 2002). Further, due to intensive fishing, reduced fish abundance might also facilitate their survival and proliferation (Hereu et al., 2012).

The bivalves (*Anadara* spp.) were found in greater abundance in October and November, 2012. The period coincided with active spawning (August to December and May to July) for these species (Suwanjarat et al., 2009). Recruitment of a large number of juveniles, as evident from the sample size (shell height: 0.5–1.5 cm), coupled with high phytoplankton biomass in the coastal waters (Gosling, 2003) might have supported the increased abundance of bivalves in this region.

In addition to the above, juveniles of a few target species such as prawns, crabs, squids, soles and sciaenids contributed to discarded bycatch. The detailed species composition of target species is given in Fig. 2. Among prawns, juveniles of *Parapeneopsis stylifera* were the most abundant (8.02%) followed by *Metapenaeus dobsoni* (2.85%), and *Metapenaeus affinis* (1.45%; Table 1). The juveniles of *P. stylifera* were highly abundant in the months of December and March to May; *M. dobsoni* in December, March and *M. affinis* in April–May. Morphometric measurements of the above three species indicated that prawns up to 6 cm total length (TL) were

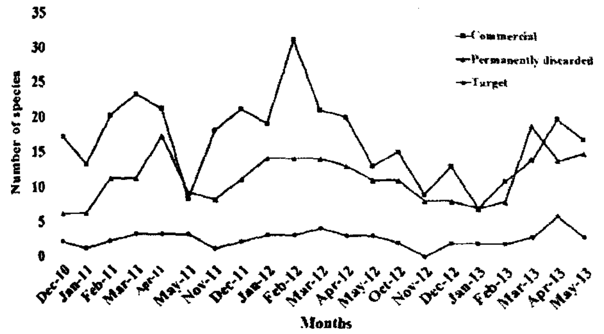

Fig. 3. Monthly variation in number of species discarded.

also observed in discarded bycatch. The occurrence of such large sized prawns in the discarded bycatch could be attributed to hasty sorting by the fishing crew. High abundance of their juveniles in the discards coincided with spawning and recruitment periods. Published literature (Achuthankutty and Parulekar, 1986) suggests that these species generally breed during October to August with certain peaks highly specific to respective species. *P. stylifera* being exclusively marine and sensitive to reduced salinity (Rao, 1968) restricts itself to nearshore coastal waters causing an increased abundance of juveniles in trawl discards as compared to the other two species. Further, this region is found to be highly productive due to habitat heterogeneity resulting in increased food availability supporting the juvenile population (Wafar et al., 1997).

Apart from prawns, juveniles of two targeted teleost species, i.e. *Johnius borneensis* (1.50%) and *Cynoglossus macrostomus* (1.05%; Table 1), showed higher abundance in trawl discard. Average discarded sizes for these species were 6.0 cm and 7.0 cm, respectively. Higher abundance of these species from December to May coincided with the spawning and recruitment period (Jayaprakash, 1999). The recruitment of juveniles during this period has contributed to the increased abundance as witnessed by discarded size. Among the discarded species, a sizable portion was formed by commercially important species as compared to trash/discarded catch species (Fig. 3). During pre-monsoon the juveniles of commercially important species share a significant portion in discarded bycatch in terms of their abundance. Among these, juvenile stages of prawns also formed a noticeable component (18.32%) in terms of their abundance (Table 1).

Published literature on the spawning biology of coastal fishes along the region suggests that, most of the fishes breed during late post-monsoon to pre-monsoon season (Qasim, 1973; Ansari et al., 1995). The present observation reveals increased abundance of juveniles which while feeding may get trapped into the trawl net as the cod end mesh size used is very small i.e. 9 mm (Hegde et al., 2013). Existence of high species diversity is one of the major reasons which contribute to the high rate of species discards in tropical waters (EJF, 2003). A major portion of trash fish occurring along this coast is discarded mainly due to low or lack of commercial value, non-edibility and lack of on-board storage facility.

