BIODIVERSITY AND ECOLOGY OF DEEP-SEA MEGAFAUNA WITHIN THE 1500 m DEPTH ZONE OF TERRACE OFF TRIVANDRUM

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Biodiversity and Ecology of deep-sea megafauna within the 1500 m depth zone of Terrace off Trivandrum

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Front Cover
A diver's view of the deep-sea, showing an anglerfish using its bioluminescence esca to lure prey.

Certificate

This is to certify that the thesis entitled "**Biodiversity and Ecology of deep-sea megafauna within the 1500 m depth zone of Terrace off Trivandrum**" is an authentic record of the research work carried out by Mr. Vinu Jacob (Reg. No.: 4188), under my scientific supervision and guidance at the Centre for Marine Living Resources & Ecology (CMLRE), Kochi, in partial fulfilment of the requirements for award of the degree of Doctor of Philosophy of the Cochin University of Science & Technology and that no part thereof has been presented before for the award of any other degree, diploma or associateship in any University. Further certified that all relevant corrections and modifications suggested during the pre-synopsis seminar and recommended by the Doctoral Committee have been incorporated in the thesis.

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Declaration

I hereby declare that the thesis entitled "**Biodiversity and Ecology of deep-sea megafauna within the 1500 m depth zone of Terrace off Trivandrum**" is an authentic record of research work conducted by me under the supervision of Dr. V. N. Sanjeevan, Former Director, Centre for Marine Living Resources & Ecology (CMLRE), Kochi and no part of it has been presented for any other degree or diploma in any University.

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Dedicated to my beloved parents
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INDEX

Chapter - 1

GENERAL INTRODUCTION 1-20

1.1 Introduction 2

1.2 The Terrace off Trivandrum 3

1.3 The megafauna 5

1.4 Oceanographic set up 5

1.5 Faunal assemblages 8

1.6 Indian fisheries 11

1.7 Deep sea fishing and regulatory policies 13

1.8 Relevance of the present study 16

1.9 Outline of the thesis 19

Chapter – 2

STUDY AREA, SAMPLING AND ANALYSIS 21-34

2.1 Study area 22

2.2 Sampling of megafauna 23

2.3 Taxonomic analysis of megafaunal samples 28

2.4 Estimation of megafaunal standing stock 29

2.5 Trophic guild 30

2.6 Length weight 31

2.7 Data analysis 31

Chapter - 3

DEEP-SEA MEGAFAUNA OF TERRACE OFF TRIVANDRUM: TAXONOMY AND FAUNAL COMPOSITION 35-102

3.1 Introduction 36

3.2 Results 40

3.2.1 Sampling sufficiency 40
3.2.2 Taxonomic diversity of ToT deep-sea megafauna. 42
3.2.3 Taxonomic account of the unique megafaunal members of ToT 45
3.3 Discussion 74

Chapter - 4

BIODIVERSITY AND COMMUNITY STRUCTURE OF THE DEEP-SEA MEGAFAUNA OF TERRACE OFF TRIVANDRUM 103-133
4.1 Introduction 104
4.2 Results 107
4.2.1 Alpha diversity 108
4.2.2 Temporal and bathymetric variations in alpha diversity 110
4.2.3 Beta diversity 112
4.2.4 Seasonal variations in megafaunal community structure 114
4.2.5 Bathymetric variations in megafaunal community structure 116
4.2.6 Megafaunal assemblages of ToT 119
4.3 Discussion 119

Chapter - 5

BIOLOGY, STANDING STOCK AND TROPHIC STRUCTURE OF DEEP-SEA MEGAFAUNAL COMMUNITY OF TERRACE OFF TRIVANDRUM 134-202
5.1 Introduction 136
5.2 Results 139
5.2.1 Biological Association: Epibiosis of a Zoanthid on the deep-sea hermit crab 139
5.2.2 Body size of deep sea megafauna 141
5.2.3 Standing stock and composition of ToT megafauna. 144

5.2.3.1 Shallow zone of ToT (950-1150 m) 147
5.2.3.2 Deep zone of ToT (1150-1450 m) 152
5.2.4 Trophic guilds of megafauna 157
5.2.5 Trophic guild classification of deep-sea megafauna of ToT and their habitat positioning within the BBL 159
5.2.6 Trophic composition and structure of megafauna within ToT 166
5.2.7 Vulnerable fishery resources of ToT 171
5.3 Discussion 176

Chapter - 6

ECOLOGY 203-227
6.1 Introduction 204
6.2 Geomorphological features 205
6.3 The environmental set up of SEAS and ToT 206
6.4 Surface production 210
6.5 Export flux to deep-sea 212
6.6 Sedimentation on continental margin of SEAS 214
6.7 Benthic fauna 217
6.8 ToT: an Ecologically or Biologically Sensitive Area (EBSA) of SEAS? 224

Chapter - 7

SUMMARY & CONCLUSION 228-234
Reference 235-267
Annexure

LIST OF ACRONYMS & ABBREVIATIONS

ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
AT	Alleppey Terrace
ATTC	Alleppey Trivandrum Terrace Complex
BBL	Benthic Boundary Layer
CBD	Convention on Biological Diversity
CKE	Chain – Kairali Escarpment
CMLRE	Centre for Marine Living Resources & Ecology
DOC	Dissolved Organic Carbon
DSFP	Deep-sea Fishing Policy
EBSA	Ecologically or Biologically Sensitive Areas
EBUS	Eastern Boundary Upwelling System
EEZ	Exclusive Economic Zone
FORV	Fishery Oceanographic Research Vessel
HSDTCV	High speed demersal trawl crustacean version
LH	Lakshadweep High
LL	Lakshadweep Low
MPA	Marine Protected Areas
NEAO	North Eastern Atlantic Ocean
NEIO	North Eastern Indian Ocean
NEPO	North Eastern Pacific Ocean
NWAO	North Western Atlantic Ocean
NWIO	North Western Indian Ocean
NWPO	North Western Pacific Ocean
OM	Organic Matter
OMZ	Oxygen Minimum Zone

POM	Particluate Organic Matter
PRIMER	Plymouth Routines in Multivariate Ecological Research
QE	Quilon Escarpment
RIMS	Royal Indian Marine Survey
SEAO	South Eastern Atlantic Ocean
SEAS	South Eastern Arabian Sea
SEIO	South Eastern Indian Ocean
SEPO	South Eastern Pacific Ocean
SIMPER	Similarity percentage
SM	Summer Monsoon
SSHA	Sea Surface Height Anomaly
SST	Sea Surface Temperature
SWAO	South Western Atlantic Ocean
SWIO	South Western Indian Ocean
SWPO	South Western Pacific Ocean
ToQ	Terrace off Quilon
ToT	Terrace of Trivandrum
WICC	Western India Coastal Current
WM	Winter Monsoon

Chapter - 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

The deep-sea, once believed to be a barren lifeless area (azoic) is recognized today as the largest ecosystem on earth. The Challenger expedition (1872- 1876) established the presence of life on the deep-sea floor throughout the worlds' oceans, refuting the concept that the great depths were devoid of life. More than a century of exploration has led to the understanding that the deep-sea represents one of the principal reservoirs of biodiversity on planet Earth. Yet, the deep-sea still remains one of the least understood ecosystems because of its remoteness and the technological challenges in investigation. Based on existing knowledge on marine fish diversity, collected over the past 250 years, Eschmeyer *et al.* (2010) concluded that two habitats where new marine fish taxa are most likely to be found are the continental slopes and deep-sea reefs, which are poorly sampled and studied so far.

Deep seabed habitats host a wealth of species estimated currently to range between 500,000 and 10 million. Scientific results highlight that higher biodiversity can enhance the functioning and efficiency of deep sea ecosystems. However, the deep sea is under increasing threat from various human activities such as destructive fishing, overexploitation of resources and emerging problems such as ship based marine pollution, marine debris including plastic wastes, seabed mineral extraction and poorly controlled research and bioprospecting on the deep sea biodiversity. The combined impacts of these threats as well as the potential impacts of climate change place several deep sea species at risk and impair the structure, function, productivity and resilience of these ecosystems. In response to these rising concerns, the 2002 World Summit on Sustainable Development in its plan of implementation called for countries to develop and facilitate the use of diverse approaches and tools including the identification of Ecologically or Biologically Sensitive Areas (EBSA) and establishment of Marine Protected Areas (MPAs) consistent with international law and based on scientific information. The present study is an attempt to gather, document and synthesize scientific information on the ecology and megafaunal diversity of the Terrace of Trivandrum (ToT), a less known deep sea habitat off the south west coast of India.

1.2 THE TERRACE OFF TRIVANDRUM

Typical continental slopes over the world oceans are inclined at about 4° i.e., in these regions, depth increases by 70 meters every kilometer. The continental slope of India is relatively steep, narrow and aligned parallel to the continental shelf edge. However the inclination of the Continental slope off south west Kerala is gradual, less steep and depicts the presence of anomalous, relatively wide terrace like features (Rao and Wagle 1997; Yatheesh *et al.* 2006). These anomalous, lateral bathymetric protrusions occur in the mid continental slope region, approximately south of Kochi and are collectively named as ‘Alleppey Trivandrum Terrace Complex (ATTC)’ (Yathesh *et al.* 2013). ATTC extend over an area of >35000 sq. km and a ‘terrace’ of such a large dimension does not exist anywhere else along the western Indian margin. The continental slope region of ATTC contains two large contiguous terrace-like features. the Alleppey Terrace (AT) and the Terrace off Trivandrum (ToT) demarcated by the Quilon Escarpment (QE) approximately 900 m in height at its steepest part (Figure 1.1).

The smaller terrace, also known as ‘Aleppey Platform’ (Singh *et al.* 1999) or ‘Terrace off Quilon’ (ToQ) (Rao and Bhattacharya 1975), extend from the shelf edge (200 m) to about 800 m depth, lies approximately between Alleppey and Quilon (9.0ºN to 8.5ºN). The boundaries of AT are delineated by the shelf edge on the east, the Chain – Kairali Escarpment (CKE) approximately 2500 m in height on the west and the QE on the south. Part of the Quilon Bank, a major fishing ground along the south-west coast is located within the AT. The larger of these two terraces lies at bathyal depths > 900m, approximately off the Trivandrum- Kanyakumari coast (8.5ºN to 6.5ºN) and is referred to as ‘Terrance off Trivandrum (ToT)’ (Yatheesh *et al.* 2006). The CKE which is approximately 1000 m height in this sector forms the western boundary and the QE the northern boundary of the ToT. The eastern boundary is marked by the 900 m isobaths which slopes gradually in the sector north of 7.45ºN Latitude and is steep in the sector south of 7.45ºN Latitude. The southern boundary merges with the Wadge Bank, an established fishing ground located between 76.5ºE and 78.0ºE longitudes and 7.0ºN and 8.3ºN Latitude. The ToT has a large areal extension of approximately 25,000 sq. km., lies broadly between 900–2,000 m isobaths and has not drawn much attention of researchers.

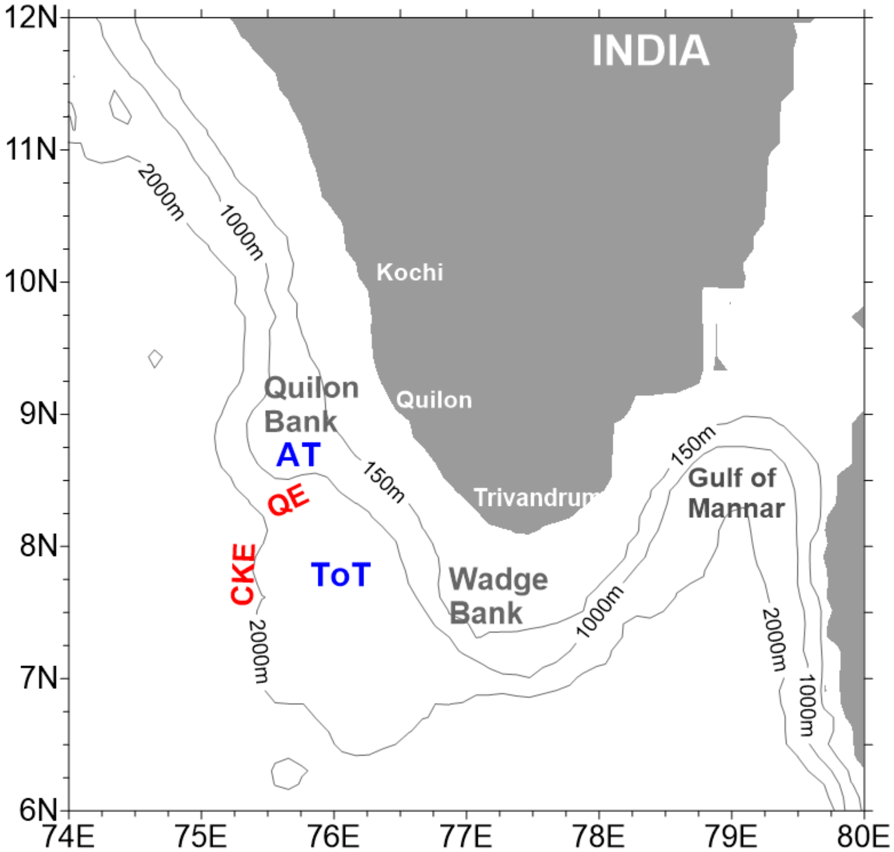

Figure 1.1. Geomorphological features of Alleppey-Trivandrum Terrace Complex (adopted from Yatheesh *et al.* 2013) and modified to include Wadge Bank, Quilon Bank and Gulf of Mannar.

1.3 THE MEGAFAUNA

The geomorphology of the continental slope has a profound influence on the animals that thrive on the seafloor. The near-bottom layer of the ocean, which represents a boundary between two oceanic biotopes (pelagic and benthic), is referred to as the Benthic Boundary Layer (BBL). The species living in the BBL belong both to pelagic and benthic biotopes (Dauvin and Vallet 2006), and constitute 2 distinct ecological groups, namely the epibenthic fauna that live on the bottom sediments and benthopelagic fauna that live in the water column just above the sediment bed. The BBL fauna are often classified on the basis of size (Gage 1978) as microfauna, meiofauna, macrofauna and megafauna. Although the precise distinctions between these size-classes sometimes vary, megafauna are defined loosely as “animals readily visible in photographs” of the seafloor (Grassle *et al.* 1975). This encompass larger, centimeter to decimeter scale invertebrates (primarily echinoderms, cnidarians and crustaceans) and demersal fishes, which are often collected by epibenthic sledges and bottom trawls with mesh size of 1-3 cm (Haedrich and Rowe 1977). Fauna that inhabit the continental slopes (~200-2000 m) and abyssal plains (~2000-4000 m) are very well adapted to live under a set of environmental extremes, including high pressure, low temperature and the absence of light. Amongst the various physicochemical and biological factors that determine the nature of deep-sea fauna, the most important factor which limits their distribution and abundance is the logarithmic decline in availability of food energy with increasing depth (Rex 1976; Haedrich 1996; Vinogradova 1997).

1.4 OCEANOGRAPHIC SET UP

On an average, only 1% of oceanic surface production reaches the deep-sea floor (Fischer *et al.* 2000), either as particulate or dissolved organic carbon (POC and DOC, respectively), making the deep-sea an extremely energy-poor environment. Most of the downward flux of POC from the euphotic zone is in the form of ‘phytodetrital aggregates' which measure millimeters to centimeters in size (Beaulieu 2003). Vertical flux of 'phytodetrital aggregates' are closely linked to the annual cycles of surface production (Deuser and Ross 1980), as well as export flux, which are influenced by mesoscale eddies, gyres, meanderings, deep-currents, turbidity flows and "statistical funneling" (Deuser *et al.* 1988), often from a large catchment areas (Gray and Elliott 2009). Thus, paradoxically, the basic energy needs of the deep-sea floor originate primarily from the sunlit surface layer of the ocean (Rex and Etter 2010).

The South Eastern Arabian Sea (SEAS) of which Terrace of Trivandrum (ToT) is a part, is essentially an Eastern Boundary Upwelling System (EBUS) characterized by annually reversing surface currents driven by the seasonally reversing monsoon winds. During summer monsoon (June to September) strong south westerlies drive the surface circulation clock-wise. The season is marked by moderate wind driven upwelling modulated by the coastally trapped equatorial Kelvin waves and its offshore propagating Rossby waves (Shankar and Shetye 1997; Smitha *et al.* 2008), southward flowing Western India Coastal Current (WICC) and a large cyclonic eddy, the Lakshadweep Low (LL) (Bruce *et al.* 1994; Shankar and Shetye 1997; Luis and Kawamura 2004). Coastal upwelling starts at the southern tip of the west coast of India, and as the season progresses it propagates northwards, resulting in high biological production along the entire south west coast of India (Banse 1959; McCreary *et al.* 1993; Smitha *et al.* 2008). Column primary production reach up to 510 mg C m^{-2} d^{-1} during summer monsoon which is more than double the winter monsoon production rate of 243 mg C m^{-2} d^{-1} (Sanjeevan *et al.* 2010).

While higher primary production and favorable environmental conditions promote secondary (Haridas *et al.* 1980; Madhupratap *et al.* 1990) as well as tertiary production (Madhupratap *et al.* 2001; Habeebrehman *et al.* 2008) in most parts of the upwelling zones of SEAS, paradoxically, the subsurface waters are hypoxic, causing the disappearance of demersal fishes from the shelf region (Banse 1959; Ommen 1985).

During the winter monsoon (November to February), the surface circulation is reversed (anti-clockwise) under the influence of the north easterlies. The season is characterized by the northward flowing West India Coastal Current (WICC), a large anti-cyclonic eddy, the Lakshadweep High (LH) (Bruce *et al.* 1994; Shankar and Shetye 1997) and influx of low saline Bay of Bengal water to the Lakshadweep Sea (Prasanna Kumar *et al.* 2004). During this season, Sea Surface Temperature (SST) across the Lakshadweep Sea gets warmer through water column stratification, enhanced heat retention and weak winds, which leads to the formation of the Arabian Sea warm pool (Rao and Shivakumar 1999; Sabu and Revichandran 2011).

In the open ocean areas of the SEAS, the cyclonic (LL)/ anti-cyclonic (LH) gyres during summer/winter seasons produce oceanic upwelling/ downwelling (Rao *et al.* 2008). These hydrodynamic features of the SEAS have a profound influence on spatial and temporal variability in primary production and the vertical flux of organic matter and sediments (Ramaswamy and Nair 1989, 1994). Griffin and Goldberg (1975) and Kolla *et al.* (1981) have reported that the settlement and transport of organic matter and sediment to the sea floor is more influenced by hydrodynamic processes than the geomorphological features. Gyres and eddies in the Arabian Sea are known to transport sediments to great depths, and are responsible for shaping the geomorphology of the region (Das *et al.* 1980). Particularly in SEAS, sedimentation over the continental shelf region south of Kollam is hindered by the seasonally reversing ocean currents (Smitha *et al.* 2008), producing a ‘no clay zone’ along the Kollam- Comorin sector (Rao and Wagle 1997; Abdul Jaleel *et al.* 2015). An increase of finer sediment fractions (clay and silt) and organic matter towards the continental slope of SEAS indicates that the settlement and deposition zone lies beyond the realm of influence of these dynamic ocean currents (Naidu 1993; Abdul Jaleel *et al.* 2014).

The Arabian Sea harbors an oxygen minimum zone (OMZ) at a depth between ~ 100 and 1000 m, below its highly productive surface waters, where the average annual flux of organic matter to the seabed is high (Wyrtki 1973). Oxygen concentration in the bottom water can be a controlling factor in the retention of organic carbon in seafloor sediments (Demopoulos *et al.* 2003; Hunter *et al.* 2011). Beyond the realm of influence of the OMZ, near bottom currents and deep-sea water masses, namely Antarctic and North Atlantic deep waters, play a crucial role in oxygenating bathyal and abyssal waters (Gage and Tyler 1991; Demopoulos *et al.* 2003).

As a result of high annual flux of organic matter from the productive surface waters of the Arabian Sea, and subsequent degradation in sub surface waters, a perennial oxygen minimum zone (OMZ) with dissolved oxygen <2 ml/l, exists in the Arabian Sea between ~150 to 1,000 m depths (Wyrtki 1973). In parts of the continental slope where these OMZ waters impinge on the seafloor, the low oxygen concentrations have profound impact on the retention and preservation of organic carbon in sea-floor sediments (Demopoulos *et al.* 2003; Hunter *et al.* 2011).

1.5 FAUNAL ASSEMBLAGES

The hydrodynamic and biological conditions prevailing over the water column in the SEAS have a combined influence on the export flux of POC and DOC in to the deep-sea, thereby fueling communities inhabiting the Benthic Boundary Layer (BBL), and determining the structure and function of its faunal assemblages. The community dynamics within the deep-sea BBL play a crucial role in the cycling of carbon through the trophic web involving diverse ecological groups. Heterogeneity of macrobenthic communities in terms of density and diversity are well studied and reported from the continental margins of SEAS up to a depth of 1000 m. These studies reveal a decreasing trend in standing crop and diversity of macrobenthos with increasing depth in the SEAS shelf (Joydas and Damodaran 2009; Joydas *et al.* 2009), while beyond the shelf break (~200m) the standing stock continues to decrease, while diversity (and evenness), particularly of polychaetes, increased (Abdul Jaleel *et al.* 2014). The macrofauna of the

SEAS shelf are strongly influenced by the seasonal hypoxia occurring over the shelf (Abdul Jaleel *et al.* 2015) as well as the perennial OMZ impinging on the slope (Ingole *et al.* 2010; Abdul Jaleel *et al.* 2014), which result in decreased richness and high dominance of opportunistic species. Thus, along the SEAS continental margin, the variations in sediment texture and dissolved oxygen of bottom water acting together play a key role in structuring the macrobenthic polychaete communities (Abdul Jaleel *et al.* 2014), rather than the amply available organic matter in the sediments.

Studies on the deep-sea megafauna of the continental slopes of India began over a century ago. Pioneering works on the taxonomy of Indian deep-sea megafauna are credited to Lt. Col. A. W. Alcock, for his works based on samples collected during the voyage of Indian marine survey streamer, RIMS *Investigator* between 1884 and 1914. The deep-sea exploratory surveys by RIMS *Investigator* along Indian Ocean provided first and detailed overview about the taxonomy of deep-sea fauna of the Indian Ocean. RIMS Investigator, specifically designed for deep-sea dredging commenced zoological collections in 1885, which were deposited in the Indian Museum, Calcutta (now Zoological Survey of India). From October 1888 to 1899, the vessel carried out 113 successful hauls between depth ranges of 100 to 1997 fathoms. Of these, 71 were under the supervision of Captain A. R. S. Anderson, who had been Surgeon-Naturalist since 1893. The second phase of RIMS *Investigator*'s deep-sea surveys (1884-1914) covered 711 stations in the Indian Ocean (5°-29° N., 46°- 98° E) and collected specimens up to a depth of 3,652 m using Agassiz trawls. Her voyage reports were published as monographs on deep sea fishes (Alcock 1899), Macrura and Anomala (Alcock 1901); account on deep sea Brachura (Alcock 1899), Madrepora (Alcock 1898), Alcynoria (Thomson and Henderson 1906), several reports on classes of Echinodermata (E.g. Koehler 1898, 1927; Koehler and Vaney 1905, 1910) etc.

The RIMS Investigator monographs documented a total of 169 deep-sea fishes, 58 species of brachuran crabs, 52 species of anomuran crabs and 117 species of shrimps under Macrura. The second major contribution to the documentation of deep-sea fauna of Indian Ocean was carried out during John Murray Expedition (1933-34). This expedition on the Egyptian Research Vessel Mabahiss surveyed 212 stations in the north-west Indian Ocean between 29°N- 7°S and 32°-73°E, with collections from up to 4,793 m depths (Sewell 1934). Detailed taxonomic report on Fishes (Norman 1939), Penaeidae (Ramadan 1938), Galathidae (Tirmizi 1964) and Dromiacea (Gordon 1950) shed light to the deep-sea megafauna of the region. Major megafaunal groups such as crustaceans and demersal fishes contribute to the inshore commercial fishery in India, and are being harvested at peak exploitation levels. Hence, most research focus on the deep-sea megafauna in Indian waters is placed on its potential as an alternate fishery resource, beyond the conventional inshore fishing grounds, rather than on its taxonomy, biodiversity and ecological significance.

In this regard, the government of India established Deep Sea Fishing Station (DSFS) at Bombay in 1946, with an aim to assess potential fishery resources beyond conventional fishing areas and to aid future policy making. Various exploratory surveys were conducted all along the Indian waters under the aegis of the DSFS, along with the establishment of regional bases at Cochin, Mangalore, Veraval, Tuticorin, Madras, Visakhapatanam and Port Blair. The program was renamed as ‘Exploratory Fishery Project’ in (EFP) in 1974 and later as Fishery Survey of India (FSI) in 1983. Valuable information regarding the diversity, distribution and abundance of demersal resources of south west coast of India have been generated through FSI surveys up to a depth of 500 m (Joseph *et al.* 1976, 1987; Sivaprakasam 1986; Sudarsan *et al.* 1988; Ninan *et al.* 1992; Sajeevan and Nair 2006; Sajeevan *et al.* 2009).

Concurrent with the above efforts, the Indo-Norwegian Project (INP) which was established in 1952 at Neendakara, Kollam and subsequently shifted to Cochin in 1963 (renamed as Integrated Fisheries Project, IFP, in 1972) initiated exploration of demersal resources along the shelf and slope of the SEAS. Most of these deep-sea resource assessments surveyed the areas between the 150 and 500 m contours. They revealed the existence of deep-sea lobster resources between 180 and 270 m off Quilon and Mandapam, and deep-sea prawn and fish resources on the Quilon Bank (300–450 m) (Tholasilingam *et al.* 1964; Silas 1969; Suseelan 1974; Mohammed and Suseelan 1973; Oommen 1985). Since 1984, the Fishery Oceanographic Research Vessel *Sagar Sampada* (FORV SS), under Department of Ocean Development (Now the Centre for Marine Living Resources and Ecology, Ministry of Earth Sciences), has been conducting surveys to assess the biodiversity, distribution and resource potential of demersal stocks beyond 200 m depth, especially in the SEAS (Sivakami 1989; Suseelan *et al.* 1990; Feroz Khan *et al.* 1996; Jayaprakash *et al.* 2006; Somvanshi *et al.* 2009; Rajasree 2011; Venu 2009; Hashim 2012; Venu 2013).

These surveys established the availability of potential deep-sea fishery resources such as lobsters, prawns, cuttlefish, sharks and demersal fishes, demarcated new fishing grounds such as Quilon Bank and Wadge Bank, where high biomass was concentrated and depicted resource seasonality in the SEAS up to 1000 m. Studies based on exploratory surveys conducted by DSFS and various government agencies also documented high standing stock density of nonconventional deep-sea fishery resources especially commercially important crustaceans in the southwest coast of India off Quilon (Silas 1969; Ninan *et al.* 1992; Somvanshi *et al.* 2009). However, none of these studies documented the diversity, distribution and standing stock of megafauna of the anomalous bathymetric Terrace off Trivandrum (ToT), off southwest coast of India.

1.6 INDIAN FISHERIES

The Indian marine capture fisheries, which exploits the megafaunal resources from diverse habitats including deep-sea, currently yields around 3.6 million tonnes of fish catch per year. Technological advancement and industrialization has brought a drastic change in Indian marine fisheries from a subsistence based activity during

1950's. Around 2 lakh fishing fleets of different category ranging from catamaran to big-industrial vessels are exploiting our marine resource at various levels. While growth in fish production ensures food security and export revenue for the country, fishing cannot be considered as a simple economic activity; it is an important means of providing livelihood and food security to over 4.06 million people associated with this sector either directly or indirectly (National Marine Fisheries Census 2010). Mechanization and associated technological advancement in the fisheries sector has made it a highly competitive, capital intensive and profit oriented activity, adversely affecting the livelihood of the majority traditional fisher folk. Exploitation of a common resource by diverse sectors, having different technological capabilities, often at various levels, marginalizes the traditional sector, leads to overexploitation of certain resources, and often results in conflicts. Responsibility of judicious utilization and protection of natural resources, have made it necessary for the Indian Government to enact legislations for regulation of activities of fishing vessels within the Exclusive Economic Zone (EEZ) of India.

According to the Constitution of India, the power of enacting laws is split between the central and state governments. Marine fisheries in the 9 maritime states of India, within the territorial limits of 12 Nautical miles, are governed by the respective states' Marine Fishing Regulation Act (MFRA). These acts are formulated on the guidelines provided by the modal piece of legislation prepared by the Ministry of Agriculture, Government of India in 1979, which encouraged the traditional fishers operating unpowered fishing vessels to safeguard their fishing space and equipment from mechanized sector. Seeing the promising potential of fishery resources beyond territorial waters (referred as deep-sea resources, which include both pelagic and demersal), the central government enacted several laws and policies from time to time, for its harvest and sustainable management. The marine fishing policies announced by the central government for the sustainable use of marine resources beyond territorial waters come under the ‘deep-sea policies’. The word ‘deep-sea’ here refers to the resources beyond territorial waters (outside of the states’ jurisdiction limit), which include both pelagic, demersal resources of neritic as well as oceanic waters. These ‘deep-sea policies’ focused almost entirely on the developmental needs of the deep-sea sector, leaving issues pertaining to the traditional sector to the respective marine states and union territories. Hence these ‘deep-sea policies’ evoke strong opposition and agitations from the traditional sectors of all nine maritime states.

1.7 DEEP SEA FISHING AND REGULATORY POLICIES

Commercial deep-sea fishery exploitation in Indian waters began during the 1970’s, by chartering foreign vessels. Recognizing the fact that Indian fishermen were ill-equipped and poorly trained for deep-sea fishery, and also lacked financial resources, the Indian government started a joint venture by chartering deep sea fishing vessels imported from USA in 1972. Thus began a new era in the exploitation of oceanic and deep-sea resources around India. Taking into account the untapped resource potential beyond the conventional fishing zones, India government in 1972 opened a new avenue of joint ventures with large charted trawlers from other counties to explore deep-sea fishery resources.

The first deep-sea policy was announced by the Government of India in 1977, providing arrangements for chartering foreign operators, which was followed by a Charter Policy in 1981, for introduction of sophisticated foreign fishing vessels for promotion of deep sea fishery. However, these chartered deep-sea fishing vessels exploited mostly the inshore grounds up to 50 m, and rarely went beyond 100 m water depth. This led to conflicts with the traditional fishermen who depend exclusively on the inshore resources. Upon the delimiting of the region beyond 80 m depth for offshore fishing operations by the Maritime Zones of India Act 1981 (MZI Act 1981) followed by its rules in 1982, almost all the chartered vessels ceased operations in India.

In 1991, the Indian government announced the Deep-sea Fishing Policy (DSFP) for augmenting its marine capture fishery production and recognized an untapped deep-sea potential of 1.64 million tonnes from the Indian EEZ (Sudarsan *et al.* 1991). The potential of the deep-sea resource has been estimated by means of exploratory surveys, and comprises 45.25% pelagic stock, 39.8% demersal stock and 15% of oceanic species. The policy aims to bridge the gap between potential and production from deep-sea, and allowed private Indian entrepreneurs to enter into joint ventures with foreign counterparts for exploiting the hitherto under exploited fishery resources beyond inshore area, using state-of-the-art technologies (Shajahan 1996).

The country fishermen had apprehensions on the possible intrusion of DSFP 1991 vessels into their coastal waters and thereby affecting the fish stock and their livelihood. Responding to protests and agitations by fish workers all over the country against the DSFP, Government of India appointed a commission headed by Sri Murari to examine the issue. The Murari Committee constituted by the central Government in 1996 came up with very good recommendation to sustain the resources along with protecting the interest of the fishermen and utilization of the deep-sea resources in the EEZ. The commission recommended that issuing license to foreign vessels must be stopped and indigenous potential for exploiting deep-sea fishery resources should be assessed and promoted. Accordingly, the Government stopped issuing new licenses and emphasized the need to search for indigenous means of harvesting the unexploited deep sea resources of India.

While the issue of licensing foreign vessels to fish the deep-sea waters of Indian EEZ stopped after the recommendations of Murari committee, the resource depletion and crowding of fishery crafts in the inshore waters impelled indigenous trawl operators from Kerala (November 1999 onwards) and the fishermen of southeast coast of Tamilnadu (from 2001) to venture into the deep-sea by employing conventional trawlers (OAL: 12-18 m; engine power: 100-250 hp). Fishery was mainly concentrated in the

150-500 m depth zones of the southwest and southeast coasts of India, especially the Kollam Bank region. The very first season which start by November and ends in March recorded a landing of 25,647 tons in Kerala (Nandakumar *et al.* 2001). The winter monsoon (November-March) deep-sea shrimp fishery appeared promising in its initial phase with increasing number of fleets as well as landings. However after the initial booming phase, the landing as well as fleet size showed a declining trend and at present (CMFRI Annual report 2015) the landing has reduced to 722 tons in Kerala.

In parallel with the deep-sea bottom trawl fishery, long lining for deep-sea chondrichthyan resources emerged as a new fishery in the southwest coast of India. Fishery started with incidental landing of deep-sea sharks, which slowly progressed and established a 50% share to the total chondrichthyan landing at Cochin during the year 2006-2007 (Akhilesh *et al.* 2011). Most of the deep-sea shark landings were contributed by the deep-sea going artisanal fishermen of Thoothoor (Kanyakumari district). The fishery has a fleet size of about 588 mechanized boats of Thoothoor (overall length: 12 to 24 m) employing about 6,000 fishermen. They have been fishing through the entire west coast of India (migratory fishing) for oceanic as well as deep-sea resources mainly the tunas, sharks and bill fishes. They are highly specialized in deep-sea shark fishing in mechanized vessels by using long lines for deep-sea sharks especially at depths between 100-300 m. The deep-sea fishing activities of indigenous fishermen have significantly contributed to the marine fish production and changes in its composition by the addition of new fishery commodities such as oceanic tunas, bill fishes, oceanic and deep-sea chodrichthyans, cuttlefishes, deep-sea prawns, lobsters and fishes.

While ban on issuing new deep-sea fishing license for foreign vessels exists as per the recommendations made in Murari committee report, Government of India (Ministry of Commerce and Industry) under the EXIM (Export-Import) policy of the in 2000-01 permitted import of fishing vessels through the special import license scheme. Conflicts in government policies and dispute among various stakeholders of the sector forced the government to develop an integrated policy for this sector fulfilling the national objectives. The committee constituted in this regard framed a Comprehensive Marine Fishing Policy in 2004 (CMFP 2004), by bringing the traditional and coastal fishermen also in to the focus together with stakeholders in the deep-sea sector so as to achieve harmonized development of marine fishery both in the territorial and extra territorial waters of our country. After a period of 10 years of long gap, an expert committee for 'Comprehensive Review of the Deep Sea Fishing Policy and Guidelines (CDFP&G 2014)' was constituted under the policy of 'Blue revolution' for sustainable exploitation of the fisheries wealth from the marine and other aquatic resources of the country. Recommendations made by CDFP&G 2014 also invited criticism from both the fishermen community as well as the scientific community.

At present registration of all Indian fishing vessels are made through the provisions in the Merchant Shipping Act as amended in 1983 (MSA 1983). Regulation and licensing of fishing vessels up to 20 m Over All Length (OAL) within the territorial waters are dealt under the state's Marine Fishing Regulation Act (MFRA). Deep-sea vessels (above 20 m OAL) are operating by Letter of Permit (LOP) issued under various 'deep-sea fishing policies'. The fishing pressure towards deep-sea is ever increasing due to overcrowding and resource depletion in the inshore waters along with the growth in technological capabilities of the traditional deep-sea sector to explore deeper waters along with LOP vessels. While the LOP was issued for six categories of fishing vessels targeting specific resources, the traditional deep-sea sector expanded its fleet size targeting nonconventional resources. Additionally fishing activity of both of these sectors are not monitored by any legal instruments.

1.8 RELEVANCE OF THE PRESENT STUDY

Earlier studies on the BBL megafauna of the SEAS mainly addressed the qualitative and quantitative aspects in areas less than 1000 m depth. Results from these studies, clearly indicate high biomass and taxonomic diversity, particularly in the southern areas (ATTC). In addition these assessment surveys were restricted to the upper continental slope regions, mainly the ‘Terrace off Quilon (ToQ)’. A much larger bathyal plateau off Trivandrum, Terrace off Trivandrum (ToT) has gone completely unnoticed, except for few taxonomic samplings by *HMS Investigator* during 1890s. Lack of knowledge on the deep-sea megafaunal community of ToT limits our understanding on deep-sea biodiversity as well as its contribution towards the wider structure and function of deep-sea ecosystems in the southwest coast of India.

The ATTC is expected to have rich biodiversity comprising of faunal assemblages with unique adaptations that permit successful occupation of these hostile habitats. The presence of several gigantic species in our collections from the ToT area, justify this assumption. The bottom fauna of ToT exclusively depend on the organic matter exported from the euphotic zone and are therefore vulnerable to even subtle changes in surface productivity. Surface productivity of ToT area show very high seasonal variability associated with the seasonal reversal of surface currents, meandering of WICC, intrusion of low saline surface waters and formation of cold core/ warm core eddies etc.

Overlapping parts of the ATTC such as the Wadge Bank and the Quilon Bank are subjected to intense bottom trawling. These destructive fishing practices carried over the past few decades have led to the sharp decline in the catches from these rich fishing grounds. The possible existence of meta-populations within the ATTC need to be ascertained. Similarly, large quantities of marine debris seem to get deposited in the bottom sediments of ToT. The presence of fresh grass, palm leaves, plastic wastes, fishing gear accessories, cans etc in the trawl catches (Figure 1.2) obtained during the present study indicate the immense risks to which the deep sea ecosystem of ToT is exposed. The ATTC and the coastal areas associated with it are the main spawning and nursery grounds of several species of fishes including the Indian mackerel and oilsardine. Many of the facts stated above falls under the criteria chosen by CBD to delineate EBSAs and MPAs. Results from the present study can provide scientific information to assess such requirements.

Figure 1.2. Marine debris deposits recovered in the trawl catches from ToT, collection locations are: a. sea anemone attached to a PVC pipe, b Oil drum, c. bottle, d. garbage bag, e. banana palm, f. green grass, h. clothes and tooth paste, i & j. coconut husk, k. plastic bags.

Quantitative and qualitative information on the megafaunal diversity, its community structure and ecological linkages are essential prerequisites for any management measures for its sustainable use and protection. In this regard, international efforts under the Convention on Biological Diversity (CBD), to which India is a Party demands the collection, documentation and synthesis of data and information on relatively unexplored and ecologically sensitive areas, such as seamounts and the deep-sea regions for setting up conservation priorities in the form of Marine Protected Areas (MPAs) and EBSAs (Ecologically or Biologically Sensitive Areas). Against this backdrop, the present study was undertaken within the 1,500 m depth zone of ToT with focus on the biodiversity and ecology of deep-sea megafauna of Terrace Trivandrum (ToT), based on bottom trawl surveys of FORV *Sagar Sampada*. Specific objectives of the present study are to;

- Document the diversity and distribution of deep-sea megafauna.
- Explain the megafaunal biodiversity and community structure.
- Estimate standing stock and trophic organization of deep-sea megafaunal community
- Explain the ecology of deep-sea megafauna and correlate it with the environmental settings of ToT.

1.9 OUTLINE OF THE THESIS

Chapter 1: General Introduction

This chapter provides an overview of the study area, its oceanographic settings and major research highlights on the deep-sea megafauna of SEAS, including policy guidelines. The significance, relevance and objectives of the present work are explained.

Chapter 2: Study area, sampling and analysis

In this chapter, the study area is described with sampling locations and detailed explanation on the sampling methodologies adopted. The methods used to study the biology, for quantification of megafauna and statistical approaches used to describe the megafaunal community structure are also explained.

Chapter 3: Deep-sea megafauna of Terrace off Trivandrum: Taxonomy and faunal composition

This chapter addresses the taxonomic composition of the deep-sea megafauna of ToT and highlights its unique biological features such as deep-sea gigantism exhibited by the various taxonomic groups. A checklist of all megafaunal species collected during the survey, their distribution and taxonomic remarks are also provided along with photographic plates.

Chapter 4: Biodiversity and community structure of the deep-sea megafauna of Terrace off Trivandrum

This chapter discuss the biodiversity patterns of megafauna of ToT, based on univariate and multivariate statistical analyses and illustrates changes in megafaunal community structure of ToT in relation to the Summer and Winter monsoon seasons, depth as well as between sampling locations.

Chapter 5: Biology, standing stock and trophic structure of deep-sea megafaunal community of Terrace off Trivandrum

The chapter address the distinctive biological features of the ToT megafauna viz. biological associations, body proportions and size of dominant species, spatio-temporal variations in the standing stock of megafauna, trophic relations and delineation of vulnerable non-conventional fishery resources.

Chapter 6: Ecology

This chapter addresses the findings observed in the preceding chapters viz. unique and unusual patterns of megafaunal diversity, biology, standing stock and trophic relations of ToT from an ecological perspective of the South Eastern Arabian Sea. The uniqueness and distinctiveness of the ToT megafauna and its habitat are subjected to a critical evaluation following the criteria adopted by CBD in the delineation of Ecologically and Biologically Sensitive Areas (EBSAs)/ Marine Protected Areas (MPAs).

Chapter 7: Summary and Conclusion

This chapter summarizes the salient findings of the study, and gives recommendations and suggestions for future work.

Chapter - 2

STUDY AREA, SAMPLING AND ANALYSIS

2.1 STUDY AREA

The continental slope off the west coast of India is relatively steep, narrow and parallels the trend of the continental shelf edge. However the continental slope is characterized by the presence of anomalous broad lateral bathymetric protrusions (Figure 2.1). The anomalous, terrace like feature of the south western continental margin of India, located in the mid-continental slope region approximately south of the latitude of Kochi, and is collectively named by Yatheesh *et al.* (2013) as 'Alleppey Trivandrum Terrace Complex (ATTC)'. The ATTC covers totally an area of >35000 km^2. The ATTC contains two large contiguous terrace like features, the smaller of which is the well known as Quilon Bank, lying approximately between latitudes of Alleppey and Quilon extending from shelf edge to about 800 m depth, and also referred as 'Terrace off Quilon (ToQ)' (Rao and Bhattacharya 1975) or 'Alleppey Terrace (AT)' (Singh *et al.* 1999). The larger anomalous bathymetric protrusion had not drawn much attention of researchers till its delineation as 'Terrance off Trivandrum' (ToT) by Yatheesh *et al.* 2006.

The 'Terrance off Trivandrum' (ToT) is located approximately south of the latitude of Trivandrum (6°30'N to 8°30'N and 75°30'E to 77°00'E) further off the well known fishing ground of the Wadge Bank. ToT occupies bathyal depths between 900 - 2000 m, and covers an area of approximately 25,000 km^2. Multichannel seismic reflection studies (Yatheesh *et al.* 2013) depicted the entire continental basin of ToT as filled and blanketed with thick layer of sediment of approximately 1.27 km thickness (approximately 1.7 sec two way travel time). Under this huge sediment trap, ToT depict an undulating continental basement with a basement-high in its central part, gently sloping easterly and relatively steeper in the westerly surface. The apparent flatness of the top-terrace region is due to the blanket of thick sediment cover over the uneven continental basement.

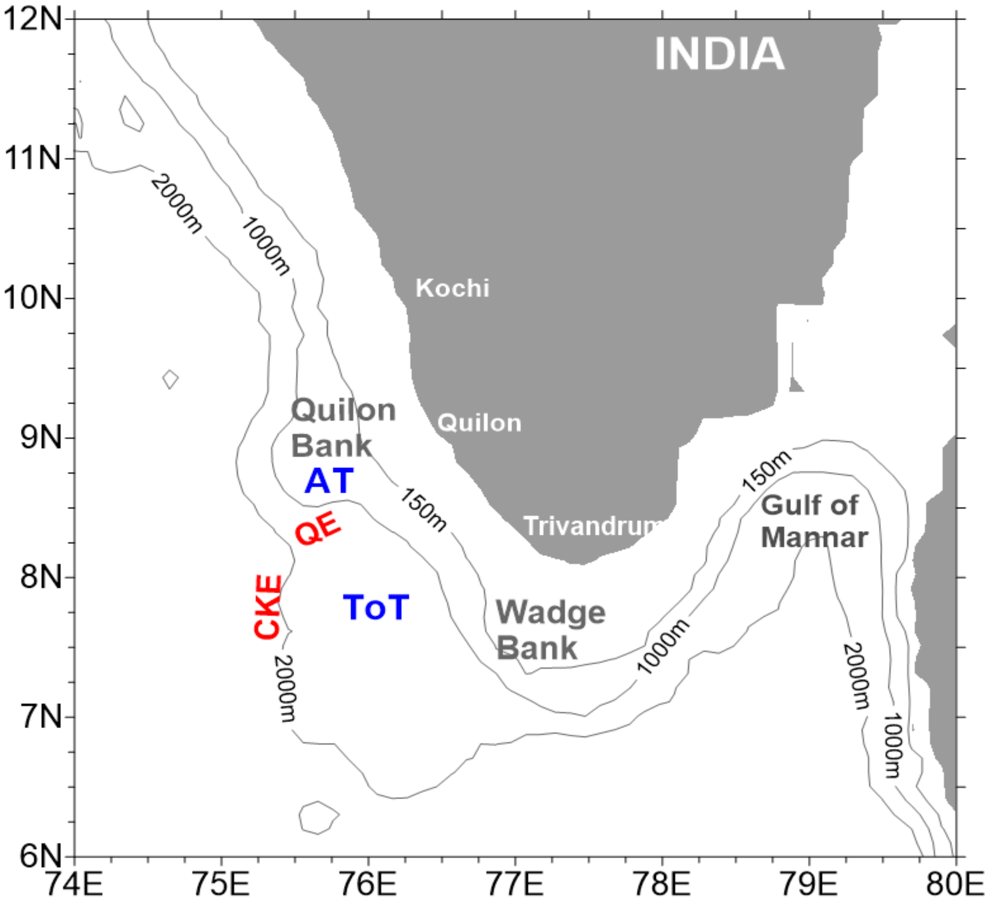

Figure 2.1. Geomorphological features of Alleppey-Trivandrum Terrace Complex (adopted from Yatheesh *et al.* 2013) and modified to include Wadge Bank, Quilon Bank and Gulf of Mannar.

2.2 SAMPLING OF MEGAFAUNA

Systematic bottom trawl surveys were carried out on board *FORV Sagar Sampada* (FORV-SS) for the quantitative and qualitative coverage of the deep-sea megafauna of ToT. In total, 14 bottom trawl operations were carried out in the study area involving 8 cruises on board FORV-SS (Figure 2.2). The surveys were focused to collect random samples from the study area covering two major seasons namely: summer monsoon

(SM) and winter monsoon (WM). The selection of trawl stations were made at random in such a way to ensure coverage of different depth strata's as well as geographical extensions in every cruise. The present operational capabilities of *FORV Sagar Sampada* limit the maximum possible bottom trawl operations to 1500 m and hence samplings of the present study were restricted to the upper terrace of Trivandrum (800-1500 m). Sampling locations (Figure 2.3) of bottom trawled stations are given in Table 2.1.

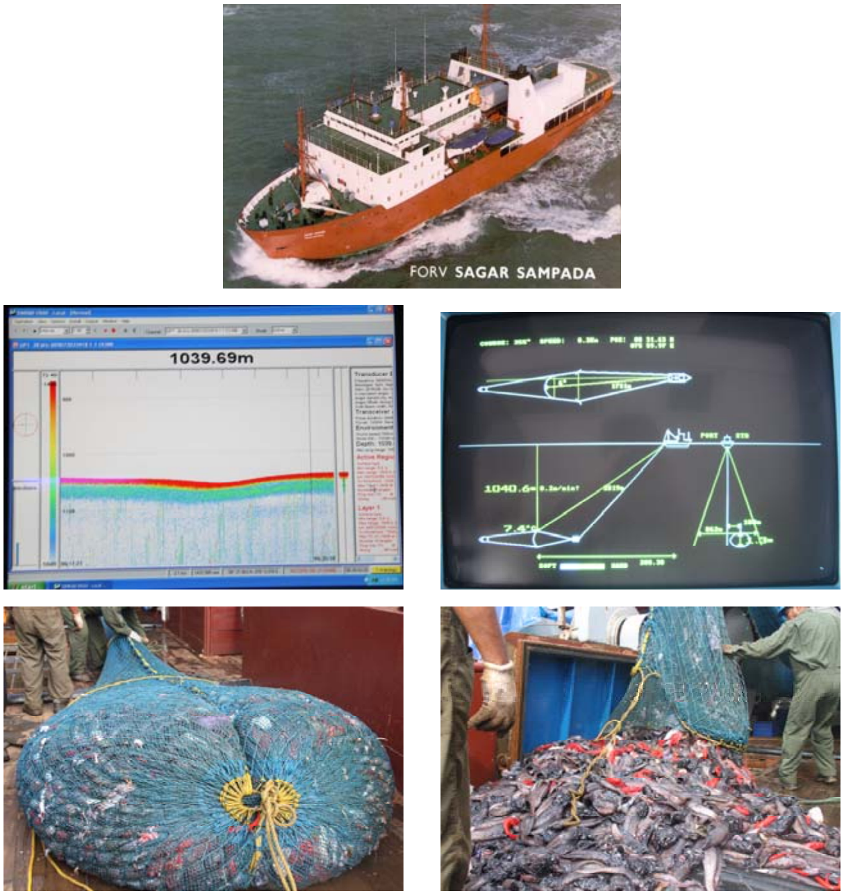

Figure 2.2. a) Research Platform FORV *Sagar Sampada*, b) Screenshot of Echo sounder during operation, c) Screenshot of ITI sensor interphase during net operation d) Cod end of HSDT CV net immediately after landing of catch on board research vessel and e) Transfer of catch to the fish lab.

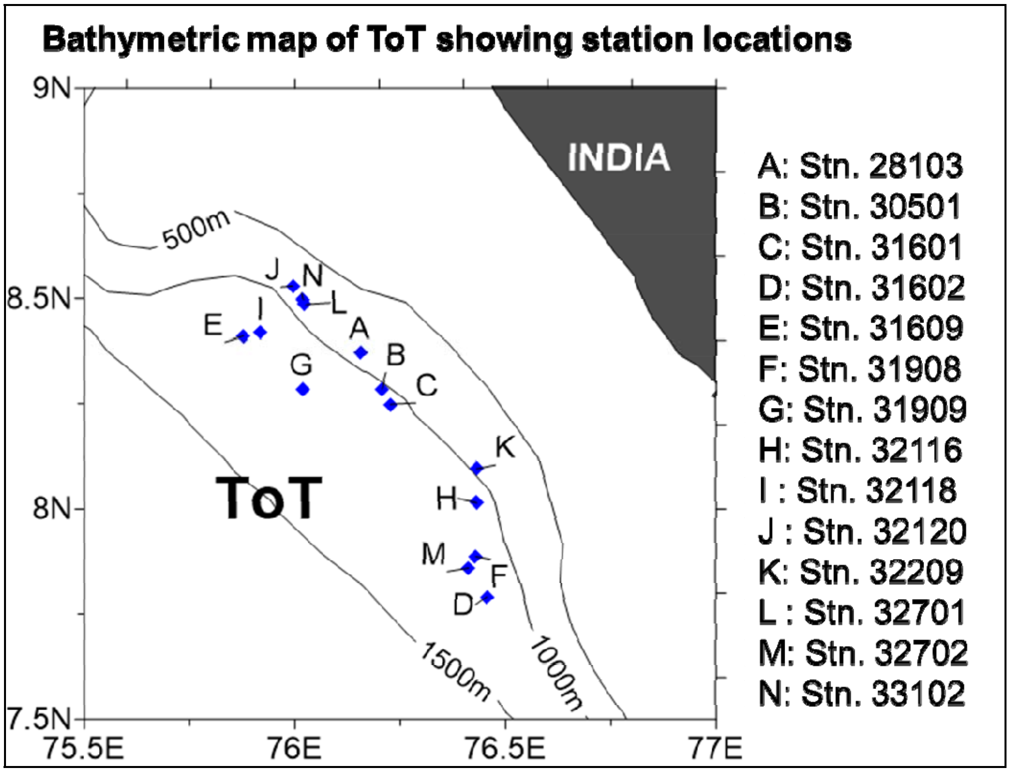

Figure 2.3 Locations of the sampling stations in Terrace off Trivandrum (ToT).

Fishing grounds suitable for bottom trawling operations were delineated through acoustic surveys using SIMRAD EK 60. Trawl grounds were identified parallel to the bathymetric contours and scanning of bottom was performed prior to all operations in order to get a clear picture about the bottom. Though the trawl dragging time was fixed as 1 hour in an even bottom, quite often the trawls were to be hauled up earlier due to the obstruction from seabed or because of strongly opposing under water currents.

Two types of bottom trawls, namely High Speed Demersal Trawl- Crustacean Version (HSDT II CV) and EXPO-Model trawls were employed for sampling of megafauna from ToT. The HSDT II (crustacean version), is an indigenously (by CIFT) developed gear for high speed demersal trawling in the Indian EEZ and successfully field tested from FORV *Sagar Sampada* (Panicker 1990; Panicker *et al.* 1993). It is a

2-warp twin-otters bottom trawling net, 58.6 m in total length with a head rope length of 38 m, foot rope of 44.5 m and cod-end with a stretch mesh size of 30 mm, gradually increasing to 130 mm in the front trawl sections. EXPO model trawl is an imported design operated by Fishery Survey of India (FSI) vessels. The EXPO model has a total length of 79.4 m, with a head rope length of 45.6 m, foot rope 55.8 m and cod-end with a stretch mesh size of 30 mm, increasing up to 400 mm in the belly and wing sections of the trawl.

Table 2.1. Details of sampling locations in Terrace off Trivandrum (ToT)

Station No.	Date	Gear	Start lat.	End lat.	Start long.	End long.	Depth of operation
28103	12-10-2010	HSDT CV	8°22.305'	8°23.951'	76°09.394'	76°07.555'	982-994
30501	19-10-2012	HSDT CV	8°17.133'	8°18.603'	76°12.435'	76°09.662'	1069-1050
31601	14-07-2013	HSDT CV	8°14.910'	8°13.606'	76°13.663'	76°14.265'	1080-1078
31602	15-07-2013	HSDT CV	7°47.482'	7°45.610'	76°27.317'	76°29.119'	1324-1351
31609	17-07-2013	HSDT CV	8°24.611'	8°24.860'	75°52.714'	75°53.850'	1237-1245
31908	09-09-2013	EXPO	7°53.244'	7°51.155'	76°25.768'	76°27.598'	1254-1262
31909	10-09-2013	EXPO	8°17.117'	8°15.283'	76°01.560'	76°01.886'	1275-1311
32116	10-12-2013	HSDT CV	8°00.845'	8°00.819'	76°25.914'	76°25.969'	1154-1151
32118	11-12-2013	HSDT CV	8°25.107'	8°24.226'	75°55.184'	75°56.920'	1241-1247
32120	12-12-2013	HSDT CV	8°31.775'	8°30.290'	75°59.743'	76°01.740'	1047-1043
32209	12-01-2014	HSDT CV	8°29.190'	8°30.450'	76°01.377'	76°00.597'	1031-1037
32701	25-07-2014	HSDT CV	7°51.553'	7°49.589'	76°24.838'	76°25.863'	1060-1067
32702	26-07-2014	HSDT CV	8°29.844'	8°29.953'	76°01.215'	76°01.289'	1334-1360
33102	03-11-2014	HSDT CV	8°05.718'	8°05.985'	76°25.844'	76°25.758'	1024-1030

Remote-sensing transducers (Trawl-sonde, Simrad: FR 500) sensors were attached to the net to estimate opening geometry as well as details of arrival and departure from the bottom. The dimensions of the gear and its proximity with the bottom were constantly monitored using the signals from Trawl-sonde. Vertical opening of the gear (HSDT II-CV) varied between 1.2 and 2.0 m and the horizontal opening between otter boards was between 70 and 90 m. Sampling efficiency of these two gears in FORV *Sagar Sampada* was evaluated by Boopendranath *et al.* (1996) and its standardization for the assessment of deep-sea megafauna onboard has been established. Diagrammatic representations of the sampling gears are given in Figure 2.4.