Despite the fact that trawl net is basically operated to target prawns, non-target species make a significant contribution to the total catch in terms of their number and biomass as elucidated in the present investigation. Similar trends have been reported from other parts of the country (Bijukumar and Deepthi, 2006; Pillai et al., 2014). The present study indicates clearly that continuous discarding of juveniles of commercially important and target species will definitely have long term implications affecting the local recruitment pattern. The observations made in the present study suggest that the fate of other demersal fishery resources such as soles, squids, crabs, sciaenids, etc. is changing due to increased demand for consumption in local markets especially when prawn catches are low.

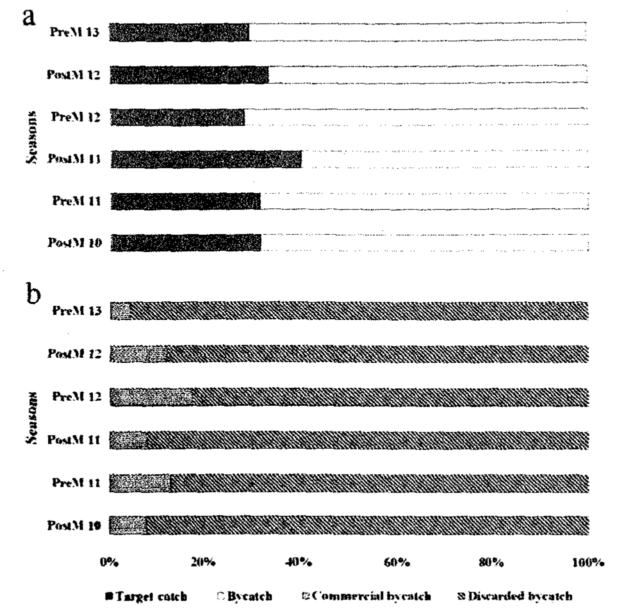

Fig. 4. Seasonal variation in biomass (weight) of (a) target catch and bycatch; (b) commercial and discarded bycatch.

3.3. Seasonal trends of biomass

An analysis of trawl catch biomass indicated greater contribution of bycatch to trawl catch with consistently higher values (68%) irrespective of season (Fig. 4(a)). Within this, discarded bycatch was the major component (61%) followed by commercial bycatch (07%; Fig. 4(b)). Regression analysis revealed a significant linear relationship between total catch and bycatch ($R^2 = 0.89$), and a weak relationship between total catch and target catch ($R^2 = 0.63$). This suggests that bycatch constituted bulk of the total trawl catch. Similarly, regression analysis between bycatch and discarded catch revealed a strong linear relationship ($R^2 = 0.94$) suggesting most of the bycatch was discarded into the sea; a very weak relationship was observed between bycatch and commercial catch ($R^2 = 0.08$). The preponderance of non-commercial species and juveniles in the trawl catches is attributed to intensive use of non-selective fishing gear with small cod end mesh size (9 mm) in biologically rich habitats that serve as potential nursery grounds for most marine organisms (Ansari et al., 1995).

3.4. Season-wise species associations

Cluster analysis of discarded bycatch revealed three and four major clusters in pre-monsoon and in post-monsoon season (Fig. 5), respectively. In the pre-monsoon season (Fig. 5(a)), Cluster I comprised of *T. toreumaticus*, an unidentified red prawn, *M. nepa*, *P. stylifera* and *A. indicus*. Cluster II comprised of *Thryssa dussumieri*, gastropods, *J. borneensis*, *Sepiella inermis*, *Muraenesox cinereus*, *C. macrostomus*, *Charybdis feriata*, and *Thryssa mystax*. Cluster III comprised of *Arius maculatus*, *Portunus sanguinolentus*, *Lactarius lactarius*, *M. affinis*, *Uroteuthis duvaucelii*, *M. dobsoni*, *Opisthopterus tardoore*, *Trichiurus lepturus* and *Lagocephalus spadiceus* (Fig. 5(a)). During pre-monsoon, species associations could be attributed to feeding aggregations as observed by the dominance of juveniles in the discarded bycatch. Coastal waters serve as nurseries for a variety of marine species (Sheaves et al., 2014). They support a high density of juveniles (Orth and van Montfrans, 1987) and contribute significantly to adult recruitment of marine fish (Camp et al., 2011). The species represented in cluster I are epi-benthic and use the habitat for feeding and spawning (Loh and Todd, 2011;

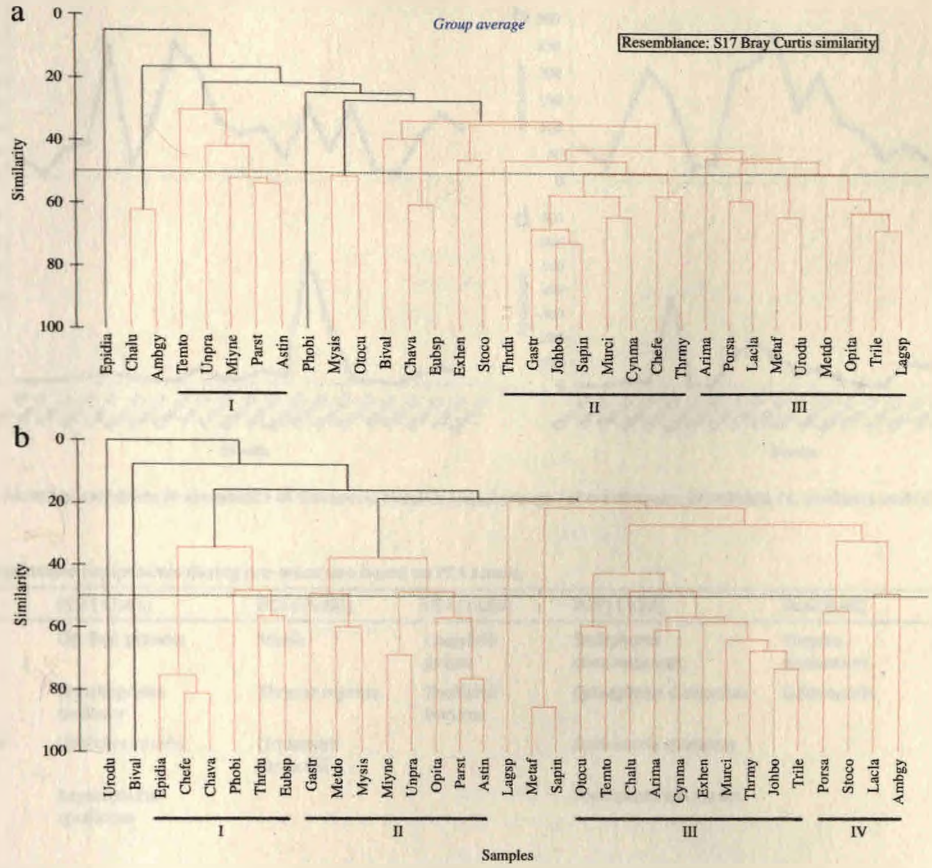

Fig. 5. Dendrogram showing clustering of species in (a) pre-monsoon season (b) post-monsoon season.

Hereu et al., 2012). Hence, the cluster could be also attributed to habitat use. Cluster II comprises a mixture of both benthic and pelagic species indicating bentho–pelagic coupling of food chains or trophic interactions due to shallow depth of coastal waters (Álvarez et al., 2012). Cluster III comprises of predator fish species (*A. maculatus*, *U. duvaucelii* and *L. spadiceus*) and other benthic and pelagic species. These predator species are known to feed on other species observed in this cluster (Abdurahiman et al., 2010; Froese and Pauly, 2014) suggesting the existence of a prey–predator relationship.