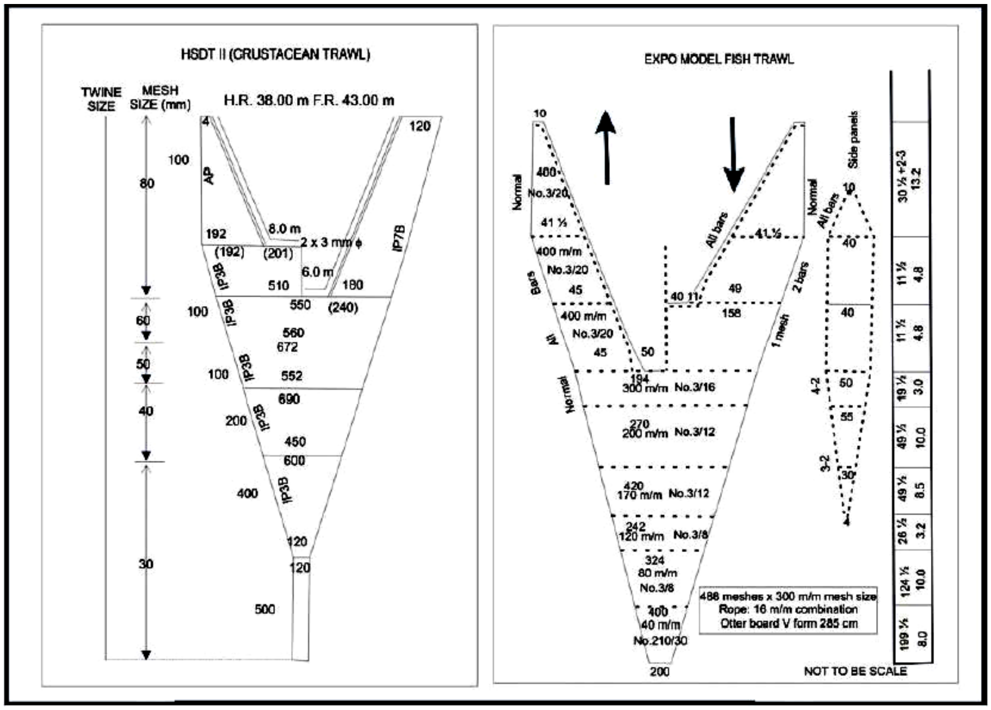

Figure 2.4 Diagrammatic representation of the sampling gears HSDT CV and EXPO

Perfect (Denmark) economy model V-shaped otter boards of 285x126 cm, approximately 2800 kg weight per set with through flow and square keel and weathering surface, connected to the net mouth with a wire rope of length of 50 m were used for all operations. During operations the trawl was dragged at speeds between 2–3 knots depending on the depth and resistance from bottom currents. The ratio of the wire paid out (warp out) to depth was approximately 2:1. All hauls were made during daylight hours, so that no bias was introduced by differential fish behavior between day and night.

Simultaneous to the collection of megafaunal samples, observations were also made on physicochemical characteristics of seawater (temperature, dissolved oxygen, salinity) as per standard procedures using the on-board CTD (SBE 911 Plus). Texture of sediment samples entrapped in otter board during the bottom trawl operation at (Stn. 31602) were analyzed using a particle size analyzer. Organic carbon content was estimated by the wet oxidation method of El-Wakeel and Riley (1957) which was then converted into organic matter (Trask 1939).

2.3 TAXONOMIC ANALYSIS OF MEGAFAUNAL SAMPLES

Megafaunal samples landed onboard by bottom trawl operations were sorted up to species level. After preliminary identification, representative specimens for each species were preserved in 8 % formaldehyde, and brought to the shore laboratory for taxonomic identification and voucher specimen deposition with the CMLRE Referral Centre. Taxonomy of major megafaunal invertebrate group the Crustaceans and vertebrate group, Pisces were carried out with appropriate meristic counts and morphometric measurements were made either by projection on a ruler or by caliper to the nearest millimeter on preserved specimens in the shore laboratory. The species identities were established based on taxonomic keys, as well as descriptions available in monographs and recent literature. Identities were ascertained and confirmed after a detailed comparison of morphometric and meristic features, with its type specimens. Other megafaunal invertebrate groups such as Cnidarians, Molluscs and Echinoderms were identified in consultation with colleagues and experts working on the corresponding taxon. Species taxonomy was retrieved and updated from the World Register of Marine Species (WoRMS). Voucher specimens for each species collected from the study area were given a unique code and deposited with the Referral Centre, CMLRE- Kochi.

2.4 ESTIMATION OF MEGAFAUNAL STANDING STOCK

Megafaunal samples from bottom trawl operations were sorted and segregated to species level to the best extent possible. Number of individuals (Cn) present in each megafaunal species lot was counted to find its numerical abundance. Catch in weight (Cw) of each megafaunal species lot was taken using marine scale with an accuracy of 0.5 g for obtaining its biomass. Number of individuals (Cn) and catch in weight (Cw) of each megafaunal species were standardized in to absolute density for an area of 1 km^2, following the catch per unit area (CPUA) on the basis of the 'area swept' (Sparre and Venema 1998). Absolute density of biomass and numerical abundance were calculated as,

Numerical abundance (n) $= \frac{Cn}{a}$ Individuals/km^2

Where

$Cn =$ Number of individuals in catch (Individuals)

a = swept area (km^2)

Biomass (b) $= \frac{Cw}{a}$ kg/km^2

Where

Cw = Catch in weight (kg)

a = swept area (km^2)

The "*swept area*" or the "effective path swept" is defined as the area which is the length of the path times the width of the trawl. The swept area, a, is estimated as:

Swept area, $a = D \times hr \times X2$

Where:

D = Distance covered by trawl (estimated in nm and converted to km)

The distance covered by the trawl (D) estimated in units of nautical miles (nm), calculated using the formula:

$$D = 60 \times \sqrt{(Lat1 - Lat2)^2 + (Lon1 - Lon2)^2 \times \cos^2(0.5 \times (Lat1 + Lat2))}$$

Where:

Lat1 = latitude at start of haul (degrees)
Lat2 = latitude at end of haul (degrees)
Lon1 = longitude at start of haul (degrees)
Lon2 = longitude at end of haul (degrees)

hr = Head-rope length, 38 m for HSDT and 45.6 m for EXPO model trawl.

X2 = The fraction of the head-rope length, (hr), which is equal to the width of the path swept by the trawl.

The (hr*X2), known as "wing spread", is the effective horizontal trawl opening. The ‘wing spread’ varies with hauling speed, weather conditions, current velocity and direction as well as warp length, and is therefore not well defined. Even though the ‘wing spread’ had been monitored using remote sensing transducers (Simrad: Net sonde), it varied with hauling speed, weather conditions, current velocity and direction and warp length. Hence in the present study the value of the fraction of head-rope length, X2 is taken as 0.5, suggested as the best compromise for tropical waters by Pauly (1983).

2.5 TROPHIC GUILD

Trophic guilds within the BBL of ToT were established following Root (1967), by combining ‘diet categories’ on which the megafauna depend upon and ‘feeding strategies’ adopted for feeding. The classification proposed here is a modified version of trophic guild classification of deep-sea fishes proposed by Gartner *et al.* (1997). The categorization was done based on both the direct observations on gut contents or from literature on diet composition and functional (trophic) traits of organism, considering both morphological and behavioral specialization for acquiring food. Body cavities of abundant deep-sea fishes were opened for direct observations on the diet composition in the alimentary tract. Diets were analyzed largely from intestinal contents rather than from stomach. This is necessitated by general possession of gas-filled swim-bladders in these species, which often causes eversion of stomach during ascent to the surface. The relative contribution of each food type to the total diet was expressed in percentage of Index of Relative Importance (IRI) following (Pinkas *et al.* 1971). IRI was calculated for each prey type from the formula: $IRI = (N + V) F$. Where, N is the percentage of numerical abundance (the number of individuals of each type of food expressed as a percentage of the total number of food items found in all stomachs), V is the percent volume (the volume of each food type expressed as a percentage of the total volume of food from all stomachs) and F is the percent frequency of occurrence (the number of stomachs in which a food type occurred expressed as a percentage of the total number of stomachs containing food). For the megafaunal species where diet data was not available it was taken from published information. Based on the 'diet categories' and 'feeding strategies' of each species to gather its food, deep-sea megafaunal species were grouped in to 11 trophic guilds. The details of these guilds are presented in chapter 5.

2.6 LENGTH WEIGHT

Length weight relationship of fishes and crustaceans were established for abundant deep-sea fishes and crustaceans collected from ToT. Specimen length was measured to the nearest 1 mm (total length or standard length or carapace length in case of crustaceans) and weighed to the nearest 0.1 g (weight, W). The relationship between the length and weight is expressed by the equation $W = a \times L^b$ (Le Cren, 1951; Ricker 1973) where W is body weight, L is total length, 'a' and 'b' are constants (Beverton and

Holt 1957). Archived data of length and weight of deep-sea fishes of SEAS collected during FORV *Sagar Sampada* cruises were also used for the comparison of growth patterns of deep-sea fishes from different depth stratum.

2.7 DATA ANALYSIS

In the present study, the 14 stations were represented with 5 digit numeric code: the first three letters representing FORV *Sagar Sampada* Cruise number and last two digit indicating sampling station number. Progressive depth categories were taken with 100 m intervals, to elucidate change in relation to bottom depth. Two major seasons, Summer monsoon (SM) and Winter monsoon (WM) were taken to test the temporal changes. Sampling at station 31909 partially failed due to net damage, hence the data from this station was omitted during quantitative analysis, but the samples retrieved were included for taxonomic studies.

Statistical software, PRIMER 6+ (Plymouth Routines in Multivariate Ecological Research) and SPSS 20 were primarily used for statistical analysis. SURFER-11 was used to plot and visualize the bathymetry of the region, utilizing Indian Ocean bathymetric data, modified ETOPO2 (Sindhu *et al.* 2007).

Biodiversity and community structure analysis were carried out using the Plymouth Routines in Multivariate Ecological Research package-6 (PRIMER-6) (Clarke and Warwick 2001). Numerical abundance (Number/km^2) data matrix of megafauna, prepared from the species composition at each sampling site, was used as input for analysis using PRIMER software. Sampling sufficiency in the study area was tested using species accumulation plot. The plot generated by this tool shows the number of new species added to the total species list with addition of samples. Based on observed curve pattern in the species accumulation plot, species predictors (such as Chaos1, Chaos2, Jacknife1, Jacknife2, Ugland-Grey or UGE and Michleis-Menten estimators in PRIMER 6) were used to estimate the number of species which could be encountered when the sampling approach to infinity (reviewed in Magurran 2013). Alpha-diversity indices, viz. species richness (Margalef's index, d), Species rarefaction (ES100), Species equitability (Pielou's index, J'), species diversity (Shannon-Weiner index, H'), taxonomic distinctiveness (delta) and phylogenetic diversity (sPhi+) were computed for each sampling locations using DIVERSE tool. Dominance plot tool was used to get a picture on the cumulative dominance over the total species observed in each samples. Species richness and rarefaction are measures of total number of species present in a given number of individuals, while species equitability or evenness shows how evenly the individuals are distributed among the different species and species diversity shows the distribution of species in a given number of individuals. Taxonomic distinctiveness gives the average path length in the taxonomic tree between every pair of individuals in a sample. It is a variant of the Related Shannon-Weiner diversity index (H'), which additionally incorporates taxonomic separation between the species. The phylogenetic diversity (sPhi+) is a straightforward measure of total branches (or total path length) in the full taxonomic tree of each sample, which is indicative of the degree of taxonomic diversification.

Taxonomic distinctiveness, B+ (PRIMER 6) between stations was used to assess patterns of beta diversity. The similarity was calculated using square-root transformed (in order to normalize the variations between samples) species abundance data, in order to assess to group the samples with similar community composition or ecological conditions, following the procedure described by Clarke and Warwick (1994). Significance of variations among sites, based on factors such as depth class and seasons, were tested using Analysis of Similarity (ANOSIM), using the Bray-Curtis similarity matrix. The similarity matrixes were used for cluster analysis and non-metric multidimensional scaling (n-MDS) ordination, employing group average linkage (Ludwig and Reynolds 1988). SIMPER tool was used to identify those species that most typify the grouping in the cluster and MDS analysis. Based on direct observations on their feeding habits and information available from literature, all species of the study area were classified into 11 ‘trophic guilds’, in order to assess the overall trophic organization of the communities in the study area. This was done by pooling the abundance of species into 11 guilds and performing the above mentioned statistical analyses on the pooled dataset (i.e. Bray-Curtis similarity, nMDS, cluster analysis, ANOSIM, SIMPER etc.).

Data on sediment texture and organic matter from the upper slope region of ToT and adjacent areas were taken from the benthic data (Damodaran 2010; Abdul Jaleel *et al.* 2014) generated during the 10th and 11th plan period of Marine Living Resource (MLR) program of CMLRE. Surface primary production trends in the study area were gathered from FORV Data Centre (Nair *et al.* 2010; Sanjeevan *et al.*2013). Available reports on deep-sea resources and biomass from the south west coast of India (Survey reports of Fishery Survey of India, Sudharsan *et al.*1998; Survey report of FORV *Sagar Sampada*, Somvanshi *et al.*2009) were taken for comparison with the study area.

Chapter - 3

DEEP-SEA MEGAFAUNA OF TERRACE OFF TRIVANDRUM: TAXONOMY AND FAUNAL COMPOSITION

3.1 INTRODUCTION

The largest biome of planet earth, the deep-sea is increasingly threatened by human impacts, such as over fishing, pollution, deposition of waste and deep-sea mining (Ahnert and Schriever 2001; Glover and Smith 2003). The biodiversity crisis arises because world events threaten to destroy much of the evidence of evolution of biological diversity before it can be discovered and described (Hodkinson and Parnell 2007). The necessity and urgency to describe and catalogue the species diversity of the world oceans is therefore well recognized. Taxonomy, which is the science that catalogues the fundamental unit of diversity, i.e. the species, is faced with numerous impediments (Wheeler *et al.* 2004; Agnarsson and Kunther 2007; Zhang 2008). According to Wilson (1985) “taxonomy can justly be called the pioneering exploration of life on a little known planet". The goal of discovering, describing, and classifying the species of our planet assuredly qualifies as big science (Wheeler *et al.* 2004). Without taxonomy, phylogeny is impoverished (Wheeler 2004; Korf 2005), ecology is deprived of one its fundamental units of currency (Gotelli 2004), and conservation biology loses focus and aim (Godfray and Knapp 2004; Mace 2004). The fauna of deep-sea habitats of world oceans are generally poorly sampled and poorly described.

The documentation of deep-sea biodiversity is a difficult task considering the technological as well as economic challenges in obtaining biological samples, especially the mobile forms such as megafauna. Recent technological advances in sampling the deep sea led to the description of a great many species new to science at a time when the pool of taxonomic experts is dwindling (Godfray and Knapp 2004). Large deep-sea sample repositories require expert review, so as to correct errors arising from poorly understood levels of variation and classifications influenced by outdated assumptions. As with ecology, deep-sea research is badly in need of more effective and less subjective taxonomy (Gotelli 2004). Improved knowledge of deep-sea faunal distribution, driven by either scientific questions or regulatory necessity, is absolutely dependent upon the consistent and correct identification of species (Carney 2005).

The documentation of biological diversity and distribution pattern of species are essential for developing ecologically representative systems of protected areas, as envisaged in international agreements such as the Convention on Biological Diversity (CBD) (Spalding *et al.* 2007). Census of Marine Life (CoML), was a 10-year (2000-2010) international effort undertaken in this regard to document the biological diversity, distribution, and abundance of marine life engaging some 2,700 scientists from around the globe. These efforts produced the most comprehensive inventory of known marine life ever compiled and cataloged, forming a foundation for future research, with more than 30 million species-level records. One of the major achievements of CoML is the world’s largest online repository of geo-referenced data for marine species, the Ocean Biogeographic Information System (OBIS), which nations can use to develop national and regional assessments and to meet their obligations to the conservation of biological diversity. The Indian Ocean Biogeographic Information System (IndOBIS) is one of the seven regional nodes of OBIS, which is responsible for the collection, collation, and dissemination of data about the biodiversity in the Northern Indian Ocean region. The Centre for Marine Living Resources and Ecology (CMLRE), Ministry of Earth Sciences, is the recognized nodal center for IndOBIS.

Local and regional species checklists are in demand for conservation and fisheries management, ecological surveys, and training in marine ecology (Costello *et al.* 2013). However, these lists are inevitably compromised by either not being updated by experts, by inheriting past misuse of names, by using the same name for dissimilar species in different locations, by using differing names for the same species in different regions, or, by combinations of these problems. The recent trends in rapid ecological assessments and the sole dependence on molecular tools for species identification, undermine fundamental taxonomy and often the lack of voucher specimen terminates the possibility of conducting taxonomic confirmation or correction.

Most modern marine ecological studies make use of ‘bad taxonomy’ which are devoid of any supporting information justifying or guaranteeing the correctness of identification of the organisms studied or manipulated to generate primary errors which cascade in final ecological assumptions of the study (Bortolus 2008). Additionally such reports diminish the quality of advanced digital databases such as OBIS and National Centre for Biotechnology Information (NCBI), which are meant to directly or indirectly document the diversity of life on earth. Unless the biological studies are strongly rooted on correct taxonomic documentation, the recent technological and computational skills will prove redundant.

Taxonomic documentation of deep-sea biodiversity started after the circumglobal expedition of HMS *Challenger* during 1872-1876. Several expeditions followed the *Challenger* in describing, illustrating and documenting the vast biodiversity of the deep-sea. Studies on the taxonomy of deep sea megafauna of Indian continental slope span over a century. A wealth of valuable information on the marine fauna of India was amassed during the pre-independence period, through the RIMS *Investigator* surveys, particularly in the case of deep-sea megafauna. The reports include monographs on deep sea fishes (Alcock 1899a), macrura and anomala (Alcock 1901); account on deep sea brachura (Alcock 1899b), madrepora (Alcock 1898), alcynorians (Thomson and Henderson 1906), several reports on classes of echinoderms (E.g. Alcock 1898; Koehler 1898, 1927; Koehler and Vaney 1905, 1910) etc.

After independence, the research focus on deep-sea megafauna got shifted to fishery resource assessment rather than taxonomy. Several exploratory surveys were carried out to assess the fishery resource potential in the continental slope region of Indian EEZ, especially off southwest coast of India. Some of these studies documented the faunal diversity of deep-sea megafaunal groups (Tholasilingam *et al.* 1964; Tholasilingam *et al.* 1968; Silas 1969; Mohammed and Suseelan 1973; Suseelan 1974; Josepth *et al.* 1976; Oommen 1985; Pillai and Sathiarajan 1987; Sivaprakasam 1986; Joseph *et al.* 1987; Sudarsan *et al.* 1988; Sivakami 1989; Suseelan *et al.* 1989; Ninan *et al.* 1992; Feroz Khan *et al.* 1996; Sajeevan and Nair 2006; Sajeevan *et al.* 2009; Jayaprakash *et al.* 2006; Rajasree 2011; Venu 2009; Hashim 2013;Venu 2013). However, most of these surveys on the taxonomy and megafaunal diversity were restricted to 1000 m depth zone, and the vast expanses of the deep sea including the Terrace off Trivandrum were left out from these studies.

Terrance off Trivandrum (ToT) is a flat anomalous extension of the continental slope off southwest coast of India extending over bathyal depths between Lat. 6.5ºN–8.5ºN; Long. 75.5ºE–77.0ºE (Yatheesh *et al.* 2006). The ToT covers a geographically flat area of approximately 25,000 km^2 between 900 and 2000 m depth contours. Despite being a large terrace located adjacent to the productive Kollam Bank, with suitable topography for bottom trawling, the megafaunal communities, including fishery resources, of ToT have gone unnoticed, without any surveys being done there till date. Terrace of Trivandrum (ToT) is an offshore part of a well-studied eastern boundary upwelling system of the South Eastern Arabian Sea (SEAS), characterized by annually reversing surface currents that are driven by seasonally reversing monsoon winds. Cyclonic (Lakshadweep Low) and anti-cyclonic (Lakshadweep High) eddies prevail in the open ocean waters of ToT and adjacent areas during summer and winter seasons respectively. These eddies are known to produce open ocean upwelling/ downwelling (Rao *et al.* 2008). Hydrodynamic features such as cyclonic/ anticyclonic eddies have profound influence on spatial and temporal variability in primary production and the vertical flux of organic matter and sediments to the deep-sea bottom (Nair *et al.* 1989) which in turn fuel the deep-sea fauna. This upwelling phenomenon triggers various biological processes in the region such as reproduction and growth of many species.

Similarly, the effect of seasonally reversing eddies and surface currents on the biological productivity and benthic faunal assemblages have not been investigated so far. There is absolutely no information on the biology of ToT megafauna, occupying the deep sea habitats below the core region these eddies.

The objectives of this chapter are;

- to taxonomically document the BBL megafaunal diversity within the 1,500 m depth zone area of ToT which remain totally unexplored.
- to document the unique attributes of the deep-sea megafauna of ToT, and
- to compare the biogeograhical distribution of these megafaunal species across world oceans.

3.2 RESULTS

3.2.1 Sampling sufficiency

Sampling sufficiency was tested using species accumulation plot (PRIMER). Species accumulation plots estimates the increasing total number of different species observed (*Sobs*), as samples are successively added (often referred to as the ‘Sobs’ curve). Species extrapolators (Chao 1, Chao 2, bootstrap, Jacknife 1 and 2) attempts to predict the true total number of species that would be observed as the number of samples tends to be infinity (‘the asymptote’ of the species accumulation curve), assuming that a closed community is being successively sampled. These are non-parametric approaches, depending on simple functions of the number of species seen only in 1 or 2 samples (Chao 2, Jacknife 1 and 2), or the number of species that have only 1 or 2 individuals in the entire pool of samples (Chao 1), or the set of proportion of sample that contain each species (bootstrap). Michaelis-Menton (MM) and Ugland-Grey (UGE) are parametric model estimators based on observed number of species (*Sobs*).

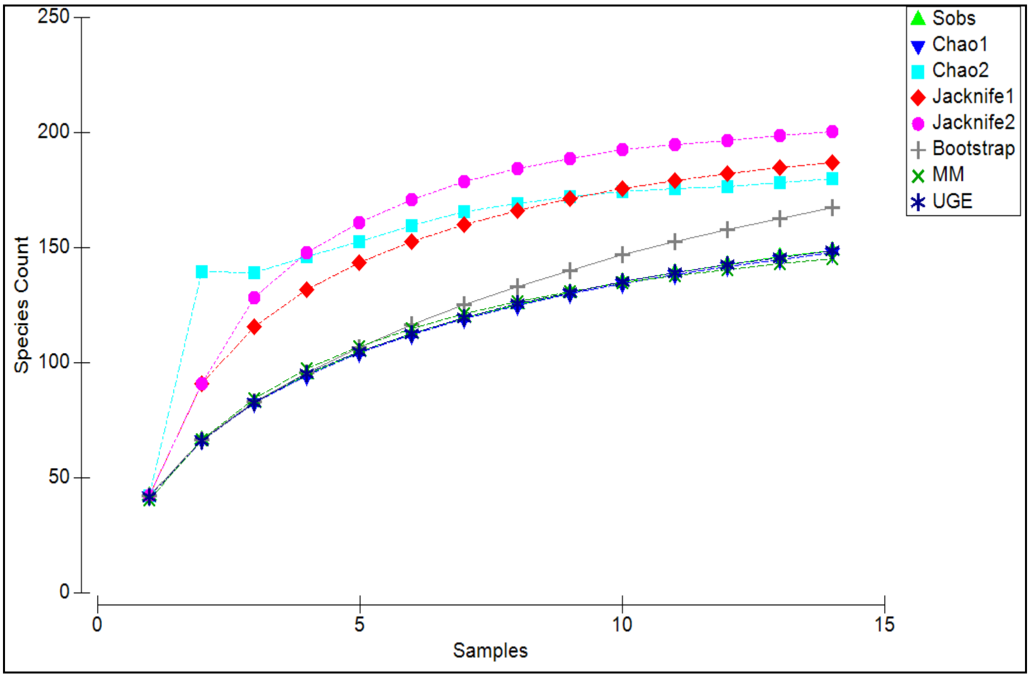

Figure 3.1 Species accumulation plot on estimating taxonomic sampling sufficiency of ToT

Curves showing cumulative number of species-observed (*Sobs*) crossed its exponentially increasing phase and nearly touching the asymptote when the number of samples reaches 14 (Figure 3.1). The trend of *Sobs* curve indicates that the area is well sampled with the present level of sampling effort. Statistical species number estimators, Chao 1, MM and UGE curve progression closely overlap and is therefore treated as a single *Sobs* curve (bottom most curve). However, estimators such as Chaos 2, Bootstrap, Jacknife 1 and Jacknife 2 predict the expected number of species to reach up to 180±13, 167, 187 and 201 respectively upon more intensified sampling from the area (Table 3.1). Thus from the estimator's predictions, the present sampling effort had recoded around 85% of the megafaunal species that could be obtained from this area.

Table 3.1 Values of species estimators

Species observed	**148 Nos.**	
Estimators predictions	**Number**	**% of sampling sufficiency**
Chao 1	165	89.69
Chao 2	180 +/-13	82.22
Jacknife 1	187	79.14
Jacknife 2	201	73.63
Bootstrap	167	88.62

3.2.2 Taxonomic diversity of ToT deep-sea megafauna.

The present study recorded 148 megafaunal species belonging to 122 genera in 86 families, 45 orders, and 17 classes under 5 phylum (Table 3.2).

A check list of all species recorded in ToT is provided at the end of this chapter (Table 3.3) along with information on global distribution and collection locations.

Phylum Chordata was the most species rich group, followed by Arthropoda and Echinodermata (Figure 3.2). Phylum Chordata was represented by 5 classes and among them class Actinoptergii was the most speciose group with 67 species in 55 genera and 31 families under 12 orders, followed by classes Elasmobranchii (10 species), Holocephali (3 species), Myxini (1 species) and Reptalia (1 species). Phylum Arthopoda represented by 2 classes, Class Malacostraca with 30 species (22 genera in 16 families and 2 orders), and class Pycnogonida with 1 species. Phylum Echinodermata was represented by 4 classes, among them Class Asteroidea was the most species rich group with 10 species in 8 genera. 5 families under 4 orders, followed by classes Ophiuroidea with 4 species, Echinoidea (2 species) and Holothuroidea (2 species). Phylum Mollusca was represented by 3 classes, among them Class Cephalopoda and Gastropoda were represented by three species each followed by classes Bivalvia with 1 species. Phylum Cnidaria was represented by 3 classes and among them Class Anthozoa was the most speciose group with 6 species, 4 genus, 4 families and 4 orders, followed by classes Scyphozoa (3 species) and Alcyonacea (1 species).

Table 3.2. Taxonomic diversity of megafaunal phyla in the Terrace off Trivandrum

Phylum	Class	No. of Classes	No. of Orders	No. of Families	No. of Genus	No. of Species
Cnidaria		**3**	**8**	**8**	**8**	**10**
	Alcyonacea		1	1	1	1
	Anthozoa		4	4	4	6
	Scyphozoa		3	3	3	3
Arthropoda		**2**	**3**	**17**	**23**	**31**
	Malacostraca		2	16	22	30
	Pycnogonida		1	1	1	1
Mollusca		**3**	**5**	**7**	**7**	**7**
	Bivalvia		1	1	1	1
	Cephalopoda		3	3	3	3
	Gastropoda		1	3	3	3
Echinodermata		**4**	**9**	**13**	**16**	**18**
	Asteroidea		4	5	8	10
	Echinoidea		2	2	2	2
	Holothuroidea		2	2	2	2
	Ophiuroidea		1	4	4	4
Chordata		**5**	**20**	**42**	**68**	**82**
	Actinopterigii		12	31	55	67
	Elasmobranchii		5	7	8	10
	Holocephali		1	2	3	3
	Myxini		1	1	1	1
	Reptilia		1	1	1	1
Total		**17**	**45**	**86**	**122**	**148**

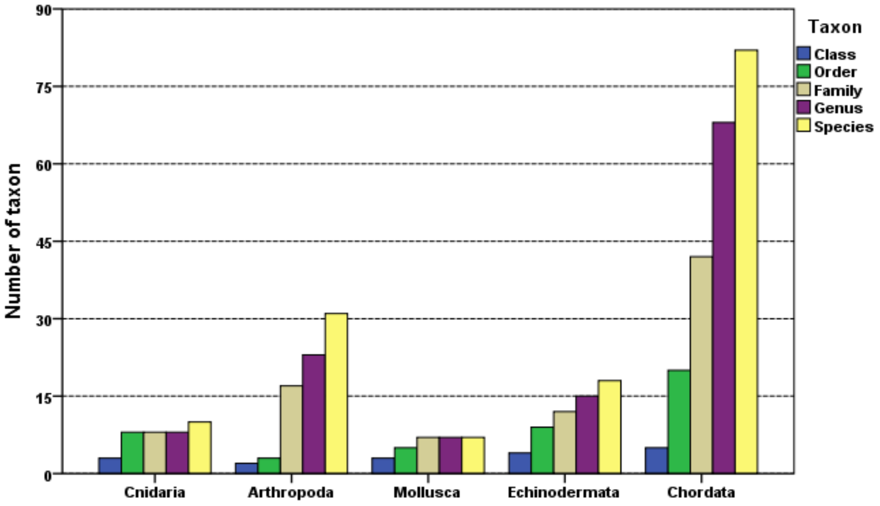

Figure 3.2 Taxonomic composition of megafaunal phyla represented in ToT.

In summary, megafaunal taxa of ToT is best represented by four classes, viz. Actinopterigii (45%), Malacostraca (20%), Asteroidea (7%) and Elasmobranchii (7%) which together contributed 79% of the total species recorded (Figure 3.3). The remaining 13 classes contribute only 21% of the total species.

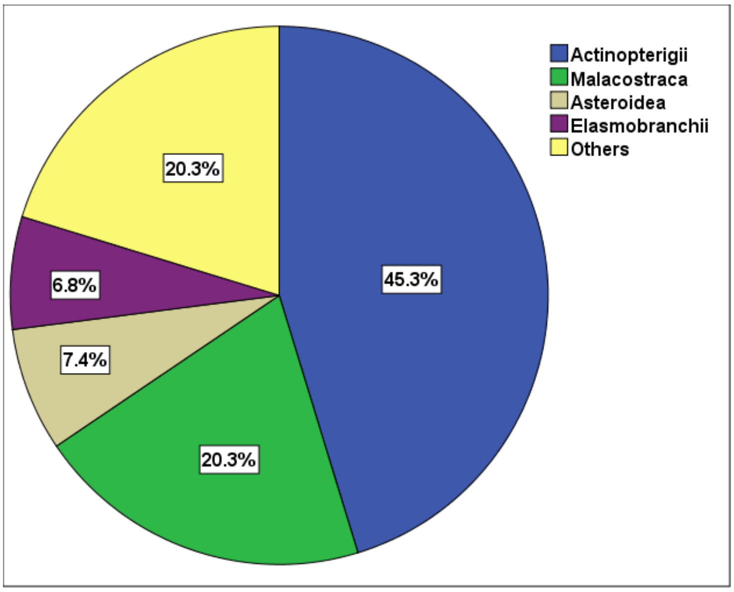

Figure 3.3 Dominant taxonomic classes, representing the major megafaunal taxa of Terrace off Trivandrum

3.2.3 Taxonomic account of the unique megafaunal members of ToT

Taxonomic account of the representative taxa of the five phyla recorded from ToT are presented here, which highlight the unique nature of the habitat. Focus is placed here on biological traits and biogeographic distribution of these taxa, rather than descriptive account. Locations of the sampling stations in ToT are given in Figure 3.4.

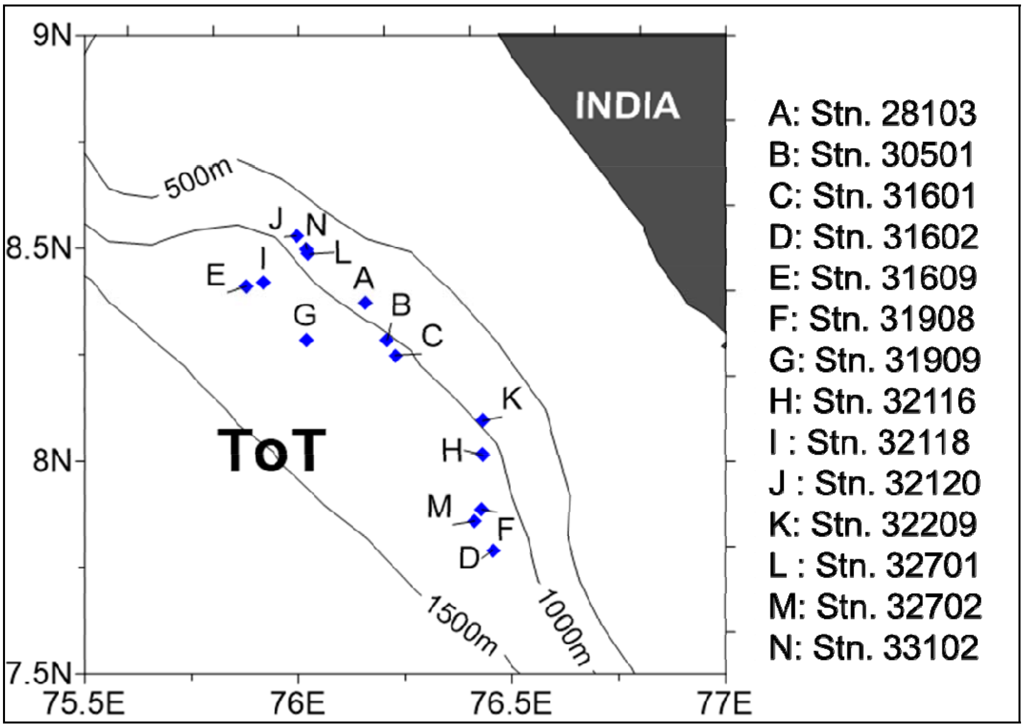

Figure 3.4 Locations of the sampling stations in Terrace off Trivandrum (ToT)

Phylum CNIDARIA

Class ANTHOZOA

Order ZOANTHARIA

***Epizoanthus* cf. *paguriphilus* Verrill, 1883**

Location & Sampling Depth: 31602 (1338 m), 31908 (1258 m), 31909 (1293 m), 32118 (1244 m), 32701 (1064 m).

Voucher Specimen No.: CMLRE 3211805.

Distribution: Order Zoantharia is represented by only one species in the study area. Alcock (1901) had reported *Epizoanthus* species from both the Arabian Sea (Malabar Coast), the Laccadive Sea and Bay of Bengal. The genus *Epizoanthus* shows a Circumglobal distribution with 82 valid species (WoRMS).

Diagnosis: Epibiont on hermit crab shell, advanced stage of association has a cog-like appearance, with up to 18 polyps (Figure 3.5A) radiating outwards (12-15 polyps on the rim, 1-2 on the dorsal and 1 on ventral surface); with a ventral opening through which the hermit crab protrudes (Figure 3.5 B & C).

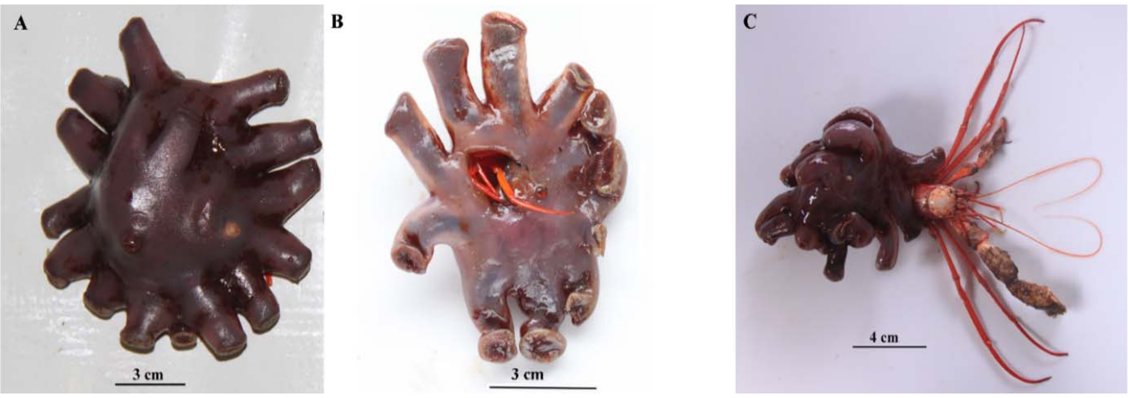

Figure 3.5 *Epizoanthus pagurophilus* A. dorsal view, B. Ventral view, C. Hermit crab protruding from within zoanthid colony

Remarks: The epibiotic zoanthids *Epizoanthus pagurophilus* was a member of a notable biological association. The zoanthids were found encrusting upon gastropod shells occupied by the hermit crabs, *Parapagurus* cf. *pilosimanus*. This association was observed quite commonly in the ToT surveys.

Class ANTHOZOA

Order SCLERACTINIA

Family CARYOPHYLLIIDAE.

***Carryophyllia ambrosia* Alcock, 1898**

Location & Sampling Depth: 28103 (988 m), 30501 (1060 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 33102 (1027 m).

Voucher Specimen No.: CMLRE 3211624.

Distribution: Class Anthozoa is represented in the ToT by the Orders Actiniaria (one species) Pennatulacea (one species) and Scleractinia (3 species). Details on these species are given in Table 3.3. The genus Caryophyllia is the most diverse genus within the azooxanthellate Scleractinia, comprising 66 recent species and a purported 195 nominal fossil species (Kitahara *et al.* 2010). Survey of *RIMS Investigator* off Travancore (ToT locality) reported huge quantities of solitary corals from this locality. The survey naturalist of RIMS Investigator (Anderson) enumerated the catch of a dredging operation off Travancore at 787 m as “nearly half a ton of living and dead coral….. Such a haul I have never seen" (Alcock 1898). Based on the RIMS *Investigator* materials Alcock (1898, 1902) recorded 6 species of *Caryophyllia* from Indian waters viz. *Caryophyllia ambrosia* Alcock, 1898, *C. cinticulata* (Alcock, 1898), and *C. paradoxa* (=*C. paradoxus* Alcock, 1898), *C. ephyala* Alcock, 1901, *C. quadragenaria* Alcock, 1902 and *C. scobinosa* Alcock, 1902 of which *C. ambrosia*, *C. paradoxus* and *C. ephyala* are from the ToT area. In the present study also all the 3 species were obtained from ToT. Details on the deep sea coral *C. ambrosia* is given below.

Diagnosis: Exclusively azooxanthellate. Solitary cornuted corallum. Calice circular or elliptical. One crown of pali present before penultimate or rarely the antipenultimate cycle of septa. Columella fascicular, composed of several twisted laths. Distinguishable from *C. paradoxus* by the presence of elliptical mass of thin curling ribbon-like processes in the collumella (Figure 3.6).

Figure 3.6 *Carryophyllia ambrosia*, corallum and polyp

Remarks: Large number of dead and living *Caryophyllia* spp. corallum is common in the catches from ToT. Non-zooxanthellate corals are usually not reef-building forms; they can be found most abundantly below about 500 m of water. They thrive at much colder temperatures and can live in total darkness, deriving their energy from the capture of plankton and suspended organic particles. The growth rates of most species of non-zooxanthellate corals are significantly slower than those of their counterparts (Piper 2007).

Class SCYPHOZOA

Order SEMAEOSTOMEAE

Family ULMARIDAE

Deepstaria enigmatica

Location & Sampling Depth: 31609 (1241 m), 32701 (1064 m).

Distribution: This is the first report of *Deepstaria enigmatica* from Indian waters. Two species of *Deepstaria* are known to science viz. *D. enigmatica* Russell, 1967 and *D. reticulum* Larson, Madin & Harbison, 1988. The blob like gigantic jellyfish *Deepstaria* sp., with over 2 m bell size, are rarely seen intact. Wrenn (2012) reported an underwater camera footage of the, *Deepstaria* sp. of Monterey Bay Aquarium Research Institute.

Diagnosis: The present specimen, although badly torn, is clearly recognizable as *Deepstaria enigmatica*. It landed onboard as a large sheet of opaque pale brown colored jelly with hexagonal markings (Figure 3.7).

Figure 3.7 *Deepstaria enigmatica* [FORV SS 31609], insight picture: live organism (picture courtesy:www.pinterest.com)

Remarks: They are known as ‘balloon of death’, as they overwhelm their prey and enclose them within their vast medusa (Wrenn 2012).

Phylum ARTHROPODA

In the ToT area, Arthropods are represented by Class Pycnogonidia with one species and Class Malacostraca which include 30 species under the Order Decapoda and one species under Order Isopoda. For full details kindly see Table 3.3.

Class PYCNOGONIDA

Order PANTOPODA

Family COLOSSENDEIDAE

Colossendeis colossea Wilson, 1881

Location & Sampling Depth: 33102 (1293 m), 32118 (1244 m)

Voucher Specimen No.: CMLRE 3190802

Distribution: This is the first record of the species from North Western Indian Ocean. Members of the genus *Colossendeis* prefer cold freezing environments. An extraordinary diversity and richness of *Colossendeis* species is present in the Antarctic and sub-Antarctic seas; and at least 27 species are endemic to the Southern Ocean (Munilla and Soler 2009). The specimen of *Colossendeis colossea* Wilson, 1881 collected from ToT is the largest pycnogonid species known to science, with a leg span of up to 70 cm (Vinu *et al.* 2016). This record of *Colossendeis colossea* from the ToT extends the distribution range of this species into tropical waters of the North Western Indian Ocean.

Diagnosis

Gigantic pycnogonid; proboscis much longer than trunk, with great median and distal swelling; lateral processes well separated and not touching; legs very long; ocular tubercle low and un-pigmented; distal 3 palp segments straight and sub equal; oviger terminus not sub-chelate (Figure 3.8).

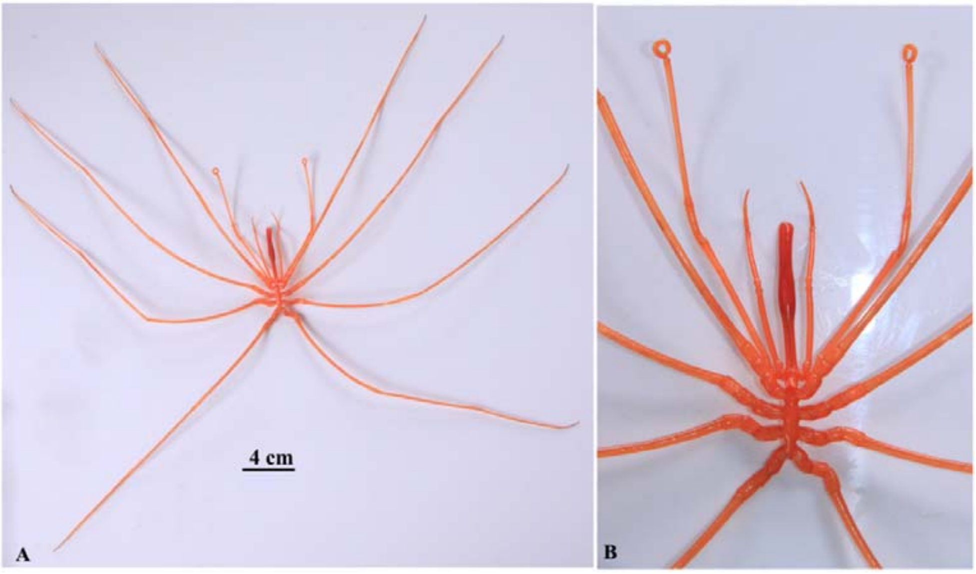

Figure 3.8 *Colossendeis colossea* [FORV SS 31908] A. Entire organism B. Enlarged view of body

Remarks: *Colossendeis colossea* is a parasitic pycnogonid (Gage and Tyler 1991). Sea spiders are generally predators on cnidarians, sponges, polychaetes and bryozoans or scavengers. Use their long proboscis to suck food from cnidarian polyps. Preferred prey animals, such as solitary corals and deep-sea anemones, were also observed in bottom trawl catches along with *C. colossea*.

Class MALACOSTRACA

Order DECAPODA

Family ARISTEIDAE

Genus ARISTAEOPSIS

***Aristaeopsis edwardsiana* (Johnson, 1868)**

Location & Sampling Depth: 28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32120 (1034 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m), 32120 (1034 m)

Voucher specimen No.: CMLRE 2810319.

Distribution: Circumglobal. Formerly reported from Indian waters as *Plesiopenaeus edwardsianus* (Alcock 1901). This species is fished commercially in the south eastern Atlantic (Senegal, Guinea, Congo, and Angola) and south western Atlantic (French Guyana). *Aristaeopsis edwardsiana* is abundantly present in the trawl catches from ToT.

Diagnosis: Scarlet red colored Aristeid shrimp. Monotypic member of the genus. Integument glabrous. Rostrum moderately elongate in females and juvenile males, reaching beyond apex of antennal scale; somewhat shorter in adult males not reaching third antennular peduncle segment, bearing 2 basal teeth followed by single post rostral tooth. Antennal scale of males has an elongate acuminate tip. Carapace with antennal and branchiostegal spines on anterior margin supported by strong carina. Pereopods lacking exopods (Figure 3.9).

Figure 3.9 *Aristaeopsis edwardsiana* [FORV SS 32701]

Remarks: The Aristeid shrimp *Aristaeopsis edwardsiana* is popularly known as the deep-sea scarlet shrimp, and is one of the largest shrimp of the family Aristeidae. Apart from the sexual dimorphism with respect to abdominal appendages, this species also exhibits dimorphism in body size, rostral shape and antennal scales. Males are comparatively smaller in size than females. Total length of male varied from 160 to 250 mm, while female ranged between 200 to 310 mm.

Family NEPHROPIDAE

Genus ACANTHACARIS

***Acanthacaris tenuimana* Spence Bate, 1888**

Location & Sampling Depth: 31908 (1258 m), 32118 (1244 m), 32701 (1064 m).

Voucher Specimen No: CMLRE 3211812.

Distribution: Rarely reported gigantic species**.** Found in the North & South Indian Ocean, Northwest Pacific Ocean (Holthuis 1991).

Diagnosis: Body cylindrical, without setae; cervical groove deep. Carapace with well-developed laterally compressed rostrum, with lateral spines. Antennae long; scaphocerite (antennal scale) with inner margin unarmed, curved. Long, robust chelipeds equal in size. Walking legs 1–3 chelate, 4th simple (Figure 3.10).

Figure 3.10 *Acanthacaris tenuimana* [FORV SS 32118]

Remarks: This species is known to be one of the largest in its genus (Carpenter and Niem 1998). A gigantic male specimen of total length of 37 cm (72 cm including chelate leg) collected from ToT during the present study is the largest specimen ever reported in this genus.

Family LITHODIDAE

Genus NEOLITHODES

Neolithodes alcocki Dawson and Yaldwyn 1985

Location & Sampling Depth: 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32118 (1244 m), 32701 (1064 m).

Voucher Specimen No.: CMLRE 3211813.

Distribution: Only known from Northwestern Indian Ocean.

Diagnosis: Lithodid crab with carapace armed with granules, tubercles or spines; spiniform rostral process, overreaching distal margins of corneas; firm, partially calcified abdomen; abdominal tergites 3–5 are with calcified nodules; sternite of somite XI (pereopods 2) with deep longitudinal medial groove or pit (Figure 3.11).

Figure 3.11 *Neolithodes alcocki* [FORV SS 3218]

Remarks: Alcock (1901) reported *Neolithodes agassizii* (Smith, 1882) from the Travancore and Malabar coasts of India. However the specimen cited and figured by Alcock differ from *N. agassizii* (Dawson and Yaldwyn 1985). Dawson and Yaldwyn (1985) pointed out, the Indian Ocean species possibly is a different species, which they named *N. alcocki*. The specimens collected from ToT agree quite well with the specimens figured by Alcock (1901), representing a rediscovery of the species. King crabs are the largest crabs that are routinely caught for human consumption, and commands the highest price among any crabs in the global market (Stevens 2014). Crabs of carapace length 10–14 cm weighing 280-400 g are common in catches from ToT.

Order ISOPODA

Family CIROLANIDAE

Genus BATHYNOMUS

Bathynomus keablei Lowry & Dempsey, 2006

Location & Sampling Depth: 28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32120 (1034 m).

Voucher Specimen No.: CMLRE 2810333.

Distribution: Gigantic isopod, only known from North Indian Ocean.

Diagnosis: *Bathynomus keablei* is a supergiant, most similar to *B. giganteus*, which have a medium length lateral setal fringe on the exopod and 11 straight pleotelsonic spines. It differs from its congeneric species in the shape of the clypeus which has concave distal margins and in the non-produced distolateral corners of the uropod exopod (Figure 3.12).

Figure 3.12 *Bathynomus keablei* [FORV SS 32701]

Remarks: The giant scavenging isopod genus in the deep-sea, *Bathynomus* is a very common megafaunal species in the trawl catches from ToT. Historical collections of *Bathynomus* specimens of the RIMS *Investigator* collections (Lloyd 1908) from the Indian Ocean were assigned to *B. giganteus*. Lowry and Dempsey (2006) taxonomically reviewed the *Bathynomus* specimens collected from various regions of Indo-west Pacific, and assigned the Indian species as *Bathynomus keablei.* Specimens of *B. keablei* of maximum size of length up to 30 cm and a weight of 1500 g were collected from ToT.

Phylum MOLLUSCA

Phylum Mollusca is represented in the ToT by 7 species, belonging to Class Bivalvia (one species), Cephalopoda (3 species) and Gastropoda (3 species). Details are provided in Table-3.

Class CEPHALOPODA

Order OEGOPSIDA

Family ARCHITEUTHIDAE

***Architeteuthis dux* Steenstrup, 1857**

Location & Sampling Depth: 28103 (988 m), 31601 (1079 m), 32702 (1347 m)
Voucher Specimen No.: CMLRE 3160102.

Distribution: Since the original description of this species, over 20 species in the genus *Architeteuthis* have been described from Pacific, Atlantic and Indian Ocean. However, many of these descriptions are questionable, and new genetic evidence suggests that only a single species exists with minimal genetic variation among ocean basins (Winkelmann *et al.* 2013).

Diagnosis: Colossal sized Oegopsid squid which lack a corneal membrane, thus exposing the eyes directly to the sea; suckers are absent on the buccal lappets. Tentacular clubs with 4 rows of suckers on manus, a large cluster of very numerous small suckers on carpus with small suckers and knobs extending in pairs proximally along the stalk (Figure 3.13).

Figure 3.13 *Architeteuthis dux* [FORV SS 31601]

Remarks: The longest cephalopod known to science is the giant squid, *A. dux*. The maximum reported length (mantle plus tentacles) of *A. dux* is 17.37 m (Verrill 1897). The largest recorded and well-preserved specimen in the contemporary, peer-reviewed literature is 12 m (Bustamante *et al.* 2008). A damaged specimen of *Architeuthis dux* documented from ToT is estimated to be 3.5 m (mantle and tentacles) in length. Although the giant squid is one of the biggest invertebrates and an effective predator, it is not invulnerable (Piper 2007). The sperm whale appears to be a specialist predator of this massive cephalopod. In the tissues of the squid there are high levels of ammonium chloride, a substance that acts like a buoyancy aid but imparts the flesh with a foul taste to which the sperm whale must be oblivious.

Class GASTROPODA

Order NEOGASTROPODA

Family CALLIOTROPIDAE

Calliotropis metallica (Wood-Mason & Alcock, 1891)

Location & Sampling Depth: 28103 (988 m), 30501 (1060 m), 32118 (1244 m), 33102 (1027 m).
Voucher Specimen No.: CMLRE 3211804.

Distribution: *Calliotropis metallica* having been originally described from the Gulf of Mannar, and further recorded also in central Indonesia and East to South Africa, including Madagascar (Vilvens 2007). Found in South Western and North Western Indian Ocean.

Diagnosis: A comparatively large *Calliotropis* species (Height up to 26 mm, Width up to 22 mm) with high spire, conical shape, nacreous yellowish-white in colour, with two sharp-nodulose cords on spire whorls and on last whorl; broad and deep umbilicus, three to five spiral cords on base. All the bands produced from the spiral cords are characteristically concave (Figure 3.14).

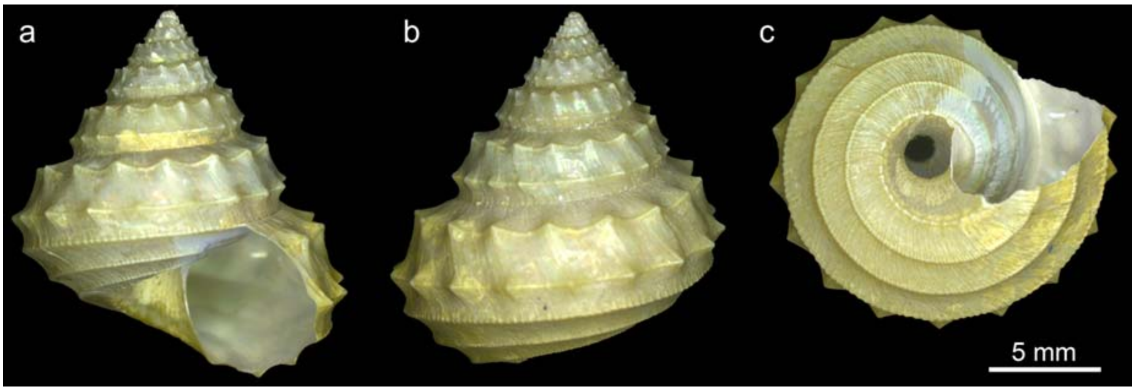

Figure 3.14 *Calliotropis metallica* [FORV SS 32118] a. apertural view, b. abapertural view, c. umbilical view

Remarks: The genus *Calliotropis* encompasses a series of widely distributed small, deep-water snails with conical, mostly umbilicated and usually heavily ornamented shells. However, *C. metallica* is known from few specimens and much information is not available regarding their distribution, population biology and ecology. In the ToT collections, the dead shells of *C. metallica* were occupied by the hermit crab *Parapagurus* cf. *pilosimanus*, and the shells were infested with the epibiont *Epizoanthus paguriphilis*.