During the post-monsoon period (Fig. 5(b)), Cluster I is composed of *Epinephelus diacanthus*, *C. feriata*, *Charybdis vadorum*, *Photopectoralis bindus*, *Thryssa dussumieri* and *Eubleekeria splendens*. Cluster II is composed of gastropods, *M. dobsoni*, mysis, *M. nepa*, unidentified red prawns, *O. tardoore*, *P. stylifera* and *A. indicus*. Cluster III is represented by *Otolithes cuvieri*, *T. toreumaticus*, *C. feriata*, *A. maculatus*, *C. macrostomus*, *Exhippolysmata ensirostris*, *M. cinereus*, *T. mystax*, *J. borneensis* and *T. lepturus*. Cluster IV comprises of *P. sanguinolentus*, *Stolephorus commersonii*, *L. lactarius* and *Ambassis gymnocephalus* (Fig. 5(b)). In Cluster I *E. diacanthus*, *C. feriata* and *C. vadorum* exhibit a prey–predator relationship as *E. diacanthus* is known to feed on *C. feriata* and *C. vadorum* (Abdurahiman et al., 2010). The latter three species in this cluster are pelagic planktivores (Froese and Pauly, 2014) and hence their presence could be attributed to feeding association. Cluster II comprised of epi-benthic species except *O. tardoore* suggesting sharing of habitat. Two species, namely *P. stylifera* and *A. indicus*, exhibited highest similarity in abundance due to increased sensitivity to reduced salinity and preference to higher salinities (Rao, 1968; Kinne, 1971). This cluster also revealed a prey–predator relationship to some extent as *O. tardoore* feeds on mysis and shrimps (Froese and Pauly, 2014) and *A. indicus* actively feeds on gastropods (Loh and Todd, 2011). Cluster III comprised of carnivores and planktivorous species, and their association suggested a prey–predator relationship (Froese and Pauly, 2014). Cluster IV comprised of zooplanktivores and zoo-benthivores (Froese and Pauly, 2014) and hence the cluster may be attributed to feeding aggregation while the presence of *P. sanguinolentus* was due to preferred habitat.

The trawl bycatch was represented by juveniles of all species and adults of trash species. The variability in cluster formations during pre-monsoon and post-monsoon season is primarily due to differential recruitment patterns as observed by the occurrence of a large number of juvenile species, leading to changes in their abundance. Cluster formation is also influenced by species-specific response or preference to environmental conditions as it varied between seasons, habitat preferences and feeding associations and trophic dynamics. Another reason may be the shallow depth of coastal waters which favours bentho–pelagic coupling of the food chain that determines species associations.

An analysis of temporal variations of four major faunal groups (teleosts, crustaceans, echinoderms and molluscs) in the discarded bycatch revealed that during pre-monsoon, echinoderms, crustaceans and teleosts were most abundant whereas, during the post-monsoon season molluscs, crustaceans, teleosts and echinoderms were dominant (Fig. 6). The species-wise seasonal variations are explained with the help of PCA analysis.

3.5. Environmental influence on species

Principal component analysis was carried out to identify significantly correlated species and to explain the variation inherent in the data during pre-monsoon and post-monsoon.

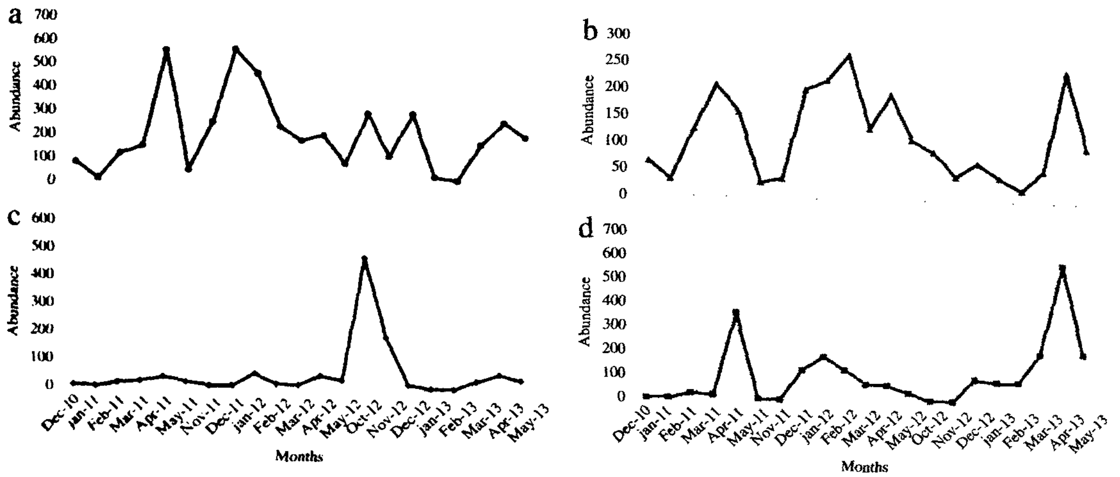

Fig. 6. Monthly variations in abundance of discarded bycatch faunal groups (a) crustaceans, (b) teleosts, (c) molluscs and (d) echinoderms.

Table 2
Species contribution to principle components during pre-monsoon based on PCA scores.

PC1 (24.90)	PC2 (17.43)	PC3 (15.90)	PC4 (14.89)	PC5 (11.28)	PC6 (8.46)	PC7 (7.10)
Miyakella nepa	Un. Red prawns	Mysis	*Charybdis feriata*	*Stolephorus commersonnii*	*Thryssa dussumieri*	*Cynoglossus macrostomus*
Metapenaeus affinis	*Opisthopterus tardoore*	*Thryssa mystax*	*Trichiurus lepturus*	*Epinephelus diacanthus*	Gastropods	
Parapeneopsis stylifera	*Otolithes cuvieri*	*Uroteuthis duvacelli*		*Eubleekeria splendens*		
Arius maculatus	*Lagocephalus spadiceus*			*Photopectoralis bindus*		
Temnopleurus toreumaticus						
Protunus sanguinolentus						
Muraenesox cinereus						
Lactarius lactarius						
Johnius borneensis						

Table 3
Species contribution to principle components during post-monsoon based on PCA scores.

PC1 (40.64)	PC2 (19.79)	PC3 (13.67)	PC4 (11.86)	PC5 (8.65)	PC6 (5.35)
Charybdis feriata	Un. Red prawns	*Metapenaeus affinis*	Gastropods	*Charybdis lucifera*	*Stolephorus commersonii*
Charybdis vadorum	*Lagocephalus spadiceus*	*Sepiella inermis*			
Parapeneopsis stylifera	*Uroteuthis duvauceli*				
Exhippolysmata ensirostris					
Mysis					
Epinephelus diacanthus					
Photopectoralis bindus					
Opisthopterus tardoore					
Muraenesox cinerius					
Arius maculatus					
Lactarius lacterius					
Johnius borneensis					
Trichiurus lepturus					
Astropecten indicus					
Bivalves					

PCA evaluation demonstrated seven principal components (PCs) on the basis of eigenvalues in pre-monsoon and six in post-monsoon season with dissimilar species composition. The first five components in pre-monsoon and first four in post-monsoon explained 84% and 86% of the variation in faunal abundance (Tables 2 and 3).

During the pre-monsoon season, *P. sanguinolentus*, *L. lactarius*, *J. borneensis*, *T. toreumaticus*, and *A. maculatus* (positive loadings) and *M. nepa*, and *M. cinereus* (negative loadings) explained 25% of the total variance along the first principal axis (Fig. 7(a)). These species showed weak positive or weak negative correlation with environmental parameters (temperature, salinity and dissolved oxygen) owing to little variation in these parameters during the pre-monsoon season.