Phylum Echinodermata:

Phylum Echinodermata is represented by 18 species in the ToT, belonging to Class Asteroidea (10 species), Echinoidea (2 species), Holothuroidea (2 species) and Ophiuroidea (4 species). Details are provided in Table 3.3.

Class ASTEROIDEA

Order FORCIPULATIDA

Family ZOROASTERIDAE

Zoroaster alfredi Alcock, 1893b

Location & Sampling Depth: 28103 (988 m), 31602 (1338 m), 31609 (1241 m).
Voucher Specimen No.: CMLRE 3160225.

Distribution: North Eastern Indian Ocean. *Zoroaster alfredi* was first described from the continental slope of the western Bay of Bengal during RIMS *Investigator* surveys (Alcock 1893). The present report is the first subsequent record of this species, and the first report from the Arabian Sea. This species is widely represented in the ToT samples.

Diagnosis: Zoroasterid with Arms 18-22 mm; disc raised above the tumid arms, overall form rigid; disc with large stellate plates covered in membrane-clad spinelets. Arms with 13 rows of plats, of which the central is prominent, sub-hexagonal; covered with needle-like spinelets and minute pedicellariae. Alternate adambulacral plates with prominent ridges, bearing a row of 3-4 spinelets, each with a large pedicellariae at the end, and also paired bunches of small pedicellariae attached by ligaments to their base. Colour bright salmon (Figure 3.15).

Figure 3.15 *Zoroaster alfredi* [FORV SS 31602]

Remarks: The specimens of *Z. alfredi* collected in the present study are significantly larger (18-22 cm) than the other species of Zoroasteridae.

Class Holothuroidea

Order Elasipodida

Family Psychropotidae

Benthodytes typica Théel, 1882

Locations & Sampling Depths: 28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31908 (1258 m), 32116 (1153 m), 32120 (1034 m).

Distribution: Cosmopolitan. *Benthodytes glutinosa* Perrier, 1896, reported from Indian waters, is a synonym (WoRMS). In the ToT, *Benthodytes typica* is a common species, often collected in high abundance.

Diagnosis: Elasipodid holothurian with length up to 15 cm (in intact specimen), width up to 5 cm, gelatinous body with a thin skin which is lost in most specimen. Mouth ventral, with 20 tentacles. A thin, scalloped edge to the ventral side, which is more pronounced around the anterior end. Anus terminal. Spicules scattered in the thin skin, not very dense; primarily in the form of irregularly spinose rods with thin, lateral ramifications. Colour light to dark violet, darker at the margins (Figure 3.16).

Figure 3.16 *Benthodytes typica* [FORV SS 31601]

Remarks: In general, the order Elasipodida comprises deep-sea species that sometime occur abundantly in the abyssal plains around the world, and are important sediment gleaner of the deep-sea floor.

Phylum CHORDATA

Chordates of ToT include 82 species belonging to Class Myxinii (One Species), Holocephalii (3 species), Elasmobranchii (10 species), Actinopterigii (67 species) and Reptilia (one species). Details are at Table 3.3.

Class HOLOCEPHALI

Order CHIMAERIFORMES

Family RHINOCHIMAERIDAE Garman, 1901

Genus RHINOCHIMAERA Garman, 1901

Rhinochimaera africana Compagno, Stehmann & Ebert, 1990

Location & Sampling Depth: 31602 (1338 m), 31908 (1258 m), 32120 (1034 m).
Voucher Specimen No.: CMLRE 3190801.

Distribution: South East Atalantic (Compagno *et al.* 1990). South West Indian (Compagno *et al.* 1990) North West Pacific (Didier and Nakaya 1999). North East Pacific (Angulo *et al.* 2014) and North West Indian Ocean (Present study).

Diagnosis: *Rhinochimaera*, have an extremely long, broad, paddle-shaped, bluntly pointed snout; low and small first dorsal fin; vomerine tooth plates with stepped cutting edges, mandibular and palatine tooth plates with very short mesial edges and elongated latero-posterior ends; a short caudal fin with a vestigial filament; and dark blackish brown coloration (Figure 3.17).

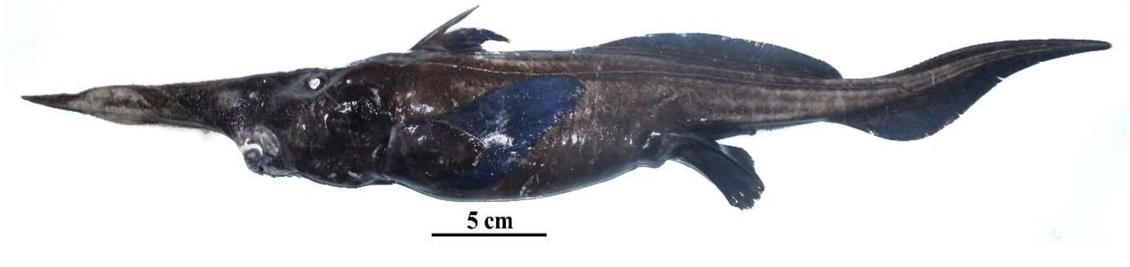

Figure 3.17 *Rhinochimaera africana* [FORV 31908]

Remarks: The genus *Rhinochimaera* is represented by 3 valid species worldwide (WoRMS). This is the first distributional record of *R. africana* from tropical northwestern Indian waters. Though Venu (2009) reported *R. atlantica* from Indian waters, the figures in that work indicate that it is in fact a species under genus *Harriotta*. Specimens of *R. africana* collected from ToT are of gigantic size, its total length between 115-135 cm and weight between 5-5.4 kg.

Class: ELASMOBRANCHII

Order SQUALIFORMES

Family CENTROPHORIDAE Bleeker, 1859

Genus CENTROPHORUS Müller & Henle, 1837

***Centrophorus atromarginatus* Garman, 1913**

Location & Sampling Depth: 28103 (988 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32118 (1244 m), 32701 (1064 m), 33102 (1027 m), 32120 (1034 m)

Voucher Specimen No.: CMLRE 3270204.

Distribution: North West Indian Ocean, South West Indian Ocean, North West Pacific Ocean.

Diagnosis: Dorsal fin with grooved spines. Anal fin absent. Denticles block shaped and wide spaced. Long thick snout. Rear tips of pectoral fins narrowly angular and elongated. Second dorsal fin spine origin over the inner margin of pelvic fins. Colour: Grey above; lighter below, prominent black tips in most fins (Figure 3.18).

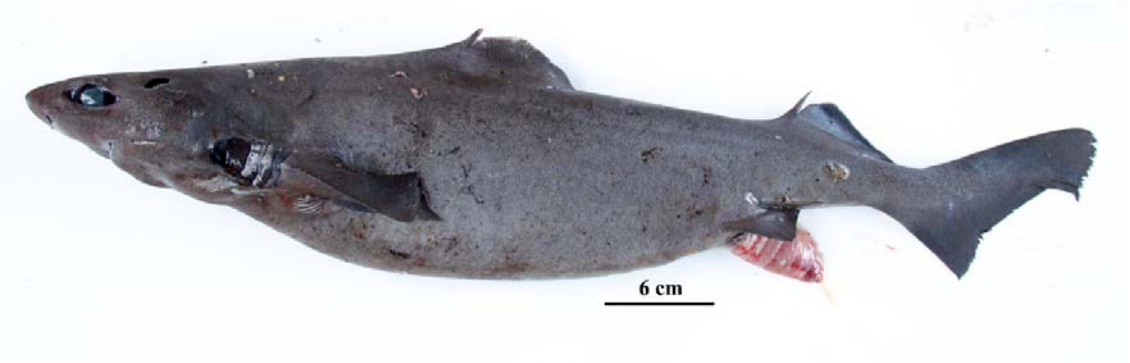

Figure 3.18 *Centrophorus atromarginatus* [FORV SS 32702]

Remarks: *Centrophorus atromarginatus* is commonly found in the catches from ToT. A targeted fishery of this species exist in the southwest coast of India (Akhilesh. 2014). Species identification within the genus *Centrophorus* is problematic and many reports of *Centrophorus* spp. from southwest coast of India are doubtful and require confirmation (Akhilesh 2014). Poor taxonomic resolution, poor descriptions and absence of type specimens make it difficult to ascertain the species status within the genus. The members of the genus are medium sized apex predators in the deep-sea.

Order TORPEDINIFORMES

Family NARCINIDAE Gill, 1862

Genus BENTHOBATIS Alcock, 1898

Benthobatis moresbyi Alcock, 1898

Location & Sampling Depth: 2810, 30501 (1060 m), 31601 (1079 m), 32120 (1034 m), 32701 (1064 m), 33102 (1027 m), 32120 (1034 m)
Voucher Specimen No.: CMLRE 2810302

Distribution: This species appears to be endemic of Northwestern Indian Ocean. *Benthobatis moresbyi* is poorly known from only five type specimens. However the species is found abundantly in the trawl catches from ToT. Carvalho (1999) considered the reports of this species from Eastern Indian Ocean and Pacific regions as dubious or misidentifications.

Diagnosis: *Benthobatis moresbyi* distinguished from congeners by the combination of dark brown dorsal and ventral surfaces; ventral surface entirely dark; elongated snout, usually more than one-third in disc length; disc oval, longer than wide; dorsal fins with long, fleshy bases, bases much longer than height of dorsal fins; origin of first dorsal well anterior to posterior tip of pelvic fins, close to mid pelvic length; dorsal fins close together, interdorsal space less than length of dorsal bases; distance between second dorsal fin and caudal fin much smaller than length of base of second dorsal fin; caudal fin extremely elongated, reaching almost one-half tail length as measured from posterior tips of pelvic fins (Figure 3.19).

Figure 3.19 *Benthobatis moresbyi* [FORV SS 31601]

Remarks: This weird looking electric ray appears as a 'flabby tissue' due to loose skin and lack dermal hard structures, such as denticles and spines. Eyes are extremely reduced and presumably non-functional.

Class ACTINOPTERIGII

Order ANGUILLIFORMES

Family CONGRIDAE Kaup, 1856

***Bathyuroconger vicinus* (Vaillant, 1888)**

Locations & Sampling depth: 28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m), 32120 (1034 m).

Voucher Specimen No.: CMLRE 2810330, 3270207.

Distribution: Circumglobal.

Diagnosis: Body moderately elongate, preanal length less than 40% TL; dorsal fin begins over or slightly behind the base of pectoral fin; jaws nearly equal with strong fang like teeth; intermaxillary teeth enlarged in two transverse rows; lateral line pores to anus 40-47 (Figure 3.20).

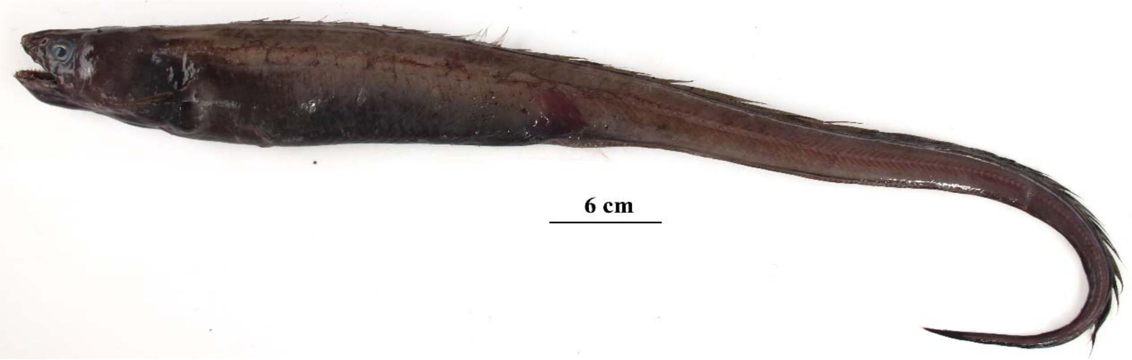

Figure 3.20 *Bathyuroconger vicinus* [FORV SS 32701]

Remarks: *Bathyuroconger vicinus* is the most abundant Congrid eel found in trawl catches from ToT. Its formidable dentition suggests that it is an active predator in the deep-sea habitat. Size of the specimens collected from ToT is the highest ever recorded for this species. Total length of *B. vicinus* specimens collected from ToT ranged 46.5-94.0 cm with an average of 63 cm; and weight ranged 143-1,100 g with an average of 362 g.

Order OPHIDIIFORMES

Family OPHIDIIDAE

Lamprogrammus niger Alcock, 1891

Location & Sampling Depth: 28103 (988 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32120 (1034 m).

Voucher Specimen No.: CMLRE 2810316, 3160121.

Distribution: Circum-tropical, occasionally circum-subtropical. Though the *L. niger* is distributed circumtropically Kobyliansky and Orlov (2015) noted that members of the genus are rare in catches from the deep-sea and are never collected in considerable numbers.

Diagnosis: Body elongate, compressed; tail long, tapering; mouth terminal; head compressed with soft, almost membranaceous, frilled and crested bones; teeth granular, none enlarged; lateral line covered with small scales, beneath which lie vertically oriented, spindle-shaped neuromasts, each of which is mounted on a large, vertically elongate scale; pelvic fins absent (Figure 3.21).

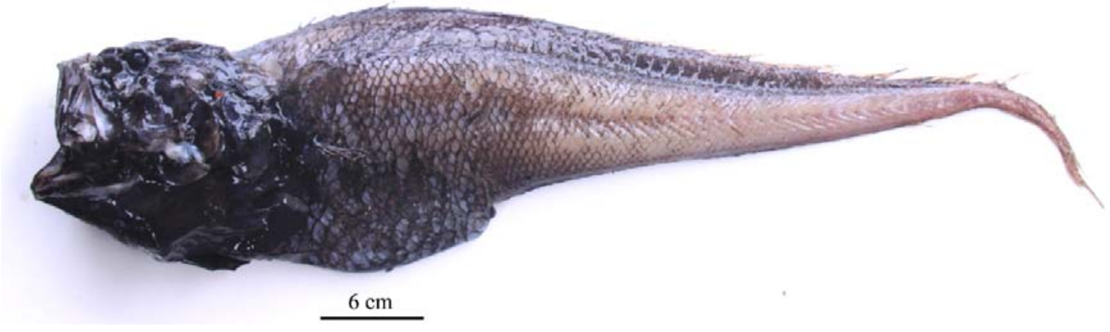

Figure 3.21 *Lamprogrammus niger* [FORV SS 31601]

Remarks: *Lamprogrammus niger* is the single most abundant species in the catches from ToT, and is often represented by gigantic specimens. In the ToT, *L. niger* alone contributes an average of 45% of biomass of the total trawl catch in the ToT, with total length of 25.5-86 cm and weight of 50-1,900 g.

GADIFORMES

Family MACROURIDAE

Coryphaenoides hextii (Alcock, 1890)

Locations & sampling depth: 31602 (1338 m), 31609 (1241 m), 33102 (1293 m), 32118 (1244 m), 32702 (1347 m)

Voucher Specimen No.: CMLRE 3160108

Distribution: *Coryphaenoides hextii* is only known from two specimens. The original type materials (designated by Alcock) purportedly housed in the Zoological Survey of India are missing, and the neotype designate is housed at the Natural History Museum, London (Shcherbachev and Iwamoto 1995). The species identity of the second known specimen collected off Somalia, by the Vityaz expedition is questionable (Shcherbachev and Iwamoto 1995). The present study rediscovered *C. hextii* from ToT, a locality adjacent to the type locality, after its initial description 100 years ago. Since no reports of this species have been made from other parts of the world, it may well be endemic to the Northwestern Indian Ocean, particularly off southwest coast of India.

Diagnosis: Seven pelvic rays; underside of head completely scaled; upper jaw 34-39% HL; maxillary extends to below posterior ½ to ¼ of orbit, rictus to below middle third of orbit; barbel 16-21 % HL; pyloric caeca 12-15; premaxillary teeth in broad band with outer enlarged series, mandibular teeth in narrow band about 3 teeth wide, inner series slightly larger than outer two (Figure 3.22).

Remarks: Bottom trawl catches from ToT yielded gigantic sized *C. hextii* specimens in large numbers. Though Alcock (1899) had reported a maximum size of 58 cm, the present study has recorded specimens up to a maximum length of 80 cm and weight of 2.95 kg.

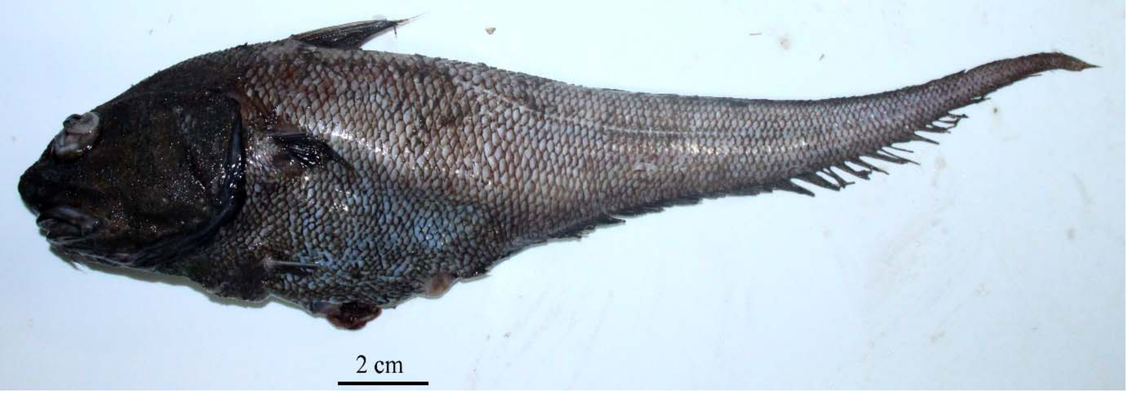

Figure 3.22 *Coryphaenoides hextii* [FORV SS 31601]

Family MORIDAE

***Lepidion inosimae* (Günther, 1887)**

Locations & sampling depth: 32702 (580 to 1100 m depths).

Voucher Specimen No.: CMLRE 3270201.

Distribution: Reported from North West and South West Pacific Ocean (Nakaya *et al.* 1980; Paulin 1984; Paulin and Roberts 1997; Mundy 2005). The present surveys reported the first distribution record of *L. inosimae* from North western Indian Ocean (Vinu *et al.* 2016). Only two species of *Lepidion* are known to be distributed in the Indian Ocean, viz. *L. capensis* Gilchrist, 1922 and *L. natalensis* Gilchrist, 1922.

Diagnosis: First dorsal fin very much elongated, 1.7 times of head length (HL); snout very short 3 in HL upper margin of eye touching the dorsal profile of the head; posterior nostril immediately anterior to eye; orbit diameter 5.5 in HL; second dorsal fin with 55 rays; anal fin with 51 rays; small round shaped vomerine tooth patch (Figure 3.23).

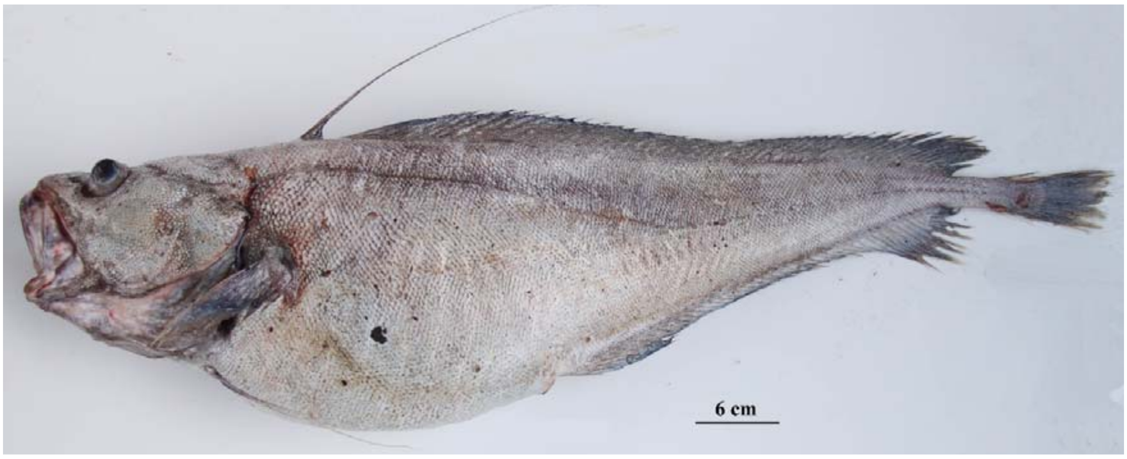

Figure 3.23 *Lepidion inosimae* [FORV SS 32702]

Remarks: The maximum size of *L. inosimae* reported is up to 640 mm from New Zealand waters (Paulin 1984). The present female specimen of *L. inosimae* (TL 800 mm, weight 6.2 kg) is the largest of its kind reported so far.

Order OSMERIFORMES

Family ALEPOCEPHALIDAE

Genus ALEPOCEPHALUS

Alepocephalus blanfordii Alcock, 1892

Locations & sampling depth: 28103, 30501, 31601, 31602, 31609, 31908, 31909, 32118, 32120, 32701, 32702 & 32209. (1650 m).

Voucher Specimen No.: CMLRE 3160114.

Distribution: Reported from North West Indian Ocean, North East Pacific Ocean (Okamura *et al.* 1995) and SEAS (Venu 2009).

Diagnosis: Alepocephalid species with comparatively small head, less than 40% of standard length; obtusely pointed depressed snout; large orbit nearly 30% of head length; anal fin with 17-19 rays, its base 12-15% of SL; dorsal fin with 16-18; about 64-70 scales in longitudinal series; 15-17 pyloric caeca (Figure 3.24).

Figure 3.24 *Alepocephalus blanfordii* [FORV SS 30501]

Remarks: *Alepocephalus blanfordii* is the most abundant species of the Order Osmeriformes in the trawl catches from ToT, and recorded from all the 14 sampled locations. Large specimens of standard length ranged 20.5-45 cm with an average of 37 cm; weight ranged from 70 to 1,000 g, with an average of 600 g common in the catches from ToT.

Order LOPHIIFORMES
Family DICERATIIDAE
Genus BUFOCERATIAS

Bufoceratias shaoi Pietsch, Ho and Chen, 2004
Location & sampling depth: 31602 (800 m).
Voucher Specimen No.: CMLRE 3160210

Distribution: Specimens of Diceratiidae are very rare. *Bufoceratias shaoi* was previously known from only four specimens, three collected from off Taiwan and a fourth in the Mozambique Channel, Western Indian Ocean (Pietsch *et al.* 2004). The fifth known specimen was collected in the present study from ToT. This extends the distribution towards the northern Indian Ocean, and is also the largest specimen known to science (154 mm SL) (Rajeesh Kumar *et al*. 2016)

Diagnosis: *Bufoceratias* species is characterized by having a short and stout body, the depth approximately 50% SL; a larger and complex structure of the esca; illicial length 25–40 % SL (Figure 3.25).

Figure 3.25 *Bufoceratias shaoi* [FORV SS 31602]

Remarks: In all species of deep-sea angler fish, the first spine of the dorsal fin is modified to form the lure used to attract prey (Piper 2007). The light from this lure is not produced by the fish, but by marine bacteria, which enter the fish's lure through small vents. Floating about in the sea water, these bacteria never emit light as they are never found in high enough densities, but inside the fish, they can multiply rapidly, producing chemicals that eventually reach high enough concentrations to trigger the production of an eerie glow.

Order BERYCIFORMES

Family TRACHICHTHYIDAE

Hoplostethus (Leiogaster) melanopus Weber, 1913

Locations & sampling depth: 28103 (988 m), 32120 (1034 m), 33103, 32120 (1034 m)

Voucher Specimen No.: CMLRE 2810306.

Distribution: Reported from South Western Indian Ocean, North West Indian Ocean, South West Pacific Ocean (Kotlyar 1986). *Hoplostethus (L.) melanopus* is found fairly abundant in trawl catches from ToT.

Diagnosis: Body of fresh specimen appear greyish with a silver tint; muciferous portions of the head with an orange sheen; pectoral, pelvic, dorsal, anal and caudal fins are black; on preservation, body colour changes to greyish-black. Belly scutes are small (Figure 3.26).

Figure 3.26 *Hoplostethus (Leiogaster) melanopus* [FORV SS 28103]

Remarks: Congeneric species, *Hoplostethus (Hoplostethus) atlanticus* popularly known as orange roughy, is considered a seafood delicacy. Orange roughy is slow-growing and late to mature, resulting in very low resilience which makes them extremely susceptible to overfishing. The UK Marine Conservation Society has categorized orange roughy as "vulnerable to exploitation”. Specimens of total length ranging 23-31.2 cm with an average of 26.45 cm; and weight range 175-500 g with an average of 300g are common in the catches from ToT.

3.3 DISCUSSION

Present study is the first attempt to document the biological diversity of megafauna beyond the 1,000 m depth zone off southwest coast of India. It reveals the unique nature of the megafaunal diversity of a totally unknown bathyal terrace; the Terrace off Trivandrum (ToT). The mega faunal diversity of ToT is unique in terms of the high abundance and diversity of sparsely recorded endemic deep-sea species from Indian Ocean such as *Fenestraja mamillidens*, *Coryphaenoides woodmasoni*, *Harpadon squamosus*, *Nezumia brevirostris*, *Dicrolene vaillanti*, *Holcomycteronus pterotus*, *Monomitopus conjugator* etc. These species were reported and described in the *RIMS Investigator* surveys, more than 100 years ago. The present survey is the first attempt to record, document and archive specimen of these rare and important species after the *Investigator* Survey’s conducted 100 years back.

Several of the records from the ToT provide geographical range extensions of the corresponding species. The present survey also adds to the inventory on biodiversity of the SEAS, with numerous new records. For example, the recently described deep-sea cat-shark species *Apristurus breviventralis* known only from few specimens collected off Socotra Islands, Gulf of Aden, has now been recorded in the ToT. Deep-sea angler fish *Bufoceratias shaoi* previously known from only four specimens, three of which were collected from off Taiwan, and a fourth from the Mozambique Channel, is a new record from the Northern Indian Ocean (Rajeesh Kumar *et al.* 2016). A new species of the deep-water frogmouth fish of genus *Chaunax* Lowe, 1846 (unpublished) was also collected from ToT during the present study.

Another important and unique aspect of the deep-sea megafaunal diversity of ToT is that, the area harbors diverse array of gigantic species belonging to diverse taxonomic groups. These gigantic species which are quite common in the ToT; include the gigantic pycnogonid *Colossendeis colossea*, gigantic isopod *Bathynomus keablei*, deep-sea lobster *Acanthacaris tenuimana*, deep-sea holothurian *Perizona magna*, deep-sea asteroid *Zoroaster alfredi*, Giant squid *Architeuthis* cf. *dux,* gigantic chimaera *Rhinochimaera africana*, gigantic skate *Dipturus johannisdavisi,* cusk-eel *Lamprogrammus brunswigi,* morid cod *Lepidion inosimae*, etc. All of these species are gigantic representatives within their respective higher taxa. For instance, *Colossendeis colossea* the largest member of the class Pycnogonida, *Lepidion inosimae* the largest cod of the family Moridae. Many species found to inhabit the ToT are gigantic relatives to their congeners, for example *Lamprogrammus brunswigi* is the largest species within the genus. This unique nature of the deep-sea megafauna of ToT, evoke many questions regarding the existence of such gigantic representatives of various taxon in the study area in spite of its remoteness from productive coastal and surface waters.

Patterns of changing animal size with depth within the deep marine environment, have been documented in several invertebrates (Thiel 1975; Haedrich and Rowe 1997; Rex and Etter 1998; Olabarria and Thurston 2003) and fish (Polloni *et al.* 1979; Macpherson and Duarte 1991). The size to which an organism grows, relate to all aspects of its biology and determining what controls body size is a fundamental question in ecology (Atkinson and Sibly 1997). In this regard, the present study elucidates the bathymetric variations of fin-fish size (length and weight) off south west coast of India. Length and weight data of finfish species recorded from three depth zones viz. 130-400 (shelf break), 400-800 (upper ToT) and 800-1400 (ToT) were pooled and is depicted as Figure 3.27. An increase in the average size of deep-sea fin fishes is clear from shelf break regions to the bathyal depths of ToT. Silas (1969) noted the average size of the frequently (dominant) found fishes which are caught from the shelf edge as well as in the upper slope are smaller in length and weight compared to those generally trawled in shallow waters of southwest coast of India. Exceptions are the deep-sea sharks *Echinorhinus brucus* and *Atractophoris armatus*, the deep-sea rays and the Chimaeroid *Neohariotta pinnata*, which are larger than any of the other species trawled from these depths. It will be seen that most of the families are represented with average weight below 100 g. It is not unlikely that other large sized species could have escaped capture by avoiding the nets. Thus a parabolic shift in the average size of megafauna from shallow to the bathyal depths of ToT is evinced along the depth contours off southwest coast of India.

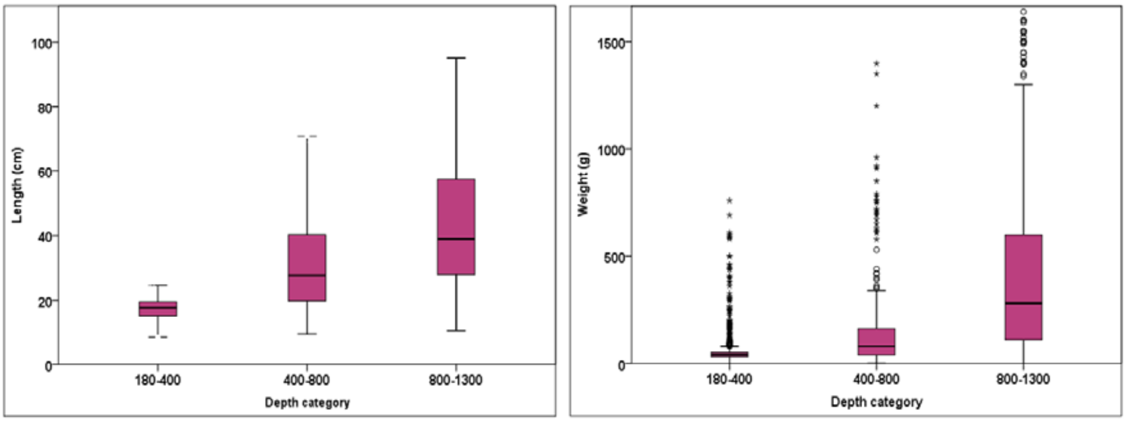

Figure 3.27 Bathymetric variation of fin-fish size off south west coast of India

Earlier studies on the demersal deep-sea ichthyofauna indicated a general pattern of increased size with depth (Haedrich and Rowe 1977; Polloni *et al.* 1979), which came to be known as Heincke's Law (following Heincke 1913). However, subsequent works demonstrated that the phenomenon was not ubiquitous (Snelgrove and Haedrich 1985), could be an artefact of sampling (Merrett *et al.* 1991) and in some regions, a decline in size with depth has been reported (Stefanescu *et al.* 1992). Study on scavenging and predatory demersal ichthyofauna of the Northeast Atlantic occupying

800-4,800 m depths (Collins *et al.* 2005), revealed a significant increase in body size of the scavenging fishes whereas, in non-scavenging fish (predatory fish) body size decrease with depth. The observed trends of both increased and decreased size with depth have been associated with the need to maintain a viable population size in the face of reduced overall energy availability (Thiel 1975), mass-specific changes in metabolic rate (Rex and Etter 1998), changes in the relative importance of mobility (Haedrich and Rowe 1977) and physiological constrains of the species concerned (Collins *et al.* 2005). Hence a clear pattern of body size of organism with depth depends on the importance of each of these factors upon the behavior and ecology of the species involved in relation to the depth gradient.

The analysis of body size further demonstrates the unique nature of the megafauna of the ToT. The biological and ecological drivers which sustain the high density and diversity of unique fauna on the ToT are explored in detail in the subsequent chapters.

Table 3.3. Checklist of deep-sea megafauna of Terrace off Trivandrum

Sl. No.	Species	Global distribution		Collections from ToT			Remarks
		Region*	Depth (m)	Station No. & (Collection depth)	Plate	Voucher No.	
	Phylum Cnidaria						
	Class Alcyonacea						
	Order Gorgoniidae						
	Family Gorgonia						
1	*Gorgonid* sp.			32116 (1153 m)	Pl. I.1	3211627	
	Class Anthozoa						
	Order Actiniaria						
	Family Hormathiidae						
2	*Hormathiid* sp.			28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31908 (1258 m), 33102 (1293 m), 32701 (1064 m), 33102 (1027 m)	Pl. I.2	3050103	
	Order Pennatulacea						
	Family Pennatulidae						
3	*Pennatula* sp.			31602 (1338 m), 32702 (1347 m)	Pl. I.3	3160222	
	Order Scleractinia						
	Family Caryophylliidae						

4	*Caryophyllia ambrosia* Alcock, 1898	NWIO	28103 (988 m), 30501 (1060 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 33102 (1027 m)		3211624	Solitory deep-sea coral
5	*Caryophyllia paradoxus* Alcock, 1898	NWIO	30501 (1060 m), 32116 (1153 m), 32701 (1064 m)	Pl. I.4	3211625	Solitory deep-sea coral
6	*Caryophyllia* sp 3		32116 (1153 m)	Pl. I.5	3211626	
	Order Zoantharia					
	Family Epizoanthidae					
7	*Epizoanthus* cf. *paguriphilus* Verrill, 1883		31602 (1338 m), 31908 (1258 m), 33102 (1293 m), 32118 (1244 m), 32701 (1064 m)		3211805	Epibiont on *Parapagurus* cf. *pilosimanus*
	Class Scyphozoa					
	Order Coronatae					
	Family Atollidae					
8	*Atolla* sp.		28103 (988 m), 32116 (1153 m)	Pl. I.6		
	Order Rhizostomeae					
	Family Cepheidae					
9	*Cephea* sp.		28103 (988 m), 31601 (1079 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32701 (1064 m)	Pl. I.7		
	Order Semaeostomeae					
	Family Ulmaridae					

10	*Deepstaria enigmatica*			31609 (1241 m), 32701 (1064 m)			Gigantic species. First record from NWIO
	Phylum Arthropoda						
	Class Malacostraca						
	Order Decapoda						
	Family Acanthephyridae						
11	*Acanthephyra curtirostris* Wood-Mason & Alcock, 1891	Mesopelagic, circumglobal	190-1,500	32118 (1244 m)	Pl. I.8	321826	
12	*Acanthephyra eximia* Smith, 1884	Mesopelagic, circumglobal	200-4,700	32116 (1153 m)	Pl. I.9	3211611	
13	*Acanthephyra fimbriata* Alcock & Anderson, 1894	NWIO, NEIO	412-1785	31601 (1079 m)	Pl. I.10	3160129	
14	*Acanthepyra sanguinea* Wood-Mason [in Wood-Mason & Alcock, 1892]	SWIO, NWIO, NEIO, SEIO, NWPO	567-1756	28103 (988 m), 30501 (1060 m), 32116 (1153 m), 32118 (1244 m), 32702 (1347 m)	Pl. II.1	3211616	
15	*Ephyrina hoskynii* Wood-Mason & Alcock, 1891	NWIO, NEIO		32116 (1153 m)	Pl. II.2	3211619	
	Family Aristeidae						
16	*Aristaeopsis edwardsiana* (Johnson, 1868)	Circumglobal	274 - 1,850	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32120 (1034 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m), 32120 (1034 m)		2810319	Fished commercially in the eastern Atlantic.

17	*Pseudaristeus crassipes* (Wood-Mason in Wood-Mason & Alcock, 1891)	NWIO, NEIO		28103 (988 m), 31601 (1079 m), 32116 (1153 m), 32701 (1064 m), 32702 (1347 m)	Pl. II.3	3211601	
	Family Ethusidae						
18	*Ethusa indica* Alcock, 1894	NWIO		28103 (988 m)			
	Family Geryonidae						
19	*Chaceon alcocki* Ghosh & Manning, 1993	NWIO	410-520	32121	Pl. II.4	3212101	Only known from holotype described based on RIMS Investigator specimen. Rediscovery.
	Family Glyphocrangonidae						
20	*Glyphocrangon investigatoris* Wood-Mason & Alcock, 1891	NWIO, NEIO, NWPO	258-1087	31601 (1079 m), 32116 (1153 m), 32702 (1347 m), 33102 (1027 m)	Pl. II.5	3211618	
21	*Glyphocrangon unguiculata* Wood-Mason & Alcock, 1891	NWIO, NWPO	878-1732	32116 (1153 m), 32118 (1244 m)	Pl. II.6	3211605, 3212118	
	Family Lithodidae						
22	*Neolithodes alcocki* Dawson and Yaldwyn 1985	NWIO		31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32118 (1244 m), 32701 (1064 m)		3211813	Only known from type specimen. Rediscovery.
23	*Paralomis investigatoris* Alcock & Anderson, 1899	NWIO, NEIO		31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32702 (1347 m)	Pl. II.7	3160904	Rarely reported species
	Family Munididae						

24	*Munida microps* Alcock, 1894	NWIO, NEIO, NWPO	498-1260	32116 (1153 m), 32118 (1244 m)	Pl. II.8	3211609	
	Family Munidopsidae						
25	*Munidopsis stylirostris* Wood-Mason, 1891	NWIO	1349-1730	32116 (1153 m), 32118 (1244 m)	Pl. II.9	3211608	Only type record data available. Only known from Northern Indian Ocean
26	*Munidopsis wardeni* Anderson, 1896	NWIO, NEIO	742-1086	32118 (1244 m), 32120 (1034 m)	Pl. II.10	3211802	Only type record data available. Only known from Northern Indian Ocean
	Family Nephropidae						
27	*Acanthacaris tenuimana* Spence Bate, 1888	SWIO, NWIO, NEIO, SEIO, NWPO	300-1463	31908 (1258 m), 32118 (1244 m), 32701 (1064 m)		3211812	Gigantic species, rarely reoprted
28	*Nephropsis atlantica* Norman, 1882	NWAO, SWAO, NWIO	470-1804	28103 (988 m), 30501 (1060 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m)	Pl. III.1	3211615	
29	*Nephropsis ensirostris* Alcock, 1901	NWIO, NEIO, NWPO	580-1160	31908 (1258 m), 32116 (1153 m), 32120 (1034 m)	Pl. III.2	3211614	
	Family Oplophoridae						
30	*Oplophorus gracilirostris* A. Milne-Edwards, 1881	Mesopelagic, circumglobal		28103 (988 m), 32116 (1153 m), 33102 (1027 m)	Pl. III.3	3211612	
	Family Pandalidae						

31	*Heterocarpus dorsalis* Spence Bate, 1888	SWIO, NWEIO, NEIO, NWPO	185-1400	30501 (1060 m), 33102 (1293 m), 32116 (1153 m)	Pl. III.4	3211602	
	Family Parapaguridae						
32	*Parapagurus* cf. *pilosimanus* Smith, 1879	NWAO, SWAO, SEIO	1289-3652	31602 (1338 m), 31908 (1258 m), 33102 (1293 m), 32118 (1244 m), 32701 (1064 m)	Pl. III.5	3211807	
	Family Pasiphaeidae						
33	*Glyphus marsupialis* Filhol, 1884	SWIO, NWIO		32116 (1153 m), 32118 (1244 m)	Pl. III.6	3211604	
	Family Parapasiphae						
34	*Parapasiphae (Eupasiphae) gilesii* Wood-Mason, 1892	NWIO		32116 (1153 m)	Pl. III.7	3211603	Only type record data available
35	*Psathyrocaris fragilis* Wood-Mason in Wood-Mason & Alcock, 1893	NWIO		32116 (1153 m)	Pl. III.8	3211606	Only type record data available
36	*Psathyrocaris platyophthalmus* Alcock & Anderson, 1894	NWIO		32116 (1153 m)	Pl. III.9	3211617	Only type record data available
	Family Polychelidae						
37	*Stereomastis nana* (Smith, 1884)	Circumglobal	300-4000	32116 (1153 m), 32118 (1244 m)	Pl. III.10	3211613	
38	*Stereomastis sculpta* (Smith, 1880)	Circumglobal	200-4000	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m)	Pl. IV.1	2810328, 3211610	

	Family Solenoceridae						
39	*Haliporus taprobanensis* Alcock & Anderson, 1899	NWIO		28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31609 (1241 m), 33102 (1293 m), 32116 (1153 m), 32701 (1064 m), 32702 (1347 m)	Pl. IV.2	3211607	
	Order Isopoda						
	Family Cirolanidae						
40	*Bathynomus keablei* Lowry & Dempsey, 2006	NWIO, NEIO		28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32120 (1034 m)	Pl. IV.3	2810333	Gigantic isopod, only known from Northwestern Indian Ocean
	Order Pantopoda						
	Family Colossendeidae						
41	*Colossendeis colossea* Wilson, 1881	Circumglobal		33102 (1293 m), 32118 (1244 m)		3190802	Parasitic gigantic pycnogonid, first record from Northwestern Indian Ocean
	Phylum Mollusca						
	Class Bivalvia						
	Pectinoida						
	Propeamussiidae						
42	*Propeamussium alcocki*	NWIO, NEIO, NWPO	891-1244	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 32118 (1244 m),	Pl. IV.4		

				33102 (1027 m), 32120 (1034 m)			
	Cephalopoda						
	Octopoda						
	Opisthoteuthidae						
43	*Opisthoteuthis philipii* Oommen, 1976	NWIO	275-365	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31908 (1258 m), 33102 (1293 m)	Pl. IV.5	3160127	Only type record data available. Only known from south eastern Arabian Sea
	Oegopsida						
	Architeuthidae						
44	*Archituethis dux* Steenstrup, 1857			28103 (988 m), 31601 (1079 m), 32702 (1347 m)		3160102	Gigantic squid
	Teuthida						
	Histioteuthidae						
45	*Histioteuthis* sp.			28103 (988 m), 31601 (1079 m), 31609 (1241 m), 33102 (1027 m)	Pl. IV.6	3160106	
	Gastropoda						
	Neogastropoda						
	Calliotropidae						
46	*Calliotropis metallica* (Wood-Mason & Alcock, 1891)	SWIO, NWIO		28103 (988 m), 30501 (1060 m), 32118 (1244 m), 33102 (1027 m)		3211804	
	Neogastropoda						

	Conidae				Pl. IV.7		
47	*Conus* sp.			30501 (1060 m)		28103	
	Order Neogastropoda						
	Family Turridae						
48	*Pleurotoma* sp.			28103 (988 m), 30501 (1060 m), 32118 (1244 m), 33102 (1027 m)		3211804	
	Phylum Echinodermata						
	Class Asteroidea						
	Order Brisingida						
	Family Brisingidae						
49	*Brisinga insularum* Wood-Mason & Alcock 1891	NWIO	1900	31602 (1338 m)		3160231	
	Order Forcipulatida						
	Family Zoroasteridae						
50	*Cnemidaster zea* Alcock 1893	NWIO	2200	30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32118 (1244 m), 32702 (1347 m)	Pl. IV.10	3160229	Rediscovery, first report after original description.
	Family Zoroasteridae						
51	*Zoroaster alfredi* Alcock 1893	NEIO	1000-1400	28103 (988 m), 31602 (1338 m), 31609 (1241 m)		3160225	Rediscovery, first report after original description. Large specimens common in ToT.
52	*Zoroaster angulatus* Alcock	NWIO	900-	30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m),		3160226	Rediscovery, first report

	1893		1500	32116 (1153 m), 32702 (1347 m)			after original description.
	Order Paxillosida						
	Family Astropectinidae						
53	*Asteropectinid* sp.			28103 (988 m)			
54	*Persephonaster rhodopeplus* Wood-Mason & Alcock 1891	NWIO, NEIO	1300-1600	28103 (988 m), 31602 (1338 m), 33102 (1293 m), 32702 (1347 m)		3160231	Rediscovery, first report after original description.
	Family Porcellanasteridae						
55	*Sidonaster vaneyi* Koehler 1909	NWIO	1300-2000	31609 (1241 m), 32116 (1153 m)		3160914	
	Order Valvatida						
	Family Goniasteridae						
56	*Ceramaster cuenoti* Koehler 1909	NWIO	1840	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32116 (1153 m), 32118 (1244 m), 32701 (1064 m)	Pl. IV.8	3050113	Rediscovery, first report after original description.
57	*Nymphaster moebii* Studer 1884	SWIO, NWIO, NEIO, SEIO	400-2400	28103 (988 m), 31602 (1338 m), 31609 (1241 m), 32118 (1244 m)	Pl. IV.9	31609115	
58	*Pseudarchaster jordani* Fisher 1909	NWIO, NEIO, NWPO, SWPO	800-1000	28103 (988 m), 31602 (1338 m), 33102 (1293 m), 32118 (1244 m), 32702 (1347 m)		3211815	Rediscovery, first report after original description.
	Class Echinoidea						
	Order Cidaroida						

	Family Histocidaridae					
59	*Histocidaris denticulata* Koehler 1927	NWIO, NEIO	400-750	32120 (1034 m)	3212012	Rediscovery, first report after original description.
	Order Echinothurioida					
	Family Echinothuriidae					
60	Echinothuriidae			32116 (1153 m), 32120 (1034 m)	3211617	
	Class Holothuroidea					
	Order Elasipodida					
	Family Psychropotidae					
61	*Benthodytes typica* Theel 1882	Cosmopolitan	1800-4700	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31908 (1258 m), 32116 (1153 m), 32120 (1034 m)		Large specimens, common in ToT.
	Order Molpadida					
	Family Molpadiidae					
62	*Molpadia musculus* Risso 1826	NWIO, NEIO	300-2700	32118 (1244 m)	3211811	
	Class Ophiuroidea					
	Order Ophiurida					
	Family Amphiuridae					
63	*Amphiurid* sp.			32116 (1153 m)	3211631	
	Family Ophiochitonidae					
64	*Ophiochiton ambulator* Koehler 1897	NWIO, NEIO	300-1600	32116 (1153 m), 32118 (1244 m)	3211632	

	Family Ophiodermatidae						
65	*Bathypectinura heros* Lyman 1897	AI, IO, SWPO	250-2900	32118 (1244 m)		3211820	
	Family Ophiuridae						
66	*Ophioceramis tenara* Koehler 1987	NWIO, SWIO	400-1100	32702 (1347 m)		3270208	
	Phylum Chordata						
	Class Myxini						
	Order Myxiniformes						
	Family Myxinidae Rafinesque, 1815						
67	*Eptatretus* sp.			31609 (1241 m), 32118 (1244 m)	Pl. V.1	3211809	
	Class Holocephali						
	Order Chimaeriformes						
	Family Rhinochimaeridae Garman, 1901						
68	*Rhinochimaera africana* Compagno, Stehmann & Ebert, 1990	SEAO, SWIO, NWPO, NEPO	549–1,450	31602 (1338 m), 31908 (1258 m), 32120 (1034 m)	Pl. V.2	3190801	Gigantic specimens in ToT. Rare worldwide. New distribution record to NWIO.
69	*Harriotta raleighana* Goode & Bean, 1895	Circumglobal but patchily distributed.	380–2,600	31602 (1338 m), 31908 (1258 m)	Pl. V.3	3160205, 3190801	Rare worldwide.
	Family Chimaeridae Rafinesque, 1815						

70	*Hydrolagus africanus* (Gilchrist, 1922)	SEAO, SWIO, NWIO	300–1,030	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32120 (1034 m)	Pl. V.4	3212004	Rare worldwide but common in catches of ToT.
	Class Elasmobranchii						
	Order Carcharhiniformes						
	Family Pentanchidae Smith, 1912						
71	*Apristurus breviventralis* Kawauchi, Weigmann & Nakaya, 2014	NWIO	1,000-1,120	31601 (1079 m), 31602 (1338 m), 32120 (1034 m), 32702 (1347 m)	Pl. V.5	3212002	New record from Eastern Arabian Sea. Only known from few speciems off Socotra Islands, Gulf of Aden.
72	*Apristurus saldanha* (Barnard, 1925)	SWIO, NWIO	914	30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32120 (1034 m), 32702 (1347 m)	Pl. V.6	3160204; 3050101	Rare, no type speceimens. New record from Indian EEZ.
	Order Myliobatiformes						
	Family Hexatrygonidae Heemstra & Smith, 1980						
73	*Hexatrygon bickelli* Heemstra & Smith, 1980	SWIO, NWIO, NEIO, NWPO		32120 (1034 m)	Pl. V.7	3212005	Rare, primitive sting ray. Monophyletic offshoot of Myliobatiformes.
	Order Rajiformes						
	Family Rajidae de Blainville, 1816						

74	*Dipturus johannisdavisi* (Alcock, 1899)	NWIO	500-951	30501 (1060 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32702 (1347 m), 32204, 32120 (1034 m)	Pl. V.8	3270204	Gigantic skate. Only known from Southwest coast of India. Common species im ToT.
75	*Fenestraja mamillidens* (Alcock, 1889)	NWIO	1092	31602 (1338 m)	Pl. V.9	3160210	Rediscovery, only type specimens available. Only known from Southwest coast of India.
	Order Torpediniformes						
	Family Narcinidae Gill, 1862						
76	*Benthobatis moresbyi* Alcock, 1898	NWIO	823-1071	2810, 30501 (1060 m), 31601 (1079 m), 32120 (1034 m), 32701 (1064 m), 33102 (1027 m), 32120 (1034 m)	Pl. V.10		Only known from Arabian sea. Common in ToT.
	Order Squaliformes						
	Family Centrophoridae Bleeker, 1859						
77	*Centrophorus atromarginatus* Garman, 1913	NWIO, SWIO, NWPO,		30501 (1060 m), 32120 (1034 m), 32701 (1064 m)		3270204	Rare, but relatively common in ToT.
78	*Centrophorus squamosus* (Bonnaterre, 1788)	Circumglobal		28103 (988 m), 32120 (1034 m)		2810308	
	Family Etmopteridae Fowler, 1934						

79	*Centroscyllium* cf. *kamoharai* Abe, 1966	SEIO, NWPO, SWPO		30501 (1060 m), 31601 (1079 m), 31609 (1241 m), 31908 (1258 m), 32116 (1153 m), 32120 (1034 m), 32702 (1347 m), 33102 (1027 m)	P. VI.1	3160101	Species identity not resolved. Rare worldwide, relatively common in ToT.
	Family Somniosidae Jordan, 1888						
80	*Centroscymnus crepidater* (Barbosa du Bocage & de Brito Capello, 1864)	Circumglobal		28103 (988 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32118 (1244 m), 32701 (1064 m), 33102 (1027 m), 32120 (1034 m)	P. VI.2	3160105	Rare worldwide, relatively common in ToT.
	Class Actinopteri						
	Order Anguilliformes						
	Family Congridae Kaup, 1856						
81	*Bathycongrus cf. guttulatus* (Alcock, 1894)	SWIO, SEIO, NWPO, SWPO	215-850	27802, 30501 (1060 m), 31602 (1338 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32120 (1034 m)	P. VI.3	2780212	Species identity not resolved.
82	*Bathyuroconger vicinus* (Vaillant, 1888)	Circumglobal	229-1318	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m), 32120 (1034 m)	P. VI.4	2810330, 3270207	Gigantic speciemens from ToT, larger than congenrs. Abundant in trawl catches from ToT.
83	*Promyllantor purpureus* Alcock, 1890	NWIO, NWPO	1830	33102 (1293 m)	P. VI.5	3190801	Rare, only two specimens available globally.

	Family Muraenesocidae					
84	*Gavialiceps taeniola* Alcock, 1889	NWIO, SWIO, NEIO, NWPO,	439-494	32120 (1034 m)	P. VI.6	
	Family Nemichthyidae					
85	*Avocettina infans* (Günther, 1878)	Circumglobal		32702 (1347 m)	P. VI.7	
86	*Nemichthys scolopaceus* Richardson, 1848	Circumglobal		33102 (1027 m), 32120 (1034 m)		2810337
87	*Venefica proboscidea* (Vaillant, 1888)	Circumglobal		32702 (1347 m)	P. VI.8	3270206
	Family Serrivomeridae					
88	*Serrivomer sector* Garman, 1899			28103 (988 m), 31609 (1241 m), 33102 (1293 m), 32116 (1153 m)		3211623
	Family Synaphobranchidae					
89	*Synaphobranchus affinis* Günther, 1877	Circumglobal	290-2,334	28103 (988 m)	P. VI.9	2810332
90	*Synaphobranchus brevidorsalis* Günther, 1887	Circumglobal	1,000-2,500	31602 (1338 m)	P. VI.10	
	Order Aulopiformes					
	Family Ipnopidae					
91	Bathypterois (Bathypterois) atricolor Alcock, 1896	Nearly circuumglobal	258-5,150	28103 (988 m), 31601 (1079 m), 31602 (1338 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 33102 (1027 m)	P. VI.11	3160135

92	*Bathypterois guentheri* Alcock, 1889	SWIO, NWIO, SEIO, NEIO, NWPO	720-1,163	30501 (1060 m), 31602 (1338 m), 31609 (1241 m), 32120 (1034 m)	P. VI.12	3160109	
93	*Bathytyphlops marionae* Mead, 1958	NEAO, NWAO, SWIO	869-2,651	31602 (1338 m)	P. VI.13	3160211	Very rarely reported from other regions. First record from NWIO.
	Family Synodontidae						
94	*Harpadon squamosus* (Alcock, 1891)	NEIO	440-500	31602 (1338 m), 31908 (1258 m), 33102 (1293 m)	P. VI.14	3160136	Rediscovery, only type specimen available. Only known from Eastern Arabian Sea.
	Order Beryciformes						
	Family Anoplogastridae						
95	*Anoplogaster cornuta* (Valenciennes, 1833)	Circumglobal		28103 (988 m), 31601 (1079 m), 32118 (1244 m), 32120 (1034 m)	Pl. VII.1	2810314	
	Family Trachichthyidae						
96	*Hoplostethus (Leiogaster) melanopus* (Weber, 1913)	SWIO, NWIO, SWPO	457-798	28103 (988 m), 32120 (1034 m), 33103, 32120 (1034 m)	Pl. VII.2	2810306	Few specimens worldwide, but common in ToT.
	Order Gadiformes						
	Family Macrouridae						
97	*Bathygadus furvescens* Alcock, 1894	NWIO, SWPO	1050-1,315	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 32116 (1153 m), 32120 (1034 m), 32701 (1064 m)	Pl. VII.3	3160110	Few specimens worldwide, but commonly found in ToT.

98	*Coryphaenoides hextii* (Alcock, 1890)	NWIO	1582-1,609	31602 (1338 m), 31609 (1241 m), 33102 (1293 m), 32118 (1244 m), 32702 (1347 m)		3160108	Gigantic speciemens collected from ToT, larger than congenrs. Rediscovery, only type specimen available. Only known from Eastern Arabian Sea, comon in ToT.
99	*Coryphaenoides macrolophus* (Alcock, 1889)	NWIO, NEIO	521-741	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 32118 (1244 m), 32120 (1034 m), 33102 (1027 m)	Pl. VII.4		Few specimens worldwide, but commonly found in ToT.
100	*Coryphaenoides* sp.			31601 (1079 m)	Pl. VII.5	3160130	
101	*Coryphaenoides woodmasoni* (Alcock, 1890)	NWIO	1829	28103 (988 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31609 (1241 m), 33102 (1293 m), 32701 (1064 m)	Pl. VII.6	3160122	Rediscovery, only type specimens available. Only known from Eastern Arabian sea
102	*Nezumia brevirostris* (Alcock, 1889)	NWIO	896	31602 (1338 m), 31908 (1258 m), 32116 (1153 m)		3160120	Rediscovery, only type specimens available. Only known from Eastern Arabian sea
103	*Nezumia* sp.			31602 (1338 m), 31609 (1241 m), 32702 (1347 m)	Pl. VII.7		
	Family Moridae						
104	*Lepidion inosimae* (Günther, 1887)	NWPO, SWPO	580-1,100	32702 (1347 m)	Pl. VII.8	3270201	Gigantic speciemen collected from ToT, larger than congenrs. Rare worldwide.