During the post-monsoon season, *C. vadorum*, *C. feriata*, *E. diacanthus*, *P. bindus* and bivalves (positive loadings) and *P. stylifera*, *E. ensirostris*, mysis, *O. tardoore*, *M. cinereus*, *A. maculatus*, *L. lactarius*, *J. borneensis*, *T. lepturus* and *A. indicus* (negative loadings) along first principal axis (Fig. 7(b)) explained 41% of the total variance. The species with positive loadings during post-monsoon showed positive correlation with temperature and weak positive or negative correlation with salinity and

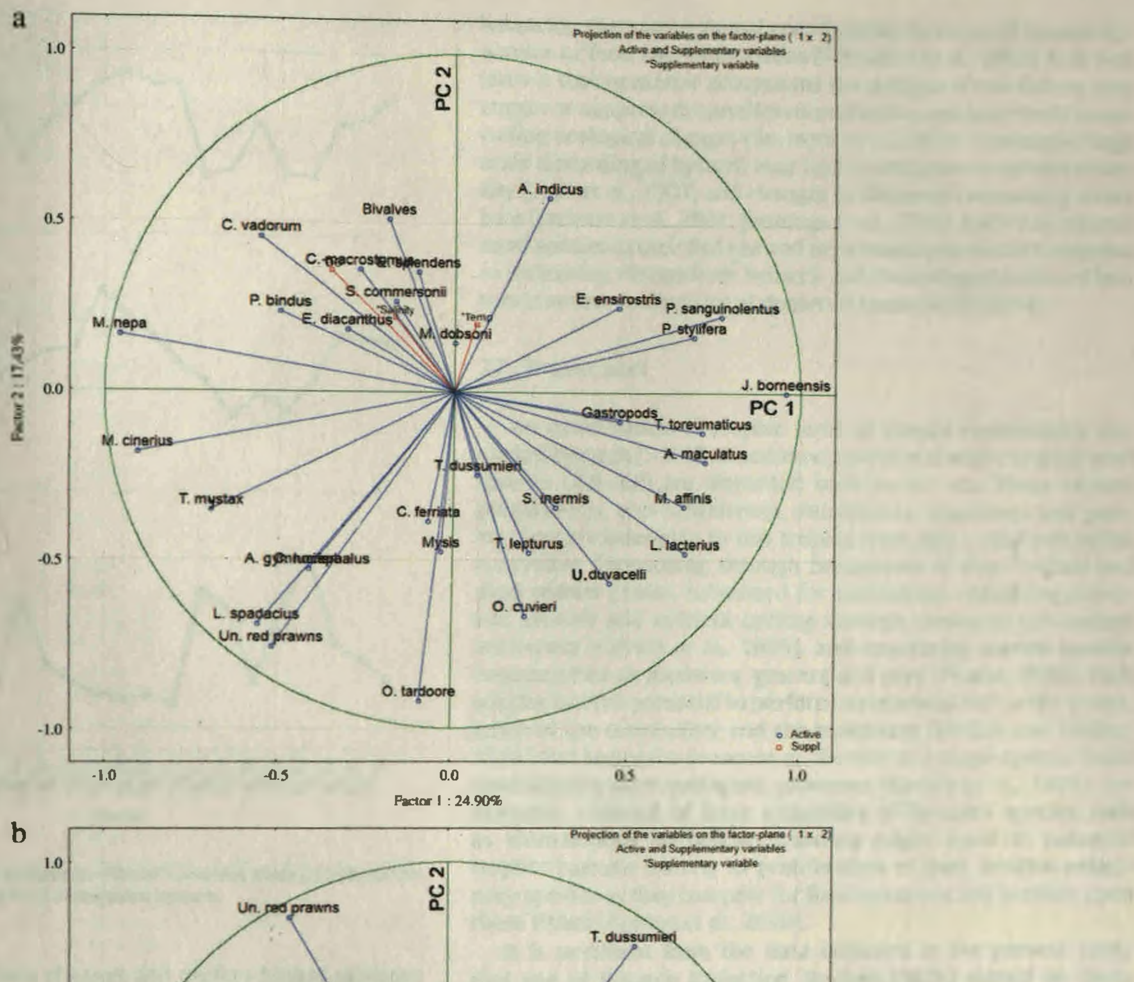

Fig. 7. Principle component analysis (correlation-based PCA) of (a) pre-monsoon season; (b) post-monsoon season.