	Order Lophiiformes						
	Family Chaunacidae						
105	*Chaunax* sp.nov.			28103 (988 m), 30501 (1060 m), 32120 (1034 m)	Pl. VII.9	2810315	New species of *Chaunax*.
	Family Diceratiidae						
106	*Bufoceratias shaoi* Pietsch, Ho & Chen, 2004	SWIO, NWPO	0-800	31602 (1338 m)		3160210	Rare worldwide. Largest specimen of the species. First record from North western Indian Ocean
107	*Diceratias trilobus* Balushkin & Fedorov, 1986	SWIO, NWPO		28103 (988 m), 31601 (1079 m)	Pl. VII.10	3160107	Rare worldwide. Largest specimen of the species. First record from North western Indian Ocean
108	*Paraoneirodes* sp.			31601 (1079 m)	Pl. VIII.1	3160108	
	Family Lophidae						
109	*Lophiodes triradiatus* (Lloyd, 1909)	NWIO, SEIO, NWPO	208-1,412	28103 (988 m), 30501 (1060 m), 32120 (1034 m)	Pl. VIII.2	2810311, 3212003	Rare worldwide. Redescription of the species is based on speciemen collected from ToT.
	Family Ogcocephalidae						
110	*Coelophrys micropa* (Alcock, 1891)	SWIO, NWIO, NEIO, SEIO, NWPO	440-850	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31609 (1241 m), 32120 (1034 m)	Pl. VIII.3	3160123	
111	*Halicmetus ruber* Alcock,	NWIO, NEIO,	344-743	28103 (988 m), 31908 (1258 m)	Pl.		

	1891	NWPO			VIII.4		
	Order Myctophiformes						
	Family Neoscopelidae						
112	*Scopelengys tristis* Alcock, 1890	Circumglobal	400-1,800	31601 (1079 m)	Pl. VIII.5	3160132	
	Order Notacanthiformes						
	Family Halosauridae						
113	*Aldrovandia affinis* (Günther, 1877)	Circumglobal		31602 (1338 m), 32701 (1064 m)	Pl. VIII.6	3160201	
114	*Halosaurus carinicauda* (Alcock, 1889)	NWIO, NEIO	500-1,600 m	30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 32116 (1153 m), 32118 (1244 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m)	Pl. VIII.7	3160103	Few specimens worldwide, only known from Northern Indian Ocean.
115	*Halosaurus parvipennis* Alcock, 1892	NWIO, NEIO	897	28103 (988 m), 31601 (1079 m), 31602 (1338 m), 32116 (1153 m), 32118 (1244 m), 32702 (1347 m)	Pl. VIII.8	3160129	Synonymized *H. parvipennis* to *H. carinicauda*. But present specimen match with the description of *H. parvipennis* Alcock 1892, pointing to the validity of the species.
	Family Notacanthidae						
116	*Notacanthus indicus* Lloyd, 1909	NWIO	936	28103 (988 m), 30501 (1060 m)	Pl. VIII.9	2810331	Very rare, endemic to Northern Indian Ocean.
	Order Ophidiiformes						

	Family Bythitidae						
117	*Hephthocara simum* Alcock, 1892	NWIO	800-1,650	30501 (1060 m), 31601 (1079 m), 31609 (1241 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32702 (1347 m)	Pl. VIII.10	3160111	Only type specimens available, common in ToT. Endemic to Northern Indian Ocean.
	Family Ophidiidae						
118	*Dicrolene vaillanti* (Alcock, 1890)	NWIO	1,353	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m), 32120 (1034 m)	Pl. IX.1	3160112	Rediscovery of the species, only type specimens available, but common in cathes from ToT. Endemic to Northern Indian Ocean.
119	*Holcomycteronus pterotus* (Alcock, 1890)	NWIO, NEIO	1000-3199	28103 (988 m), 30501 (1060 m), 31602 (1338 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m), 32120 (1034 m)	Pl. IX.2	3160115	Rediscovery of the species, only type specimens available, but common in cathes from ToT. Endemic to Northern Indian Ocean.
120	*Lamprogrammus brunswigi* (Brauer, 1906)	Circumglobal patchy	800-1,600	30501 (1060 m), 31602 (1338 m), 31609 (1241 m), 32118 (1244 m), 32702 (1347 m)	Pl. IX.3	3050107	Gigantic speciemens collected from ToT, larger than congenrs. Commonly found in trawl catches fro ToT.
121	*Lamprogrammus niger* Alcock, 1891	Circumtropical/ Occasionally Circumsubtropi	500-1,300	28103 (988 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32118 (1244 m), 32120 (1034 m),	Pl. IX.4	2810316, 3160121	Rare worldwide, but gigantic specimen abundant to ToT.

		cal		32701 (1064 m), 32120 (1034 m)			
122	*Luciobrotula bartschi* Smith & Radcliffe, 1913	Circumtropical/ Occasionally Circumsubtropical	500-1,000	31601 (1079 m)	Pl. IX.5	3160128	Rare
123	*Mastigopterus imperator* Smith & Radcliffe, 1913	SEIO, NWIO	1,500-2,365	31602 (1338 m), 32702 (1347 m)	Pl. IX.6	3160203	Monotypic species. First report from Eastern Arabian sea. Rare worldwide.
124	*Monomitopus conjugator* (Alcock, 1896)	NWIO, NEIO	540-760	30501 (1060 m), 31602 (1338 m), 31609 (1241 m), 32702 (1347 m)	Pl. IX.7	3160202	Rediscovery of species, only type speceimens available. Common in ToT. Endemic to Northern Indian Ocean.
	Order Osmeriformes						
	Family Alepocephalidae						
125	*Alepocephalus blanfordii* Alcock, 1892	NWIO, NEPO	1650	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32702 (1347 m), 32120 (1034 m)	Pl. IX.8	3160114	Rare worldwide, abundant in ToT. Gigantic specimen collected from ToT.
126	*Alepocephalus longiceps* Lloyd, 1909	NEIO, NWPO	604	31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 32116 (1153 m), 32118 (1244 m), 32702 (1347 m)	Pl. IX.9	3160206	Rare, common in ToT. First report from NWIO.
127	*Bathytroctes squamosus* Alcock, 1890	NWAO, NWIO, SWIO,	1,000-2,000	31609 (1241 m), 31908 (1258 m), 32116 (1153 m), 32118 (1244 m),	Pl. IX.10	3160119	Rare worldwide.

		SEPO		32120 (1034 m), 32701 (1064 m), 32120 (1034 m)			
128	*Conocara microlepis* (Lloyd, 1909)	NWIO, SWIO, NWPO	1,097-1,555	31602 (1338 m), 31609 (1241 m), 32116 (1153 m), 32118 (1244 m), 32702 (1347 m)	Pl. X.1	3160212	Rare worldwide.
129	*Leptoderma affinis* Alcock, 1899	NEIO, SEIO, NWPO	1378	30501 (1060 m), 31601 (1079 m), 31908 (1258 m)	Pl. X.2		Rare worldwide.
130	*Narcetes* cf. *erimelas* Alcock, 1890	NWIO	1354	28103 (988 m), 30501 (1060 m), 31601 (1079 m), 31908 (1258 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32120 (1034 m)	Pl. X.3	3160117	Three species of the genus repoted from Indian waters, but taxonomy requires revision. Rare. Large specimens common in ToT.
131	*Narcetes* cf. *stomias* (Gilbert, 1890)	Circumglobal		28103 (988 m), 30501 (1060 m), 31602 (1338 m), 31609 (1241 m), 32116 (1153 m), 32118 (1244 m), 32120 (1034 m), 32701 (1064 m), 32702 (1347 m), 33102 (1027 m)	Pl. X.4	3160914	
132	*Rouleina guentheri* (Alcock, 1892)	NWIO, NEIO, SWIO, NWPO		31602 (1338 m), 31609 (1241 m), 31908 (1258 m), 33102 (1293 m), 32116 (1153 m), 32118 (1244 m), 32702 (1347 m), 32120 (1034 m)	Pl. X.5	3160208	Rare, found commonly in ToT.
133	*Rouleina squamilatera* (Alcock, 1898)	NWIO, NEIO, SWIO, NWPO	790-1100	31602 (1338 m), 31908 (1258 m), 32118 (1244 m), 32120 (1034 m), 33102 (1027 m), 32120 (1034 m)	Pl. X.6	3160209	Rare, found commonly in ToT.
134	*Talismania longifilis* (Brauer, 1902)	NWIO, SWIO, NWPO		28103 (988 m), 31601 (1079 m), 31609 (1241 m), 32118 (1244 m), 32120 (1034 m)	Pl. X.7	3160116	Rare.

135	*Talismania* sp.			31601 (1079 m), 32116 (1153 m)			
	Family Platytroctidae						
136	*Holtbyrnia* sp.			28103 (988 m)	Pl. X.8		
137	*Platytroctes mirus* (Lloyd, 1909)	NWIO, NEIO	914	32118 (1244 m), 32702 (1347 m)	Pl. X.9	2810340	Only known from Northern Indian Ocean.
	Order Perciformes						
	Family Chiasmodontidae						
138	*Kali kerberti* (Weber, 1913)			31601 (1079 m)	Pl. X.10	3160133	
	Family Scombrolabracidae						
139	*Scombrolabrax heterolepis* Roule, 1921	Circumglobal		28103 (988 m)	Pl. XI.1	2810327	
	Family Trichiuridae						
140	*Aphanopus microphthalmus* Norman, 1939	SWIO, NWIO, NWPO		28103 (988 m), 30501 (1060 m), 32701 (1064 m), 33102 (1027 m), 32120 (1034 m)		2810305	Rare worldwide. First report from Eastrn Arabian Sea.
	Order Scorpaeniformes						
	Family Psychrolutidae						
141	*Psycroleutius* sp.			32120 (1034 m)	Pl. XI.2		
	Family Setarchidae						
142	*Setarches longimanus* (Alcock, 1894)	NWIO, NEIO		31602 (1338 m), 32116 (1153 m), 33102 (1027 m)	Pl. XI.3	3160215	Only known from Northern Indian Ocean.
	Order Stomiiformes						
	Family Gonostomatidae						

143	*Cyclothone elongata*(Günther, 1878)	NWIO	28103 (988 m), 31602 (1338 m)	Pl. XI.4	3160125
	Family Sternoptychidae				
144	*Argyropelecus* sp.		28103 (988 m), 30501 (1060 m), 31602 (1338 m), 32118 (1244 m)		
	Family Stomiidae				
145	*Astronesthes* sp.		32702 (1347 m)	Pl. XI.5	3050506
146	*Borostomias* sp.		28103 (988 m)		2810347
147	*Chauliodus pammelas* Alcock, 1892	NWIO, NEIO	28103 (988 m), 31601 (1079 m), 32116 (1153 m), 32701 (1064 m)	Pl. XI.6	3211625
	Phylum Chordata				
	Class Reptilia				
	Order Testudines				
	Class Cheloniidae				
148	*Lepidochelys olivacea* (Eschscholtz, 1829)	Circumglobal	30501 (1060 m)		

* **NEAO :** North Eastern Atlantic Ocean, **NEIO :**North Eastern Indian Ocean, **NEPO:** North Eastern Pacific Ocean **NWAO :** North Western Atlantic Ocean, **NWIO:** North Western Indian Ocean, **NWPO :** North Western Pacific Ocean, **SEAO:** South Eastern Atlantic Ocean, **SEIO :** South Eastern Indian Ocean, **SEPO :** South Eastern Pacific Ocean, **SWAO :** South Western Atlantic Ocean, **SWIO :** South Western Indian Ocean, **SWPO :** South Western Pacific Ocean

PLATE I


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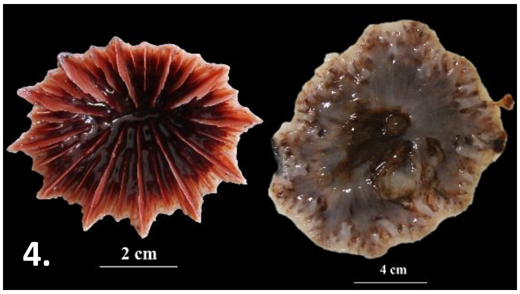
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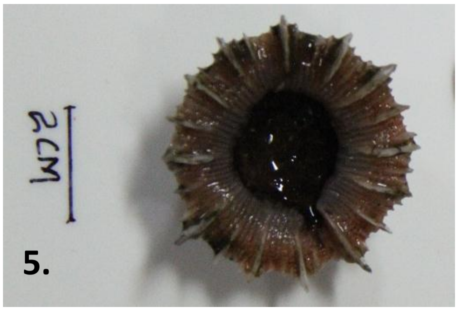
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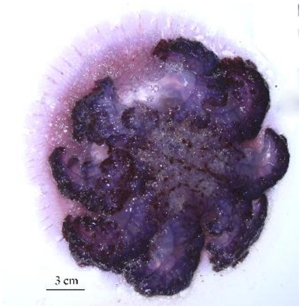
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1. Gorgonid sp., 2. Hormathiid sp. , 3. Pennatulid sp., 4. *Caryophyllia paradoxus*, 5. *Caryophyllia* sp. 3, 6. *Atolla* sp., 7. *Cephea* sp., 8. *Acanthephyra curtirostris*, 9. *Acanthephyra eximia*, 10. *Acanthephyra fimbriata*

PLATE II

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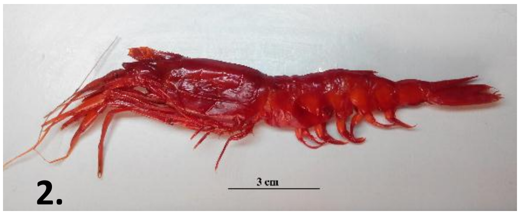

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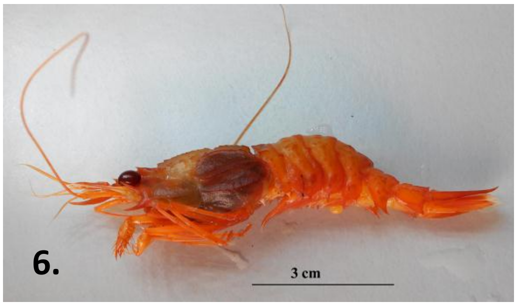

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1. *Acanthepyra sanguinea*, 2. *Ephyrina hoskynii*, 3. *Pseudaristeus crassipes*, 4. *Chaceon alcocki*, 5. *Glyphocrangon investigatoris*, 6. *Glyphocrangon unguiculata*, 7. *Paralomis investigatoris*, 8. *Munida microps*, 9. *Munidopsis stylirostris*, 10. *Munidopsis wardeni*

PLATE III

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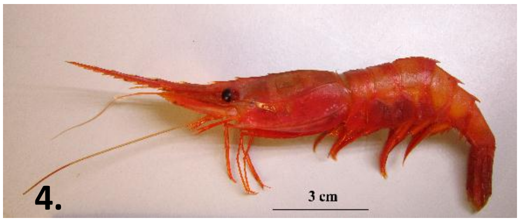

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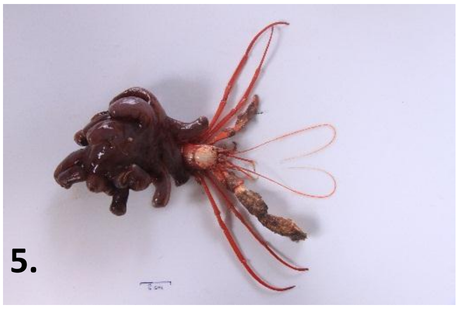

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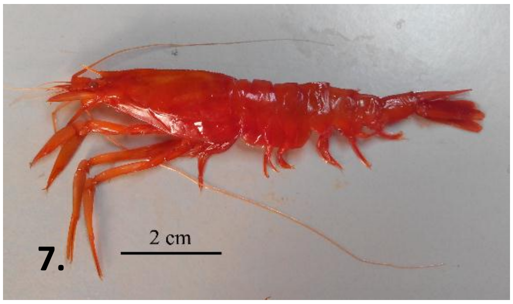

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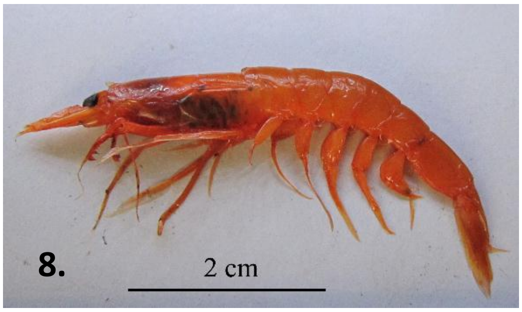

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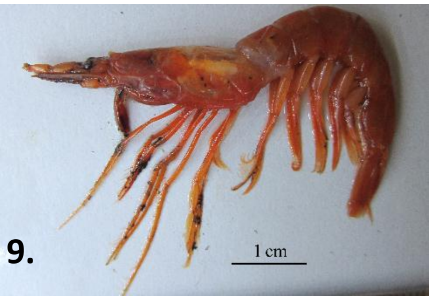

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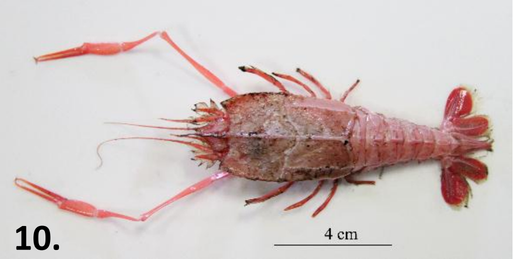
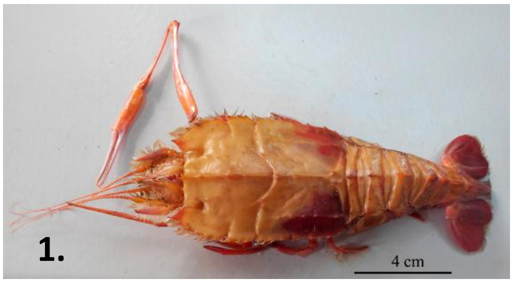


1. *Nephropsis atlantica*, 2. *Nephropsis ensirostris*, 3. *Oplophorus gracilirostris*, 4. *Heterocarpus dorsalis*, 5. *Parapagurus* cf. *pilosimanus* 6. *Glyphus marsupialis*, 7. *Parapasiphae (Eupasiphae) gilesii* , 8. *Psathyrocaris fragilis*, 9. *Psathyrocaris platyophthalmus*, 10. *Stereomastis nana*

PLATE IV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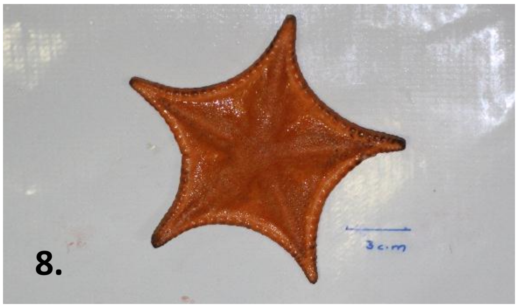
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1. *Stereomastis sculpta*, 2. *Haliporus taprobanensis*, 3. *Bathynomus keablei*, 4. *Propeamussium alcocki*, 5. *Opisthoteuthis philipii*, 6. *Histioteuthis* sp., 7. *Conus* sp., 8. *Ceramaster cuenoti*, 9. *Nymphaster moebii*, 10. *Cnemidaster zea*

PLATE V

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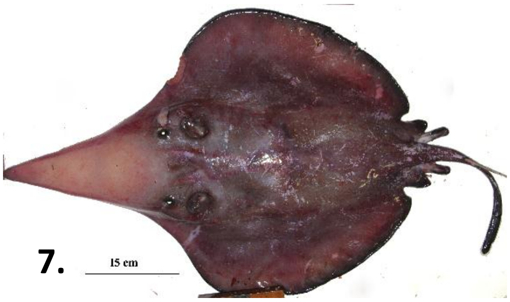

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1. *Eptatretus* sp., 2. *Rhinochimaera africana*, 3. *Harriotta raleighana*, 4. *Hydrolagus africanus*, 5. *Apristurus breviventralis*, 6. *Apristurus saldanha*, 7. *Hexatrygon bickelli*, 8. *Dipturus johannisdavisi*, 9. *Fenestraja mamillidens*, 10. *Benthobatis moresbyi*

PLATE VI

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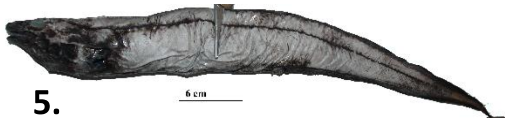

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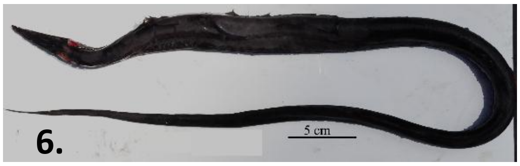

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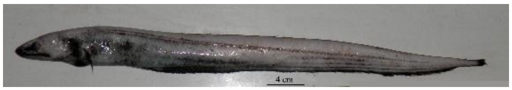

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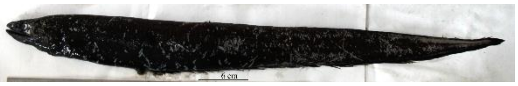

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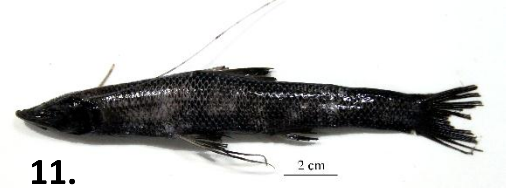

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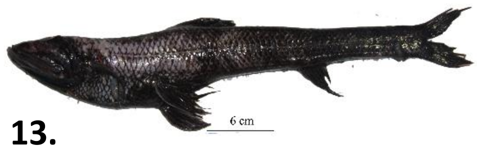

13.

14.

1. *Centroscyllium* cf. *kamoharai*, 2. *Centroscymnus crepidater*, 3. *Bathycongrus* cf. *guttulatus*, 4. *Bathyuroconger vicinus*, 5. *Promyllantor purpureus*, 6. *Gavialiceps taeniola*, 7. *Nemichthys scolopaceus*, 8. *Venefica proboscidea*, 9. *Synaphobranchus affinis*, 10. *Synaphobranchus brevidorsalis*, 11. *Bathypterois (Bathypterois) atricolor*, 12. *Bathypterois guentheri*, 13. *Bathytyphlops marionae*, 14. *Harpadon squamosus*

PLATE VII


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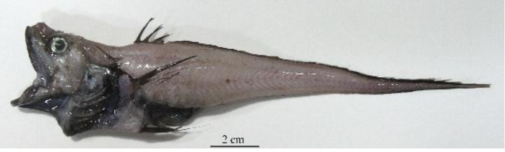

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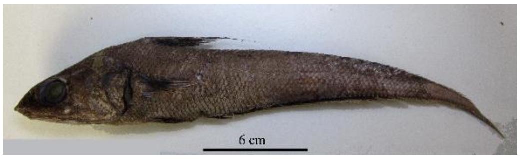

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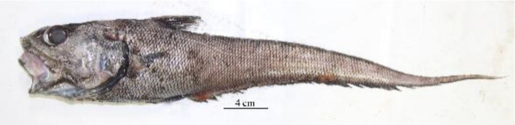

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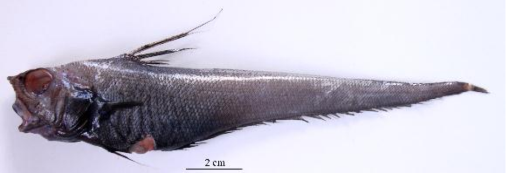

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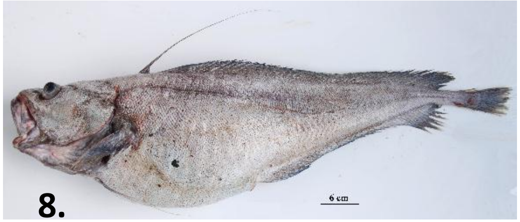
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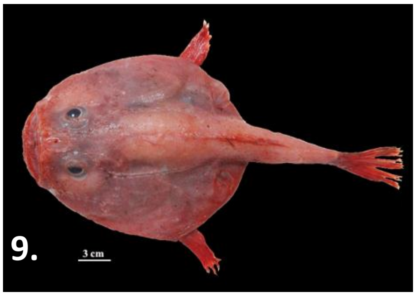
9.


10.

1. *Anoplogaster cornuta*, 2. *Hoplostethus (Leiogaster) melanopus*, 3. *Bathygadus furvescens*, 4. *Coryphaenoides macrolophus*, 5. *Coryphaenoides* sp., 6. *Coryphaenoides woodmasoni*, 7. *Nezumia brevirostris*, 8. *Lepidion inosimae*, 9. *Chaunax* sp.nov., 10. *Diceratias trilobus*

PLATE VIII

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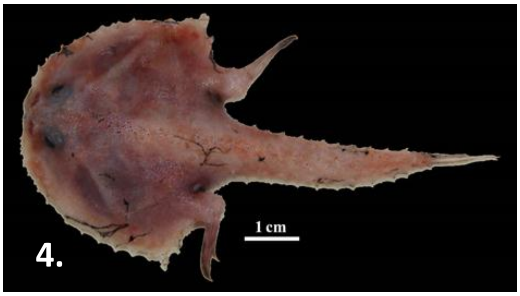

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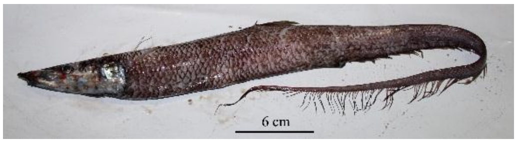

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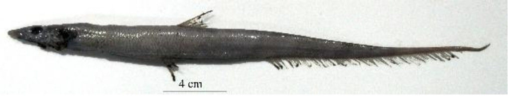

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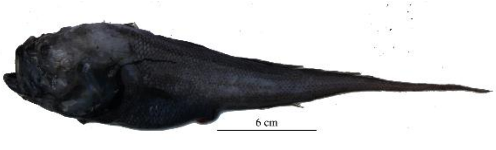
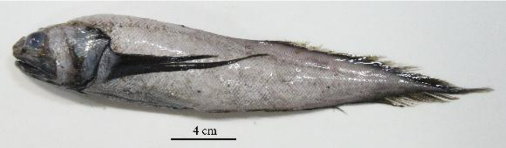


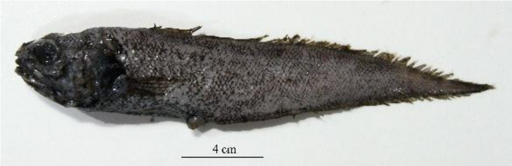
10.

1. *Paraoneirodes* sp., 2. *Lophiodes triradiatus*, 3. *Coelophrys micropa*, 4. *Halicmetus ruber*, 5. *Scopelengys tristis*, 6. *Aldrovandia affinis*, 7. *Halosaurus carinicauda*, 8. *Halosaurus parvipennis*, 9. *Notacanthus indicus*, 10. *Hephthocara simum*

PLATE IX



1.



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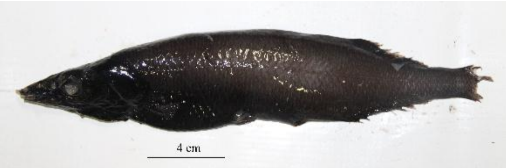

9.

10.

1. *Dicrolene vaillanti*, 2. *Holcomycteronus pterotus*, 3. *Lamprogrammus brunswigi*, 4. *Lamprogrammus niger*, 5. *Luciobrotula bartschi*, 6. *Mastigopterus imperator*, 7. *Monomitopus conjugator*, 8. *Alepocephalus blanfordii*, 9. *Alepocephalus longiceps*, 10. *Bathytroctes squamosus*

PLATE X

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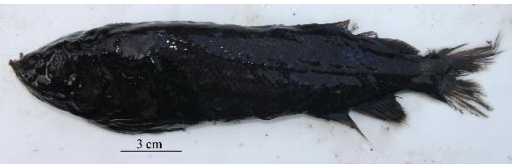


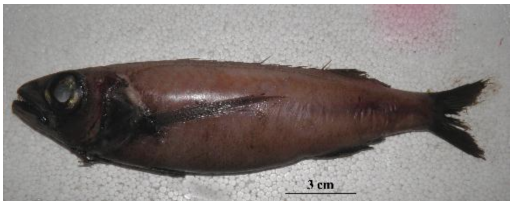
8.

9.

10.

1. *Conocara microlepis*, 2. *Leptoderma affinis*, 3. *Narcetes* cf. *erimelas*, 4. *Narcetes* cf. *stomias*, 5. *Rouleina guentheri*, 6. *Rouleina squamilatera*, 7. *Talismania longifilis*, 8. *Talismania* sp. , 9. *Platytroctes mirus*, 10. *Kali kerberti*

PLATE XI



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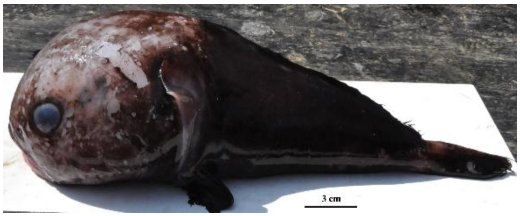

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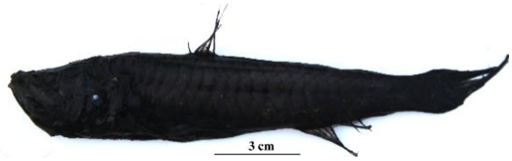

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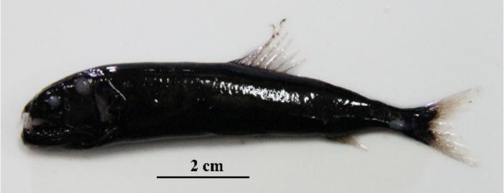


5.

6.

1. *Scombrolabrax heterolepis*, 2. *Psycroleutius* sp., 3. *Setarches longimanus*,
4. *Cyclothone elongata*, 5. *Astronesthes* sp., 6. *Chauliodus pammelas*

Chapter - 4

BIODIVERSITY AND COMMUNITY STRUCTURE OF THE DEEP-SEA MEGAFAUNA OF TERRACE OFF TRIVANDRUM

4.1 INTRODUCTION

Biological diversity or biodiversity is defined as the ‘variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems’ (CBD 1992; Article-2). Biological resources of Planet Earth and ecosystem services thereof are being rapidly depleted as human activities increasingly encroaches on unique natural habitats that are rich in biodiversity. The realizations that each distinct species is a unique evolutionary mile spot that cannot be replaced once it is lost explain the necessity and urgency in the conservation of these resources. Lack of systematic scientific data remains a central obstacle to defining the biodiversity problem.

Biodiversity of an ecosystem or a habitat is measured as an attribute of two components viz. richness and evenness (Magurran 2013). Richness is defined as the number of groups of genetically or functionally related individuals. In most ecological studies, richness is expressed as the number of species and is usually called species richness. Evenness is the proportion of species or functional groups present in a site. The more equal species are in proportion to each other the greater the evenness of the site. A site with low evenness indicates that a few species dominate the site. Thus, as a measure, biodiversity combines both richness and evenness of a habitat or ecosystem. Food and energy for life on earth are in essence provided by the biodiversity of the planet. Besides providing humans with biomedical products and recreation, biodiversity play an important role in regulating climate services through various biogeochemical processes. In general, biodiversity signifies the health of an ecosystem. Documentation and measurement of marine biodiversity at the global, regional and local scales is a key requirement to evaluate the possible response of marine ecosystems and its biotic component to the changes induced by human activities and climate variability (Garcia *et al.* 2014).

Major international efforts in this direction include the Convention on Biological Diversity (CBD) on the conservation and sustainable use of biological diversity, the Census of Marine Life (CoML) for documentation of marine biodiversity at the global, regional and local scales and the Ocean Biogeographic Information System (OBIS) for archival and dissemination of biodiversity information. India is a signatory to CBD, and therefore has legally binding commitment to conserve its biological diversity, to sustainably use its components and to share equitably benefits arising from the use of genetic resources. Similarly, the Centre for Marine Living Resources & Ecology (CMLRE), Ministry of Earth Sciences, is the recognized Regional Node of OBIS for North Indian Ocean (IndOBIS).

Biodiversity of a community encompasses a range of different levels of organization from the genetic variation between individuals and populations to species diversity, assemblages, habitats, landscapes, and biogeographic provinces (Gray 2001). An ecological community comprises a defined group of actually or potentially interacting populations of species living in the same place or habitat. Whittaker (1960) suggested a range in spatial scales to characterize different aspects of biodiversity, partitioning it into alpha, beta, gamma, and epsilon components. Several factors can be invoked to explain the spatial patterns of biodiversity: historical, phylogenetic, and climate processes are important determinants of regional pools of species (i.e., gamma diversity), whereas biotic interactions play a key role in determining local diversity (i.e., alpha diversity). Changes in the physical characteristics of the habitat can strongly affect variation in composition and abundance of species along a gradient, thus influencing beta diversity (Danovaro *et al.* 2004, 2008; Balata *et al.* 2007; Pusceddu *et al.* 2009). Biodiversity imparts increased stability, increased productivity, resistance to invasion, and other disturbances to an ecological community. The spatial scale and patterns of biodiversity plays a crucial role in structure and function of a biological community, within a habitat or an ecosystem.

The deep-sea, the most extensive ecosystem on earth, host a large proportion of undiscovered biodiversity. The faunal communities of the deep-sea benthic boundary layer (BBL) play a key role in many ecological and biogeochemical processes, such as cycling of carbon on a global scale (Smith 1992). Danovaro *et al.* (2008) elucidate that biodiversity loss in deep-sea ecosystems might be catastrophic, associated with exponential reductions of their functions. The global scale of the biodiversity crisis has stimulated investigations that explore the relationships between biodiversity, productivity, stability, and services in different ecosystems of the world (Naeem *et al.* 1994; Loreau *et al.* 2001; Worm *et al.* 2006; Cardinale *et al.* 2012). The quantitative information needed to evaluate the consequences of biodiversity loss from the BBL faunal community of the deep ocean floor are completely lacking from many regions, especially the Indian Ocean.

India's National Biodiversity Action Plan 2014 (NBAP 2014) is broadly aligned to the Global Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets, adopted in the Nagoya conference, Japan in 2010. Among the national biodiversity targets included as Appendix 1 to NBAP 2014, Targets-6, 10, 11, 15 & 19 are of particular importance to the ocean sector. Target-6 stipulates that "By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits". As per Target-10, "By 2015, the multiple anthropogenic pressures on coral reefs and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning". Target-11 aims to achieve " By 2020 at least 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, and conserve through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures”. Target-15 envisage “ By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration of at least 15% of degraded ecosystems thereby contributing to climate change mitigation and adaptation and to combating desertification”. As per Target-19 “By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends and the consequences of its loss, are improved, widely shared and transferred, and applied”.

Though India has 24 designated MPAs, most parts of these MPAs extends over the land and do not strictly fall under the norms of an MPA. As of now, the total area under MPA is less than 1% of our EEZ area and there are no deep-sea MPAs. To meet our commitments outlined above, there is an urgent need to document and inventorize all marine species and biodiversity patterns, identify and delineate Vulnerable Marine Ecosystems (VMEs) and Ecologically and Biologically Sensitive Areas (EBSAs) that need to be declared as Marine Protected Areas (MPAs). The present study is a pioneering effort to measure and document the patterns of biodiversity and megafaunal community structure of a totally uncharted deep-sea habitat, the Terrace of Trivandrum (ToT). The objective of this chapter is to quantitatively elucidate the spatial patterns and community structure of megafaunal diversity in the BBL of ToT.

4.2 RESULTS

The present study recorded 148 megafaunal species belonging to 122 genera in 86 families, 45 orders, and 17 classes under 5 phyla. The qualitative aspects of the biodiversity of ToT megafauna is detailed in Chapter 3. The present chapter addresses the temporal and spatial variations in the megafaunal species diversity of ToT.

Conventional univariate measures of diversity were used *in lieu* of alpha diversity, while beta diversity was worked out following multivariate methods.

4.2.1 Alpha diversity

The alpha diversity gives a quantitative measure of diversity in each sample and is generally referred to as point diversity. Alpha diversity is the mean species diversity in a site or habitat at a local scale (Whittaker 1960). In its simplest form alpha diversity considers the number of nominal species present in a sample. During the present study, the total number of species in a sample ranged between 24 (Stn. 32209, 1,039 m, WM 2014) and 57 (Stn. 32116, 1,153 m, WM 2013) species per haul. Number of species recorded from each sampling station are listed in Table 4.1. Majority of species (40 Nos.) obtained from the study area are single site observations. Only one species (*Alepocephalus blanfordii*) was ubiquitously present in all the 14 sampling sites and two species were found in 13 locations.

Heterogeneity diversity indices are alpha diversity measures that combine the species richness and evenness into a single measure, and therefore provide more robust point information about communities (Gray 2001). Heterogeneity diversity indices namely Shannon-Weiner ($H'\log_e$), Margalef index (d), Pielou evenness (J'), expected number of species in 100 individuals (ES_{100}), taxonomic distinctness (Delta) and total phylogenetic diversity (sPhi+) were computed for all sampling locations using PRIMER, as detailed in Table 4.1. Detailed information regarding the indices used and their derivations are given in Chapter 2. Diversity index, H' ($\log_e$) varied from 1.6 at Stn. 31601 (1,079 m, SM 2013) to 3.4 at Stn. 31609 (1,241 m, SM 2013). Margalef index of species richness (d) varied from 2.1 at Stn. 32209 (1,034 m, WM 2014) to 6.2 at Stn. 31602, (1,338 m, SM 2013). Pielou evenness index (J') varied from 0.41 at Stn.31601 (1,079 m, SM 2013) to 0.92 at Stn. 31909 (1,241 m, SM 2013). Expected species number in 100 samples (ES_{100}) varied from 14.4 at Stn.31601 (1,079 m, SM 2103) to 33.3 at Stn.32116 (1,153 m WM 2013). Taxonomic distinctiveness (Delta+)

varied from 36.8 at Stn. 31601 (1,079 m, SM 2013) to 82.5 at Stn. 31909 (1,241 m, SM 2013). Total phylogenetic diversity (sPhi+) varied from 1052 at Stn. 32209 (1,039 m, WM 2014) to 2281 at Stn. 28103 (988 m, SM 2010).

Table 4.1. Diversity indices of deep-sea megafauna in the sampling locations.

Station No.	Species observed (S)	Shannon-Weiner index (H'[log$_e$])	Margalef index (d)	Pielou evenness index (J')	Expected species in 100 samples (ES[100])	Taxonomic distinctiveness (Delta)	Total phylogenetic diversity (sPhi+)
28103	55	3.2	5.9	0.8	29.5	72.0	2281.5
30501	48	2.9	5.0	0.8	24.7	74.0	2109.1
31601	48	1.6	4.5	0.4	14.4	36.8	2013.7
31602	56	3.1	6.2	0.8	29.6	57.6	2030.5
31609	43	3.4	4.5	0.9	31.2	78.3	1758.1
31908	39	2.1	4.6	0.6	21.3	59.8	1677.7
31909	28	3.1	3.9	0.9	24.7	82.5	1343.7
32116	57	3.2	4.5	0.8	33.3	71.8	2031.9
32118	55	2.2	5.2	0.5	24.7	42.9	2116.7
32120	37	1.8	3.4	0.5	14.6	49.8	1489.8
32701	33	2.7	3.7	0.8	22.6	65.7	1528.6
32702	39	2.9	4.4	0.8	23.0	67.6	1509.2
33102	27	2.8	3.3	0.8	20.4	71.9	1330.6
32209	24	2.4	2.1	0.8	16.8	54.9	1052.3

The cumulative dominance (k-dominance) curve (Figure 4.1) provides a graphical representation of the intrinsic diversity pattern, considering both richness and evenness, of all 14 sampling stations. Species are ranked in the order of abundance along the X-axis with their corresponding contribution to the total abundance in the Y-axis. Dominance curve of four stations (31601, 32118, 32120, and 31908) start very high in the y-axis, indicating that a single species contributed to 60% of the numerical abundance. Cumulative dominance of 2 species of shrimps, *Pseudaristeus crassipes* and *Haliporus taprobanensis* contributing largely to the total numerical abundance make low evenness to these stations. In remaining of the 10 stations cumulative dominance curve starts well below 30%, indicating high evenness and diversity. Curves which runs close to the base of the plot, viz. Stn. 31609 (1241 m, SM 2013) and Stn. 31909 (1241 m, SM 2013) were the most diverse.

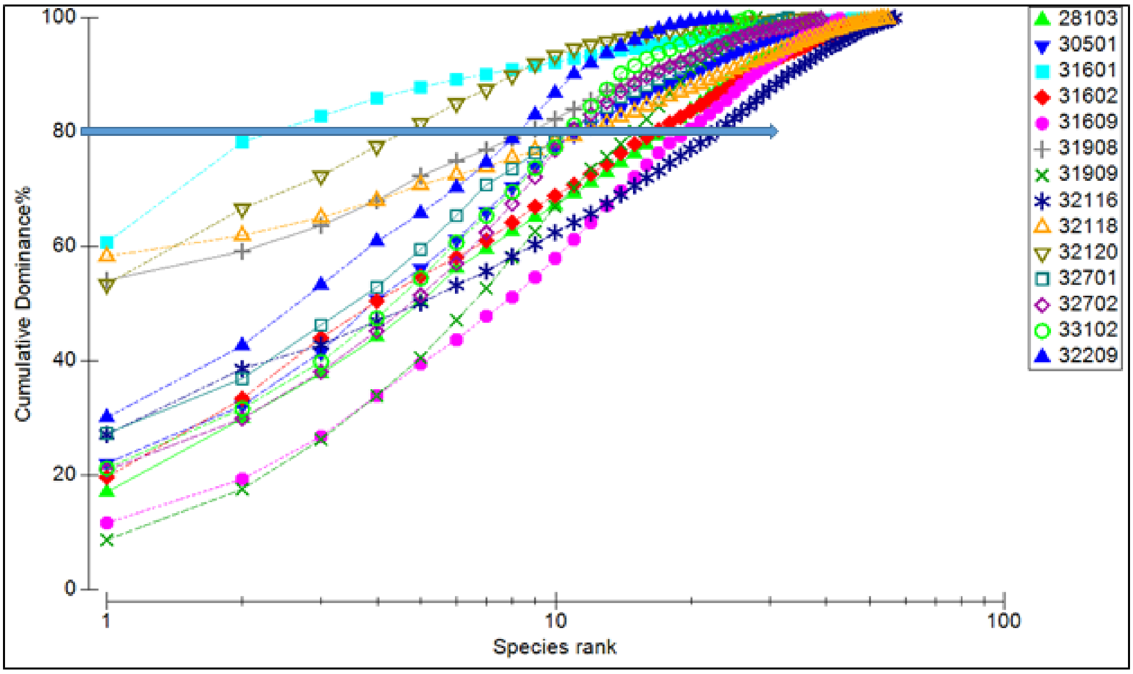


Figure 4.1. k-dominance curve for deep-sea megafauna of ToT in the sampling locations

4.2.2 Temporal and bathymetric variations in alpha diversity

A total of 9 observations covering all 5 depth categories in the study area were made during summer monsoon (SM), while during winter monsoon (WM), 5 observations were made in two depth categories (Table 4.2). Based on the current sampling effort, a total of 122 species were recorded in the SM observations and 107 species in the WM. Among the 148 total megafaunal species recorded, 81 species were represented during both seasons, while 41 species were found only during SM and 26 species were found only during WM. Means and standard deviations of alpha diversity measures during SM & WM are listed in Table 4.2. Mean value of all diversity indices were found to be slightly higher during summer monsoon. However, results of one-way ANOVA indicate that none of these indices varied significantly (P>0.1) between seasons (Table 4.2).

Table 4.2. Results of ANOVA showing variations in alpha diversity between seasons.

Biodiversity index	**Range**		**Mean & Standard deviation**		**ANOVA between Seasons**	
	SM	**WM**	**SM**	**WM**	**F**	**Sig.**
No. of samples	9	5	9	5	-	-
S	28—56	24—57	43.2 ±9.5	40 ±15.4	0.24	0.633
H'(loge)	1.6—3.4	1.8—3.2	2.8 ±0.6	2.5 ±0.5	0.961	0.346
d	3.7—6.2	2.1—5.2	4.8 ±0.8	3.7 ±1.2	3.603	0.082
J'	0.4—0.9	0.5—0.8	0.7 ±0.2	0.7 ±0.2	0.421	0.529
ES(100)	14.4—31.2	14.6—33.3	24.6 ±5.2	22 ±7.4	0.601	0.453
Delta+	36.8—82.5	42.9—71.9	66 ±13.6	58.3 ±13.1	1.071	0.321
sPhi+	1343.7—2281.5	1052.3—2116.7	1805.8 ±318	1604.3 ±457.7	0.951	0.359

Among various depth categories, highest number of species (94 species) was recorded from 1150-1250 m depth category followed by, 950-1050 m (79 species), 1050-1150 m (76 species), 1250-1350 m (74 species). The 1350-1450 m depth category recorded least number (39 species, based on a single observation). Only 14 species were found to be distributed across all depth categories, and 53 species were found only at one depth category, while the remaining 81 species showed intermediate levels of bathymetric distribution. Mean and standard deviations of S, d, H'($\log_e$), J', ES (100), Delta and sPhi+ for the each depth category is listed in Table 4.3. Detailed analysis indicates that these indices did not vary significantly between successive depth categories (Table 4.3). Moreover, the alpha biodiversity indices do not depict any trends from shallow to the deeper part of ToT.

Table 4.3. Results of ANOVA showing variations in alpha diversity between depth categories.

Biodiversity index	Mean & Standard deviation				ANOVA between depth categories	
	950-1050	1050-1150	1150-1250	1250-1350	F	Sig.
S	35.8 ±14	43 ±8.7	51.7 ±7.6	41 ±14.1	0.813	0.548
H'(loge)	2.6 ±0.6	2.4 ±0.7	2.9 ±0.6	2.8 ±0.6	0.327	0.853
d	3.7 ±1.6	4.4 ±0.7	4.8 ±0.4	4.9 ±1.2	0.618	0.661
J'	0.7 ±0.1	0.6 ±0.2	0.7 ±0.2	0.8 ±0.2	0.214	0.324
ES(100)	20.3 ±6.6	20.6 ±5.5	29.7 ±4.4	25.2 ±4.2	1.625	0.25
Delta	62.2 ±11.5	58.8 ±19.5	64.3 ±18.8	66.7 ±13.8	0.122	0.371
sPhi+	1538.6 ±527.2	1883.8 ±311.3	1968.9 ±187.4	1684 ±343.5	0.748	0.583

4.2.3 Beta diversity

Variations among stations, or beta diversity, was measured by computing similarity among stations (Bray-Curtis similarity) and using various multivariate techniques in PRIMER-6 (Detailed in Chapter 2)

4.2.4 Seasonal variations in megafaunal community structure

Analysis of Similarity (ANOSIM) routine was employed to test the differences in species composition between seasons, using species distribution matrix (square-root transformation) and Bray-Curtis Similarity. The result revealed significant changes (R=0.35, P=1%) in species composition of ToT with respect to seasons (Figure 4.2). The species contributing to the differences between seasons was elucidated using SIMPER tool (on untransformed data). Average dissimilarity between two seasons was 74%, where SM stations aggregate at an average similarity of 35% and WM stations share a similarity of 25%. Individual and cumulative contribution of megafaunal species to the total variability between seasons are given in Table 4.4. About 30 species in the study area contribute up to 60% of the total dissimilarity between seasons.

Furthermore, five of these species (*Lamprogrammus niger*, *Pseudaristeus crassipes, Rouleina squamilatera, Aristaeopsis edwardsiana, Hoplostethus melanopus*) together contribute a cumulative dissimilarity of 21% between seasons. It is also evident that average abundance of all these species shows a marked increase during WM than that of SM.

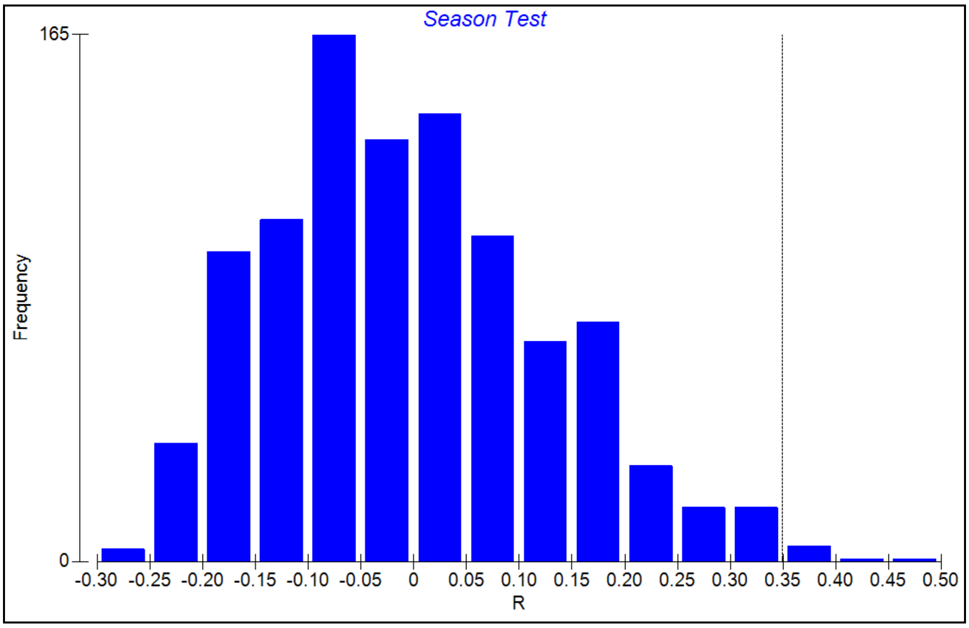


Figure 4.2. ANOSIM showing differences in megafaunal species distribution between seasons.

Among the species which were collected during both seasons, much higher abundance was found during WM. In addition to the changes in the density of these common megafaunal species, 67 species were found only during a single season (41 during SM and 26 during WM), which is indicative of considerable species replacement or migration between seasons. While differential sampling effort from different depth strata in the two seasons may account for the higher number migrant fauna, the total absence of a species during one season, which was highly abundant in the other, strongly indicates seasonal migration of megafaunal species. For example, anomuran crab species such as *Munidopsis wardeni, M. stylirostris* and *Munida microps* which are particularly abundant during WM, were found totally absent during SM. Species such as *Leptoderma affinis, Monomitopus conjugator, Aldrovandia affinis,* and *Paralomis investigatoris* were found only during summer monsoon collections. In general, the results indicate that there are seasonal changes in the megafaunal density from SM to WM.

4.2.5 Bathymetric variations in megafaunal community structure

A Bray-Curtis resemblance matrix based ANOSIM analysis (Figure 4.3) of species distribution reveal statistically significant changes in species composition of ToT with regard to depth. A relatively high R value (0.38 at 0.3% significance level), indicate there is considerable species replacement between the gradient of depth categories with an interval of 100 m. A SIMPER analysis revealed species which were unique to each depth category. Among 79 megafaunal species present in the 950-1050 m depth category, only 39 accounted for an average group similarity of 34% (Table 4.5). The top six species which contribute to the similarity within the 950-1050 m depth category are *Aristaeopsis edwardsiana, Lamprogrammus niger, Coryphaenoides woodmasoni, Benthobatis moresbyi, Alepocephalus blanfordii and Bathyuroconger vicinus.* These six species cumulatively contribute about 60% of the average group similarity. The adjacent depth category 1050-1150 m was represented with 76 megafaunal species and among them 39 species contributed significantly to the similarity (41.43% similarity) within the group (Table 4.6). Of these species, 10 species contribute to 60% of the similarity within this category, including 5 species that appeared in the preceding depth category (except *Lamprogrammus niger*) along with *Dicrolene introniger, Bathygadus furvescens, Pseudaristeus crassipes, Haliporus taprobanensis* and *Hormathiid sp.*

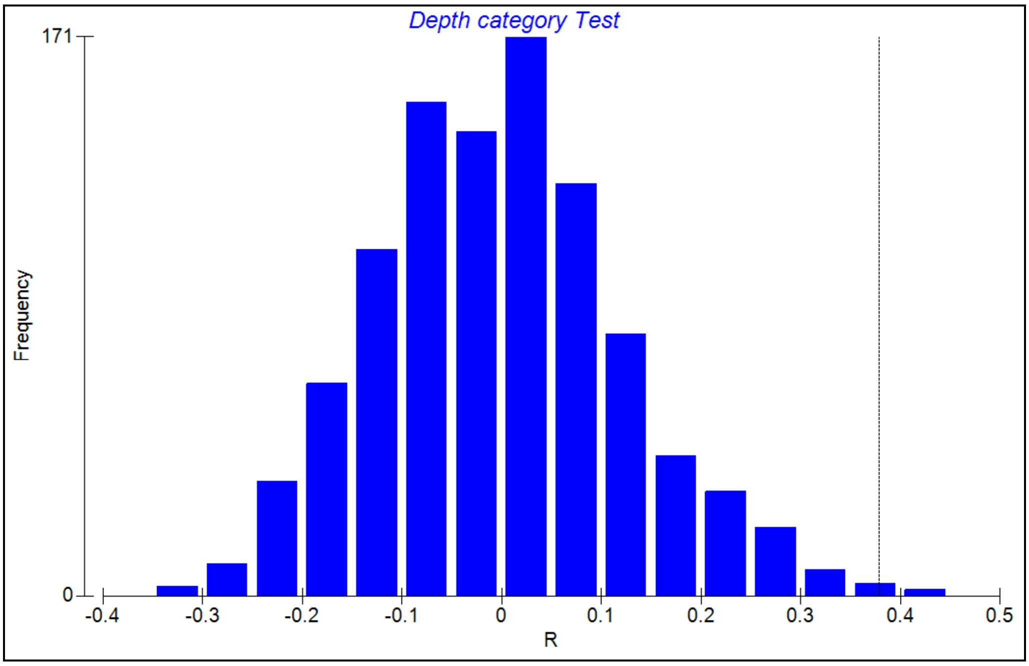


Figure 4.3. ANOSIM showing differences in megafaunal species distribution between depth categories.

In the next depth category 1150-1250 m, comprising a total of 96 species only 44 species accounted for an average group similarity at 30.5% (Table 4.7). About 13 species contribute to the 60% similarity within the depth category. Top six of them are *Dicrolene introniger*, *Lamprogrammus niger*, *Caryophyllia communis*, *Bathyuroconger vicinus*, *Bathytroctes squamosus* and *Conocara microlepis*. Thirty seven species out of a total of 74 species (Table 4.8) contribute to a group average similarity of 36.95% within the 1250-1350 m depth category. Species best representing the 60% closeness within the depth zone comprise 12 species, the top six among them were the symbiont, *Parapagurus pilosimanus* with *Epizoanthus paguriphilus*, hormathiid sp., *Caryophyllia communis*, *Dicrolene introniger*, *Rouleina guentheri* and *Alepocephalus blanfordii*.

The average dissimilarity from 950-1050 m depth category to the successive depth categories namely: 1050-1150 m, 1150-1250 m, 1250-1350 m, 1350-1450 m are 62%, 74%, 78% and 79% respectively. Among various depth categories, minimum dissimilarity was observed between adjacent depth categories, while those which fall far apart showed maximum dissimilarity. In other words, considerable overlapping in species distribution was found between successive depth categories, while only minimal overlapping was found between distant depth categories. Among the 148 species recorded, only 14 species were found distributed in all the five depth zones. Even though these were recorded from a wider depth range, their distribution was not uniform. For example; higher abundance of species such as *Aristaeopsis edwardsiana, Bathyuroconger vicinus, Coryphaenoides woodmasoni* and *Alepocephalus blanfordii* were noticed in the shallow regions of ToT, i.e. in the first two depth categories (950-1150 m), while species such as *Haliporus taprobanensis, Halosaurus carinicauda, H. parvipennis, Dicrolene introniger, Holcomycteronus pterotus, Narcetes stomias, Apristurus saldanha, Centroscyllium kamoharai*, and *Cnemidaster zea* were found more abundantly at the middle depth zone (1150-1250 m) rather than at shallow or deeper stations.

4.2.6 Megafaunal assemblages of ToT

Megafaunal species assemblages within the 1500 m depth zone of ToT were established by analyzing the variability in species distribution, on the basis of taxonomic dissimilarity index (phylum to species) across the 14 sampling locations. Hierarchical cluster analysis and SIMPROF test based on taxonomic distinctiveness (B+) of species distribution between all 14 stations resulted in 3 significantly different ($p<0.05$) clusters (Figure 4.4). The clusters can be identified by the black lines in the dendrogram, while red branches indicate that SIMPROF-test could not find statistically significant distinctions within the clusters. The cluster analysis clearly indicates the differentiation of the sites of the survey into two zones (designated as A and B). Dissimilarity between these zones was 62.21, with a test static of Pi: 2.15, and highly statistical significance of 0.1%. The clustering pattern reveals that depth associated factors are responsible for this major zonation among sampling locations. Zone A include all sampling locations below 1100 m (designated shallow zone), while zone B comprises of sampling locations above this depth (deep zone). Samples from the adjacent depth categories were clustered together in progressively dissimilar manner within each zone. It is also apparent from SIMPROF test that the third significant subgroup distinction is within the deeper zone of ToT (zone B) clustered based on seasonal factors. Results indicate that even though dissimilarities between stations appeared also in zone A, seasonality significantly affects (dissimilarity: 58.55, pi: 1.86, p: 0.055) the community structure in the deeper parts of ToT (>1100m) rather than the shallower parts (<1100m).

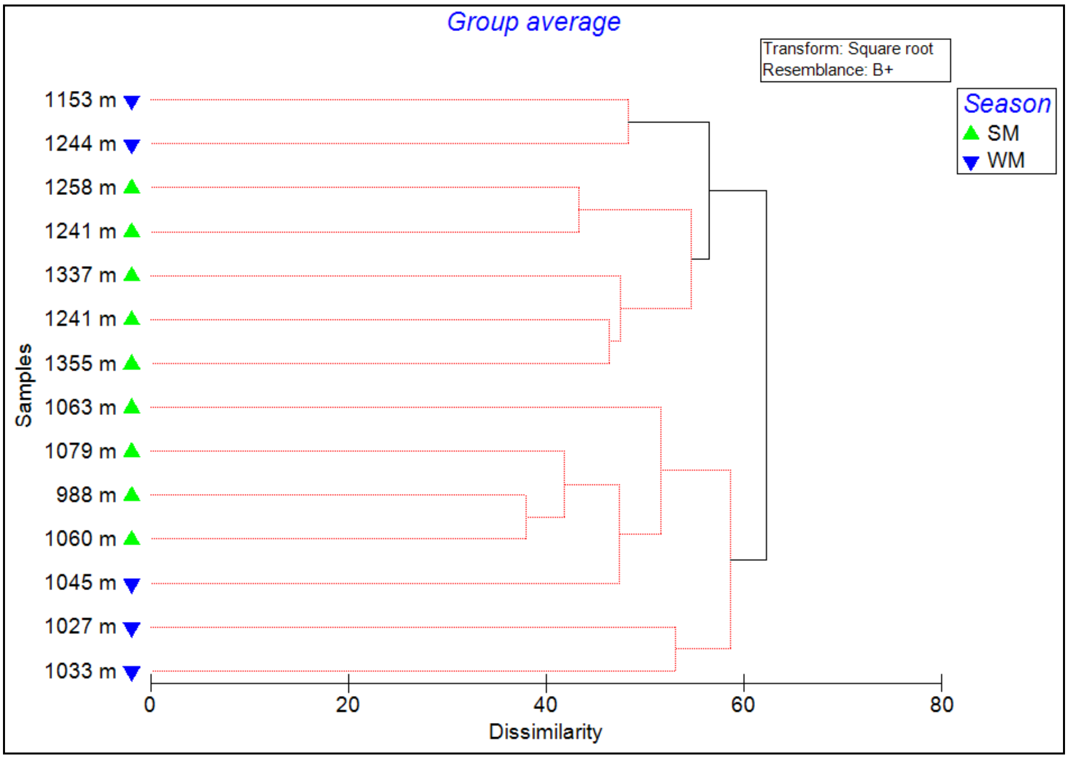


Figure 4.4 Hierarchical cluster plot showing taxonomic distinctiveness (B+) of species distribution between 14 sampling stations.

The affinities among the stations were more clearly established using nonparametric multi-dimensional scaling (MDS) technique. MDS plot (Figure 4.5) depict degree of coupling and distance between samples shown in the cluster plot in a two dimensional ordination. As observed in the cluster analysis, MDS illustrate two separate faunal assemblages at 60% dissimilarity between them. Adjacent depth groups were found to adhere more closely while distant depth groups lay apart. Pattern of mega faunal species assemblage of ToT within 1500 m display a clear zonation in its faunal composition at a depth of 1100 m.

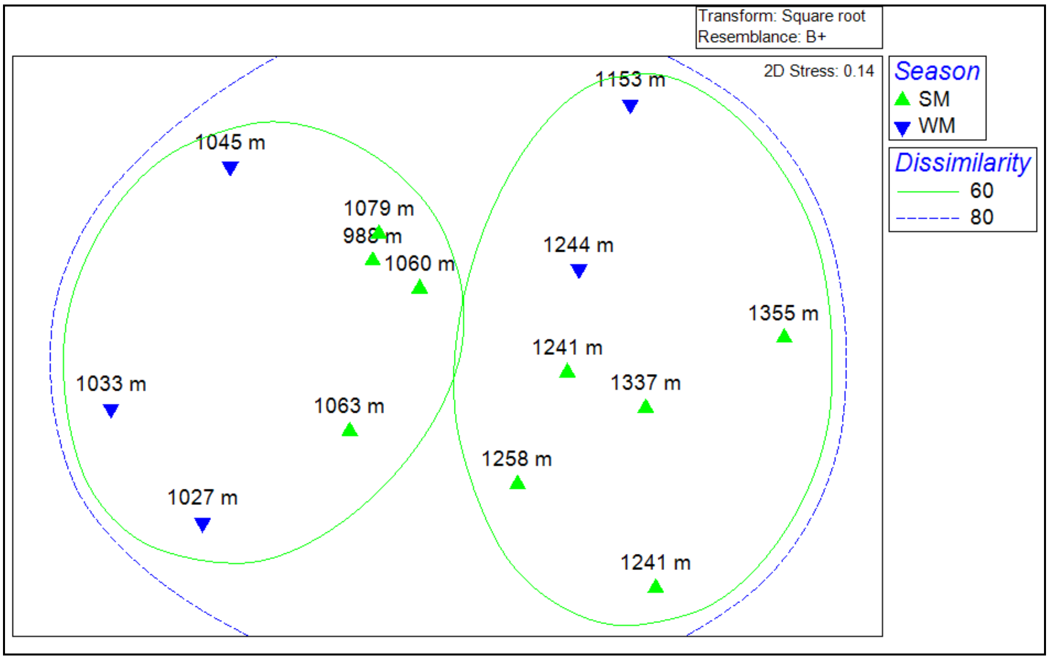


Figure 4.5 MDS plot showing taxonomic distinctiveness (B+) of species distribution between 14 sampling stations.

The MDS clearly depicts two distinct megafaunal assemblages between 950-1150 m (shallow zone) and 1150-1450 m (deep zone) depths. Biodiversity indices of the two assemblages are given Table 4.10a (page 131). On comparing the alpha diversity measures of the two depth zones, the mean diversity indexes of the shallow zone are found lower but the variations are not significant as compared to the deep zone, whereas ES(100) index show significant variations (F=5.49, P=0.37) between the assemblages. The above results indicate that alpha diversity measures do not vary significantly between sites. However on a habitat scale the megafaunal diversity of ToT represent two distinct assemblages.

A SIMPER analysis was performed to distinguish communities of the shallow and deep zones of ToT (Table 4.9). Species such as *Benthobatis moresbyi, Coryphaenoides macrolophus, Hoplostethus melanopus, Aphanopus microphthalmus, Centrophorus atromarginatus* and *C. squamosus* etc. were found only in shallow zone (zone A) of ToT. While species such as *Rouleina guentheri, Coryphaenoides hextii, Alepocephalus longiceps, Conocara microlepis, Pseudarchaster jordani, Nymphaster moebii, Nezumia brevirostris, Mastigopterus imperator* and *Glyphocrangon unguiculata* were recorded only from deeper zone (zone B) of ToT. Moreover relative abundance of species such as *Lamprogrammus niger, Aristaeopsis edwardsiana, Rouleina squamilatera, Bathyuroconger vicinus, Coryphaenoides woodmasoni* etc were more at shallow depth zone (zone A) than at deeper zone. Species such as *Pseudaristeus crassipes, Haliporus taprobanensis, Dicrolene intronigеr, Caryophyllia communis, Bathytroctes squamosus, Cephea coerulea, Halosaurus carinicauda* etc. were distributed more abundantly at deeper zone (zone B).

4.3 DISCUSSION

Present study in the bathyal depths of the Terrace off Trivandrum document exceptionally high species richness and diversity of deep-sea mega fauna. Bathymetric trend of megafaunal diversity was first analyzed by Vinogradova (1958, 1962); by pooling depth records of species on a global scale. These studies provided the first indication that diversity shows a unimodal trend with depth, with a peak at bathyal depths. That is, for the megafauna as a whole, diversity increased sharply from the upper continental slope to about 2000 m and then declined toward the abyss and remained low from abyssal to hadal depths. The concept that the deep-sea fauna is actually more diverse than temperate subtidal fauna (Sanders 1968) revolutionized the understanding of deep-sea biodiversity. Such unimodal patterns of diversity across a wide bathymetric transect, was observed in the western North Atlantic (Haedrich *et al.* 1975, 1980; Rex 1981), with greatest diversity of species at some mid or deeper level on the slope and peak diversities at around 2000 m (~1800 and 2200 m for fishes and invertebrates respectively). But in some other regions of the Atlantic and Pacific, the diversity of demersal fishes appears to basically decrease with depth, with some individual features and no clear unimodality (Pearcy *et al.* 1982; Haedrich and Merrett 1988; Kendall and Haedrich 2006).

A comparison of heterogenetic diversity index, taken here as the expected number of species from 50 individuals in a sample ES(50) was made between ToT (Table 4.10b, Page 131) with similar observations in the western North Atlantic (Haedrich *et al.* 1975, 1980) that showed a unimodal megafaunal diversity peak at the bathyal depths. The ES(50) index in the 1000-2500 m depth zone (‘megafaunal peak diversity zone’) of western North Atlantic of fishes ranged between 5.0-12.5 with an average of 7.6 and in invertebrates it ranged between 4-13 with an average value of 8.2 (Rex 1981). Compared to the North Atlantic the ES (50) index of ToT were much higher both in the shallow (950-1150 m) and deep zone (1150-1450 m). The mean ES (50) values for the shallow zone were 7.9 for invertebrates and 13.3 fishes, whereas for the deeper zone ES (50) index were 14.1 for invertebrates and 13.8 for fishes. And in the deep zone the mean ES(50) index were 14.1 and 13.8 for invertebrates fishes respectively. This clearly indicates that the megafaunal diversity of ToT is higher than one of the well-studied deep-sea habitats.

Bathymetric variations in the megafaunal composition and species turnover of the southwest coast of India have been enumerated through various fishery resource assessment surveys. The pioneer effort among them was based on 418 otter trawl operations carried out on board R. V. *Varuna* between 1962 and 1968, in the depths from 75 to 450 m by Silas (1969). The study addressed the variability in demersal fish diversity and composition with depth as a factor in the whole region between the latitudes of 7° to 15° N. The study revealed changes in the faunal composition with regard to the depth by compartmentalizing the whole fauna in to three successive depth zones, viz. 10-75, 75-180, 180-450. Among these the first depth zone, 51 demersal fin-fish species were recorded in the inner shelf (10-75 m), 63 species in the off shore shelf (75- 180 m) and 135 species in the upper continental slope (180-450 m). Incorporating these surveys and additional samples collected during the exploratory trawl survey carried out by the Indo-Norwegian project between 1965-1968, Mohamed and Suseelan (1973) reported 33 species of deep-sea decapods (18 shrimps, 4 lobsters and 11 species of other decapods) in the upper continental slope region (125-430 m) off south west coast of India.

A systematic survey to study the distribution and composition demersal fishery resources of the Wadge Bank area was carried out during the period of 1981-1983 by Fishery Survey of India. The Wadge Bank area is the continental shelf zone of the peninsular India, which is the shallow complement region of ToT. These surveys recorded 93 species of commercially important demersal fishes including crustaceans and cephalopods between 18-223 m depths (Joseph *et al.* 1987). Based on exploratory survey onboard MFV *Matsya Varshini* of Fishery Survey of India, Sajeevan and Nair (2006) inventoried 98 demersal teleost fish species belonging to 79 genera 52 families and 16 orders from the south west coast of India (7°- 10° N), between 100 and 500 m depths.

Extensive deep-sea resource assessment surveys were conducted onboard FORV *Sagar Sampada*, especially in the south west coast of India, which documented deep-sea faunal diversity of the region (Suseelan *et al.* 1989; Jayapraksh *et al.* 2006; Somvanshi *et al.* 2009; Rajasree 2011; Venu 2009; Hashim 2012; Venu 2013). Jayaprakash *et al.* (2006) recorded a total of 77 species of fin fishes, 11 species of crustaceans, 3 species cephalopods within the 100 to 1100 m depth of south west coast of India (9º N-16º N). While Govindam *et al.* (2013) had reported 74 species of teleost fishes belonging to 45 families, 14 species of elasmobranchs belonging to 8 families, 9 species of crustaceans and 5 species of molluscs from the region. These two studies reported maximum number of species from the two depth zones ranging from 500-900 m (48 species from 500-700 m, 43 species from 700-900 m), while 2 shallow depth zones between 100- 500 m (27 species from 100-300 m, 26 species from 300-500 m) and deepest zones 900-1100 m (22 species) showed lesser number of species. Rajasree (2011) had reported 15 species of deep sea prawns in the depth zone 150-550 m off Kerala coast. Venu (2013) reported a total of 149 deep-sea fish species belonging to 123 genera, 17 families, and 24 orders from off south west coast of India. Venu (2013) observed maximum number of species (94 Nos.) in the 500-800 m, even higher than the shallower (200-500 m) depth zone (63 species).

The present study indicates two distinct species assemblages (950-1150 m & 1150-1450 m) associated with depth. Similar observations were also recorded along the south west coast of India in the surveys conducted by *R V Varuna* (1962-1968), *MFV Matsya Varshini* (1981-1983) and *FORV Sagar Sampada* (1984 onwards). The surveys of *RV Varuna* were restricted below 450 m depth zone using otter trawls and are therefore not comparable with the present results. However, these results indicates there is an increasing trend in species diversity with depth with 51 species of demersal finfishes from the inner shelf (10-75 m), 63 species from the offshore shelf (75-180 m) and 135 species in the upper continental slope (180-450 m). The surveys of *MFV Matsya Varshini* in the Wadge Bank (adjacent shallow depth zones of ToT) and *FORV Sagar Sampada* are comparable with the present observation as all of these surveys were made using HSDT and EXPO model trawls. The present study demonstrates exceptionally higher megafaunal diversity in ToT (950-1450 m) which probably support the assumption of unimodal diversity peak exist in the ToT region. A comparison in depth associated trend in species richness along the south west coast of India using the present data in conjunction with the data obtained from secondary source (*FORV Sagar Sampada* data, Venu 2013) is given in Table 4.11. For this synthesis of depth associated species richness trend, only finfishes are considered to maintain consistency between datasets. Results from this synthesis (Figure 4.6) indicate a unimodal progression in species richness throughout the southwest coast of India. The unimodal species richness peak at 800 m depth along the northern latitudes (9-11, 11-13 and 13-15), while in the southernmost latitude (7-9) the progression of species richness extends up to 1150 m depth with a peak in the ToT area, unlike other northern sectors of the south west coast of India.

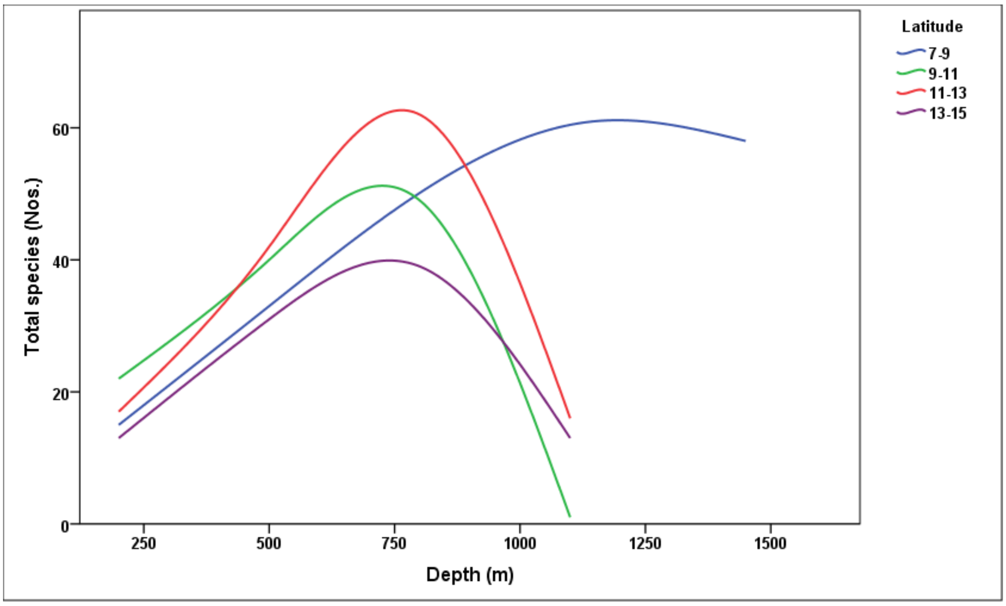


Figure 4.6 Depth associated trends in species richness along latitudinal transects off south west coast of India (A synthesis of present observation with *FORV Sagar Sampada* data from adjacent areas (Venu 2013)

From the earlier explorations of the deep-sea, it was observed that faunal composition changes with depth. Initial studies on bathymetric trends in megafaunal assemblages, recognized “zones” where homogenous communities, separated by abrupt transitions. Further studies on deep-sea fauna revealed that discrete zones were largely illusory and a relic of sampling bias. Both the rate of faunal turnover and the degree of clinal variation in individual species correspond to the rate of change in depth, being highest in the steep upper bathyal zone and very subtle in the deep abyssal plain (Etter and Rex 1990; Hecker 1990). The present study conducted within the bathyal depths (900-1500 m) of ToT reveled two distinct zones which differ significantly in faunal composition. Multivariate techniques clearly depicts that changes in the megafaunal composition with depth reflect an underlying continuum of species replacements with a distinct boundary at 1100 m. It is well established today that the environmental gradients driving species turnover are a function of the rate of change in depth (Rex and Etter 2010). The deep-sea faunal changes are continuous with depth, though they show some variations in the species replacement rate (Sanders and Hessler 1969; Haedrich *et al.* 1980; Carney *et al.* 1983; Haedrich and Merret 1990; Rex and Etter 2010). Hence the 1100 m depth of ToT could be arbitrary boundary, where species replacement rate change significantly between the shallow and deeper part of ToT. The results also indicate seasonality changes in megafaunal diversity, which is more pronounced in the deeper zone of ToT.

Depth range restriction of a species represents a balance between adaptive properties of a species and the ecological variables that select for or against them (Rex and Etter 2010). Relevant adaptive characters of species have been proposed to explain this, including feeding and habitat type (Jumars and Fauchald 1977), metabolism and locomotor capacity (Seibel and Drazen 2007), morphological specialization (Thistle and Wilson 1996), larval disposal (Young *et al.* 1997) adult mobility (Haedrich *et al.* 1980), body size (Rex *et al.* 1999), body shape (Soetaert *et al.* 2002), and enzymatic activity

(Siebenaller and Somero 1978). Numerous ecological factors account for diversity-depth patterns, including competition (Sanders 1968), predation (Dayton and Hessler 1972), biological interactions mediated by productivity (Rex 1976), area effects (Osman and Whitlath 1978), environmental heterogenity (Etter and Caswell 1994), physical disturbances (Gage *et al.* 1995), oxygen concentration (Levin and Gage 1998), source-sink dynamics (Rex *et al.* 2004) and various combinations of these. Undoubtedly, the complete explanation for these patterns is multivariate, especially for unimodal diversity-depth patterns (Rex and Etter 2010).

Several influential hypotheses aim to explain the apparent paradox of high diversity in an environment that was seemingly homogenous and stable, and where food was scarce. These hypothesis remain at the forefront of ecological thinking and research in deep oceans, but surprisingly many fundamental facets remain incompletely understood today (McClain and Schlacher 2015).

Latitudinal as well as ocean wide scale variations in deep-sea biodiversity indicates that the deep-sea environment is not uniform throughout (Rex *et al.* 2006; Rex and Etter 2010). Latitudinal gradients of deep-sea biodiversity pattern appear to differ fundamentally from those in marine coastal systems. Exploratory surveys conducted all along the Indian coast (Somvanshi *et al.* 2009; Hashim 2012) clearly portray a rich taxonomic diversity towards deeper parts (200-1,000 m) in southern latitudes of Indian peninsula. Their study indicate a steady reduction in species number encountered, from southern latitude (7º-10ºN with 65 species) towards northern latitudes (11º-14ºN with 45 species, 15º-17º N with 20 species and 18-21 with 16 species). Present study in the bathyal region of ToT also supports the earlier findings of high megafaunal biodiversity in the deep-sea of south west coast of India. Latitudinal gradients in deep-sea biodiversity were unexpected because it was assumed that the environmental gradients that cause large-scale patterns in shallow waters could not affect communities living at great depths (Jones and Sanders 1972). The latitudinal patterns in deep-sea biodiversity is controlled by regional process rather than latitudinal environmental gradients (Rex *et al.* 2000). Therefore large-scale bathymetric and geographic patterns of species diversity in the deep-sea can be addressed only by incorporating the influence of oceanographical, ecological and evolutionary process that are imposed at regional scales.

Present study identified the hitherto unknown Terrace off Trivandrum as a unique habitat, holding rare and extremely diverse megafauna. Present study also revealed the intrinsic megafaunal diversity parameters of ToT which appears to be higher than any other such habitat known to the world. Under these circumstances, India being a signatory to the CBD, should focus attention for its protection by declaring the ToT as an EBSA. Since Indian government policies promote deep and distant water fisheries, prior management regulations for ToT should be included in the National Biodiversity Action Plan to protect its biodiversity and to sustain its ecosystem functions.

Table 4.4 Results of SIMPER showing species contributing to dissimilarity between seasons

Species	**SM Av.Abund**	**WM Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Lamprogrammus niger	14.37	82.5	5.41	1.25	7.29	7.29
Pseudaristeus crassipes	23.47	49.43	2.9	0.79	3.91	11.2
Rouleina squamilatera	1.09	36.77	2.79	0.79	3.75	14.95
Aristaeopsis edwardsiana	22.04	34.58	2.6	1.25	3.5	18.45
Hoplostethus melanopus	1.46	23.98	1.8	0.74	2.42	20.88
Dicrolene introniger	17.64	38.33	1.77	1.82	2.38	23.26
Haliporus taprobanensis	13	32.15	1.73	0.83	2.33	25.59
Benthobatis moresbyi	7.32	21.53	1.72	1.11	2.32	27.91
Bathyuroconger vicinus	14.52	36.9	1.71	1.27	2.31	30.22
Coryphaenoides woodmasoni	20.75	26.12	1.66	1.32	2.23	32.45
Bathytroctes squamosus	3.22	33.17	1.64	1.51	2.22	34.66

Alepocephalus blanfordii	13.35	34.58	1.59	1.62	2.14	36.8
Caryophyllia communis	10.22	25.64	1.25	1.37	1.69	38.49
Coryphaenoides macrolophus	8.16	10.55	1.2	0.92	1.62	40.11
Bathycongrus macrocercus	1.89	22.31	1.14	1.39	1.53	41.64
Cephea coerulea	8.41	16.79	1.09	1.23	1.47	43.12
Rouleina guentheri	6.28	17.25	1.06	1.22	1.43	44.54
Bathygadus furvescens	7.97	12.77	0.99	0.94	1.34	45.88
Ceramaster cuenoti	7.82	17.71	0.94	1.32	1.27	47.15
Coryphaenoides hextii	7.03	13.13	0.9	1.06	1.21	48.36
Narcetes stomias	7.41	17.84	0.89	1.61	1.2	49.56
Holcomycteronus pterotus	7.06	20.39	0.88	1.63	1.19	50.75
Alepocephalus longiceps	7.28	12.85	0.87	0.93	1.17	51.93
Benthodytes typica	6.11	16.53	0.85	1.04	1.14	53.07
Bathynomus keablei	8.42	15.16	0.82	1.3	1.11	54.18
Narcetes erimelas	2.49	15.09	0.8	1.37	1.08	55.26
Halosaurus carinicauda	8.04	14.49	0.79	1.25	1.07	56.33
Acanthephyra fimbriata	6.22	6.19	0.79	0.8	1.06	57.39
Glyphocrangon investigatoris	1.1	13.45	0.77	0.81	1.04	58.43
Nephropsis ensirostris	0.93	15.03	0.75	0.84	1.02	59.45
Bathypterois guentheri	2.12	9	0.74	0.61	0.99	60.44
Hephthocara simum	8.09	10.85	0.7	1.16	0.94	61.38
Nephropsis atlantica	5.72	11.82	0.7	1.18	0.94	62.32
Centroscyllium kamoharai	4.39	13.26	0.68	1.3	0.91	63.24
Acanthepyra sanguinea	4.65	12.02	0.66	0.98	0.89	64.13
Halosaurus parvipennis	5.24	11.34	0.64	1.09	0.86	64.99
Calliotropis metallica	0.75	6.03	0.62	0.8	0.84	65.83
Centroselachus crepidater	4.4	7.56	0.59	0.95	0.79	66.61
Caryophyllia sp1	2.74	13.71	0.58	0.67	0.78	67.39
Lamprogrammus brunswigi	6.83	2.69	0.57	0.93	0.77	68.16
Cnemidaster zea	7.52	2.12	0.56	1.25	0.75	68.91

Dipturus johannisdavisi	3.67	12.68	0.54	1.49	0.73	69.65
Pleurotoma	0.95	5.36	0.54	0.79	0.73	70.38
Bathypterois atricolor	4.84	6.03	0.54	1.18	0.73	71.11
Stereomastis sculpta	4.04	10.7	0.54	1.26	0.72	71.83
Conocara microlepis	3.9	7.76	0.53	0.94	0.72	72.55
Talismania longifilis	3.98	5.12	0.51	0.85	0.69	73.24
Munidopsis wardeni	0	6.83	0.5	0.75	0.67	73.91
Propeamussium alcocki	5.17	4.48	0.5	0.9	0.67	74.57
Glyphocrangon unguiculata	0	13.91	0.49	0.68	0.66	75.23

Table 4.5 Results of SIMPER showing species contributing to similarity within 950-1050 m depth

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Aristaeopsis edwardsiana	53.29	4.93	2.22	14.61	14.61
Lamprogrammus niger	61.56	3.66	2.22	10.84	25.45
Coryphaenoides woodmasoni	36.36	3.43	1.78	10.17	35.62
Benthobatis moresbyi	33.66	3.12	2.14	9.26	44.89
Alepocephalus blanfordii	30.84	2.99	3.11	8.86	53.75
Bathyuroconger vicinus	28.99	2.18	5.32	6.46	60.2
Coryphaenoides macrolophus	19.07	1.56	0.9	4.62	64.82
Hoplostethus melanopus	33.26	1.23	0.81	3.63	68.45
Dicrolene introniger	21.46	1.18	0.86	3.49	71.94
Bathynomus keablei	13.24	0.87	0.91	2.57	74.51
Rouleina squamilatera	38.45	0.68	0.8	2.03	76.54

Table 4.6 Results of SIMPER showing species contributing to similarity within 1050-1150 depth.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Aristaeopsis edwardsiana	36.94	5.21	6.69	12.59	12.59
Coryphaenoides woodmasoni	22.74	3.94	19.01	9.52	22.11
Bathyuroconger vicinus	23.93	3.73	8.74	9	31.11
Dicrolene introniger	19.86	2.45	2.49	5.9	37.01

Bathygadus furvescens	18.11	2.07	7.21	4.99	42
Alepocephalus blanfordii	15.81	2.02	1.3	4.87	46.87
Haliporus taprobanensis	31.17	1.58	2.99	3.82	50.69
Hormathiidae	9.75	1.53	15.24	3.7	54.39
Benthobatis moresbyi	12.97	1.52	13.79	3.68	58.07
Pseudaristeus crassipes	53.31	1.48	0.58	3.58	61.66
Hydrolagus africanus	8.12	1.46	7.21	3.53	65.18
Ceramaster cuenoti	8.57	1.37	8.14	3.3	68.49
Bathynomus keablei	12.29	1.32	1.82	3.19	71.68
Halosaurus carinicauda	6.89	1.22	9.61	2.94	74.62

Table 4.7 Results of SIMPER showing species contributing to similarity within 1150-1250 m depth.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Dicrolene introniger	55.03	2.72	1.8	8.92	8.92
Lamprogrammus niger	65.97	1.97	2.31	6.46	15.38
Caryophyllia communis	48.81	1.86	2.03	6.09	21.47
Bathyuroconger vicinus	36.67	1.84	2	6.05	27.52
Bathytroctes squamosus	39.35	1.35	1.82	4.43	31.95
Conocara microlepis	17.9	1.25	1.88	4.1	36.05
Narcetes stomias	27.18	1.24	2.02	4.08	40.13
Bathynomus keablei	17.98	1.19	2.09	3.91	44.04
Ceramaster cuenoti	35.79	1.19	2.09	3.91	47.95
Rouleina guentheri	31.89	1.11	2.15	3.62	51.58
Alepocephalus longiceps	25.25	1.01	2.08	3.32	54.89
Coryphaenoides hextii	25.02	0.99	2.45	3.25	58.14
Nephropsis atlantica	24.66	0.94	2.09	3.09	61.23
Alepocephalus blanfordii	24.62	0.94	1.6	3.09	64.32
Hephthocara simum	17.94	0.94	1.74	3.08	67.4
Coryphaenoides woodmasoni	14.72	0.91	0.58	2.99	70.39
Halosaurus carinicauda	26.5	0.88	1.81	2.89	73.28
Talismania longifilis	12.73	0.77	0.58	2.54	75.81

Table 4.8 Results of SIMPER showing species contributing to similarity within 1250-1350 m depth.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Parapagurus pilosimanus	8.12	2.64	3.36	7.15	7.15
Epizoanthus paguriphilus	7.89	2.54	2.95	6.88	14.03
Hormathiidae	7.2	2.24	3.38	6.06	20.09
Caryophyllia communis	9.51	2.11	3.47	5.72	25.81
Dicrolene introniger	7.11	2.06	3.67	5.57	31.37
Rouleina guentheri	8.63	1.96	2.09	5.29	36.66
Alepocephalus blanfordii	10.39	1.73	2.17	4.68	41.35
Cnemidaster zea	6.32	1.71	3.99	4.63	45.98
Apristurus saldanha	4.93	1.47	3.59	3.97	49.95
Cephea coerulea	7.44	1.37	0.58	3.72	53.67
Coryphaenoides hextii	12.09	1.3	4.95	3.51	57.18
Holcomycteronus pterotus	4.68	1.26	4.69	3.42	60.6
Nephropsis atlantica	5.52	1.16	0.58	3.14	63.74
Lamprogrammus niger	18.09	1.16	0.58	3.14	66.89
Benthodytes typica	9.18	1.15	0.58	3.1	69.99
Harpadon squamosus	3.69	1.04	3.59	2.81	72.8
Opisthoteuthis philipii	3.71	1.02	3.52	2.77	75.57

Table 4.9 Results of SIMPER showing species contributing to dissimilarity between depth zones.

Species	950-1150 m Av.Abund	1150-1450 m Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Lamprogrammus niger	41.38	36.03	3.89	1.01	5.27	5.27
Pseudaristeus crassipes	25.33	40.17	3.22	0.78	4.37	9.63
Aristaeopsis edwardsiana	46.28	6.75	3.17	1.66	4.29	13.93
Benthobatis moresbyi	24.8	0	2.04	1.57	2.77	16.7
Rouleina squamilatera	21.97	5.69	1.76	0.59	2.39	19.09
Haliporus taprobanensis	13.85	25.83	1.75	0.76	2.37	21.46
Bathyuroconger vicinus	26.82	18.21	1.75	1.28	2.37	23.82
Coryphaenoides woodmasoni	30.53	14.8	1.75	1.31	2.37	26.19
Coryphaenoides macrolophus	18.02	0	1.63	1.17	2.2	28.4

Dicrolene introniger	20.77	29.29	1.6	1.61	2.16	30.56
Rouleina guentheri	0	20.39	1.42	1.99	1.92	32.49
Coryphaenoides hextii	0	18.41	1.34	1.66	1.81	34.3
Hoplostethus melanopus	19.01	0	1.32	0.63	1.79	36.09
Caryophyllia communis	6.46	24.99	1.3	1.47	1.76	37.85
Alepocephalus longiceps	0	18.54	1.29	1.25	1.75	39.6
Alepocephalus blanfordii	24.4	17.46	1.29	1.21	1.74	41.35
Bathygadus furvescens	14.32	5.05	1.24	1.06	1.69	43.03
Bathytroctes squamosus	10.24	17.59	1.18	1.11	1.6	44.63
Cephea coerulea	4.62	18.19	0.99	1.15	1.34	45.97
Halosaurus carinicauda	4.88	15.81	0.87	1.32	1.18	47.15
Bathynomus keablei	12.83	8.82	0.87	1.32	1.18	48.33
Ceramaster cuenoti	5.36	17.35	0.87	1.27	1.18	49.5
Benthodytes typica	5	14.66	0.84	1.12	1.14	50.64
Holcomycteronus pterotus	8.44	15.2	0.83	1.63	1.13	51.77
Narcetes stomias	7.9	14.37	0.83	1.49	1.12	52.9
Hephthocara simum	9.58	8.58	0.83	1.1	1.12	54.02
Acanthephyra fimbriata	7.44	4.97	0.81	0.85	1.09	55.11
Bathycongrus macrocercus	8.3	10.07	0.8	0.99	1.09	56.2
Nephropsis atlantica	2.86	12.93	0.75	1.29	1.02	57.22
Lamprogrammus brunswigi	2.24	8.46	0.75	1.15	1.02	58.24
Conocara microlepis	0	10.56	0.74	1.35	1	59.24
Pseudarchaster jordani	0	7.03	0.69	0.99	0.94	60.18
Acanthepyra sanguinea	3.68	10.88	0.69	0.95	0.94	61.12
Halosaurus parvipennis	4.21	10.63	0.68	1.13	0.92	62.05
Centroscyllium kamoharai	4.43	10.69	0.65	1.27	0.89	62.93
Bathypterois atricolor	7.14	3.4	0.64	1.18	0.87	63.8
Narcetes erimelas	7.34	6.64	0.63	1.11	0.85	64.66
Hydrolagus africanus	8.3	2.18	0.61	1.33	0.83	65.48
Bathypterois guentheri	7.04	2.11	0.59	0.59	0.8	66.29
Centroselachus crepidater	7.34	3.72	0.59	0.96	0.79	67.08
Caryophyllia sp1	3.52	9.79	0.59	0.68	0.79	67.87
Cnemidaster zea	3.75	7.44	0.58	1.24	0.79	68.67
Glyphocrangon investigatoris	2.92	8.1	0.57	0.68	0.78	69.45
Talismania longifilis	3.32	5.45	0.57	0.9	0.77	70.22
Nephropsis ensirostris	4.54	7.38	0.56	0.7	0.75	70.97
Parapagurus pilosimanus	1.08	5.83	0.55	1.01	0.75	71.72

Propeamussium alcocki	5.34	4.51	0.55	0.98	0.74	72.46
Epizoanthus paguriphilus	1.08	5.73	0.54	0.99	0.74	73.2
Nymphaster moebii	0	6.36	0.53	0.79	0.72	73.92
Stereomastis sculpta	4.37	8.46	0.52	1.28	0.71	74.63
Dipturus johannisdavisi	3.64	10.14	0.51	1.44	0.7	75.33

Table 4.10a Results of ANOVA showing variations in alpha diversity index between depth zones.

Biodiversity index	Range		Mean & Std. Deviation		ANOVA between zones	
	Shallow zone (950-1150 m)	Deep zone (1150-1450 m)	Shallow zone (950-1150 m)	Deep zone (1150-1450 m)	F	P
No. of samples	7	7	7	7	-	-
S	24-55	28-57	38.9 ±11.7	45.3 ±11.0	1.115	0.312
d	2.1-5.9	3.9-6.2	4 ±1.3	4.8 ±0.7	1.931	0.19
J'	0.4-0.8	0.5-0.9	0.7 ±0.2	0.8 ±0.1	0.573	0.463
ES(100)	14.4-29.5	21.3-33.3	20.4 ±5.6	26.8 ±4.5	5.494	0.037
H'(loge)	1.6-3.2	2.1-3.4	2.5 ±0.6	2.8 ±0.5	1.514	0.242
Delta	36.8-74	42.9-82.5	60.7 ±14	65.8 ±13.6	0.476	0.504
sPhi+	1052.3-2281.5	1343.7-2116.7	1686.5 ±453.1	1781.1 ±292.7	0.215	0.651

Table 4.10b A comparison of ES (50) of invertebrates and vertebrates between two depth zones of ToT.

	Range		Mean & Std. Deviation	
Biodiversity index	Shallow zone (950-1150 m)	Deep zone (1150-1450 m)	Shallow zone (950-1150 m)	Deep zone (1150-1450 m)
ES(50) Invertebrates	3.9-12.9	7.8-19.2	7.9 ±3.5	14.1 ±3.2
ES(50) Fishes	9.7-16.7	7.8-17.7	13.3 ±2.4	13.8 ±3.4

Table 4.11 Trend in finfish species richness along bathymetric gradients off the southwest coast of India (A synthesis of data from present study, FORV Sagar Sampada data CMLRE (Venu 2013). For the present synthesis only finfishes are considered to maintain consistency in the analysis).

Latitude	**7-9**			**9-11**			**11-13**			**13-15**		
Depth zones **Orders**	**200-500**	**950-1150**	**1150-1450**	**200-500**	**500-800**	**800-1100**	**200-500**	**500-800**	**800-1100**	**200-500**	**500-800**	**800-1100**
Anguilliformes	2	6	7	2	5		4	8	3	4	4	2
Ateleopodiformes	1			1				1				
Aulopiformes	5	2	4	6	2		3	1	1	1		1
Beryciformes	1	2	1	1	5		1	4				
Carcharhiniformes	1	2	2	3	2		3	6		3	2	
Chimaeriformes		2	3		1			2			1	1
Gadiformes		4	6	1	8		1	8	2	2	1	1
Lampriformes									1			
Lophiiformes	1	6	3		4		3	2	1	2	2	
Myctophiformes		1		1	1		1			1		
Myliobatiformes		1										
Myxiniformes			1	1								
Notacanthiformes		4	3					2			2	
Ophidiiformes	2	7	7	3	4	1	3	12	5	2	11	2
Osmeriformes		9	12		3			4	2		2	4
Perciformes	11	3		13	6		10	5		9	6	1
Pleuronectiformes	2			2			4			3		
Polymixiiformes	1			1			1			1		
Rajiformes		1	2		1						2	
Scorpaeniformes	6	2	1	4	1		6			2	1	
Squaliformes		4	2		2		1	4	1	1	3	1
Stomiiformes		4	4		2			1			1	
Tetraodontiformes								1				
Torpediniformes		1			1			1			1	
Zeiformes				1	1		1					
Grand Total	**33**	**61**	**58**	**40**	**49**	**1**	**42**	**62**	**16**	**31**	**39**	**13**

Chapter - 5

BIOLOGY, STANDING STOCK AND TROPHIC STRUCTURE OF DEEP-SEA MEGAFAUNAL COMMUNITY OF TERRACE OFF TRIVANDRUM

5.1 INTRODUCTION

The megafauna of ToT is distinct in nature in terms of occurrence of rare species, gigantism and exceptionally high biodiversity. An examination of the biological attributes such as growth, reproduction and biological interactions of megafauna are very much essential for understanding the megafaunal community of this pristine habitat. Knowledge of body size is vital as it is a significant determinant of an organism's biological role; and size is the key underlying parameter of many allometric equations that predict a variety of physiological, anatomical, ecological, and life history parameters (Calder 1984; Peters and Wassenberg 1983). Standing stock of an ecological community represents the density of its constituent populations at a time, either as numerical abundance or in terms of biomass. Megafaunal standing stock reveals how much of the carbon pool is tied up in these animals at any one time (Haedrich and Merrett 1992). Communities of the benthic boundary layer (BBL) faunal communities of the deep-sea play key roles in ecological and biogeochemical processes on a global scale (Smith 1992). Megafaunal standing stock and its dynamics in the BBL of deep-sea is directly linked to or dependent on the export flux of organic matter and its utilization at different trophic levels. Information on biomass, abundance and trophic position of each species in a community can give an indication of its role and relative importance in the overall food web dynamics of the system.

Deep-sea ecosystems are the most extensive on earth, representing the largest reservoir of organic carbon (Danovaro *et al.* 2008), in the form of standing stock of benthic fauna and organic matter deposited on the seafloor. Life in the deep-sea (except hydrothermal vents) is essentially dependent on organic matter derived from the euphotic zone for energy to fuel growth, metabolism, and reproduction. Most of the organic matter produced within the euphotic zone is recycled by a highly efficient network of microbial action and zooplankton grazing. The remaining organic matter descends from the water column in several forms including phytodetritus, macrophyte detritus, fecal pellets, marine snow, and carrion (Gooday *et al.* 1990). Carbon flux downward through the aphotic water column varies with depth, distance from productive coastal waters, and seasons. On an average, only 1-4% of the surface production reaches the deep-sea floor (Lampitt and Antia 1997). Hence, an exponential decrease in standing stock with depth, in the size categories of benthos (viz. meiofauna, macrofauna and megafauna), is a very general phenomenon in the deep-sea (Rowe *et al.* 1982; Rowe 1983; Gage and Tyler 1991; Etter and Grassle 1992; Flach and Heip 1996; Levin *et al.* 2001; Rex and Etter 2010).

Megafaunal species are most conspicuous and widely distributed inhabitants of the marine ecosystem. Since most coastal resources are overexploited or depleted, the deep-sea is now being increasingly targeted for commercial exploitation of megafauna, for highly priced food commodities such as deep-sea shrimps, lobsters and fishes. In addition to this, other nonconventional resources, such as deep-sea fishes, are heavily utilized as alternate protein and oil sources in the fishery byproduct industry, while some other groups such as echinoderms and cnidarians are being targeted for bio-prospecting. The ever increasing demand for marine living resources and increased technological capabilities in the mechanized and motorized marine fisheries sectors has equipped Indian fishermen to explore the deep-sea for nonconventional fishery resources. Thus, areas of high megafaunal standing stock face the possibility for future commercial fishery exploitation, either for food or byproducts derived from the resident fauna.

Trophic guilds hold a central role in the study of community ecology (Simberloff and Dayan 1991), and the term refers collectively to organisms that utilize the same food resources in a similar way (Root 1967). Since it is usually impossible to study the trophic role of each species living in an ecosystem at once, guilds enable scientists to concentrate on specific groups with specific functional trophic relationships. From the ecological perspective, this is preferable over studying the composition of taxonomic groups, within which different species may perform unrelated trophic roles (Simberloff and Dayan 1991). Guilds focus attention on all sympatric competing species regardless of their taxonomic relationship. This concept eliminates the dual usage of the term "niche" as meaning both the functional role of a species in a community and the set of conditions that permits a species to exist in a particular biotope. The term niche is limited to the latter, so recognizing that groups of species having very similar ecological roles within a community are members of the same trophic guild, but do not necessarily be occupants of the same niche (Simberloff and Dayan 1991). Guilds are useful in the comparative study of communities and to assess the ecological impacts of natural and anthropogenic disturbances, including fisheries on the biota.

Exploratory surveys and commercial fishery exploitations into the deep-sea regions of Indian EEZ are mostly limited to the 400-500 m depths. The Quilon bank, which is a lateral bathymetric protrusion in the upper continental slope (200-800m) off south west coast of India (Alleppey Terrace), is highly productive and a commercially exploited deep-sea fishery ground. However, the ToT, which lies adjacent to the productive Quilon bank is totally uncharted in terms of its quantitative or qualitative biological properties, and its resources potential. There is no data or information on the standing stock of any faunal groups and their composition from the ToT area. The proper documentation of megafaunal standing stock and its resource composition, from this virgin deep-sea area is essential for future management of our deep-sea fishery resources.

In this chapter the distinctive biological features of the ToT megafauna are described viz; 1) biological association 2) body size of dominant species 3) spatio-temporal variations in the standing stock of megafauna 4) trophic relations 5) delineation of vulnerable nonconventional fishery resources. Results of this study is perhaps the first documentation of the deep-sea megafaunal biology, standing stock, composition, vulnerable fishery resources and trophic structure of the ToT, a totally uncharted deep-sea terrace in the ATTC. Benchmark data of this type will help formulate effective policies for the management and conservation of marine resources, and also serve a as baseline information to assess the ecological impacts of climate change, pollution, deep-sea bottom trawling and other exploratory surveys on the marine megafaunal communities. Moreover the quantitative aspects and the trophic structure of deep-sea megafaunal community of TOT can contribute to the wider understanding of the structure and function of deep-sea ecosystems in a tropical set up.

5.2 RESULTS

5.2.1 Biological association: Epibiosis of a Zoanthid on the deep-sea Hermit crab

Specimens (83 individuals) displaying various phases of epibiosis between the deep-sea commensalistic hermit crab, *P. pilosimanus* and *Epizoanthus sp.* (Figure 5.1) were collected during the present surveys. Epibiosis association between hermit crab and epizoanthid appears to begin with a single polyp attaching on the gastropod shell (inhabited by the hermit crab *P. pilosimanus*), and forming a thin film over it (Figure 5.1D). The epizoanthid grows in size, with the addition of polyps over the gastropod shell, so that the assemblage appears as a gastropod inhabited by a hermit crab, fully embedded in the semi-cartilaginous carcinoecium of *Epizoanthus sp*. colony (Figure 5.1 E). In the final stage, the association has a cog-like appearance, with up to 18 polyps radiating outwards (12-15 polyps on the rim, 1-2 on the dorsal and 1 on ventral surface); with a ventral opening through which the hermit crab protrudes (Figure 5.1 A-C).

The gastropod shell, which formed the basis of the association between *P. pilosimanus* and *Epizoanthus sp.*, disappears completely in the final stages, possibly by absorption (Figure 5.1 G). The nature of the carcinoecium of the *Epizoanthus sp*. colony, does not allow for replacement of the gastropod shell by the hermit crab (Brooks, 1989). However, the disappearance of the gastropod shell and the soft nature of the carcinoecium possibly affords more space for growth of the hermit crab (Ates 2003).

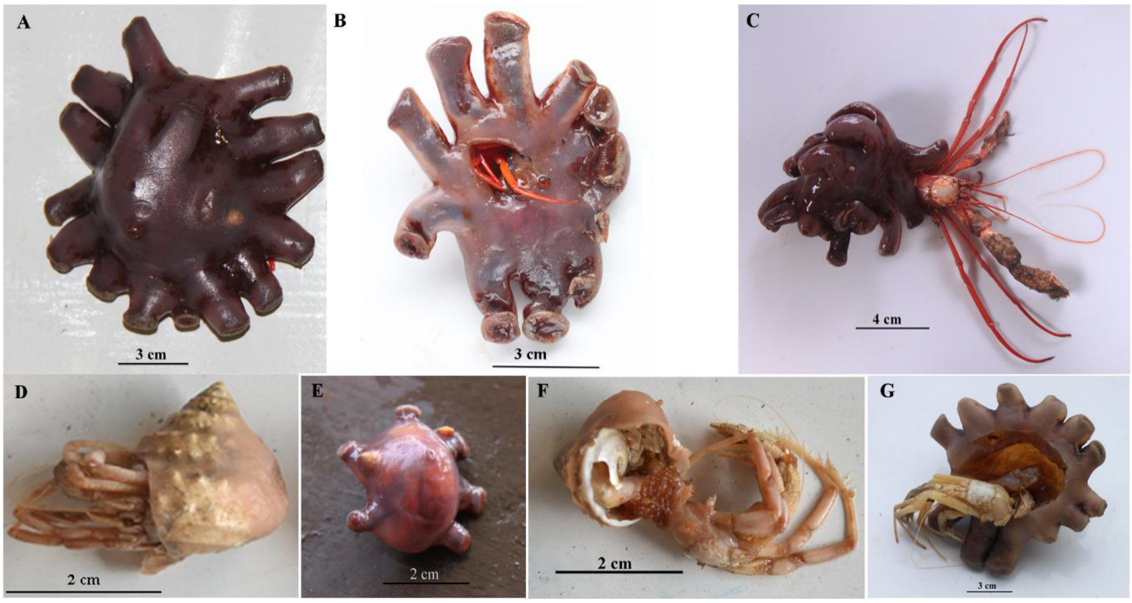


Figure 5.1. Stages of association between deep-sea Hermit crab *Parapagurus* cf. *pilosimanus* and *Epizoanthus sp.* A-B. Dorsal and ventral view of the association, C. Hermit crab protruding from within zoanthid colony, D. Early stage of infestation of epizoanthid on gastropod shell of hermit crab (preserved specimen), E. Intermediate stage of association showing developing epizoanthid polyps (preserved specimen), F. Hermit crab in an early stage of association, dissected to show eggs (preserved specimen), G. Advanced stage of association, dissected to reveal the absence of gastropod shell.

It was also observed that the hermit crabs in early stages of association (bearing one or few *Epizoanthus* polyps) possessed eggs in their gonads despite their smaller size (Figure 5.1 F), while those in advanced stages of association (and of bigger size) did not contain eggs. While this may indicate some influence on the reproductive physiology of the hermit crab by the *Epizoanthid*, this cannot be confirmed based on the current observations.

5.2.2 Body size of deep sea megafauna

A total of 13 species found in ToT are gigantic representatives in their higher taxonomic level. Body size parameters and abundance of these species recoded from ToT are compared with other regions in Indian EEZ (Table 5.1). ToT shows high abundance of gigantic species compared to other regions of the Indian EEZ (FORV *Sagar Sampada* stations). From all the instances were comparisons of the abundance in gigantic forms within and outside the ToT area could be established (Table 5.1), there is a 10 to 150 fold increase in the abundance of gigantic forms with in the ToT which implies that the ToT is a core area of abundance of these gigantic forms.

Table 5.1. Body size parameters and average abundance of these gigantic species.

Species	**Size and weight**	**Avg. abundance**	
		ToT	**Other regions of Indian EEZ**
Deepstaria enigmatica	Damaged	Individual report	Not recorded
Bathynomus keablei	15-48 cm	319 Ind/km^2	12 Ind./Km^2
Colossendeis colossea	Leg span 50 cm	Individual report	Not recorded
Acanthacaris tenuimana	72 cm	Individual report	Not recorded
Architeuthis dux	350 cm	Individual report	Not recorded
Zoroaster alfredi	Arm length: 18- 22 cm	12 Ind./km^2	1 Ind./km^2
Dipturus johannisdavisi	74-91 cm; 1,700-7,600 g	166 Ind./km^2	1 Ind./km2
Bathyuroconger vicinus	46.5-94 cm; 140-1,110 g	1280 Ind./km^2	100 Ind./km^2
Coryphaenoides hextii	TL: 35-80; 210-2,950 g	743 Ind./km^2	Not recorded
Lepidion inosimae	TL 80 cm; 7,200 g	Individual report	Not recorded
Lamprogrammus brunswigi	TL: 75.5-130 cm; 2,400-8,000 g	85 Ind./km^2	1/km^2
Lamprogrammus niger	TL: 25.5-86 cm; 110-1,900 g	4,296 Ind./km^2	39/km^2
Alepocephalus blanfordii	TL: 20.5-45 cm; 70-1,000 g	1,434 Ind./km^2	Not recorded

Length-Weight relationships (LWR) 17 Species of ToT megafauna were worked out, details of which are given in Table 5.2. The LWR of 6 species from the ToT are explained below (Figure 5.2) to illustrate that proportionality increments in weight are relatively higher in many ToT species. The LWR of *Lamprogrammus niger* (TL range from 25.5 to 73 cm, weight of 50-1,900 g and b:3.35) *Alepocephalus blanfordii* (SL 21-45 cm, weight 80-1,100 g, mean weight 600 g and b- value of 3.44), *Coryphaenoides woodmasoni* (TL 26-43 cm, 60-300 g, with a mean weight of 167 g and a b-value of 3.50) and *Bathyuroconger vicinus* (total length ranged 46.5-94 cm, and weight of 140-1100 g with an average weight of 360 g, and b:3.35) indicate that these species have allometric growth patterns higher than the typical cube proportionality. Whereas, *Hoplostethus melanopus* (total length of 23-31.2 cm, and weight of 175-500 g (average weight 300 g) growth rate (b) of 2.68) and *Benthobatis moresbyi* with a total length of 20-49.5 cm, weight of 60-1000 g (average weight 498 g) and growth rate of 2.68 indicate negative allometry.

The higher b-value (greater than 3) observed for *L. niger, A. blanfordii, C. woodmasonii,* and *B. vicinus* indicate that the typical 3-dimensional growth patterns in these species are skewed more towards weight gain, perhaps due to their effective feeding abilities and low metabolic loss in the nutrient rich ToT habitat. Most of the large specimens are thicker than the small specimens. These fishes grow much more in weight than length as age progress. Their body shape is fleshier as they grow, indicating that better nutritional availability for larger forms these fishes in ToT. On the other hand, b-value lower than 3 as observed for *Benthobatis moresbyi* and *Hoplostethus melanopus* indicates below optimal food utilization and/or higher metabolic loss in search of prey/ food due to their poor swimming and maneuvering capabilities. It is to be noted that the body shape of fishes with higher b value (>3) are cylindrical to fusiform, while fishes with low b value (<3) are either laterally or dorso-ventrally compressed.