[illegible] oxygen. Published literature suggests that temperature [illegible] sexual maturity in crabs (Soundarapandian et al., 2013), [illegible] metabolism in *E. diacanthus* (Chakraborty et al., 2014), length–weight relationship in *P. bindus* (Shadi et al., 2011) and growth rate and feeding in *Anadara* species (Broom, 1982). *Astropecten indicus* is found to be closely correlated with salinity

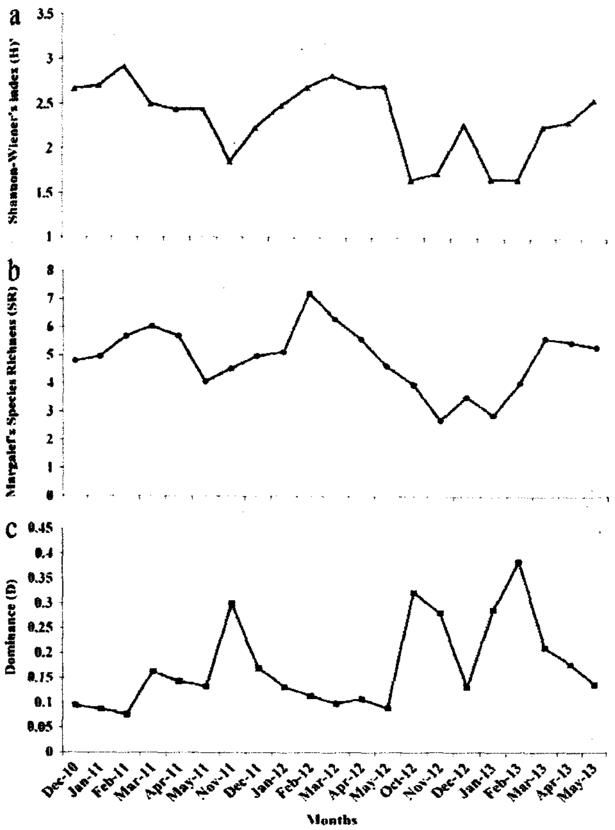

Fig. 8. Monthly variations in (a) Shannon–Wiener's diversity index (H′), (b) species richness (SR) and (c) dominance (D) of discarded bycatch.

as it is sensitive to salinity changes and prefers higher salinities (Kinne, 1971).

The species representing principal axis displays the extent of variability in the data which is influenced by recruitment patterns and their response to the environmental parameters. Higher variation in temperature and salinity during post-monsoon could be the reason for greater variability in species abundance (Fig. 7(b)), against the comparatively stable environmental parameters during the pre-monsoon season (Fig. 7(a)).

3.6. *Species diversity indices*

Shannon's diversity index (H′) did not vary significantly during the study period. It showed noticeably higher values in pre-monsoon season (2.30–2.91) whereas in post-monsoon the values varied from 1.65 to 2.69. Margalef's species richness (SR) also showed higher values during pre-monsoon season (4.05–7.22) as compared to post-monsoon (2.71–5.12). Dominance (D) did not show any specific trend; with higher values during the post-monsoon except during post-monsoon, 2010. In pre-monsoon, D values were consistently low except in the month of February, 2013 (Fig. 8).

It is obvious from the species composition and diversity indices of bycatch that the region supports a multispecies fishery with high diversity. Previous studies have also reported the existence of high diversity values along the region (Ansari et al., 1995; Hegde et al., 2013). The discards are usually considered as trash from a commercial perspective and therefore discarded directly back into the sea. However, from an ecological point of view they are equally important as target species. They play a vital role in structuring and balancing the marine faunal communities in terms of trophic dynamics or food web interactions (Schindler et al., 2002). It is well known that in marine ecosystems the collapse of one fishery may trigger or suppress the proliferation of others and may result in cascading ecological changes (Springer et al., 2003). Continuous large scale discarding of bycatch may lead to reduction in species diversity (Hall et al., 2000) and changes in demersal community structure (Jackson et al., 2001; Jennings et al., 2005). IUCN has enlisted most species in their Red List and prioritized their conservation due to increasing threats from bycatch and discarding practices of bottom trawlers to diversity of demersal fauna (IUCN, 2014).