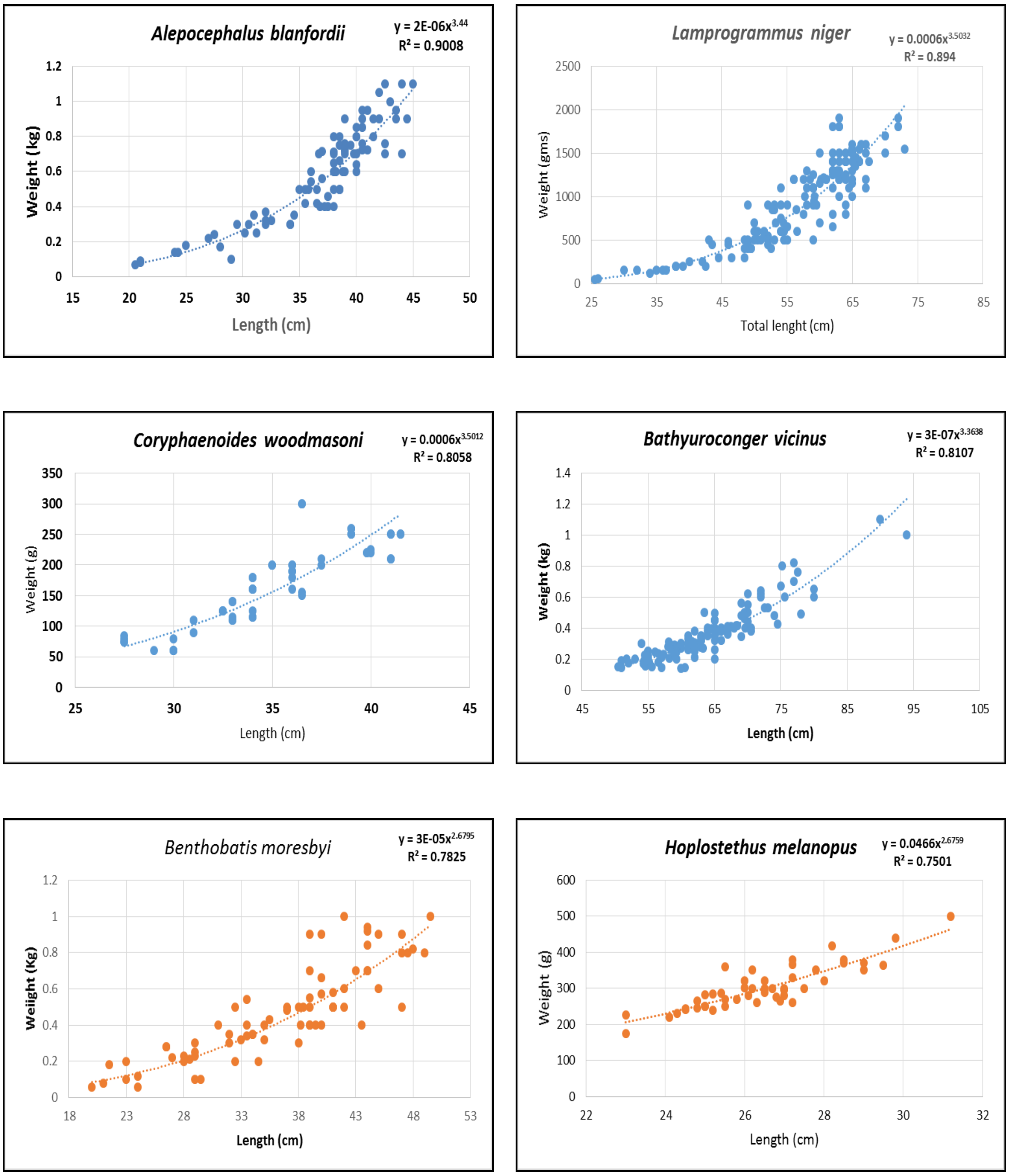


Figure 5.2 Length weight relationships of six dominant fish species from ToT.

Table 5.2 Length-Weight relationships (LWR) 17 megafaunal species of ToT.

Species	Length (cm)	Weight (gm)	a value	b value	R^2
Acanthephyra fimbriata	16.7-19 TL	25-50	0.0045	3.14	0.32
Alepocephalus blanfordii	21-45 SL	80-1100	0.0027	3.44	0.92
Alepocephalus longiceps	21-33 SL	100-350	0.0088	3.01	0.71
Aphanopus micropthalmus	60-72.5 TL	350-600	0.00098	2.9	0.96
Aristaeopsis edwardsiana	5.3-9.2 CL	34-150	0.7329	2.38	0.92
Bathygadus furvescens	16-40.5 TL	15-280	0.0023	3.14	0.89
Bathytroctes squamosus	18.5-25.2 SL	60-200	0.0025	3.4	0.83
Bathyuroconger vicinus	46.5-94 TL	141-1100	0.0003	3.35	0.77
Benthobatis moresbyi	20-49.5 TL	60-1000	0.03109	2.68	0.78
Centrophorus atromarginatus	48-80 TL	400-3000	0.00389	3.2	0.96
Conocara microlepis	22-42 TL	110-950	0.0046	3.2	0.98
Coryphaenoides woodmasoni	26-43 TL	60-300	0.0006	3.5	0.80
Dicrolene vaillanti	13-28.5 TL	5-100	0.0019	3.19	0.87
Hoplostethus melanopus	23-31.2 TL	175-500	0.0466	2.68	0.75
Lamprogrammus niger	25.5- 73TL	50-1900	0.0006	3.35	0.89
Rouleina guntheri	19-38.5 TL	50-650	0.00428	3.1	0.89
Talismania longifilis	20.2-47.7 TL	300-860	0.00361	3.2	0.91

5.2.3 Standing stock and composition of ToT megafauna.

The total megafaunal biomass in the ToT ranged between 1,115 and 31,884 kg/km^2 with a mean of 10,660 kg/km^2, while total megafaunal abundance ranged between 4,009 and 238,850 individuals per square km (Ind./km^2) with a mean of 38,521 Ind./km^2. Total megafaunal standing stock from various sampling locations are listed in Table 5.3 and illustrated in Figure 5.3 and 5.4. As discussed and depicted in Chapter 4, depth associated factors play a crucial role in determining megafaunal species distribution and composition. Based on this, the whole sampled area of ToT is divided in to two significantly different depth zones, viz. shallow (950-1150 m) and deep zone (1150-1450 m). Both the bathymetric and seasonal variations in the total megafaunal standing stock were analyzed statistically using ANOVA (Table 5.4).

Table 5.3. Standing stock of megafauna at each sampling location.

Station	Season	Average depth of operation	Zone	Biomass (kg/km^2)	NumericalAbundance (Ind./km$^{2)}$
Stn.28103	SM	988	Shallow	2169	9503
Stn.30501	SM	1060	Shallow	2885	11361
Stn.31601	SM	1079	Shallow	1455	30697
Stn.31602	SM	1338	Deep	2770	7217
Stn.31609	SM	1241	Deep	3875	10360
Stn.31908	SM	1258	Deep	2492	4009
Stn.32116	WM	1153	Deep	31884	238850
Stn.32118	WM	1244	Deep	19967	29948
Stn.32120	WM	1045	Shallow	22165	44492
Stn.32209	WM	1034	Shallow	19579	59832
Stn.32701	SM	1064	Shallow	3693	5557
Stn.32702	SM	1347	Deep	1115	5501
Stn.33102	WM	1027	Shallow	24529	43441

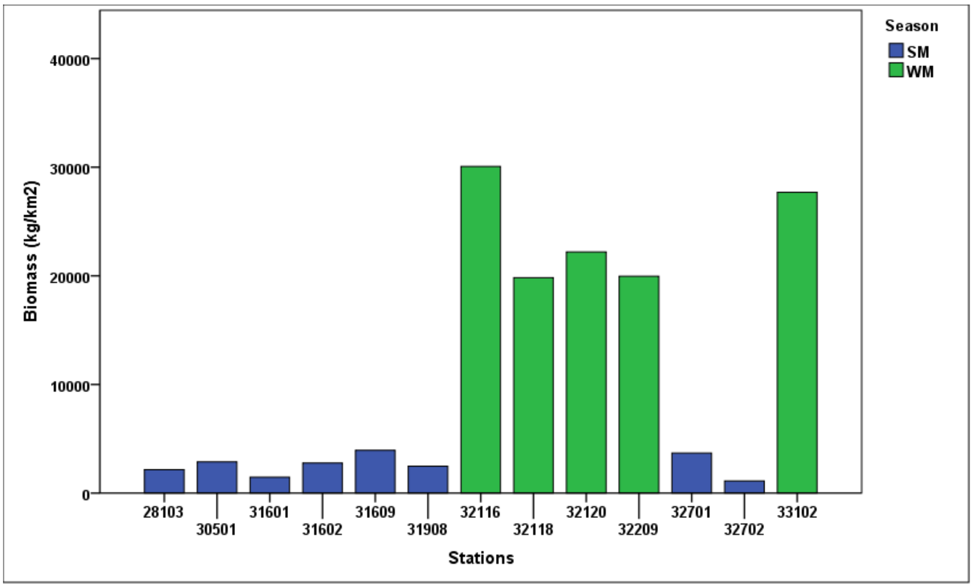


Figure 5.3. Total megafuanal biomass (kg/km^2) along sampling stations

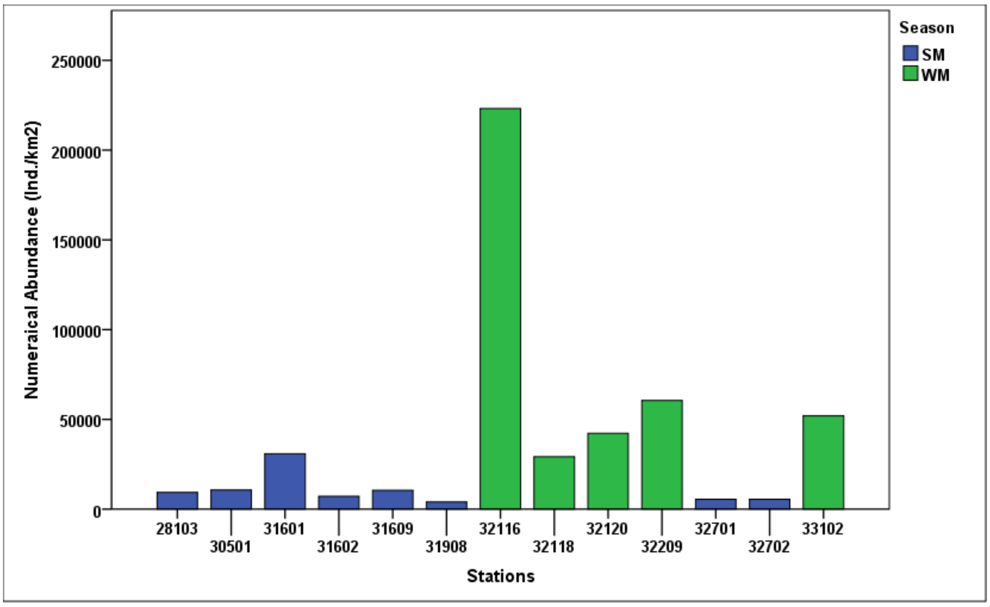


Figure 5.4. Total megafuanal abundance (Ind./km^2) along sampling stations

Table 5.4. Results of ANOVA showing bathymetric and seasonal variations in megafaunal standing stock.

ANOVA								
	Biomass (kg/km^2)				**Abundance (Ind./km^2)**			
	df	**Mean Square**	**F**	**Sig.**	**df**	**Mean Square**	**F**	**Sig.**
Between depth zones	1	1065885.66	0.01	0.93	1	1298156372	0.3	0.589
Between seasons	1	1365706367	139.68	**0.00**	1	1.6301E+10	5.7	**0.035**

Unlike the case with species distribution, there were no significant differences in total standing stock between the two depth zones, while seasonal differences in total standing stock in each depth zone were highly significant. Hence, the seasonal changes in standing stock and faunal composition within the two depth zones were analyzed separately (Figure 5.5). A nearly 10 fold increase in the mean standing stock was observed from the summer (SM) to winter monsoon (WM) season, in both the depth zones. Variations in the standing stock and faunal composition of deep-sea megafauna in each depth zone of ToT are detailed below.

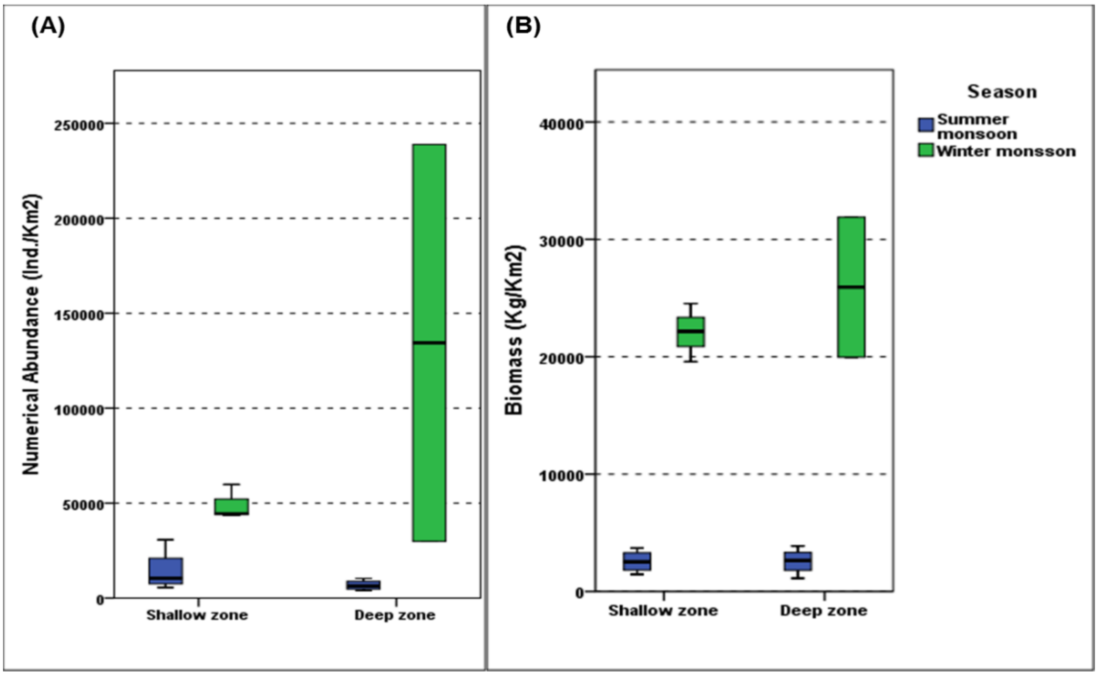


Figure 5.5. Total standing stock of megafauna in the two depth zones of ToT during SM and WM seasons

5.2.3.1 Shallow zone of ToT (950-1150 m)

The total megafaunal biomass of sampling locations in the shallow zone of ToT ranged from 1,455 to 24,529 kg/km^2 and the total abundance ranged from 5,557 to 59,832 Ind./km^2. Significant seasonal variations were noted in standing stock, with a marked increase during WM. Mean megafaunal biomass and abundance during SM were 2,551 kg/km^2 and 14,280 Ind./km^2 respectively, while during WM, the values were 22,058 kg/km^2 and 49,255 Ind./km^2 respectively. Among the 5 phyla represented in the shallow zone, Phylum Chordata contributed chiefly to the megafaunal biomass during both the seasons (79% during SM and 94% during WM). Phylum Arthropoda was numerically dominant during SM (58%) and phylum Chordata (78%) dominated during WM (Figure 5.6). Composition of megafaunal groups during both seasons in the shallow depth zone of ToT is given in Table 5.5.

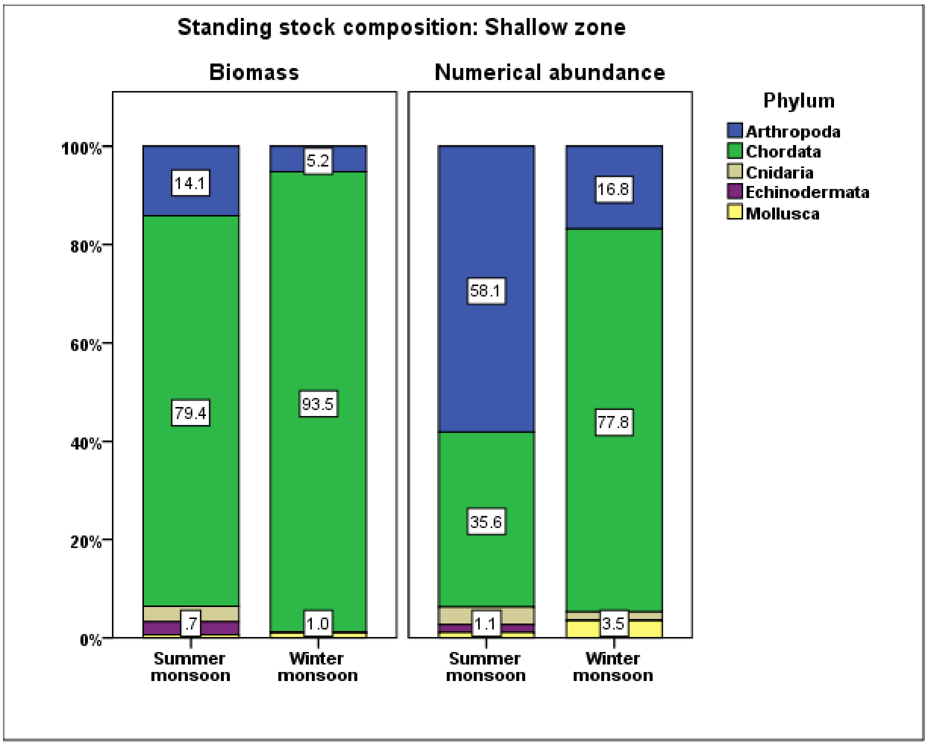


Figure 5.6. Percentage composition of megafauna in the shallow zone of ToT during SM and WM seasons.

During the SM, 38 taxonomic orders were represented in the shallow zone, amongst which 7 taxonomic orders contributed significantly to the total biomass (Figure 5.7, 5.8), and these cumulatively accounted for 81% of the total biomass. Among these, Order Ophidiiformes, represented by 7 species was the dominant group (866 kg/km^2), contributing as much as 34% of the total biomass (Figure 5.8), followed by Order Osmeriformes (8 species, total biomass 320 kg/km^2, 10% of total megafaunal biomass) and Order Decapoda (14 species, 243 kg/km^2, 9.5%). Four species contributed significantly to total biomass of the shallow zone during summer monsoon; these were *Lamprogrammus niger* (712 kg/km^2, 28% of total biomass), *Bathyuroconger vicinus* (175 kg/km^2, ie 6.9%), *Benthobatis moresbyi* (152 kg/km^2, 6%) and *Aristaeopsis edwardsiana* (147 kg/km^2, 5.8%).

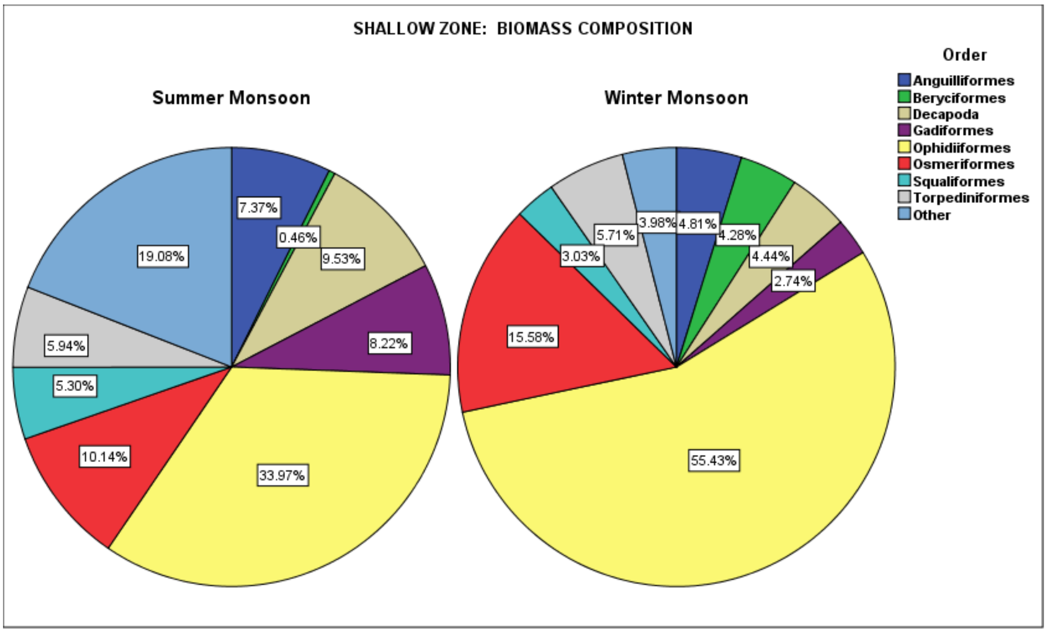


Figure 5.7. Contribution of major taxonomic orders to megafaunal biomass during the two seasons in the shallow depth zone of ToT.

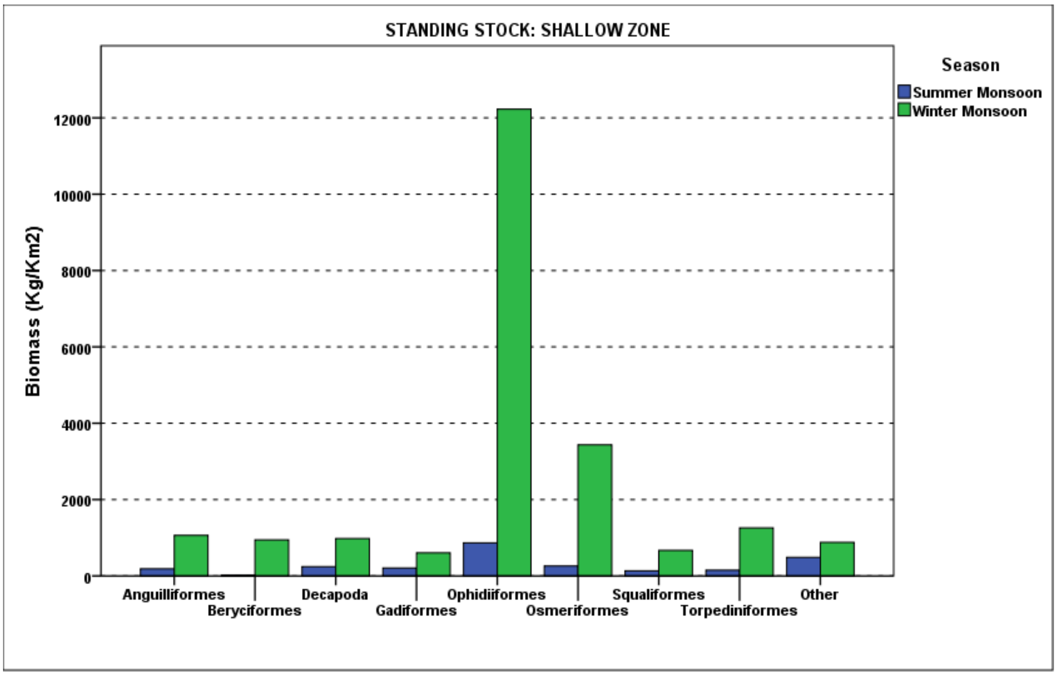


Figure 5.8. Biomass of major taxonomic orders during the two seasons in the shallow depth zone of ToT.

Six taxonomic orders contributed significantly to the total numerical abundance (Figure 5.9, 5.10) during the SM, which cumulatively accounted for 87% of the total abundance. The Order Decapoda, represented by 14 species, was numerically dominant (8,116 Ind./km^2, 57% of total abundance), followed by Order Gadiformes, represented by 4 species (1,561 Ind./km^2, 11% of total abundance) and Order Ophidiiformes, represented in 7 species (1,323 Ind./km^2, 9% of total abundance) (Figure 5.10). The four major species contributing to numerical abundance of the shallow zone during SM were *Pseudaristeus crassipes* (4,862 Ind./km^2, 57% of total abundance), *Aristaeopsis edwardsiana* (1,520 Ind./km^2, 18%), *Haliporus taprobanensis* (1,406 Ind./km^2, 17%) and *Coryphaenoides woodmasoni* (700 Ind./km^2, 8%).

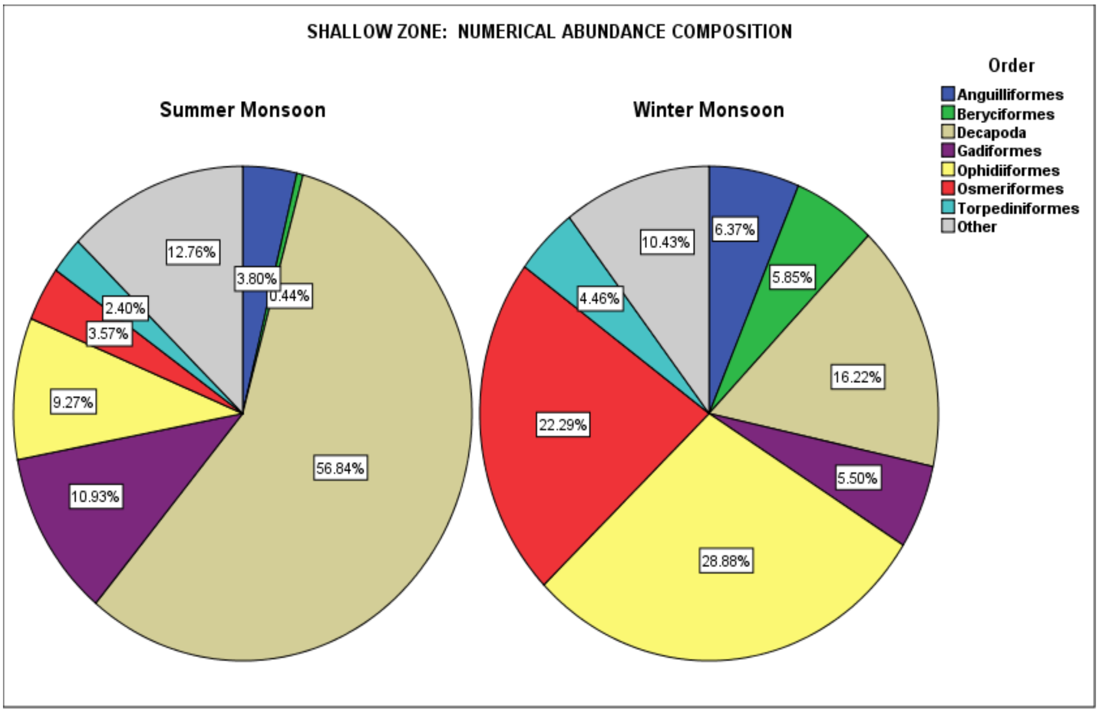


Figure 5.9. Contribution of major taxonomic orders to megafaunal abundance during the SM & WM seasons in the shallow depth zone of ToT.

During the WM, 26 taxonomic orders were represented in the shallow zone, of which only 8 contributed significantly to the total biomass (Figure 5.7, 5.8). These 8 orders cumulatively accounted for the 96% of the total biomass. Amongst these, Order Ophidiiformes (Figure 5.9), represented by 4 species contributed a total biomass of 12,227 kg/km^2 (55%), followed by Order Osmeriformes (6 species, 3,436 kg/km^2, 16%) and Order Torpediniformes (1 species, 1,260 kg/km^2, 5.7%). Among the 58 species represented, four species contributed significantly to the total biomass of the shallow zone during WM; these were *Lamprogrammus niger* (12,343 kg/km^2, 25%), *Alepocephalus blanfordii* (2,619 kg/km^2, 5%), *Benthobatis moresbyi* (2,195 kg/km^2, 5%) and *Bathyuroconger vicinus* (962 kg/km^2, 5%).

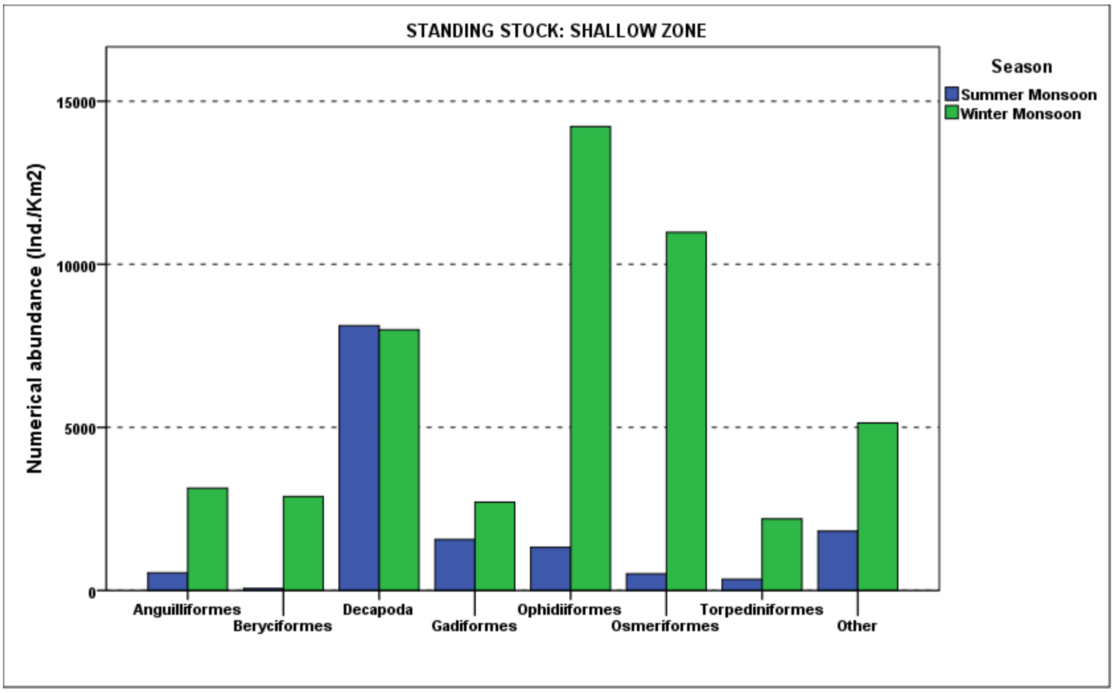


Figure 5.10. Abundance of major taxonomic orders during the SM & WM seasons in the shallow depth zone of ToT.

Seven taxonomic orders contributed more significantly to the total abundance (Figure 5.9, 5.10), and these cumulatively accounted for 90% of the total abundance. The Order Ophidiiformes (Figure 5.10), represented by 4 species, dominated numerically (14,224 Ind./km^2, 28.9%), followed by Order Osmeriformes, represented by 6 species (10,981 Ind./km^2, 22.3%) and Order Decapoda, represented by 8 species (7,991 Ind./km^2,16.22%). The species which chiefly contributed to the total numerical abundance of the shallow zone during WM are *Lamprogrammus niger* (12,343 Ind./km^2, 56% of total megafaunal abundance), *Rouleina squamilatera* (7,014 Ind./km^2, ie 18%), *Aristaeopsis edwardsiana* (5,752 Ind./km^2, 16%) and *Hoplostethus melanopus* (2,857 Ind./km^2, 8%).

5.2.3.2 Deep zone of ToT (1150-1450 m)

The total megafaunal biomass in the deep zone of ToT ranged between 1,115 and 31,884 kg/km^2, while the total abundance ranged between 4,009 and 238,850 Ind./km^2. Significant seasonal variations were found in the total megafaunal standing stock of the deep zone. As in the case of the shallow zone, an increase of megafaunal standing stock was evident during WM. Average biomass and numerical abundance of the total megafauna during SM were 2,563 kg/km^2 and 6,772 Ind./km^2, respectively, while during WM, the values were 25,926 kg/km^2 and 134,399 Ind./km^2, respectively. Among the 5 phyla represented in the deep zone, Phylum Chordata contributed chiefly to the megafaunal biomass (Figure 5.11) during both seasons (83.9% during SM and 77.4 % during WM). While Phylum Chordata (67%) dominated numerically during SM, Phylum Arthropoda (48.8%) dominated during WM (Figure 5.11). Composition of megafaunal groups during both seasons in the deep depth zone of ToT is given in Table 5.6.

During the SM, 34 taxonomic orders were represented in the deep zone of ToT, amongst which only 7 orders contributed significantly to the total biomass (Figure 5.12, 5.13). These 7 orders cumulatively accounted for the 85% of total biomass. The Order Ophidiiformes, represented by 7 species(Figure 5.13), contributed 40.4% of the total biomass of (1,035 kg/km^2), followed by Order Osmeriformes (11 species, 420 kg/km^2, 16.4%) and Order Gadiformes (6 species, 334 kg/km^2, 13%). Among 89 species represented during this season in the deep zone of ToT, the species which contributed significantly to the total biomass during SM were *Lamprogrammus niger* (567 kg/km^2, 22%), *Lamprogrammus brunswigi* (388.2Kg/km^2, 15%), *Coryphaenoides hextii* (203.7 kg/km^2, 8%) and *Dipturus johannisdavisi* (159.5 kg/km^2, 6%).

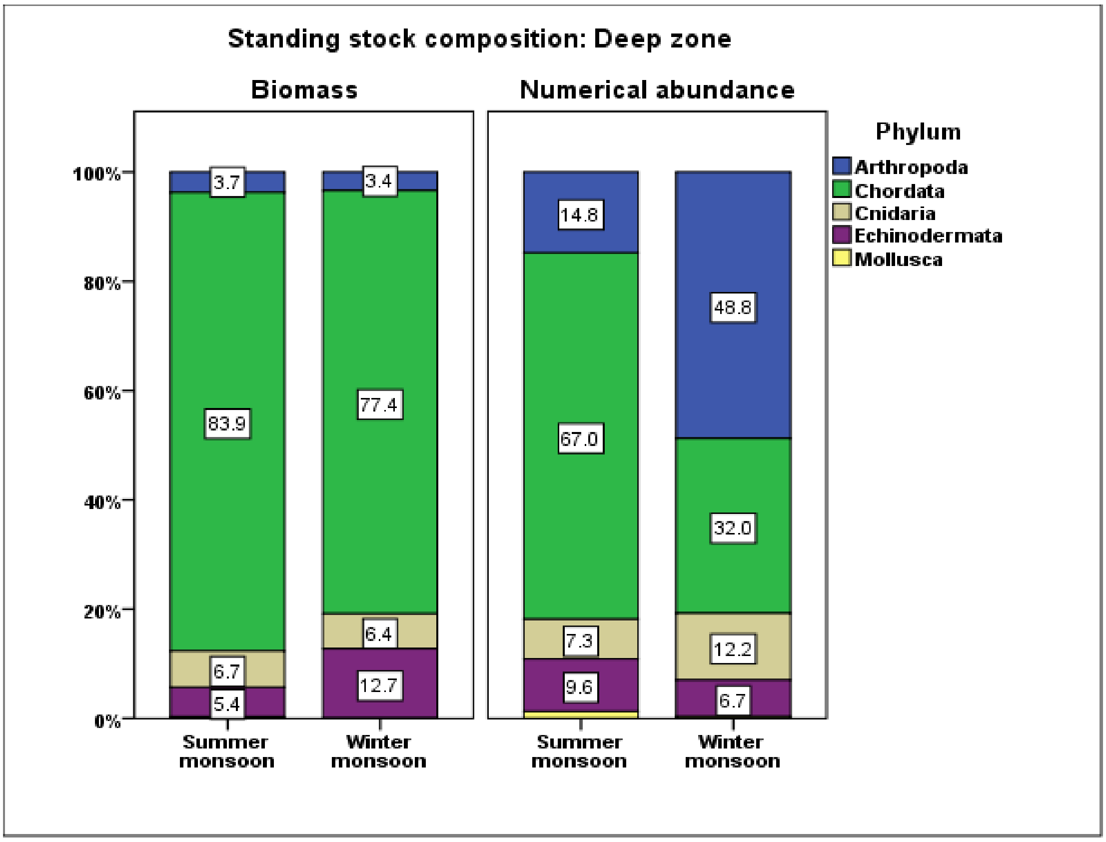


Figure 5.11. Percentage composition of megafauna in the deep zone of ToT during SM and WM seasons.

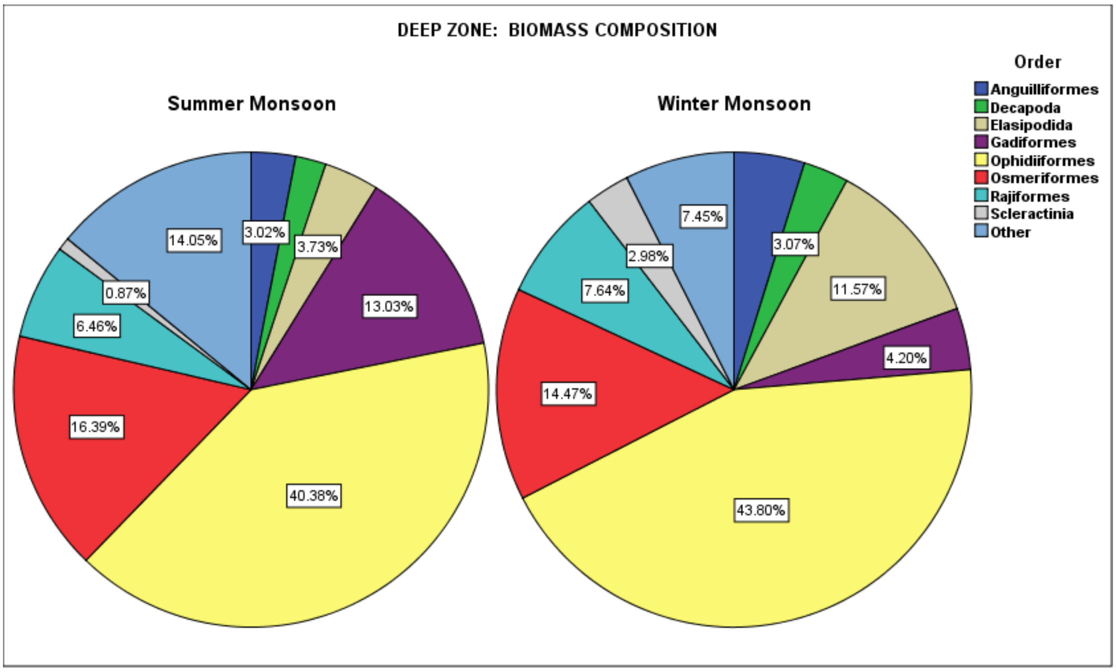


Figure 5.12. Contribution of major taxonomic orders to megafaunal biomass during the SM & WM seasons in the deep zone of ToT.

Nine taxonomic orders contributed significantly to the abundance during SM (Figure 5.14, 5.15), which cumulatively accounted for 85% of the total. The Order Ophidiiformes represented by 7 species, dominated numerically (Figure 5.15), with an abundance of 1,436 Ind./km^2 (21.2% of the total megafaunal numerical abundance), followed by Order Osmeriformes (11 species, 1,184 Ind./km^2, 17.5%) and Order Gadiformes (6 species, 1,029 Ind./km^2, 15.2%). The species which contributed significantly to the total numerical abundance of the deep zone during SM were *Lamprogrammus niger* (620 Ind./km^2, 9% of total abundance), *Coryphaenoides woodmasoni* (571 Ind./km^2, 8%), *Dicrolene vaillanti* (421 Ind./km^2, 6%) and *Alepocephalus longiceps* (378 Ind./km^2, 6%).

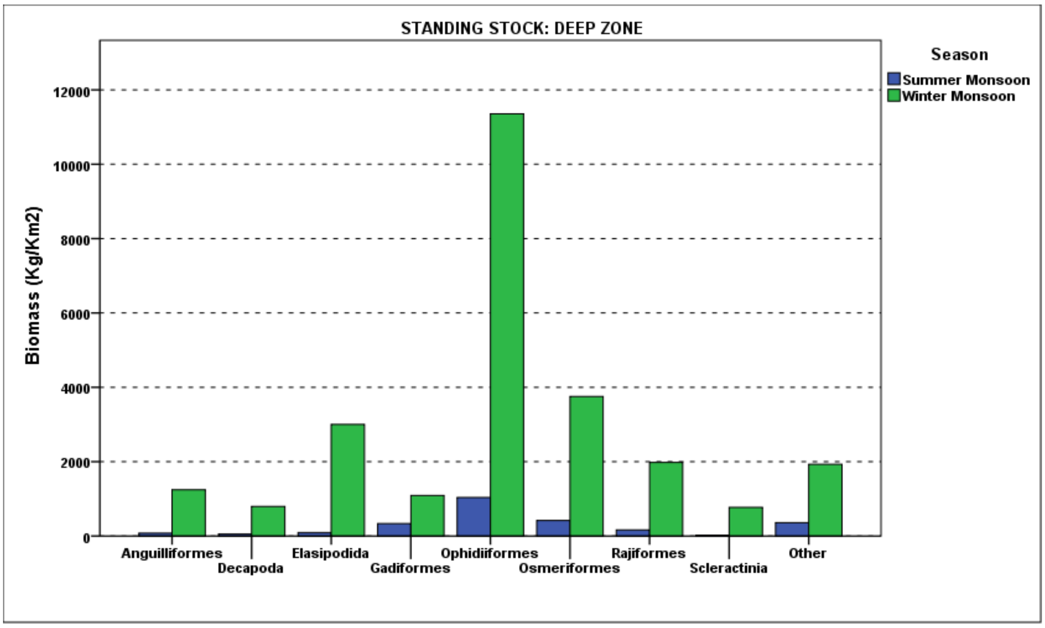


Figure 5.13. Biomass of major taxonomic orders during the SM & WM seasons in the deep depth zone of ToT.

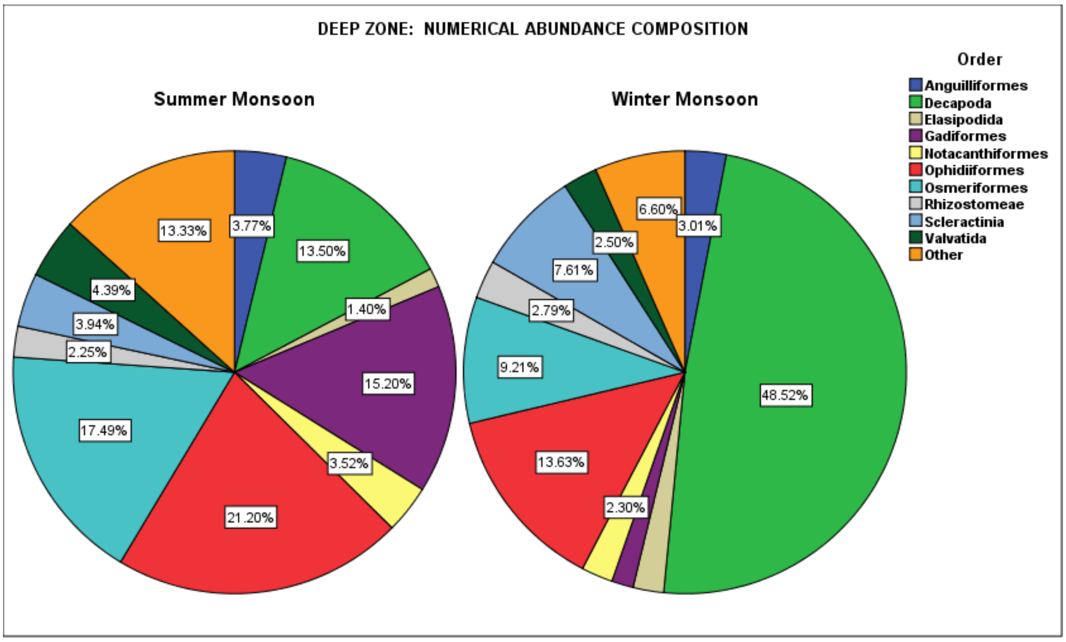


Figure 5.14. Contribution of major taxonomic orders to megafaunal abundance during the SM & WM seasons in the deep zone of ToT.

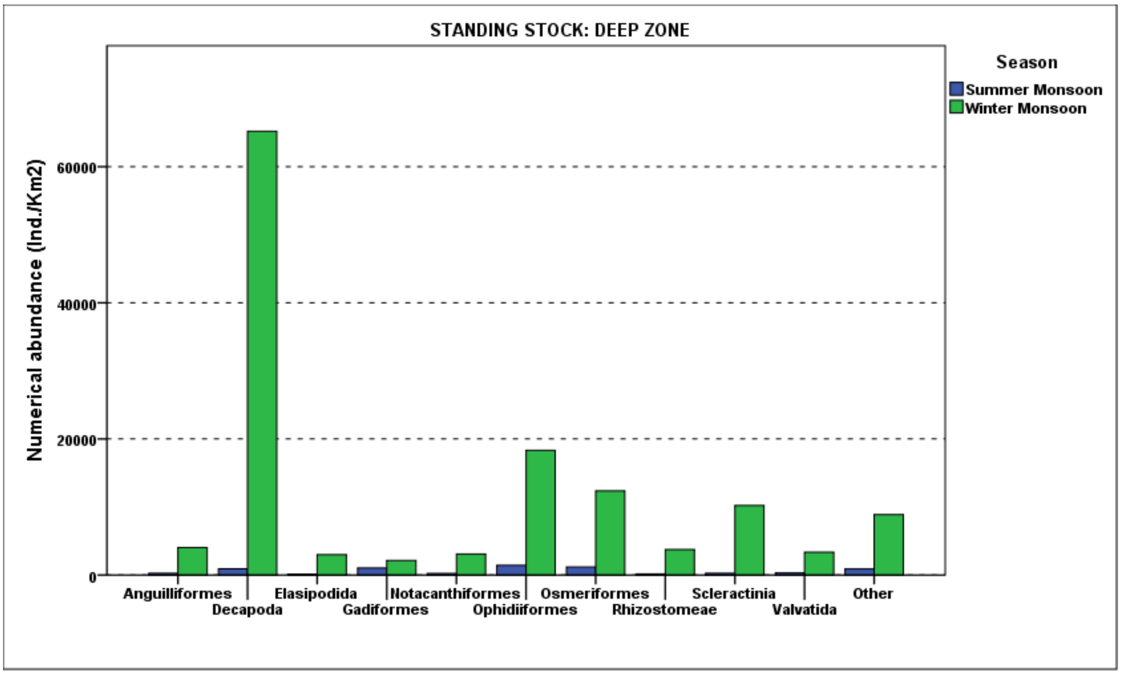


Figure 5.15. Biomass of major taxonomic orders during the SM & WM seasons in the deep depth zone of ToT.

During the WM, 30 taxonomic orders were represented in the deep zone, of which only 8 orders contributed significantly to the total biomass (Figure 5.12, 5.13). These 8 orders cumulatively accounted for the 92% of the total biomass. The Order Ophidiiformes dominated (Figure 5.13) the biomass (5 species, 11,356 kg/km^2, 43.8), followed by Order Osmeriformes (11 species, 3,752 kg/km^2, 14.5%) and Order Elasipodida (1 species, with a biomass of 3,000 kg/km^2, 11.6%). Among the 83 species represented in this zone during WM, the four dominant species were *Lamprogrammus niger* (10,784 kg/km^2, 42% of the total megafaunal biomass, *Benthodytes typica* (2,619 kg/km^2, 12%), *Dipturus johannisdavisi* (1,981 kg/km^2, 8%) and *Narcetes stomias* (1,086 kg/km^2, 4%).

Ten taxonomic orders contributed significantly to the abundance of megafauna during the WM (Figure 5.14, 5.15), and they cumulatively accounted for 97% of the total megafaunal abundance. The Order Decapoda, represented by 24 species, dominated numerically (Figure 5.15), with a total numerical abundance of 65,216 Ind./km^2 (48.5%), followed by Order Ophidiiformes, represented by 5 species (18,318 Ind./km^2, 13.6%) and Order Osmeriformes, represented by 11 species (12,375 Ind./km^2, 9%). The species which contributed significantly to the total megafaunal numerical abundance of the deep zone during WM were *Pseudaristeus crassipes* (32,500 Ind./km^2, 24%), *Haliporus taprobanensis* (13,750 Ind./km^2, 10%), *Lamprogrammus niger* (10,000 Ind./km^2, 7%) and *Dicrolene vaillanti* (5,546 Ind./km^2, 4%).

5.2.4 Trophic guilds of megafauna

For establishing the trophic categorization in the deep-sea megafauna of ToT, examination of diet contents of deep-sea megafauna was carried out only on the numerically abundant deep-sea fin fishes landed on board. As part of the study 1437 specimens belongs to 27 species of deep-sea fishes were dissected on board. Details of the dissected fishes are provided in the Table 5.7a. Dissection of alimentary tract of deep-sea fin fishes collected on board revealed most of the fishes possess empty stomach probably due to the pressure release while hauling the trawl net back after dragging. The percentage of empty stomach in megafaunal species were ranged between 77-100%. Hence quantitative information on the diet composition of deep-sea fin fishes and its spatiotemporal variations is not attempted in the present study.

Trophic interactions within deep-sea megafaunal community of the BBL play a crucial role in resource partitioning, ecological functioning, and ultimately to ecological stability. Therefore, establishing trophic structure of a community will give an idea of its ecosystem functioning in terms of energy transfer. The primary requirement to establish such a trophic ladder is the categorization of taxa into feeding guilds. Most deep-sea megafana are taxonomically euryphagous, and hence, a diet categorization based on the taxonomic composition of their gut content will not provide sufficient clarity on the trophic structure of the ecosystem (Gartner *et al.* 1997). While the fauna are generalist feeders, it is also observed that they are somewhat selective upon ‘prey-type' and 'prey size' (Headrich and Henderson 1974; Macpherson 1979; Mauchline and Gordon 1984). In the present study identification and categorization of prey-types available for the deep-sea megafauna at the BBL of ToT was done either by direct observations on its diet composition or by review of literature. A total of five 'prey types' were identified viz. plankton, nekton, epibenthos, infauna, dead and decaying materials and organic matter. Such prey-type categories were made based on their locomotion ability and their habitat position in relation to the sea-floor.

These categories often comprise of taxonomically diverse organisms with a wide range in body size. For example, planktonic resources can range from micro-zooplankton (>20µ), such as protozoans, to large sized mega-zooplankton (>20cm) such as pyrosomes and salps. It is observed that small-bodied, small mouthed fishes are limited to small prey, whereas large-bodied, large mouthed fishes can ingest both large and small prey (Merret and Marshall 1980). For example, the deep-sea grenadiers of the genus *Coryphaenoides* are epibenthos feeders, among which large sized species, such as *C. hexti*, prey upon epibenthic megafauna, while comparatively small sized species, such as *C. macrolophus*, feed on benthic macrofauna and organic matter (OM) deposited on the sediment floor. Mouth size of the predator and body size of the prey are important factors in the ultimate trophic equation between them. Based on the five 'prey type', and their size, megafaunal diets in the ToT were categorized into seven 'diet categories', viz. macroplankton, macronekton, micronekton, epibenthic megafauna, macrofauna, suspended OM matter in the water cloumn and organic matter deposits on the seabed.

In addition to the selectivity in 'diet categories' megafauna exhibit diverse feeding modes or 'feeding strategies' for acquiring food. Functional morphology of an organism, including body shape, structure of mouth, location of eyes and fins, and locomotion abilities reflect their 'feeding strategies'. The feeding strategies of the megafauna of ToT have been broadly categorized into 5 types on the basis of their functional morphology. These are - predators, grazers, browsers, scavengers, suspension feeders and parasites. The predator category includes organisms that can selectively orient towards a single prey, opens its mouth and capture them. The grazers are treated as non-selective feeders of prey aggregates, either in the water column or on the sediment surface. Water column grazers have a wide-opening mouth, which helps to gulp (gape and suck) swarming prey aggregates. Sediment grazers non-selectively process benthic sediments for organic carbon. Browsers prey selectively on whole or partially sedentary or sessile organisms, or on organic matter deposits on the seafloor. Scavengers feed on dead and decaying materials deposited on the seafloor. Suspension feeders feed on organic matter and organisms available in the BBL. Parasites are organisms that derive their nourishment at the expense of others.

Megafaunal species, - classified broadly within a particular ‘feeding strategies’- exhibit varied behavioral specializations with respect to feeding, as a result of divergent adaptations in the course of their evolution. For example, deep-sea sharks of the family Centrophoridae are ambush predators of nektons by using their fast swimming behavior, while fishes of the family Lophidae use ‘sit and wait’ strategy for predation using lures to attract nektonic prey. Thus, species competing for the same resource coexist with minimal conflicts, through their morphological and behavioral distinctions. In order to establish trophic guilds among ToT megafauna, organisms were categorized based on the ‘diet categories’ they feed and the ‘feeding strategies’ used for feeding.

5.2.5 Trophic guild classification of deep-sea megafauna of TOT and their habitat positioning within the BBL

The trophic guild concept (Root 1967) has long been popular, as the "basic building blocks" of ecological communities, and has become the standard currency of ecologists in their efforts to understand community relationships. Each trophic guild comprises a group of organisms which target a specific ‘prey-type’ with common 'feeding strategy'. Since the BBL is an ecotone of two distinct ecological habitats, namely epibenthic and benthopelagic, the megafaunal trophic guild categories, comprises members from both. Megafauna that live at the sea bottom, and are either sessile or crawling on the surface sediments (with limited ability to swim) are treated as epibenthos. The benthopelagic group comprises nektonic forms, living and feeding near the bottom. Benthopelagic fauna are divided in to two - epi-benthopelagic and hypo-benthopelagic based on their relative position in the BBL (Dauvin and Vallet 2006). Though the BBL comprised distinct faunal assemblages from all three aforementioned strata, they all interact, compete or share resources that reach the deep-sea floor through a complex network of trophic linkages.

Megafaunal groups were assigned to specific guild based on the dietary observations in the present study as well as from the published information on the diet composition of its congeneric members from other parts of the world oceans. Inferences from the studies on the diet megafaunal groups such as fishes (Gartner et al. 1997; Drazen and Sutton 2017) Decapod crustaceans (Cartes et al. 2007), Echinoderms (Jangoux and Lawrence 1982), Molluscs (Allen 1983) and Cnidarians (Gili and Coma 1998) were considered to assign trophic guild for megafauna of ToT.

A total of 11 trophic guilds were recognized among the 148 megafaunal species recorded from TOT. A detailed table listing members of each trophic guild and its habitat position is given in Table 5.7. Trophic guild characterization of deep-sea megafauna of TOT was done as follows.

a. Macronekton predators

This category primarily comprises predators of benthopelagic nektonic vertebrates, such as fishes and large sized invertebrates such as shrimps and crabs. Members of this category are mostly medium to large sized fishes with good swimming capabilities to catch prey in the water column. They possess large eyes and powerful mouth with strong canine teeth to attack and hold the prey. Deep-sea squaloid sharks *Centrophorus atromarginatus, Centrophorus squamosus,* congrid eel *Bathyuroconger vicinus, Aphanops microphthalmus* are typical members, which attack prey in the water column. Food items recorded from their stomach include fishes, myctophids, cephalopods, and crabs. Anglerfishes of the Order Lophiiformes such as *Lophoides infrabrunneus,* employ a ‘sit-and-wait strategy’ on the sediment surface, using lures to attract and catch nektonic animals in the water column. Two other anglerfish species, *Bufoceratias shaoi* and *Diceratias trilobus* use the same strategy in the water column. Cephalopods such as colossal squid *Archituethis* and *Histioteuthis* are swift swimmers, possessing long arms and tentacles. Remnants of large shrimps (*Aristeopsis sp.*) were found in its stomach.

Macronekton predators of ToT include 18 species, of which 9 species belong to hypo-benthopelagic and 9 species belong to epi-benthopelagic. Even though they utilize the same prey-type, employing the general strategy of active predation, they were distributed in different microhabitats within the BBL. Morphological as well as behavioral specialization of each species enable them to thrive in a particular microhabitat by sharing a common resource with minimal conflict.

b. Micronekton predators

This group is specialized to selectively prey on small benthopelagic invertebrates, especially crustaceans of limited locomotion capabilities. Most micronekton predators are small to medium sized fishes with terminal to superior mouths. They consume broad range of taxa, primarily of benthopelagic prey suited to their mouth and body size. Some of them use active swimming strategy to prey upon micronekton available in the water column (*Harpadon squamosus, Monomitopus conjugator, Hoplostethus melanopus*), while some others exhibit sit-and-wait predation strategy on the sediment surface (eg. Tripod-fishes, *Bathypterois spp.* and Lophiiformes fishes such as *Chaunax sp.*, Ophidiiform fishes such as *Dicrolene vaillanti* and *Mastigopterus imperator*). They prey upon small benthopelagic decapod shrimps (micronekton) by attracting them using their fin modifications followed by sudden attack. Decapod shrimps such as *Glyphus marsupialis* and *Eupasiphae gilesii* prey upon mesozooplankton in the water column. This guild is most diverse, with a total of 32 species reported from ToT, of which 12 belong to hypo-benthopelagic and 20 species belong to epi-benthopelagic.

c. Micronekton grazers

This category includes generalists fishes, i. e. non-selective feeders of off-bottom schooling benthopelagic prey, mostly small nektonic organisms, which include crustaceans, cephalopods and chaetognaths. Fishes belonging to this category are active swimmers of moderate to large size, terminal widely opening mouth without teeth and well developed gill rakers. Only one species, *Lamprogrammus niger*, found in the hypo-benthopelagic habitat of ToT, is considered under this guild The feeding strategy adopted by *L. niger* is intermediate between filtering and predation, and the species is capable of switching its feeding behavior based on prey abundance. The stomach of *L. niger* was mostly filled with swarming decapod shrimps.

d. Macroplankton predators

Slow moving gelatinous macroplankton form the primary food source for slickheads, family: Alepocephalidae (Garner *et al.* 1997). Diverse morphological features of slick-heads, such as large eyes, help them to spot transparent jellies in the water column. Slickheads also exhibit divergent structural adaptations in their mouth shapes, complemented to feed on jellies found in various microhabitats within the BBL. Slick head species feed predominantly on medusae, ctenophores and pyrosoma (Golovan and Pakhorukov 1980). Jelly like materials were recovered from *Narcetes stomias* and *Rouleina spp.* upon dissection of their visceral cavity. A total of 14 species were found in this guild, and all of them belong to epi-benthopelagic habitat.

e. Epibenthic megafaunal predators

This category includes large sized fishes which are capable of actively swimming in the water column, and which feeds on larger epibenthic fauna present on the sea bottom. The prey items predominantly include molluscs, echinoderms, crabs, shrimps and fishes. Fishes in this category possess strong inferior mouth with canine teeth to crush hard shelled epibenthic invertebrates. The gigantic skates *Dipturus johannisdavisi*, large abyssal chimaera *Rhinochimaera africana, Coryphaenoides hextii* chiefly feed on epibenthic megafauna. Eight species were grouped into this guild, all of which belong to the hypo-benthopelagic habitat.

f. Epibenthic megafaunal browsers

Medium to large sized fishes and echinoderms belongs to this guild, which feeds mostly on sessile or slow moving megafauna including anemones, soft corals, sea pens, soft-bodied molluscs, brittle stars, sea urchins, holothurians and crinoids, small crabs and shrimps. Slickheads *Alepocephalus blanfordii* and *A. longiceps* feed on epibenthic sessile megafauna, mostly corals. The former possess flat spatulate snout, while later is equipped with a long pointed snout. Stomach contents of another slickhead, *Conocara microlepis*, were found to contain jelly and remnant crab chelipeds. Another deep-sea fish belonging to this category is *Notacanthus sp.,* which prey selectively on anemones, corals, bryozoans, and colonial hydrozoans using special knife edge dentition to nip off the tenacles (Lozano Cabo 1952; Ates 1989). Large asteroids with long arms, such as *Zoroaster* spp. were also considered under this guild. Most recurring gut content of deep-sea asteroid *Zoroaster* include gastropods and bivalves, although crustacean remains and ophiuroid and echinoid plate fragments were also present (Mah 2007). A total of 12 species were grouped into this guild of which 5 belongs to epibenthic habitat and 7 species belongs to hypo-benthopelagic habitat.

g. Organic deposit cum macrofaunal browsers

This guild comprises fishes, echinoderms and crustaceans that feed on polychaetes, micro-crustaceans (eg. Amphipods, isopods, cumaceans, mysids) and organic matter deposits found on the seafloor. Some fishes belonging to this guild mainly depend on benthic macrofauna rather than organic deposit. For example fishes such as such as *Aldrovandia affinis* and *Halosaurus* spp., *Coelophrys micropa*, *Halicmetus ruber* selective feed on macrofauna. Some other fishes such as *Coryphaenoides* spp. ingest small benthic crustaceans along with considerable amount of green colored stringent smelly sediments (probably phyto-aggregate fall). The fishes that are selective on benthic macrofauna are active swimmers, and possess an inferior mouth with well-developed eyes. Shrimps such as *Aristeopsis edwardsiana* and *Acanthepyra fimbriata* are best fit to survive on a macrophagous diet composed of epibenthic crustaceans, polychaetes, nematodes and organic matter. Ophiuroid echinoderms which mainly feed upon polychaetes and small shrimps were also included under this category. Echinoderms such as *Ceramaster* are epibenthic organic deposit browsers on the sediment surface. A total of 32 species were grouped into this guild of which 12 belong to epibenthic habitat and 20 belong to hypo-benthopelagic habitat.

h. Organic deposit cum macrofaunal grazers

This guild comprises epibenthic nonselective feeders of sediment deposits, with limited locomotory skills. Fishes such as *Holcomycteronus pterotus* and *Benthobatis moresbyi* are non-selective feeders of sediment deposits for organic matter. The eyes of such species are often reduced, and vision is generally less important. Prey location may depend more on olfactory, tactile, and lateral-line sense. Holothurians such as *Benthodytes typica* can be considered as crawling gleaners of deep-sea sediments. They feed on organic detritus (phyto-aggregate fall) by processing sediments for organic matter and microscopic animals, including meiofauna and microfauna. A total of 9 species belong to this guild, of which 8 belong to epibenthic habitat and 1 belongs to hypo-benthopelagic habitat.

i. Epibenthic scavengers

Members of this guild primarily feed on food fall aggregates, like dead and decaying animal matter deposited on the sea bottom. Gigantic isopod *Bathynomus keablei,* anomuran crabs such as *Neolithodes agassizii*, *Paralomis investigatoris* and squat lobsters such as *Stereomastis sculpta* and *Nephropsis ensirostris* along with fishes such as hagfishes are grouped under this guild. Hagfishes of the genus *Eptaptretus* feed on injured fishes or carcasses, tearing off pieces of flesh with their unique rasping tongue (Gartner *et al.* 1997) and aggressive feeding behavior. Anomuran crabs and lobsters use their strong chelate legs to peel off flesh from carcasses. A total of 15 species were grouped under this guild, of which 14 species belonged to epibenthic habitat and 1 belonged to hypo-benthopelagic habitat.

j. BBL suspension feeders

This guild comprises either sessile or slow-moving animals, which mainly feed on planktonic animals or particulate organic matter which remain suspended in the water column. Sessile epibenthic members of this guild such as sea-pen *Pennatula sp.* and solitary corals of the genus *Caryophyllia* use passive strategy for feeding, while planktonic forms such as jelly fishes (*Deepstaria sp. Atolla*, *Cephea*) use an active strategy. They actively filter feed on zooplankton and particulate organic matter in suspension within the water column. A total of 14 species belong to this guild, of which 8 species belong to epibenthic habitat and 6 species to epi-benthopelagic habitat.

k. Sessile megafaunal parasites

Organisms that lives or depend on another organism for deriving nutrients at the host's expense belong to this category. Sea spiders are generally parasites on cnidarians, sponges, polychaetes and bryozoans or scavengers and use their long proboscis to suck food from cnidarians. Only one species, gigantic pycnogonid *Colossendeis colossea* was found belong to this guild. It was observed in bottom trawl catches of ToT, along with its preferred prey animals, such as solitary corals and deep-sea anemones.

5.2.6 Trophic composition and structure of megafauna within ToT

Trophic assemblages of deep-sea megafauna within the BBL of ToT were analyzed using multivariate techniques. All the analysis were performed on the trophic guild distribution matrix based on numerical abundance (square root transformed) across sampling localities. Cluster analysis and SIMPROF test (Figure 5.16) based on Bray Curtis similarity index revealed 2 significantly different clusters (Pi: 2.64 and P: 0.3), representing the two seasons (SM and WM) at 47% similarity, with two significant outliers.

Differences in trophic structure between the two seasonal groups (SM and WM) was examined by making use of the SIMPER tool. It was observed that the differences in average abundance of eight trophic guilds between seasons were responsible for the 92% dissimilarity between these two seasonal groups. Among these, five (micronekton grazers, macroplankton predators, organic deposit cum macrofaunal browsers, organic deposit cum macrofaunal grazers and micronekton predators) were represented in high abundance during WM and three (macronekton predators, BBL suspension feeders and epibenthic megafaunal browsers) were represented in high abundance during SM. Among the outlier stations, sampling at Stn. 31909 (1237-1245 m depth, summer monsoon season) had partially failed due to net damage, hence it was omitted from further analysis. The second outlier station, Stn. 32116 (1151-1154 m depth, WM) stands significantly apart (Pi: 5.15 and P: 0.1) at 64% dissimilarity from the rest of the stations. Comparatively higher abundance of organic deposit cum macrofaunal browsers, BBL suspension feeders, micronekton predators, epibenthic scavengers, organic deposit cum macrofaunal grazers were observed in this outlier (Stn. 32116) cumulatively contributing to the average dissimilarity (73%) from rest of the stations.

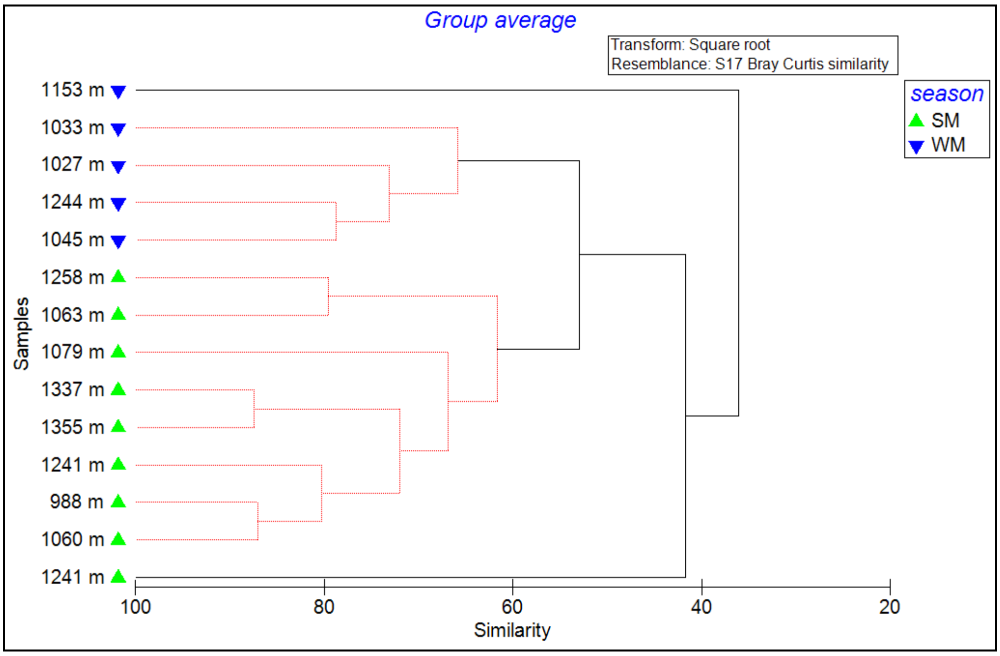


Figure 5.16 Hierarchical cluster plot showing Bray Curtis similarity of trophic guild distribution between 14 sampling stations.

Summer monsoon group (SM) share an average similarity of 69% within member stations. Three trophic guilds contributed to the group average similarity, the organic deposit cum macrofaunal browsers (25%), micronekton predators (15%) and epibenthic megafaunal browsers (12%). These three guilds cumulatively contribute about 53% of average similarity. Winter monsoon group (WM) shared an average similarity of 70%. Three trophic guilds contributing to the group average similarity are micronekton grazers (22%), organic deposit cum macrofaunal browsers (18%) and micronekton predators (13%). These three guilds cumulatively contribute about 53% of the group average similarity. Multi-dimensional scaling (MDS) ordination of sampling locations (Figure 5.17), clearly depicts the linkages and distances between them in two dimensional space at a stress value of 0.06. The analysis of trophic structure of the megafauna of ToT reveals significant seasonal shifts in its composition. The changes in the trophic structure between SM and WM are depicted in Figure 5.18, 5.19 and 5.20 (Table 5.8).

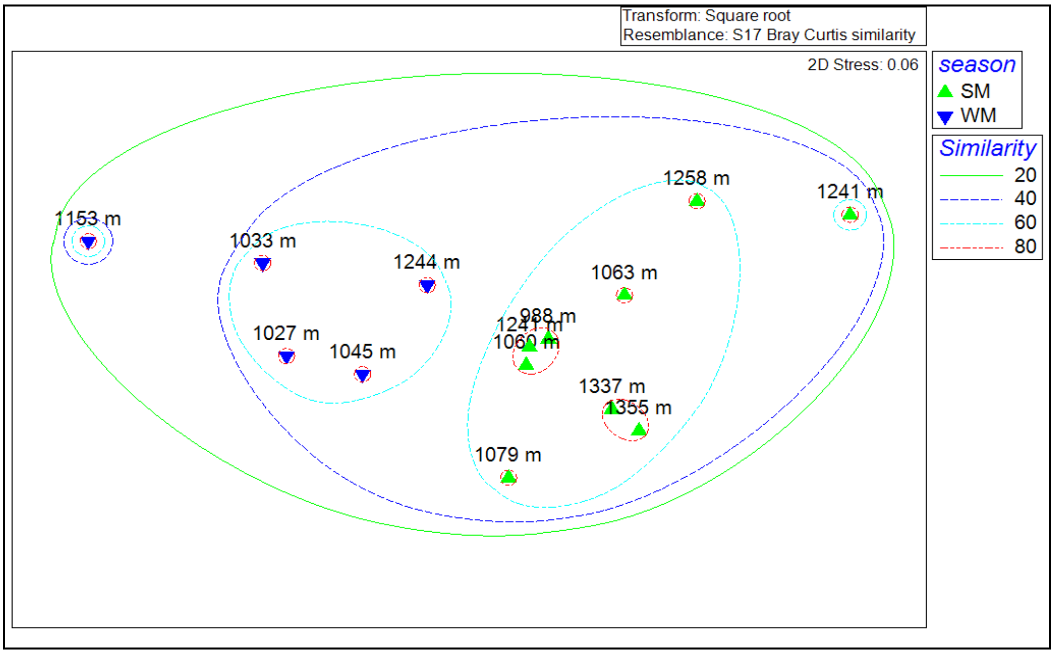


Figure 5.17 MDS plot showing Bray Curtis similarity of trophic guild distribution between 14 sampling stations.

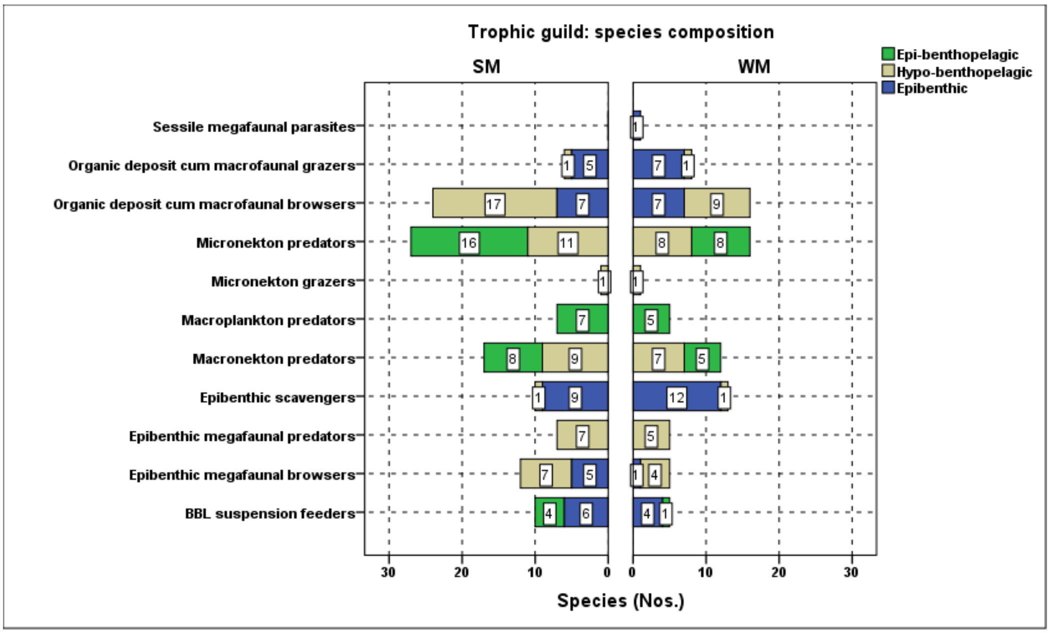


Figure 5.18 Comparison of species composition of trophic guilds during summer and winter monsoon seasons

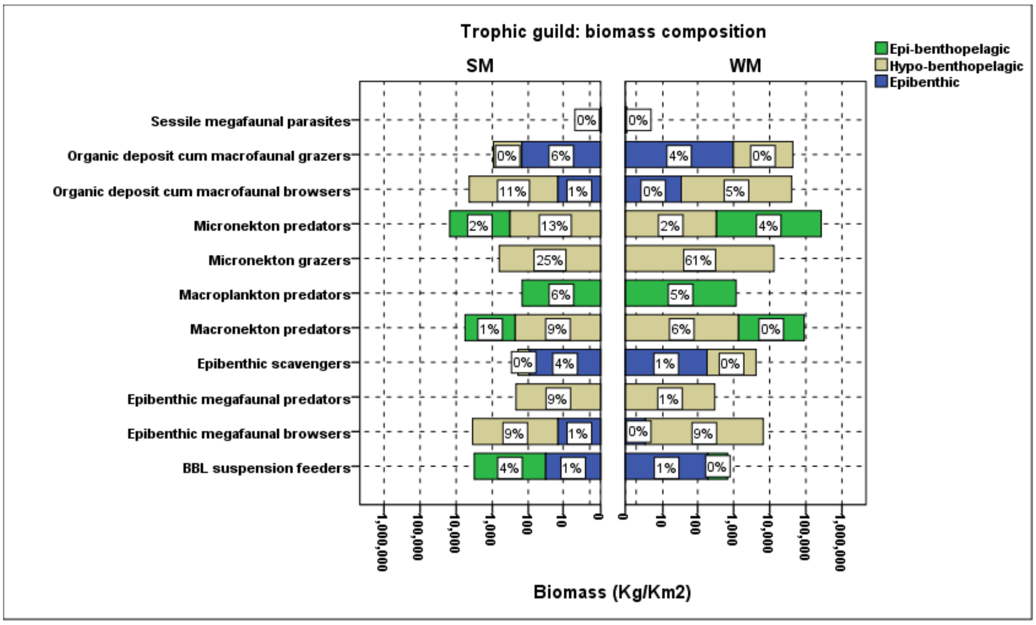


Figure 5.19 Comparison of biomass composition of trophic guilds between summer and winter monsoon seasons

During SM, 10 trophic guilds represented by 121 species were found to occur in ToT (Figure 5.18). Among them, 32 species belonged to the epibenthic habitat, 54 were hypo-benthopelagic and 35 were epi-benthopelagic. Maximum number of species were found to be micronekton predators (27 Nos.), followed by 'organic deposit cum macrofaunal browsers' (24 Nos.) and 'macronekton predators' (17 Nos.). The least diverse guild was 'micronekton grazers', with only one species *Lamprogramus niger*. Hypo-benthopelagic fauna (79.6%) were numerically dominant in the ToT during SM, followed by epibenthic fauna (12.8%) and epi-benthopelagic fauna (7.6%). The 'organic deposit cum macrofaunal browsers' were the most numerically abundant guild (55%) followed by the 'micronekton predator' (12%). Hypo-benthopelagic fauna also dominated in biomass (75.9%), followed by epibenthic fauna (12.2%) and epi-benthopelagic fauna (11.9%). 'Micronekton grazers' guild dominated in the biomass composition (25%) followed by 'micronekton predator' (15%).

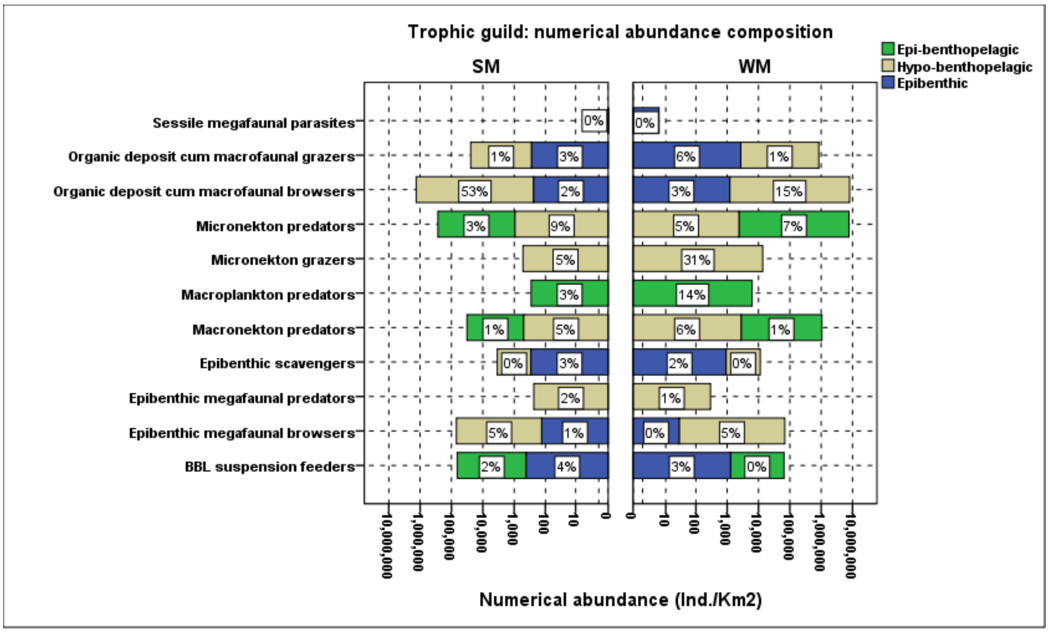


Figure 5.20 Comparison of numerical abundance composition of trophic guilds between summer and winter monsoon seasons

During the WM, 11 trophic guilds were represented, by 87 species in ToT (Figure 5.18). Among them 32 species belonged to the epibenthic habitat, 36 were hypo-benthopelagic and 19 were epi-benthopelagic. Both the micronekton predator and ‘organic deposit cum macrofaunal browsers’ were the most diverse trophic guild (16 species), followed by ‘epibenthic scavengers’ (13 species). The least diverse guilds were ‘micronekton grazers’ and ‘sessile megafaunal parasites’, with only one species *Lamprogramus niger* and *Colossendeis colossea* respectively. Hypo-benthopelagic fauna were numerically dominant (63.9%), followed by epi-benthopelagic fauna (22.2%) and epibenthic fauna (13.9%). The ‘organic deposit cum macrofaunal browsers’ was the most numerically abundant guild (31%), followed by ‘organic deposit cum macrofaunal browsers’ (18%). Hypo-benthopelagic fauna dominated biomass also (84.1%), followed by epi-benthopelagic fauna (9.5%) and epibenthic fauna (6.4%). The ‘micronekton grazers’ guild dominated in the biomass composition (61%) followed by ‘epibenthic megafaunal browsers’ (9%).

5.2.7 Vulnerable fishery resources of ToT

Industrial fishermen in search of new fishing grounds progressively explore deeper and oceanic waters with the assistance of advanced technology. It is well established that bottom trawling causes serious damage to the ecosystem. Though ToT still remain an unexplored ecosystem, its exceptionally dense standing stock of megafaunal community faces serious threats from possible exploitation in the near future and ecosystem degradation through the accumulation of marine debris. The bio-composition of ToT megafauna, as depicted in the earlier section, reveals that most of the living resources in the ToT are bizarre looking deep-sea forms, most of which have low market value. At present, targeted commercial trawl fishery operations for deep-sea shrimps and long-line fishery for deep-sea shark exist along the south west coast of India due their international market demand. Bycatch of other deep-sea fishes in the commercial landings from the targeted fishery have only low market demand in view of poor consumer preference and high oil and wax content. However, in other parts of the world, an exploited fishery exists for many such deep-sea species (grenadiers, roughies, deep-sea shrimps etc.) which are congeneric to the species found in the ToT. Due to the lack of suitable harvesting and post harvesting technologies, these deep-sea resources are not commercially exploited in India at present.

In addition to the international market for deep-sea resources, a booming domestic fish meal industry for shrimp aquaculture demands huge input of such resources. Biomedical industries are also increasingly exploring organic compounds derived from deep-sea organisms such as liver oil, wax, protein, fatty acids and therapeutics etc. Resource depletion and increased fishing pressure in the coastal waters will force the fishing industry to explore more into the deep-sea for alternate and non-conventional resources from its dense pockets. Policies and plans of Govt. of India are also promoting and equipping industrial level exploration into the deep-sea for tapping unutilized resources and diverting the fishing pressure from shallow depths. Though the suitability of most of the deep-sea resources from the ToT are low for direct human consumption, development of appropriate processing technologies can make use of this natural resources for the preparation of products such as fish meal, fish oil, wax, bioactive compounds etc. Thus areas like ToT, with rich deep-sea resources, face serious threat of fishery exploitation in the near future.

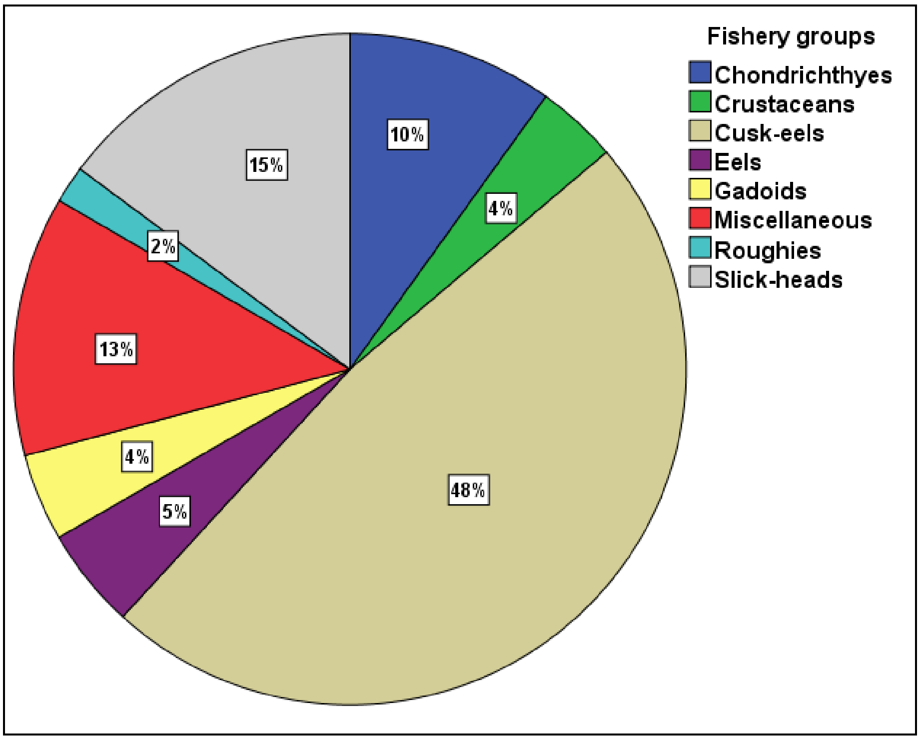


Figure 5.21. Percentage composition of fishery groups within the ToT

An examination of biodiversity and standing stock of megafauna of ToT (chapter 4 and earlier sections of this chapter) depicted the highly diverse megafaunal assemblages in the ToT. A non-selective gear (e.g. bottom trawl) based fishery will yield catches comprising multiple species catering to different market preferences and processing properties. The fishery obtained from exploratory bottom trawl operations in ToT, are grouped into a higher taxonomic levels, and its biological features such as major species with their length range, average weight and contribution to the total yield are given below. These represent the major megafaunal fishery resource of ToT, which are susceptible for future commercial fishery, considering both its resource potential in terms of high biomass and market demand. The share of each group to the average of ToT catches is represented in Figure 5.21.

Deep-sea crustaceans

Deep-sea crustaceans, which include shrimps, lobsters and crabs fetch a high international market price. Crustaceans contribute around 4% of the total catch in biomass. Deep-sea shrimps such as *Aristeopsis edwardsiana* and *Acanthepyra fimbriata* have higher possibility to emerge as a targeted trawl fishery from ToT owing to their appealing looks, size and high biomass in the area. Size of *A. edwardsiana* from TOT ranged from 19.5 to 38.5 cm in TL and weight ranged from 34 to 150 g. Size of *A. fimbriata* ranged from 16.4 to 19 cm in TL and weight ranged from 30 to 50 g. Other medium sized shrimp species of ToT, which dominate the trawl catch such as *Pseudaristeus crassipes* and *Haliporus taprobanensis*, can also support targeted fishery. Other potential crustacean by-catch from trawl fishery include gigantic lobster *Acanthacaris tenuimana*, and gigantic anomuran crabs such as *Neolithodes alcocki* and *Paralomis investigatoris*, though relative yield of these species from trawl fishery is likely to be very low.

Cusk-eels

Cusk-eels (Order Ophidiformes) are the dominant fish group in the trawl catches from ToT. Two species (*Lamprogrammus niger and L. brunswigi*) have promising fishery potential because of their abundance and large body size. *Lamprogrammus niger* alone contributes an average of 45% of biomass of the total trawl catch in the ToT. It is a large species, with a total length of 25.5-86 cm and weight of 50-1,900 g with a mean weight of 900 g. *Lamprogrammus brunswigi* is a much larger species (TL 75.5-95 cm, weight 1,400-4,900 g with a mean weight of 3,275g) , abundant in deeper waters of ToT.

Gadoids

Gadoids include Grenadiers, Rattails and Codlings. Three species of grenadier species (*Coryphaenoides hextii*, *C. woodmasoni* and *C. macrolophus*) found abundantly in trawl catches from ToT, together contributed an average of 4% in biomass in the trawl catch. Among grenadiers, *C. hexti* is the largest , and distributed in deeper areas, with a weight ranged of 110-2950 g and with a mean weight of 348 g. *Coryphaenoides woodmasoni* w(60-300 g, with a mean weight of 167 g) and *Coryphaenoides macrolophus* (110-410 g, with a mean weight of 200 g) are relatively smaller. The rattail, *Bathygadus furvescens*, recorded a total length of 16-40.5cm, and weight of 15-300g. An occasional catch of a gigantic cod, *Lepidion inosimae* of TL 80 cm and weight 7,200 g was also recorded from ToT.

Slick-heads

Slick heads are fishes under Order Osmeriformes,that contribute about 15% in biomass of the trawl catch in the ToT. Owing to their large size and comparatively high biomass, this group has a potential for targeted fishery from ToT. Nine species of slick-heads predominate in biomass are; *Alepocephalus blanfordii* (SL 20-45 cm, weight 70-1,100 g, mean weight 600 g), *A. longiceps* (SL 20-37 cm, weight 100-350 g, mean weight 210 g), *Bathytroctes squamosus* (SL 18.5-25.2 cm, weight 60-210 g, mean weight 110 g), *Conocara microlepis* (SL 22-42 cm, weight 110-950 g, mean weight 500 g), *Narcetes erimelas* (TL 27-55.5 cm, weight 175-2,350 g, mean weight 1,000 g), *N. stomias* (TL 40.5-53.2 cm, weight 700-2,500 g, mean weight 1,250g), *Rouleina guentheri* (SL 19-38.5 cm, weight 50-650 g, mean weight 200 g), *R. squamilatera* (SL 19-25 cm, weight 50-150 g, mean weight 90 g) and *Talismania longifilis* (TL 39-47.7 cm, weight 300-860 g, mean weight 500 g).

Chondrichthyes

Sharks, skates and chimaeras of the Order Squaliformes, Rajiformes and Chimaeriformes, respectively are considered as potential chondrichthyian fishery resources of ToT owing to their larger size, abundance and presence of liver-oil. Chondrichthyes contribute around 10% of the biomass. At present, deep-sea chondrichthyian based fishery exists in the southwest coast of India for the extraction liver-oil from deep-sea sharks. Species found in the ToT includes sharks *Centrophorus atromarginatus* (TL 46.5-70 cm, weight 300-2,100 g, average weight 1,370 g) and *Centroselachus crepidater* (TL 50-83 cm, weight 400-2,500 g, average weight 1,200 g); skate *Dipturus johannisdavisi* (weight 1-7.6 Kg), and chimaeras *Hydrolagus africanus* (weight 1000-1300 g) and *Rhinochimaera africana* (TL 115-135 cm, weight 4,700-5,400 g).

Roughies

Hoplostethus melanopus belonging to the Order Berryciformes is a relatively abundant species in ToT (2%), with a total length of 23-31.2 cm, and weight of 175-500 g (average weight 300 g). A congeneric species of roughy, popularly known as orange roughy (*Hoplostethus atlanticus*) forms an important commercial deep-trawl fishery resource in New Zealand and Australia, since late 1970s. Its stocks have become severely depleted within 3–20 years, but several stocks have subsequently recovered. Now the Marine Conservation Society, UK has categorized orange roughy as "vulnerable to exploitation".

Eels

Bathyuroconger vicinus of the order Anguilliformes is one of the abundant fish species in the trawl catches from ToT. Its total length ranges from 46.5-94 cm, and weight of 140-1100 g with an average weight of 360 g.

Miscellaneous group and by-catch

Bottom trawl catch composition of ToT are highly diverse, hence each trawl operation will land considerable quantity of fish belonging to diverse taxa, but in low abundance. Such diverse group of fauna which yield in less quantity in trawl catches are treated as the miscellaneous group. Congeneric species of black scabbard fish and monk fishes, *Aphanopus microphthalmus* and *Lophoides infrabrunneus* respectively, which has commercial fishery in temperate high seas are also found occasionally in the catches from ToT. By-catch from ToT refers to all other forms of marine life caught unintentionally along with the dominant resources, which include low yielding low value fishes, star fishes, holothurians, isopods, corals etc.

5.3 DISCUSSION

The availability of food resources is recognized as the most critical limiting factor that determines the benthic faunal standing stock in deep-sea (Gage and Tyler 1991). Global-scale synthesis of data on both biomass and abundance across 4 major size components of the benthic community: bacteria and metazoan meiofauna, macrofauna and megafauna was carried out by Rex *et al.* (2006) and Rex and Etter (2010). Relationships of numerical abundance and biomass to depth are significant and negative for all four benthic faunal groups. Among animals, the rate of decrease in abundance and biomass with depth is highest in larger-size classes. Larger organisms appear to be more vulnerable to the decrease in food supply with depth, and Rex (1973) and Thiel (1975) proposed that this is caused by an ‘Allee effect’. It explains that larger animals require more energy, and extreme energy constrains at great depths may depress population densities for some large species below the levels needed to be reproductively viable.

Though the global pattern in megafaunal standing stock to depth is negative, the ToT holds an exceptionally high megafaunal standing stock, compared to similar isobathic regions elsewhere. In order to compare with the global megafaunal standing stock Rex and Etter (2010) in terms of Carbon/m^2 of, the observed wet weight biomass of megafauna (kg/km^2) was converted to carbon following Parulekar *et al.* (1980). The average megafaunal biomass of ToT for summer and winter monsoon seasons (including both shallow and deep zones) in terms of grams of carbon per meter square are 0.19 g C /m^2 and 1.82 g C /m^2 respectively. A comparison with the global patterns by Rex and Etter (2010) indicated that the standing stock of ToT during SM is of comparable range with the productive regions of the global dataset. Notably, standing stock of ToT during WM is exceptionally high (Carbon value) compared to the entire global dataset. Silas (1969) also made similar observations for the southern region of southwest coast of India (between 8º-9º N). This study reported the 180-450 m depth zone (deepest depth strata of their observation) between 8º-9º N to be the most productive part, compared to its shallow counterparts off the southwest coast of India.

Hacker (1994) also reported similar and unusually rich and diverse megafaunal assemblage and standing stock at bathyal depths of the continental slope off Hatteras, northeast Atlantic and attributed it to atypically high organic carbon flux. This is caused by a unique combination of enhanced surface production associated with Gulf Stream induced upwelling, advection of nutrients from nearby coastal bays and rapid topographic funneling across the narrow shelf and the steep incised slope (Schaff *et al.* 1992; Blake and Diaz 1994; Rhoads and Hecker 1994).

While the global patterns in megafaunal standing stock was lower than that of other benthic faunal groups (viz. bacteria, meiofauna and macrofauna), the megafaunal biomass of ToT exceeds estimates of macrofaunal biomass of the continental slope region (200-1000 m depth) off southwest coast of India. The macrobenthic biomass of the region at 1000 m ranged between 0.88 g/m^2 to 9.23 g/m^2 (Abdul Jaleel 2012), while the megafaunal biomass ranged between 1.12 g/m^2 to 31.88 g/m^2. Haedrich and Rowe (1977) made similar observations on the megafaunal biomass of Gulf of Mexico. Their findings disproved the Eltonian concept of trophic relations in deep-sea fauna, that the biomass of the megafaunal component must be small compared to the macrofauna and meiofauna. Such observations focuses the role of food supply and its dynamics in the deep-sea.

The trophic ecology of deep-sea fishes has rapidly expanded due to the application of biochemical trophic biomarkers, notably stable isotopes and fatty acids. Such biomarkers have also been useful in evaluating ontogenetic and seasonal diet shifts, where large sample size requirements for gut content analysis are difficult to meet (Drazen and Sutton 2017). Diet composition and trophic relations of deep-sea megafaunal species in the North eastern Atlantic (Cartes 1993; Cartes 1998; Cartes and Carrasson 2004; Madurell and Cartes 2005; Cartes *et al.* 2007; Jeffreys *et al.* 2010), North western Atlantic (Gale *et al.* 2013), North eastern Pacific (Drazen 2002; Robison *et al.* 2010) had provided considerable insight to the deep-sea ecology. The distributions and zonation rates of deep-sea megafauna in the Western Mediterranean were influenced by the trophic variables such as food source, mean weight of predator and prey per stomach, feeding intensity and number of prey taxa in the diet on the depth-range (Stefanescu *et al.*1994; Cartes and Carrasson 2004). Most of these studies clearly indicates that hyperbenthic crustaceans are the major food source for deep-sea fishes (Fanelli and Cartes 2010).

In several studies using baited cameras and traps for comparing the bait-attending fauna of different areas within the North Atlantic and Pacific, the scavenger communities have been found to differ in terms of species composition and numbers of individuals attracted (Smith and Baldwin 1984; Priede *et al.* 1990; Armstrong *et al.* 1992; Thurston *et al.* 1995; Christiansen, 1996; Priede and Merrett 1998; JanBen *et al.* 2000; Hunter *et al.* 2011). The abundances of individual faunal groups attracted towards the bait correlated significantly with either ambient oxygen availability or the sediment C:N ratio (Wishner *et al.* 1995; Quiroga *et al.* 2009; Sellanes *et al.* 2010; Hunter *et al.*

2011). Studies on the trophic relations of deep-water decapods of North Eastern Atlantic (Cartes 1993; Cartes 1998; Cartes *et al.* 2002; Cartes *et al.* 2007) disclosed a wide variety in its feeding behaviour ranging from deposit feeders to carnivores. Cartes *et al.* 2007 has identified three trophic groups in a continuous gradient of food source: (1) plankton feeders, (2) benthos feeders, (3) intermediate group feeding on mixed diet.

Diet observations of deep-sea fin fishes collected from ToT in the course of present study had higher percentage of empty stomachs making it difficult for a seasonal analysis of stomach fullness and contents to achieve. Deep-sea macrourid fishes in the north-east Pacific brought to the surface from great depths were reported to have a high frequency of stomach eversion as their large gas bladders expand with decrease in pressure (Drazen 2002). Due to the lack of information on the diet composition (because of the eversion of stomach of deep-sea fishes), a different approach (modified version of Gartner et al. 1997) is used for present study. Gartner et al. 1997 synthesized available food habits information for demersal deep-sea fishes through combination of eco-morphological approach and diet content analysis and a similar approach adopted in the present study have resulted in the identification of 11 major guilds among deep-sea megafauna form ToT with similar feeding habits of trophic specialization.

The trophic guild classification proposed in the present study consider both the 'diet categories' on which the megafauna depend and 'feeding strategies' adopted for feeding within the ToT. Hence each trophic guild represents the functional unit within megafaunal community of ToT. Organic matter input and its availability at the seafloor have also been shown to control benthic standing stock, community composition, and diversity (Danovaro et al 2008; Smith *et al.* 2009). Though, the megafaunal standing stock dynamics within the BBL community is totally depended upon distribution of organic matter within the functional building unit of the community, or between trophic guilds, the variation in of trophic guild composition within the ToT reveals that the trophic structure and functioning in the region changes significantly with seasons than with bathymetry. While the megafaunal species assemblages of ToT showed significant bathymetric distinctions, the trophic assemblage structure changes significantly between seasons. The results imply that while the species composition of megafauna of ToT is distinct in the two depth zones, their trophic functionality remains unchanged spatially.

There is good evidence that the megafaunal trophic guild dynamics of ToT is closely linked to the seasonal variations in food supply. The two trophic guilds which depend on the organic deposit on the sea bottom are the numerically abundant megafauna of ToT during both seasons, and they are represented by relatively more number of species. Short lived invertebrates such as shrimps dominate among these, apparently forming the primary consumers of ToT. The secondary consumers, which includes micronekton predators and micronekton grazers, are dependent on growth and dynamics of the primary consumer category. Tertiary consumers include nektonic predators and epibenthic megafaunal browsers. The major portion of megafaunal biomass in the ToT is tied up to the micronekton grazers guild, represented by a single species (*Lamprogrammus niger*). This represents a single-species functional group, emphasizing their irreplaceability, and justifies their categorization as the keystone species. The trophic dynamics of ToT megafauna depends on the variations in the seasonal pulses of organic particle flux to the bottom. The winter monsoon season accounted for the peak megafaunal production, suggesting towards the existence of an efficient ecological forcing mechanism/s that pump the organic matter to the bathyal depths of ToT.

A winter monsoon based deep-sea fishery was initiated along the southwest coast of India from November 1999. Fishing effort was mainly concentrated in the 150-500 m depth zones, particularly in the Quilon Bank region. The deep-sea shrimp fishery appeared promising in its initial phase, with increasing number of fleets as well as landings in progressive years. However after the initial booming phase, the landing as well as the number of fishing vessels showed a decline. Fishery for deep-sea sharks started with the incidental landing of deep-sea sharks, which slowly progressed and established a 50% share to the total chondrichthyan landing at Cochin during the year 2006-2007 (Akhilesh *et al.* 2011). History shows that deep water fisheries are vulnerable/ non-sustainable to commercial exploitation (E.g. fisheries of Wreck fish and Roughies). Biological data on age, growth, mortality and reproduction of the deep-sea fishes studied so far, indicate slow replacement rates, characteristic of slow growing and long lived species, with low fecundity (k-selected), especially for deep-sea sharks.

Non-selective fisheries such as bottom trawling adversely affect the community structure and ecosystem stability through loss in species diversity, altered size structure and trophic interactions and habitat destruction and therefore pockets of high resource abundance such as ToT, may face serious threats from such fishing practices. Without any conservation and management measures in place, unregulated exploitation of the megafaunal resources from such a unique and sensitive deep-sea habitat like ToT would be devastating. Taking into consideration the special features of the ToT megafauna and the sensitivity and uniqueness of the ToT ecosystem, fishery policies based on EBSA concept need to be formulated and adopted to ensure the resource sustainability from ToT. In this aspect the present study provides a baseline information on the standing stock variability and ecology of deep-sea megafaunal community for making effective policies for its conservation and sustainability. Opening up of our deep-sea waters for destructive tapping without stringent monitoring and management measures will end up with ecological imbalance, which could eventually result in fishery collapse and socio-economic conflicts.

Table 5.5. Megafaunal standing stock composition of shallow zone (950-1150 m) of Terrace off Trivandrum

	Biomass (Kg/Km^2)		**Numerical Abundance (Ind./Km^2)**	
	Summer monsoon	**Winter monsoon**	**Summer monsoon**	**Winter monsoon**
Arthropoda	**360.0**	**1143.1**	**8295**	**8276**
Decapoda	**243.2**	**980.2**	**8116**	**7990**
Acanthephyridae	3.7	11.9	125	319
Acanthephyra fimbriata	1.3	11.9	41	319
Acanthepyra sanguinea	2.4	0.0	84	0
Aristeidae	208.2	909.5	6383	5752
Aristaeopsis edwardsiana	146.7	909.5	1520	5752
Pseudaristeus crassipes	61.5	0.0	4862	0
Ethusidae	0.6	0.0	15	0
Ethusa indica	0.6	0.0	15	0
Geryonidae	0.0	8.6	0	10
Chaceon alcocki	0.0	8.6	0	10
Glyphocrangonidae	0.1	26.7	10	1333
Glyphocrangon investigatoris	0.1	26.7	10	1333
Lithodidae	0.1	0.0	5	0
Neolithodes agassizii	0.1	0.0	5	0
Munidopsidae	0.0	10.0	0	167
Munidopsis wardeni	0.0	10.0	0	167
Nephropidae	3.6	10.0	57	333
Acanthacaris tenuimana	2.9	0.0	5	0
Nephropsis atlantica	0.7	0.0	52	0
Nephropsis ensirostris	0.0	10.0	0	333
Oplophoridae	0.3	3.3	12	67
Oplophorus gracilirostris	0.3	3.3	12	67
Pandalidae	0.5	0.0	37	0
Heterocarpus dorsalis	0.5	0.0	37	0
Parapaguridae	0.0	0.0	14	0
Parapagurus pilosimanus	0.0	0.0	14	0
Polychelidae	0.6	0.2	54	10
Stereomastis sculpta	0.6	0.2	54	10
Solenoceridae	25.6	0.0	1406	0

Haliporus taprobanensis	25.6	0.0	1406	0
Isopoda	**116.8**	**162.9**	**178**	**286**
Cirolanidae	116.8	162.9	178	286
Bathynomus keablei	116.8	162.9	178	286
Chordata	**2024.8**	**20634.7**	**5081**	**38340**
Anguilliformes	**187.9**	**1061.1**	**543**	**3138**
Congridae	186.5	1040.5	537	2871
Bathycongrus macrocercus	11.5	78.6	32	448
Bathyuroconger vicinus	175.0	961.9	505	2424
Muraenesocidae	0.0	16.7	0	67
Gavialiceps taeniola	0.0	16.7	0	67
Nemichthyidae	0.0	4.0	0	200
Nemichthys scolopaceus	0.0	4.0	0	200
Serrivomeridae	0.0	0.0	3	0
Serrivomer beanii	0.0	0.0	3	0
Synaphobranchidae	1.5	0.0	3	0
Synaphobranchus affinis	1.5	0.0	3	0
Aulopiformes	**4.1**	**22.4**	**112**	**781**
Ipnopidae	4.1	22.4	112	781
Bathypterois atricolor	3.0	5.7	107	114
Bathypterois guentheri	1.1	16.7	5	667
Beryciformes	**11.7**	**943.3**	**62**	**2881**
Anoplogastridae	1.9	0.5	19	24
Anoplogaster cornuta	1.9	0.5	19	24
Trachichthyidae	9.9	942.9	44	2857
Hoplostethus melanopus	9.9	942.9	44	2857
Carcharhiniformes	**5.6**	**14.8**	**19**	**33**
Pentanchidae	5.6	14.8	19	33
Apristurus breviventralis	0.5	2.9	5	14
Apristurus saldanha	5.1	11.9	14	19
Chimaeriformes	**51.4**	**96.2**	**70**	**110**
Chimaeridae	51.4	67.1	70	105
Hydrolagus africanus	51.4	67.1	70	105
Rhinochimaeridae	0.0	29.0	0	5
Rhinochimaera africana	0.0	29.0	0	5
Gadiformes	**209.5**	**604.0**	**1561**	**2707**
Macrouridae	209.5	604.0	1561	2707
Bathygadus furvescens	54.0	61.0	367	367

Coryphaenoides macrolophus	61.4	78.3	489	581
Coryphaenoides sp	0.7	0.0	5	0
Coryphaenoides woodmasoni	93.4	464.8	700	1759
Lophiiformes	**10.8**	**26.1**	**60**	**162**
Chaunacidae	1.7	1.0	7	5
Chaunax sp.	1.7	1.0	7	5
Diceratiidae	5.0	1.3	16	133
Diceratias trilobus	2.6	0.0	11	0
Paraoneirodes sp	2.5	1.3	5	133
Lophidae	3.5	23.8	5	19
Lophiodes triradiatus	3.5	23.8	5	19
Ogcocephalidae	0.6	0.0	32	5
Coelophrys micropa	0.5	0.0	26	5
Halicmetus ruber	0.0	0.0	6	0
Myctophiformes	**0.5**	**0.0**	**5**	**0**
Neoscopelidae	0.5	0.0	5	0
Scopelengys tristis	0.5	0.0	5	0
Myliobatiformes	**0.0**	**52.4**	**0**	**10**
Hexatrygonidae	0.0	52.4	0	10
Hexatrygon bickelli	0.0	52.4	0	10
Notacanthiformes	**9.5**	**6.7**	**215**	**133**
Halosauridae	8.0	6.7	196	133
Aldrovandia affinis	2.0	0.0	29	0
Halosaurus carinicauda	4.0	6.7	56	133
Halosaurus parvipennis	2.1	0.0	111	0
Notacanthidae	1.4	0.0	19	0
Notacanthus indicus	1.4	0.0	19	0
Ophidiiformes	**866.4**	**12226.5**	**1323**	**14224**
Bythitidae	42.2	4.8	248	48
Hephthocara simum	42.2	4.8	248	48
Ophidiidae	824.2	12221.7	1075	14176
Dicrolene vaillanti	28.5	146.0	497	1500
Holcomycteronus pterotus	5.9	56.7	94	333
Lamprogrammus brunswigi	74.5	0.0	31	0
Lamprogrammus niger	712.0	12019.0	434	12343
Luciobrotula bartschi	1.0	0.0	5	0
Monomitopus conjugator	2.3	0.0	14	0
Osmeriformes	**258.6**	**3435.7**	**509**	**10981**

Alepocephalidae	258.0	3435.7	507	10981
Alepocephalus blanfordii	142.6	2242.9	305	2619
Bathytroctes squamosus	1.2	42.9	14	829
Leptoderma affinis	0.1	0.0	36	0
Narcetes erimelas	33.3	177.1	36	248
Narcetes stomias	69.5	388.1	82	248
Rouleina squamilatera	0.0	571.4	0	7014
Talismania longifilis	10.8	13.3	28	24
Talismania sp.	0.5	0.0	5	0
Platytroctidae	0.6	0.0	3	0
Holtbyrnia Parr,	0.6	0.0	3	0
Perciformes	**21.3**	**56.0**	**50**	**167**
Chiasmodontidae	0.5	0.0	10	0
Kali kerberti	0.5	0.0	10	0
Scombrolabracidae	0.3	0.0	6	0
Scombrolabrax heterolepis	0.3	0.0	6	0
Trichiuridae	20.5	56.0	35	167
Aphanopus microphthalmus	20.5	56.0	35	167
Rajiformes	**6.1**	**95.2**	**8**	**52**
Rajidae	6.1	95.2	8	52
Dipturus johannisdavisi	6.1	95.2	8	52
Scorpaeniformes	**0.0**	**66.7**	**0**	**167**
Psychrolutidae	0.0	16.7	0	33
Psycroleutius sp.	0.0	16.7	0	33
Setarchidae	0.0	50.0	0	133
Setarches longimanus	0.0	50.0	0	133
Squaliformes	**135.1**	**668.1**	**109**	**600**
Centrophoridae	60.8	130.5	39	95
Centrophorus atromarginatus	60.5	52.4	33	33
Centrophorus squamosus	0.3	78.1	6	62
Etmopteridae	10.5	71.0	24	138
Centroscyllium kamoharai	10.5	71.0	24	138
Somniosidae	63.8	466.7	46	367
Centroselachus crepidater	63.8	466.7	46	367
Stomiiformes	**3.0**	**0.0**	**88**	**0**
Gonostomatidae	0.2	0.0	3	0
Cyclothone elongata	0.2	0.0	3	0
Sternoptychidae	0.1	0.0	18	0

Argyropelecus Cocco,	0.1	0.0	18	0
Stomiidae	2.7	0.0	67	0
Borostomias sp.	0.2	0.0	3	0
Chauliodus pammelas	2.5	0.0	64	0
Testudines	**91.7**	**0.0**	**2**	**0**
Cheloniidae	91.7	0.0	2	0
Lepidochelys olivacea	91.7	0.0	2	0
Torpediniformes	**151.6**	**1259.5**	**343**	**2195**
Narcinidae	151.6	1259.5	343	2195
Benthobatis moresbyi	151.6	1259.5	343	2195
Cnidaria	**81.5**	**40.0**	**517**	**867**
Actiniaria	**17.4**	**20.0**	**80**	**200**
Hormathiidae	17.4	20.0	80	200
Hormathiidae	17.4	20.0	80	200
Coronatae	**11.6**	**0.0**	**29**	**0**
Atollidae	11.6	0.0	29	0
Atolla Haeckel,	11.6	0.0	29	0
Rhizostomeae	**25.7**	**0.0**	**88**	**0**
Cepheidae	25.7	0.0	88	0
Cephea coerulea	25.7	0.0	88	0
Scleractinia	**20.3**	**20.0**	**281**	**667**
Caryophylliidae	20.3	20.0	281	667
Caryophyllia communis	12.9	20.0	172	667
Caryophyllia sp1	7.4	0.0	108	0
Semaeostomeae	**6.0**	**0.0**	**24**	**0**
Ulmaridae	6.0	0.0	24	0
Deepstaria sp.	6.0	0.0	24	0
Zoantharia	**0.5**	**0.0**	**14**	**0**
Epizoanthidae	0.5	0.0	14	0
Epizoanthus paguriphilus	0.5	0.0	14	0
Echinodermata	**67.7**	**12.4**	**231**	**38**
Cidaroida	**0.0**	**2.4**	**0**	**10**
Histocidaridae	0.0	2.4	0	10
Histocidaris denticulata	0.0	2.4	0	10
Echinothurioida	**0.0**	**0.5**	**0**	**10**
Echinothuriidae	0.0	0.5	0	10
Echinothuriidae	0.0	0.5	0	10
Elasipodida	**53.4**	**9.5**	**63**	**19**