3.7. *Trophic level*

An examination of trophic level of species representing discarded bycatch (>0.1% abundance) revealed that low trophic level species (2.0–3.0) are discarded back to the sea. These include planktivores, zoo-benthivores, detritivores, omnivores and grazers. Species belonging to this trophic level play a vital role in the ecosystem functioning through breakdown of dead animal and algal matter (Astor, submitted for pulication), enhancing microbial growth and nutrient cycling through mixing of sub-surface sediments (Covich et al., 1999), and structuring marine benthic communities as predators, grazers and prey (Pearse, 2006). Each species has the potential to perform an essential role in the persistence of the community and the ecosystem (Ehrlich and Walker, 1998) and hence the presence or absence of a single species could dramatically alter ecological processes (Covich et al., 1999). For example, removal of large quantities of by-catch species such as stomatopods by bottom trawling might result in potential trophic cascade leading to proliferation of their bentho-pelagic prey species as they compete for food resources and predate upon these fishes (Antony et al., 2010).

It is pertinent from the data obtained in the present study that use of Bycatch Reduction Devices (BRDs) should be made mandatory, apart from strict enforcement of mesh size regulations along with closed season and area closures in this region. Further, it is also suggested that reduction in towing time and priority to return live bycatch species during on-board sorting may also help in survival of fauna.

4. Conclusion

The present study demonstrates the loss of biodiversity and removal of biomass from the marine ecosystem by indiscriminate bottom trawling. Assessment of temporal variations and species associations of the bycatch species indicates distinct seasonal abundance peaks attributed to species recruitment. Further, assessment of the influence of environmental parameters on bycatch species abundance highlighted the role of temperature, salinity and dissolved oxygen in determining species occurrence. This study further demonstrates that only bycatch and discarded bycatch increased proportionally to the total trawl catch. It is very likely that such indiscriminate fishing in localized ecosystems might remove rare and endangered species, causing loss of biodiversity. Hence, it is essential to develop a fisheries database to enable evaluation of the impacts on the fisheries and biodiversity of the region.

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Appendix

Species name	Abbreviation	Species name	Abbreviation
Miyakella nepa	Miiyne	*Lactarius lactarius*	Lacla
Parapeneopsis stylifera	Parst	*Photopectoralis bindus*	Phobi
Metapenaeus affinis	Metdo	*Eubleekeria splendens*	Eubsp
Metapenaeus dobsoni	Metaf	*Otolithes cuvieri*	Otocu
Exhippolysmata ensirostris	Exhen	*Johnius borneensis*	Johbo
Portunus sanguinolentus	Porsa	*Trichiurus lepturus*	Trile
Charybdis feriata	Chafe	*Cynoglossus macrostomus*	Cynma
Charybdis lucifera	Chalu	*Ambassis gymnocephalus*	Ambgy
Charybdis vadorum	Chava	*Uroteuthisduvauceli*	Urodu
Un. red prawns	Unpra	*Sepiella inermis*	Sepin
Mysis	Mysis	*Muraenesox cinereus*	Murci
Opisthopterus tardoore	Opita	*Lagocephalus spadiceus*	Lagsp
Stolephorus commersonnii	Stoco	*Temnopleurus toreumaticus*	Temto
Thryssa mystax	Thrmy	*Astropecten indicus*	Astin
Thryssa dussumieri	Thrdu	Bivalve	Bival
Arius maculatus	Arima	Gastropods	Gastr
Epinephelus diacanthus	Epidi		

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