Psychropotidae	53.4	9.5	63	19
Benthodytes typica	53.4	9.5	63	19
Forcipulatida	**8.2**	**0.0**	**73**	**0**
Zoroasteridae	8.2	0.0	73	0
Cnemidaster zea	6.3	0.0	61	0
Zoroaster angulatus	1.9	0.0	12	0
Paxillosida	**0.0**	**0.0**	**3**	**0**
Astropectinidae	0.0	0.0	3	0
Asteropectinid sp.	0.0	0.0	3	0
Valvatida	**6.0**	**0.0**	**92**	**0**
Goniasteridae	6.0	0.0	92	0
Ceramaster cuenoti	6.0	0.0	92	0
Mollusca	**16.7**	**227.3**	**157**	**1733**
Neogastropoda	**1.6**	**13.3**	**53**	**1133**
Calliotropidae	0.2	6.7	11	667
Calliotropis metallica	0.2	6.7	11	667
Conidae	1.1	0.0	23	0
Conus sp	1.1	0.0	23	0
Turridae	0.2	6.7	18	467
Pleurotoma sp.	0.2	6.7	18	467
Octopoda	**2.7**	**0.0**	**24**	**0**
Opisthoteuthidae	2.7	0.0	24	0
Opisthoteuthis philipii	2.7	0.0	24	0
Oegopsida	**9.8**	**0.0**	**5**	**0**
Architeuthidae	9.8	0.0	5	0
Archituethis	9.8	0.0	5	0
Pectinoida	**0.1**	**200.7**	**70**	**533**
Propeamussiidae	0.1	200.7	70	533
Propeamussium alcocki	0.1	200.7	70	533
Teuthida	**2.5**	**13.3**	**5**	**67**
Histioteuthidae	2.5	13.3	5	67
Histioteuthidae	2.5	13.3	5	67
Grand Total	**2550.6**	**22057.5**	**14279**	**49255**

Table 5.6. Megafaunal standing stock composition of deep zone (1150-1450 m) of Terrace off Trivandrum

	Biomass (Kg/Km^2)		**Numerical Abundance (Ind./Km^2)**	
	Summer monsoon	**Winter monsoon**	**Summer monsoon**	**Winter monsoon**
Arthropoda	**95.7**	**887.3**	**1003.5**	**65568.2**
Decapoda	**53.3**	**796.3**	**914.4**	**65215.9**
Acanthephyridae	19.1	7.7	270.6	4125.0
Acanthephyra curtirostris	0.0	0.1	0.0	56.8
Acanthephyra eximia	0.0	2.5	0.0	1500.0
Acanthephyra fimbriata	18.5	0.0	206.5	0.0
Acanthepyra sanguinea	0.6	2.6	64.1	1318.2
Ephyrina hoskynii	0.0	2.5	0.0	1250.0
Aristeidae	13.3	450.0	433.5	32500.0
Aristaeopsis edwardsiana	10.9	0.0	145.0	0.0
Pseudaristeus crassipes	2.4	450.0	288.5	32500.0
Glyphocrangonidae	0.3	7.6	3.2	3534.1
Glyphocrangon investigatoris	0.3	2.5	3.2	1500.0
Glyphocrangon unguiculata	0.0	5.1	0.0	2034.1
Lithodidae	18.8	34.1	34.2	34.1
Neolithodes agassizii	11.3	34.1	18.0	34.1
Paralomis investigatoris	7.5	0.0	16.2	0.0
Munididae	0.0	2.6	0.0	1295.5
Munida microps	0.0	2.6	0.0	1295.5
Munidopsidae	0.0	3.2	0.0	909.1
Munidopsis stylirostris	0.0	3.1	0.0	840.9
Munidopsis wardeni	0.0	0.1	0.0	68.2
Nephropidae	0.9	19.9	95.7	2329.5
Acanthacaris tenuimana	0.0	14.8	4.3	22.7
Nephropsis atlantica	0.7	2.6	73.9	1306.8
Nephropsis ensirostris	0.2	2.5	17.4	1000.0
Oplophoridae	0.0	2.5	0.0	1500.0
Oplophorus gracilirostris	0.0	2.5	0.0	1500.0
Pandalidae	0.0	2.5	0.0	1000.0
Heterocarpus dorsalis	0.0	2.5	0.0	1000.0
Parapaguridae	0.1	0.3	31.7	136.4

Parapagurus pilosimanus	0.1	0.3	31.7	136.4
Pasiphaeidae	0.0	10.1	0.0	2022.7
Glyphus marsupialis	0.0	2.6	0.0	522.7
Parapasiphae (Eupasiphae)	0.0	2.5	0.0	500.0
Psathyrocaris fragilis	0.0	2.5	0.0	500.0
Psathyrocaris platyophthalmus	0.0	2.5	0.0	500.0
Polychelidae	0.2	5.7	6.5	2079.5
Stereomastis nana	0.0	2.6	0.0	1272.7
Stereomastis sculpta	0.2	3.1	6.5	806.8
Solenoceridae	0.6	250.0	39.0	13750.0
Haliporus taprobanensis	0.6	250.0	39.0	13750.0
Isopoda	**42.4**	**90.9**	**89.1**	**340.9**
Cirolanidae	42.4	90.9	89.1	340.9
Bathynomus keablei	42.4	90.9	89.1	340.9
Pantopoda	**0.0**	**0.1**	**0.0**	**11.4**
Colossendeidae	0.0	0.1	0.0	11.4
Colossendeis colossea	0.0	0.1	0.0	11.4
Chordata	**2150.3**	**20076.1**	**4536.8**	**43035.3**
Anguilliformes	**77.4**	**1246.8**	**255.6**	**4045.5**
Congridae	74.7	1244.3	222.0	3795.5
Bathycongrus macrocercus	1.4	363.6	8.2	1568.2
Bathyuroconger vicinus	73.3	880.7	213.7	2227.3
Nemichthyidae	0.2	0.0	3.2	0.0
Avocettina infans	0.2	0.0	3.2	0.0
Nettastomatidae	0.7	0.0	3.2	0.0
Venefica proboscidea	0.7	0.0	3.2	0.0
Serrivomeridae	1.1	2.5	21.7	250.0
Serrivomer beanii	1.1	2.5	21.7	250.0
Synaphobranchidae	0.8	0.0	5.5	0.0
Synaphobranchus brevidorsalis	0.8	0.0	5.5	0.0
Aulopiformes	**2.9**	**3.4**	**57.0**	**113.6**
Ipnopidae	2.3	3.4	49.3	113.6
Bathypterois atricolor	0.5	3.4	19.2	113.6
Bathypterois guentheri	1.2	0.0	27.4	0.0
Bathytyphlops marionae	0.5	0.0	2.7	0.0
Synodontidae	0.6	0.0	7.7	0.0
Harpadon squamosus	0.6	0.0	7.7	0.0
Beryciformes	**0.0**	**0.3**	**0.0**	**68.2**

Anoplogastridae	0.0	0.3	0.0	68.2
Anoplogaster cornuta	0.0	0.3	0.0	68.2
Carcharhiniformes	**15.9**	**0.0**	**76.9**	**0.0**
Pentanchidae	15.9	0.0	76.9	0.0
Apristurus breviventralis	6.4	0.0	39.4	0.0
Apristurus saldanha	9.6	0.0	37.5	0.0
Chimaeriformes	**16.4**	**42.6**	**18.1**	**45.5**
Chimaeridae	2.5	42.6	8.2	45.5
Hydrolagus africanus	2.5	42.6	8.2	45.5
Rhinochimaeridae	13.9	0.0	9.8	0.0
Harriotta raleighana	3.0	0.0	4.9	0.0
Rhinochimaera africana	11.0	0.0	4.9	0.0
Gadiformes	**333.8**	**1089.6**	**1029.4**	**2141.2**
Macrouridae	316.2	1089.6	1026.2	2141.2
Bathygadus furvescens	0.8	100.0	5.5	500.0
Coryphaenoides hextii	203.7	908.1	297.7	1188.1
Coryphaenoides woodmasoni	94.9	56.4	571.3	203.1
Nezumia brevirostris	12.6	25.0	119.7	250.0
Nezumia semiquincunciata	4.2	0.0	31.9	0.0
Moridae	17.6	0.0	3.2	0.0
Lepidion inosimae	17.6	0.0	3.2	0.0
Lophiiformes	**1.8**	**0.0**	**18.0**	**0.0**
Diceratiidae	1.6	0.0	2.7	0.0
Bufoceratias shaoi	1.6	0.0	2.7	0.0
Ogcocephalidae	0.1	0.0	15.2	0.0
Coelophrys micropa	0.1	0.0	10.9	0.0
Halicmetus ruber	0.0	0.0	4.3	0.0
viciMyxiniformes	**2.2**	**43.2**	**21.7**	**22.7**
Myxinidae	2.2	43.2	21.7	22.7
Eptatretus Cloquet,	2.2	43.2	21.7	22.7
Notacanthiformes	**19.5**	**79.0**	**238.7**	**3090.9**
Halosauridae	19.5	79.0	238.7	3090.9
Aldrovandia affinis	3.3	0.0	19.2	0.0
Halosaurus carinicauda	7.4	52.8	176.8	1806.8
Halosaurus parvipennis	8.8	26.1	42.6	1284.1
Ophidiiformes	**1035.1**	**11356.2**	**1435.5**	**18318.2**
Bythitidae	5.3	68.2	42.2	568.2
Hephthocara simum	5.3	68.2	42.2	568.2

Ophidiidae	1029.8	11288.1	1393.3	17750.0
Dicrolene vaillanti	12.2	184.1	421.0	5545.5
Holcomycteronus pterotus	4.3	65.9	78.3	2113.6
Lamprogrammus brunswigi	388.2	254.0	134.2	90.9
Lamprogrammus niger	567.4	10784.1	619.6	10000.0
Mastigopterus imperator	50.9	0.0	89.3	0.0
Monomitopus conjugator	6.8	0.0	50.9	0.0
Osmeriformes	**420.0**	**3752.3**	**1184.4**	**12375.0**
Alepocephalidae	420.0	3750.0	1181.2	12318.2
Alepocephalus blanfordii	99.6	715.9	187.6	1193.2
Alepocephalus longiceps	74.0	340.9	378.2	1375.0
Bathytroctes squamosus	9.0	392.0	71.7	3909.1
Conocara microlepis	53.8	160.2	106.5	397.7
Leptoderma affinis	0.0	0.0	19.6	0.0
Narcetes erimelas	3.9	429.5	4.3	568.2
Narcetes stomias	104.7	1086.4	118.5	1352.3
Rouleina guentheri	21.9	306.8	174.0	2170.5
Rouleina squamilatera	0.9	181.8	12.0	454.5
Talismania longifilis	52.2	73.9	108.7	147.7
Talismania sp.	0.0	62.5	0.0	750.0
Platytroctidae	0.0	2.3	3.2	56.8
Platytroctes mirus	0.0	2.3	3.2	56.8
Rajiformes	**165.6**	**1980.7**	**80.2**	**784.1**
Rajidae	165.6	1980.7	80.2	784.1
Dipturus johannisdavisi	159.5	1980.7	44.5	784.1
Fenestraja mamillidens	6.0	0.0	35.7	0.0
Scorpaeniformes	**0.3**	**37.5**	**2.7**	**500.0**
Setarchidae	0.3	37.5	2.7	500.0
Setarches longimanus	0.3	37.5	2.7	500.0
Squaliformes	**59.2**	**442.0**	**104.4**	**1272.7**
Etmopteridae	20.3	425.0	70.0	1250.0
Centroscyllium kamoharai	20.3	425.0	70.0	1250.0
Somniosidae	38.9	17.0	34.3	22.7
Centroselachus crepidater	38.9	17.0	34.3	22.7
Stomiiformes	**0.3**	**2.5**	**14.2**	**257.7**
Gonostomatidae	0.2	0.0	2.7	0.0
Cyclothone elongata	0.2	0.0	2.7	0.0
Sternoptychidae	0.0	0.1	8.2	22.7

Argyropelecus	0.0	0.1	8.2	22.7
Stomiidae	0.0	2.3	3.2	235.0
Astronesthes sp.	0.0	0.0	3.2	0.0
Chauliodus pammelas	0.0	2.3	0.0	235.0
Cnidaria	**171.6**	**1655.9**	**495.1**	**16363.6**
Actiniaria	**2.5**	**0.0**	**27.4**	**0.0**
Hormathiidae	2.5	0.0	27.4	0.0
Hormathiidae	2.5	0.0	27.4	0.0
Coronatae	**0.0**	**375.0**	**0.0**	**2000.0**
Atollidae	0.0	375.0	0.0	2000.0
Atolla Haeckel,	0.0	375.0	0.0	2000.0
Gorgoniidae	**0.0**	**2.5**	**0.0**	**250.0**
Gorgonia	0.0	2.5	0.0	250.0
Gorgonid	0.0	2.5	0.0	250.0
Pennatulacea	**0.3**	**0.0**	**9.2**	**0.0**
Pennatulidae	0.3	0.0	9.2	0.0
Pennatula sp.	0.3	0.0	9.2	0.0
Rhizostomeae	**37.0**	**500.0**	**152.2**	**3750.0**
Cepheidae	37.0	500.0	152.2	3750.0
Cephea coerulea	37.0	500.0	152.2	3750.0
Scleractinia	**22.3**	**772.7**	**266.6**	**10227.3**
Caryophylliidae	22.3	772.7	266.6	10227.3
Caryophyllia communis	22.3	522.7	266.6	5227.3
Caryophyllia sp1	0.0	125.0	0.0	2500.0
Caryophyllia sp2	0.0	125.0	0.0	2500.0
Semaeostomeae	**108.7**	**0.0**	**10.9**	**0.0**
Ulmaridae	108.7	0.0	10.9	0.0
Deepstaria sp.	108.7	0.0	10.9	0.0
Zoantharia	**0.9**	**5.7**	**29.0**	**136.4**
Epizoanthidae	0.9	5.7	29.0	136.4
Epizoanthus paguriphilus	0.9	5.7	29.0	136.4
Echinodermata	**138.0**	**3302.3**	**651.8**	**8966.0**
Brisingida	**0.5**	**0.0**	**2.7**	**0.0**
Brisingidae	0.5	0.0	2.7	0.0
Brisinga ?insularum	0.5	0.0	2.7	0.0
Echinothurioida	**0.0**	**25.0**	**0.0**	**750.0**
Echinothuriidae	0.0	25.0	0.0	750.0
Echinothuriidae	0.0	25.0	0.0	750.0

Elasipodida	**95.6**	**3000.0**	**95.1**	**3000.0**
Psychropotidae	95.6	3000.0	95.1	3000.0
Benthodytes typica	95.6	3000.0	95.1	3000.0
Forcipulatida	**19.7**	**30.1**	**169.0**	**556.8**
Zoroasteridae	19.7	30.1	169.0	556.8
Cnemidaster zea	15.7	5.1	100.5	56.8
Zoroaster alfredi	1.6	0.0	27.2	0.0
Zoroaster angulatus	2.3	25.0	41.3	500.0
Molpadida	**0.0**	**0.6**	**0.0**	**22.7**
Molpadiidae	0.0	0.6	0.0	22.7
Molpadia musculus	0.0	0.6	0.0	22.7
Ophiurida	**0.0**	**28.3**	**16.0**	**1022.9**
Amphiuridae	0.0	2.5	0.0	250.0
Amphiura sp.	0.0	2.5	0.0	250.0
Ophiochitonidae	0.0	25.4	0.0	761.5
Ophiochiton ambulator	0.0	25.4	0.0	761.5
Ophiodermatidae	0.0	0.4	0.0	11.4
Bathypectinura heros	0.0	0.4	0.0	11.4
Ophiuridae	0.0	0.0	16.0	0.0
Ophioceramis tenara	0.0	0.0	16.0	0.0
Paxillosida	**5.6**	**2.5**	**71.9**	**250.0**
Astropectinidae	2.4	0.0	28.4	0.0
Persephonaster rhodopeplus	2.4	0.0	28.4	0.0
Porcellanasteridae	3.3	2.5	43.5	250.0
Sidonaster vaneyi	3.3	2.5	43.5	250.0
Valvatida	**16.6**	**215.9**	**297.1**	**3363.6**
Goniasteridae	16.6	215.9	297.1	3363.6
Ceramaster cuenoti	6.8	193.2	112.6	3090.9
Nymphaster moebii	6.5	5.7	119.9	102.3
Pseudarchaster jordani	3.2	17.0	64.6	170.5
Mollusca	**7.5**	**4.7**	**84.3**	**465.9**
Neogastropoda	**0.0**	**4.5**	**0.0**	**375.0**
Calliotropidae	0.0	2.3	0.0	204.5
Calliotropis metallica	0.0	2.3	0.0	204.5
Turridae	0.0	2.3	0.0	170.5
Pleurotoma sp.	0.0	2.3	0.0	170.5
Octopoda	**1.6**	**0.0**	**4.9**	**0.0**
Opisthoteuthidae	1.6	0.0	4.9	0.0

Opisthoteuthis philipii	1.6	0.0	4.9	0.0
Oegopsida	**3.0**	**0.0**	**3.2**	**0.0**
Architeuthidae	3.0	0.0	3.2	0.0
Archituethis dux	3.0	0.0	3.2	0.0
Pectinoida	**0.1**	**0.1**	**43.6**	**90.9**
Propeamussiidae	0.1	0.1	43.6	90.9
Propeamussium alcocki	0.1	0.1	43.6	90.9
Teuthida	**2.7**	**0.0**	**32.6**	**0.0**
Histioteuthidae	2.7	0.0	32.6	0.0
Histioteuthidae	2.7	0.0	32.6	0.0
Grand Total	**2563.1**	**25926.3**	**6771.6**	**134399.1**

Table 5.7.a Seasonal variations in diet composition of finfishes of ToT based on the % values of index of relative importance (%IRI)

		Summer monsoon				Winter monsoon			
Sl. No.	**Species**	**Number of observation (n)**	**Length range in cm (TL, *SL)**	**% empty stomach**	**Dietary contents observed (% IRI)**	**Number of observation (n)**	**Length range in cm (TL, *SL)**	**% empty stomach**	**Dietary contents observed (% IRI)**
1	*Alepocephalus blanfordii*	132	20.5-45.0*	95%	Sediment (24%), crab [Charybdis sp.] (40%), Shrimp (36%)	47	29.0-44.0	98%	Sediment (52%), shrimp remnants (48%)
2	*Alepocephalus longiceps*	17	23.0-37.0*	100%	Semidigested fluid in the intestine (100%)	10	20.0-32.5	100%	Semidigested fluid in the intestine (100%)
3	*Bathygadus furvescens*	52	16.0-28.0	100%		33	23.0-40.5	100%	Semidigested shrimps in the intestine (100%)
4	*Bathytroctes squamosus*	16	20.5-23.5*	94%	Shrimp parts (100%)	24	20.5-25.2*	100%	
5	*Apristurus sp.*	7	25.2-26.2	80%	Shrimp parts (100%)				
6	*Bathypterois sp.*	7	17.0-28.0	100%					
7	*Bathyuroconger vicinus*	68	51.0-94.0	85%	Crab (Charybdis sp.) (12%), Fish chunks (30%), Shrimps (Aristaeopsis sp.) (40%), Unidentified semidigested organic matter in the intestine (18%)	72	46.5-78.0	90%	Fish [fish chunks, myctophid] (72%), Squid (11%), Shrimp (17%)
8	*Benthobatis moresbyi*	46	21.5-48.0	100%	Unidentified organic matter in the intestine, possibly phyto-detritus (100%).	53	20.0-49.5	100%	Organic debris possibly phyto-detritus in the intestine (100%)
9	*Centrophorus atromarginatus*	6	55.0-80.0	100%		16	46.5-73.0	94%	Fish [fish chunk](100%)
10	*Conocara microlepis*	34	22.0-42.0	78%	Shrimp parts (100%)	12	26.2-39.5	83%	Organic debris possibly phyto-detritus in the intestine (100%)

11	*Coryphaenoid hextii*	34	47.0-80.0	78%	Polychelus (22%), Nephropsis (23%), Glyphocrangon (18%), Shrimp 30%, Crab (7%)	35	34.0-63.0	95%	Shimp parts (65%), benthic crab (22%), Sediment (13%)
12	*Coryphaenoides woodmasoni*	56	27.5-41.0	96%	Shrimp parts (27%), Organic debris possibly phyto-detritus in the intestine (73%).	31	35.0-44.0	97%	Shrimp parts (28%), Organic debris possibly phyto-detritus in the intestine (72%)
13	*Coryphaenoides macrolophus*	13	28.0-37.0	94%	Shrimp parts (13%), Organic debris possibly phyto-detritus in the intestine (87%).				
14	*Dicrolene vaillanti*	62	13.0-28.5	100%	Organic debris from intestine (100%)	23	21.5-28.5%	100%	
15	*Dipturus johannisdavisi*	5	60.0-115.0	80%	Shrimp [Aristeopsis edwardsinus] (80%), Parts of Zoroaster sp. (20%)				
16	*Centroscyllium kamoharai*	7	38.2-61.0	77%	Squid (30%), Shrimp (55%), juvenile fish (15%)	14	45.5-62.0	78%	Shrimp parts, small shrimps (100%)
17	*Gavialiceps taeniola*	14	50.0-72.0	100%					
18	*Halosaurus spp.*	41	25.0-39.0	100%					
19	*Hephthocara simum*	17	29.0-45.5	100%		8	21.0-32.0	100%	
20	*Hoplostethus melanopus*	43	26.0-33.0	97%	Shrimp parts (100%)	50	23.0-31.2	95%	Small shrimps (100%)
21	*Hydrolagus africanus*	8	70.7-84.0	86%	Crab parts (61%), Echinoderm parts (25%), Octopus (beek) (2%), Squid (12%),				
22	*Lamprogrammus brunswigi*	24	75.5-95.0	100%	Intestine contains digested shrimp parts (100%)	14	69.5-123.0	100%	Intestine contains digested shrimp parts (100%)
23	*Lamprogrammus niger*	70	25.5-73.0	97%	Shrimps (100%), In some fishes intestine filled with semi-digested shrimp parts	83	33.0-72.0	98%	In some fishes intestine filled with semi-digested shrimp parts (100%)
24	*Narcetes spp.*	26	38.0-65.0	98%	Jelly like semi-digested substances (100%)	36	35.0-64.5	100%	In some fishes gelly like semi-digested substances (100%)

25	*Rouleina squamilatera*	22	19.0-25.0	99%	Jelly like semi-digested substances (100%)				
26	*Rouleina guentheri*					12	28.5-38.5	100%	In some fishes jelly like semi-digested substances (100%)
27	*Talismania longifilis*	15	39.0-47.7	100%		12	39.0-44.5	100%	In some fishes jelly like semi-digested substances (100%)

Table 5.7.b Trophic guild categories, species composition and seasonal variations of deep-sea megafauna in Terrace off Trivandrum.

	Summer monsoon		Winter monsoon	
	Numerical abundance (Ind./Km^2)	**Biomass (Kg/Km^2)**	**Numerical abundance (Ind./Km^2)**	**Biomass (Kg/Km^2)**
BBL suspension feeders	**568.5**	**126.8**	**1327.3**	**197.3**
Epibenthic	**410.4**	**32.2**	**1277.3**	**194.8**
Caryophyllia communis	219.6	17.6	613.6	26.4
Caryophyllia sp1	54	3.7	0	0
Caryophyllia sp2	0	0	0	0
Epizoanthus paguriphilus	21.7	0.7	68.2	2.8
Gorgonid	0	0	0	0
Hormathiidae	53.7	9.9	150	15
Pennatula sp.	4.6	0.2	0	0
Propeamussium alcocki	56.8	0.1	445.5	150.6
Epi-benthopelagic	**158.1**	**94.6**	**50**	**2.5**
Atolla Haeckel,	14.5	5.8	0	0
Cephea coerulea	120.3	31.3	0	0
Deepstaria sp.	17.5	57.4	0	0
Oplophorus gracilirostris	5.8	0.1	50	2.5
Psathyrocaris fragilis	0	0	0	0
Psathyrocaris platyophthalmus	0	0	0	0
Epibenthic megafaunal browsers	**659.3**	**245.8**	**2379.1**	**1844.4**
Epibenthic	**130.5**	**14.2**	**28.4**	**2.6**
Brisinga insularum	1.4	0.3	0	0
Cnemidaster zea	80.8	11	28.4	2.6
Ophioceramis tenara	8	0	0	0
Zoroaster alfredi	13.6	0.8	0	0
Zoroaster angulatus	26.7	2.1	0	0
Hypo-benthopelagic	**528.8**	**231.6**	**2350.7**	**1841.8**
Alepocephalus blanfordii	246.4	121.1	2185.9	1790.1
Alepocephalus longiceps	189.1	37	62.5	14.2
Conocara microlepis	53.3	26.9	73.9	36.4
Lepidochelys olivacea	1.1	45.9	0	0
Leptoderma affinis	27.8	0	0	0
Notacanthus indicus	9.5	0.7	0	0
Platytroctes mirus	1.6	0	28.4	1.1
Epibenthic megafaunal predators	**236.5**	**221.3**	**292.4**	**300**
Hypo-benthopelagic	**236.5**	**221.3**	**292.4**	**300**
Coryphaenoides hextii	148.9	101.9	124.1	42.9
Dipturus johannisdavisi	26.3	82.8	56.3	124.3
Harriotta raleighana	2.5	1.5	0	0
Hexatrygon bickelli	0	0	7.1	39.3
Hydrolagus africanus	39.2	27	101.3	71.7
Luciobrotula bartschi	2.5	0.5	0	0

Opisthoteuthis philipii	14.6	2.1	0	0
Rhinochimaera africana	2.5	5.5	3.6	21.8
Epibenthic scavengers	**301.1**	**93.3**	**927.5**	**205.1**
Epibenthic	**290.2**	**92.2**	**916.1**	**183.5**
Acanthacaris tenuimana	4.6	1.5	11.4	7.4
Bathynomus keablei	133.8	79.6	259.7	136.3
Chaceon alcocki	0	0	7.1	6.4
Ethusa indica	7.3	0.3	0	0
Munida microps	0	0	22.7	0.1
Munidopsis stylirostris	0	0	45.5	0.3
Munidopsis wardeni	0	0	159.1	7.6
Neolithodes agassizii	11.4	5.7	17	17
Nephropsis atlantica	62.9	0.7	28.4	0.1
Nephropsis ensirostris	8.7	0.1	250	7.5
Paralomis investigatoris	8.1	3.8	0	0
Parapagurus pilosimanus	23.1	0.1	68.2	0.2
Stereomastis nana	0	0	11.4	0.1
Stereomastis sculpta	30.3	0.4	35.6	0.5
Hypo-benthopelagic	**10.9**	**1.1**	**11.4**	**21.6**
Eptatretus	10.9	1.1	11.4	21.6
Macronekton predators	**557.1**	**254.1**	**3153.9**	**1414.7**
Epi-benthopelagic	**63.7**	**23.6**	**376.9**	**66**
Anoplogaster cornuta	9.3	0.9	51.9	0.5
Aphanopus microphthalmus	17.3	10.2	125	42
Archituethis	4.1	6.4	0	0
Bufoceratias shaoi	1.4	0.8	0	0
Diceratias trilobus	5.4	1.3	0	0
Gavialiceps taeniola	0	0	50	12.5
Histioteuthidae	18.8	2.6	50	10
Kali kerberti	4.9	0.2	0	0
Paraoneirodes sp	2.5	1.2	100	1
Hypo-benthopelagic	**493.4**	**230.5**	**2777**	**1348.7**
Bathycongrus macrocercus	20.2	6.4	369.8	65.7
Bathyuroconger vicinus	359.5	124.2	1931.5	755.5
Centrophorus atromarginatus	16.6	30.3	25	39.3
Centrophorus squamosus	2.9	0.1	46.4	58.6
Centroscyllium kamoharai	47.1	15.4	103.6	53.2
Centroselachus crepidater	40.3	51.3	286.4	358.5
Lophiodes triradiatus	2.6	1.7	14.3	17.9
Synaphobranchus affinis	1.5	0.7	0	0
Synaphobranchus brevidorsalis	2.7	0.4	0	0
Macroplankton predators	**285.8**	**149.1**	**6246.6**	**1164.2**
Epi-benthopelagic	**285.8**	**149.1**	**6246.6**	**1164.2**
Holtbyrnia Parr,	1.5	0.3	0	0
Narcetes erimelas	20.3	18.6	219.8	172.6
Narcetes stomias	100	87.1	236.9	334.3
Rouleina guentheri	87	10.9	210.2	90.9
Rouleina squamilatera	6	0.5	5488	519.5

Talismania longifilis	68.5	31.5	91.7	46.9
Talismania sp.	2.5	0.2	0	0
Micronekton grazers	**526.8**	**639.7**	**13632.1**	**13093.8**
Hypo-benthopelagic	**526.8**	**639.7**	**13632.1**	**13093.8**
Lamprogrammus niger	526.8	639.7	13632.1	13093.8
Micronekton predators	**1225.8**	**369.7**	**5600.8**	**1136.8**
Epi-benthopelagic	**288.5**	**45.7**	**3211.5**	**807.4**
Argyropelecus Cocco,	13.1	0	11.4	0.1
Astronesthes sp.	1.6	0	0	0
Avocettina infans	1.6	0.1	0	0
Bathytroctes squamosus	43.1	5.1	701	40.7
Borostomias sp.	1.5	0.1	0	0
Chauliodus pammelas	32	1.3	0	0
Cyclothone elongata	2.8	0.2	0	0
Glyphus marsupialis	0	0	11.4	0.1
Harpadon squamosus	3.8	0.3	0	0
Hephthocara simum	144.9	23.7	69.8	6.4
Hoplostethus melanopus	21.8	4.9	2142.9	707.1
Lepidion inosimae	1.6	8.8	0	0
Nemichthys scolopaceus	0	0	150	3
Parapasiphae (Eupasiphae)	0	0	0	0
Psycroleutius sp.	0	0	25	12.5
Scombrolabrax heterolepis	2.9	0.1	0	0
Scopelengys tristis	2.5	0.2	0	0
Serrivomer beanii	12.3	0.5	0	0
Setarches longimanus	1.4	0.1	100	37.5
Venefica proboscidea	1.6	0.3	0	0
Hypo-benthopelagic	**937.3**	**324**	**2389.3**	**329.4**
Apristurus breviventralis	22.1	3.4	10.7	2.1
Apristurus saldanha	26	7.3	14.3	8.9
Bathygadus furvescens	186.4	27.4	275	45.7
Bathypterois atricolor	63.1	1.8	142.5	6
Bathypterois guentheri	16	1.2	500	12.5
Bathytyphlops marionae	1.4	0.3	0	0
Chaunax sp.	3.7	0.9	3.6	0.7
Dicrolene vaillanti	459.2	20.3	1397.7	126.5
Lamprogrammus brunswigi	82.5	231.4	45.5	127
Mastigopterus imperator	44.6	25.5	0	0
Monomitopus conjugator	32.3	4.5	0	0
Promyllantor purpureus	0	0	0	0
Organic deposit cum macrofaunal browsers	**5802.3**	**300.3**	**7832.3**	**1168.3**
Epibenthic	**238.5**	**14.3**	**1210.3**	**34.6**
Amphiura sp.	0	0	0	0
Asteropectinid sp.	1.5	0	0	0
Bathypectinura heros	0	0	5.7	0.2
Ceramaster cuenoti	102.3	6.4	45.5	2.8
Glyphocrangon investigatoris	6.5	0.2	1000	20

Glyphocrangon unguiculata	0	0	17	0.1
Nymphaster moebii	60	3.3	51.1	2.8
Ophiochiton ambulator	0	0	5.8	0.2
Persephonaster rhodopeplus	14.2	1.2	0	0
Pseudarchaster jordani	32.3	1.6	85.2	8.5
Sidonaster vaneyi	21.7	1.6	0	0
Hypo-benthopelagic	**5563.8**	**286**	**6622**	**1133.7**
Acanthephyra curtirostris	0	0	28.4	0.1
Acanthephyra eximia	0	0	0	0
Acanthephyra fimbriata	123.7	9.9	239.3	8.9
Acanthepyra sanguinea	73.9	1.5	34.1	0.1
Aldrovandia affinis	24	2.6	0	0
Aristaeopsis edwardsiana	832.7	78.8	4314.3	682.1
Coelophrys micropa	18.3	0.3	3.6	0
Coryphaenoides macrolophus	244.5	30.7	436.1	58.7
Coryphaenoides sp	2.5	0.4	0	0
Coryphaenoides woodmasoni	635.4	94.1	1420.8	376.8
Ephyrina hoskynii	0	0	0	0
Fenestraja mamillidens	17.9	3	0	0
Halicmetus ruber	5.1	0	0	0
Haliporus taprobanensis	722.7	13.1	0	0
Halosaurus carinicauda	116.5	5.7	128.4	6.4
Halosaurus parvipennis	77	5.4	17	0.6
Heterocarpus dorsalis	18.3	0.2	0	0
Nezumia brevirostris	59.9	6.3	0	0
Nezumia semiquincunciata	16	2.1	0	0
Pseudaristeus crassipes	2575.4	31.9	0	0
Organic deposit cum macrofaunal grazers	**363.5**	**156.2**	**3030.6**	**1010.6**
Epibenthic	**277.1**	**151.1**	**2723.8**	**966.4**
Benthobatis moresbyi	171.7	75.8	1646.4	944.6
Benthodytes typica	79	74.5	14.3	7.1
Calliotropis metallica	5.7	0.1	602.3	6.1
Conus sp	11.5	0.6	0	0
Echinothuriidae	0	0	7.1	0.4
Histocidaris denticulata	0	0	7.1	1.8
Molpadia musculus	0	0	11.4	0.3
Pleurotoma sp.	9.2	0.1	435.2	6.1
Hypo-benthopelagic	**86.4**	**5.1**	**306.8**	**44.2**
Holcomycteronus pterotus	86.4	5.1	306.8	44.2
Sessile megafaunal parasites	**0**	**0**	**5.7**	**0.1**
Epibenthic	**0**	**0**	**5.7**	**0.1**
Colossendeis colossea	0	0	5.7	0.1

Table 5.8. SIMPER results showing differences in trophic structure between the two seasons (SM and WM).

Species	Avg. abundance SM	A Avg. abundance WM	Avg. Dissimilarity	Dissimilarity /SD	Contributing %	Cumulative %
Micronekton grazers	15.19	110.6	12.54	2.07	26.66	26.66
Macroplankton predators	15.03	67.16	6.32	1.36	13.42	40.08
Organic deposit cum macrofaunal browsers	64.55	84.74	5.76	1.73	12.24	52.32
Organic deposit cum macrofaunal grazers	16.67	52.74	4.51	2.03	9.59	61.91
Micronekton predators	33.03	68.21	4.32	1.14	9.17	71.08
Macronekton predators	21.64	51.99	3.81	1.47	8.1	79.19
BBL suspension feeders	21.98	24.12	3.1	1.65	6.59	85.78
Epibenthic megafaunal browsers	24.48	48.16	2.97	2.21	6.32	92.1

Chapter - 6

ECOLOGY

6.1 INTRODUCTION

Deep-sea megafauna are exposed to conditions such as freezing temperatures, extreme hydrostatic pressures, absence of sunlight, and low food availability (Rex 1981) and therefore it is widely assumed that the deep-sea habitat presents a hostile environment. While considering the variability of the physical factors alone, the deep-sea is characterized as a monotonous and stable environment (Sanders 1968; Thistle 2003). The tremendous adaptive radiation evident in deep-sea organisms has been attributed most frequently to the unusual stability of the deep-sea environment (Thistle 1983). However, there is considerable disagreement about the relative importance of ecological mechanisms that act to maintain the biological diversity in this relatively stable regime. While the physical factors are rather uniform, the most important factor limiting the diversity and distribution of the fauna in the deep-sea floor is the availability of food (Thiel 1979; Vinogradova 1997). The deep-oceans, which encompass depths greater than 200 m (Sanders and Hessler 1969), cover most of the Earth and are particularly energy deprived systems.

Despite these ecological constraints, very interesting and unexpected results emerged from the present study in the form of high faunal diversity, occurrence of gigantic fauna among most of the taxa, occurrence of rare and endemic species, and unusually high standing stock in the bathyal depths of ToT. The chemical energy that sustains most deep-sea organisms is sequestered from sinking particulate organic carbon (POC) derived from primary production in the euphotic zone, far above (McClain *et al.* 2012). The unique biological attributes of ToT megafauna cannot be explained without considering the trophic factors and export flux of organic matter (OM) from the productive surface layers of the South Eastern Arabian Sea (SEAS). The present chapter addresses the key ecological characteristics of SEAS that may fuel the unique biological attributes of the deep-sea ToT megafauna. This chapter explains the factors which give rise to and sustain the unique megafaunal diversity of the ToT through the collation and synthesis of primary and secondary data on the geomorphological, physical as well as biological oceanographic settings of the area.

6.2 GEOMORPHOLOGICAL FEATURES

Marine sediments are considered as the largest reservoir of organic carbon on earth, and continental margins are important sites for the accumulation and burial of organic matter (Demaison and Moore 1980; Walsh *et al.* 1985; Cowie 2005). Geomorphologies of SEAS show sedimentary basins and anomalous terraces and a widely varying shelf width. Along the west coast of India, the shelf break occurs at between 80 and 150 m depth (Rao and Wagle 1997). The shelf is relatively wider in the northern region (except Saurashtra), being more than 300 km in the areas north off Mumbai coast, whereas towards south, shelf width gradually narrows to about 50 km off Trivandrum (Yatheesh *et al.* 2006). In contrast, the continental slope is relatively steep and narrow in the north and wider towards the south. A comparatively gentle slope area occurs in the south, forming two relatively flat terraces in the continental slope, viz. Terrace off Quilon (ToQ) between 180 and 800 m depth (Rao and Bhattacharya, 1975) and Terrace off Trivandrum (ToT) between 900 and 2,000 m depth (Yatheesh *et al.* 2006). These two anomalous lateral bathymetric protrusions of the SEAS, which is located in the mid-continental slope region, approximately south of the latitude of Kochi, are collectively named as ‘Alleppey Trivandrum Terrace Complex (ATTC)’ (Yatheesh *et al.* 2013).

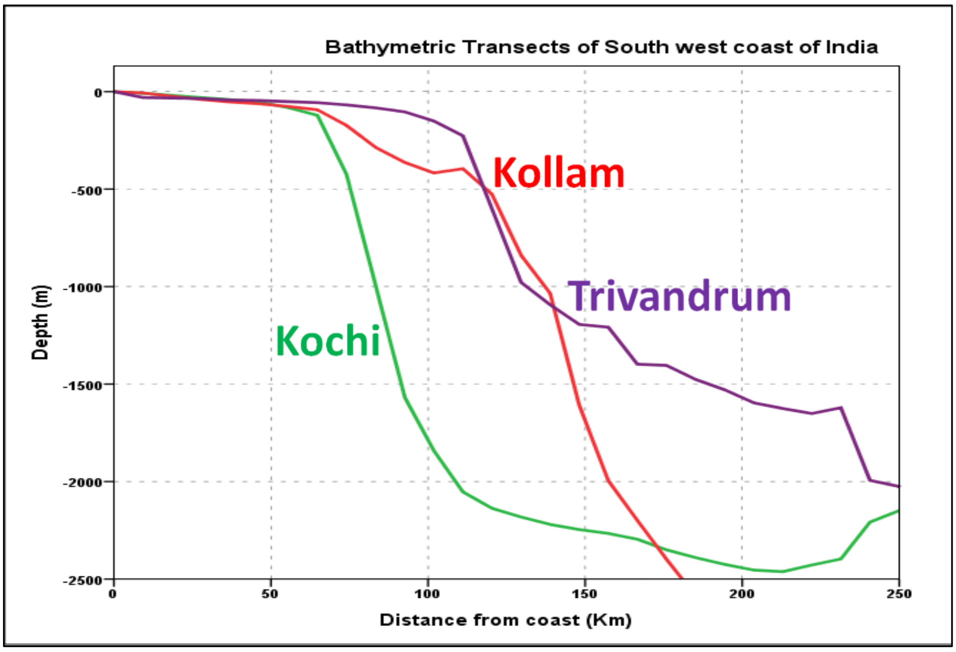


Figure 6.1 Depth and distance configurations of three bathymetric transects off southwest coast of India- Green: off Kochi, Red: off Kollam and Purple: off Trivandrum

Figure 6.1 shows a comparison of the topographic depth profiles across three successive transects (Kochi, Kollam, and Trivandrum) in the SEAS. It clearly depicts the two terraces ToQ and ToT in the Kollam and Trivandrum transects, respectively. The continental slope angle off Kochi is steep up to 2,000m depth, with a steady 1m increase in depth for every 20 m distance offshore. The angle off Kollam shows a gentle slope region between 200 to 600 m and then an abrupt slope to 2000m depth. The continental slope angle off Trivandrum shows a gentle slope up to 7.45° N and a steep slope in the sector south of this, representing the flat ToT.

6.3 THE ENVIRONMENTAL SET UP OF SEAS AND ToT

The South Eastern Arabian Sea (SEAS) of which Terrace of Trivandrum (ToT) is a part, is essentially an Eastern Boundary Upwelling System (EBUS), characterized by annually reversing surface currents driven by seasonally reversing monsoon winds.

SEAS experiences two dominant seasons, the Summer Monsoon (SM) season (June to end September) and the Winter Monsoon (WM) season from November to end February, interspaced by the Fall Inter-monsoon (FIM) in October and the Spring Inter monsoon (SIM) from March to end May. During SM season strong south-westerlies drive a moderately strong equator-ward Western India Coastal Current (WICC). During the winter monsoon (WM, November to February), this surface circulation is reversed under the influence of the north easterlies, with a strong poleward flowing West India Coastal current (WICC). Schematic representation of the surface coastal currents of the region is given in Figure 6.2.

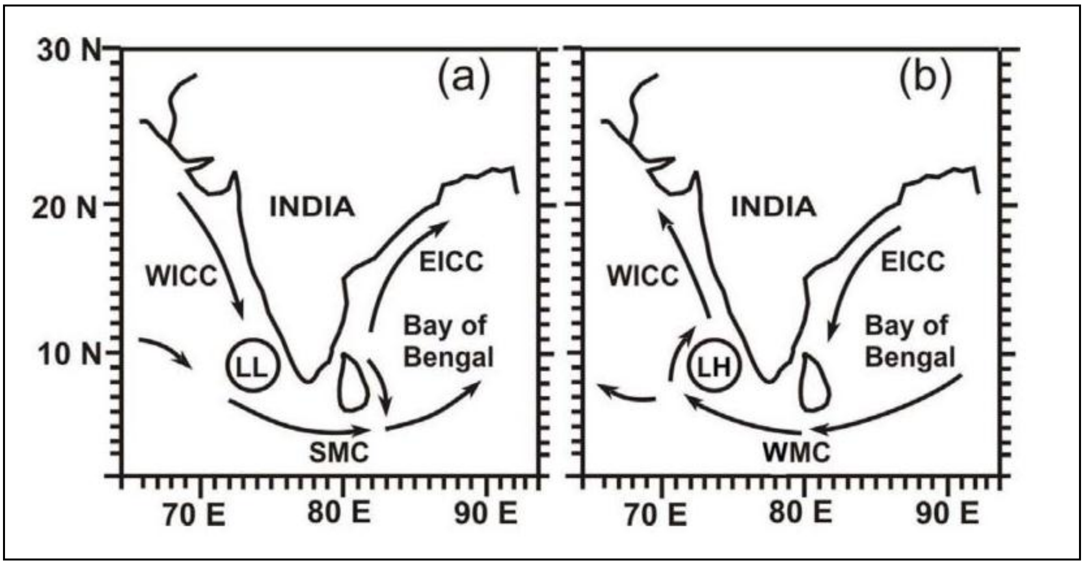


Figure 6.2 Schematic picture of the surface coastal current pattern in the Arabian Sea and Bay of Bengal, during: (a) summer monsoon; and (b) winter monsoon period (based on Luis and Kawamura 2004, Masson *et al.*, 2005). Key: WICC –West Indian Coastal Current; LL – Lakshadweep Low; LH – Lakshadweep high; SMC – Summer Monsoon Current; EICC – East Indian Coastal Current; and WMC – Winter Monsoon Current.

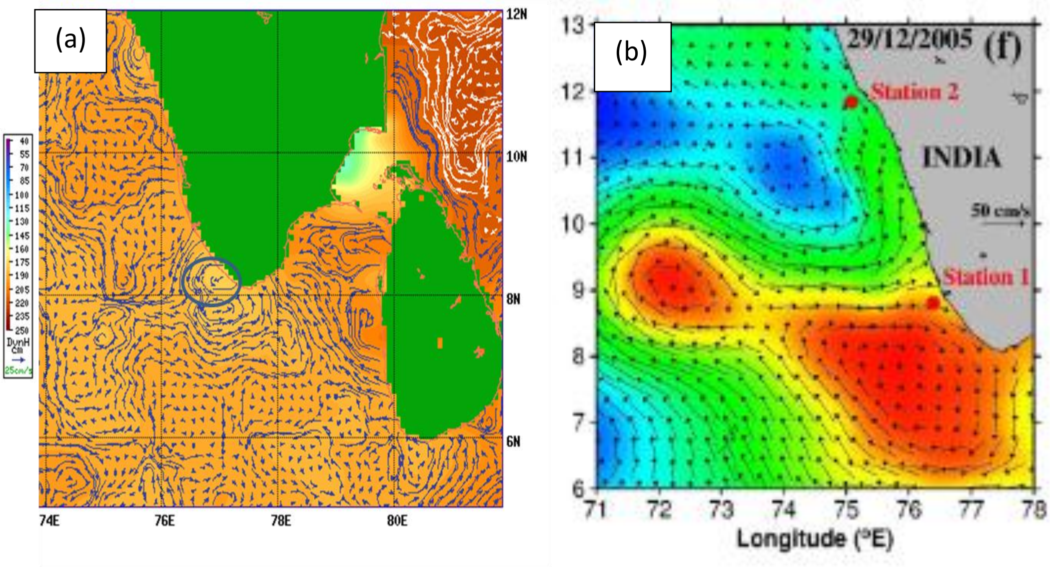


Figure 6.3 (a) SM cold core eddy derived from Jason altimetry for June 2009 and (b) WM warm core eddy adopted from Jineesh *et al.* (2015).

Coastal Upwelling along the SEAS is moderate to intense, details of which including the forcing mechanisms involved are well documented (Bakun *et al.* 1998; Pankajakshan *et al.* 1997; Smitha *et al.* 2008; Shah *et al.* 2015). In the southern tip of SEAS (South of 8.5° N Lat.) the coastal morphology is distinct from other areas of SEAS (coast oriented inwards), upwelling is intense and forced exclusively by winds that flow tangential to the coast (Bakun *et al.* 1998; Smitha *et al.* 2008). Unlike the northern sectors of SEAS (area north of 8.5° N), the influence of coastally trapped Kelvin waves and its offshore radiating Rossby waves on upwelling are rather limited or nil along this sector. The Kelvin waves have a downwelling peak in December and an upwelling peak in July (Shenoi *et al.* 1999). During SM season of ToT, the upwelling mode of Kelvin act in conjunction with surface winds, forcing the equatorward WICC to meander northwards thereby setting up the surface cyclonic eddy circulation or the Lakshadweep Low (LL) along the southern tip (Shankar and Shetye 1997; Shenoi *et al.* 1999). This surface circulation pattern is characterized by the presence of one or more mesoscale eddies (cold core eddy) and several small scale transient eddies (Figure 6.3a), which help to pump nutrients to surface waters, thereby supplementing the upwelling process to enhance surface productivity.

The reverse of this happens during the WM season. The downwelling mode of Kelvin forces an anticyclonic surface circulation in the ToT area (Lakshadweep High or LH), the intrusion of the low saline nutrient poor surface waters of Bay of Bengal (BoB) to the ToT and the formation of warm core eddy/ies (Figure 6.3 b). The spread of BoB waters lead to strong surface stratification and appearance of oligotrophic conditions over the ToT area. The downwelling (or upwelling) Rossby waves that are radiated by downwelling (or upwelling) coastal Kelvin waves along the west coast of India are instrumental in generating the LH (or LL) observed in the Lakshadweep Sea; a high forms shortly after December, and a low forms in July (Shenoi *et al.* 1999).

Vertical profiles (CTD) on water quality parameters from sampling locations of ToT are given in Figure 6.4. Seasonality is restricted to the upper water column, while the deeper region remains relatively stable. Near bottom hydrographic parameters of isobathic depths of ToT showed no significant spatial and temporal variations. Near bottom (1,000 m) temperature ranged from 6.9 to 7.4ºC, salinity from 35.4 to 35.5 and dissolved oxygen between 0.7 and1.0 ml/L. The deepest CTD cast (at Stn. 32702, 1350 m, SM 2014) recorded temperature, salinity and DO values of 5.6ºC, 34.9 and 1.3 ml/L, respectively. It is significant to note that contrary to other areas of SEAS where bottom DO levels fall below 0.2 ml/L (suboxic conditions) during SM season, in the 1000 m isobaths of ToT the DO is near 1 ml/L and in fact increases with depth. The relatively high dissolved oxygen level that is maintained in ToT during both the seasons indicates to the possibility that this area may be receiving small supply of Antarctic Bottom Waters.

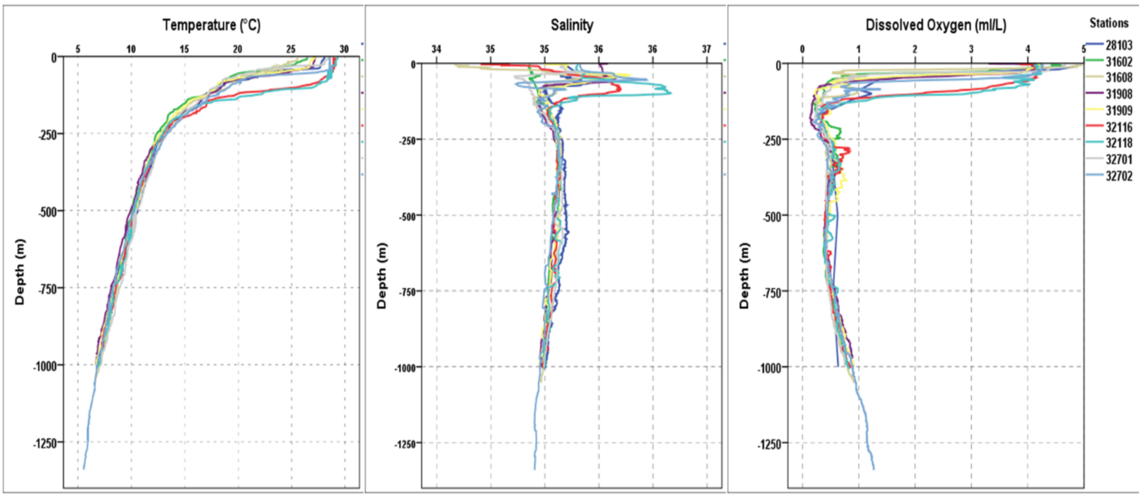
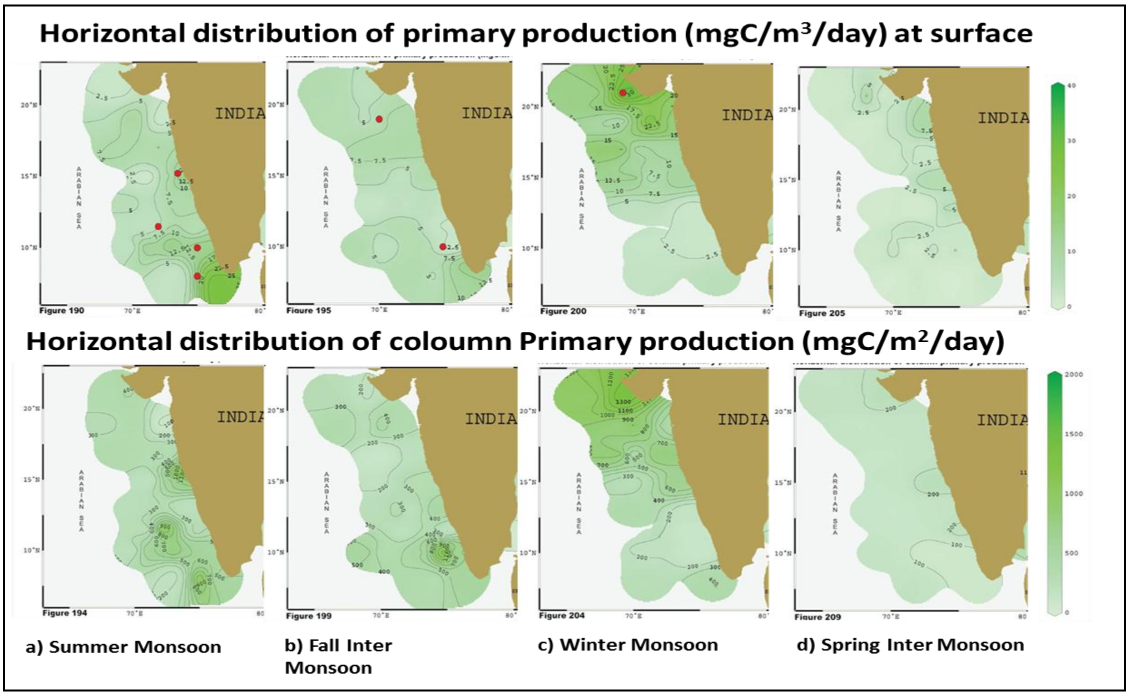


Figure 6.4 CTD profiles of temperature, salinity and dissolved oxygen in sampling locations of ToT.

6.4 SURFACE PRODUCTION

The SM season in the SEAS is marked by moderate wind driven coastal upwelling modulated by the coastally trapped equatorial Kelvin waves and its offshore propagating Rossby waves (Shankar and Shetye 1997; Smitha *et al.* 2008). Upwelling of nutrient rich subsurface water to the euphotic zone fuels high primary production in the SEAS. Coastal upwelling starts at the southern tip of the west coast of India, and as the season progresses it propagates northwards, resulting in high biological production along the entire stretch of SEAS (Banse 1959; McCreary *et al.* 1993; Habeebrehman *et al.* 2008; Jyothibabu *et al.* 2010). Figure 6.5 shows the spatial and temporal variations in primary production in the ToT as well as along the west coast of India (Nair 2010). The average coastal and oceanic column production in SEAS reach up to 1252 mgC/m^2/day and 526 mgC/m^2/day, respectively during summer monsoon (Sanjeevan *et al.* 2011). The higher primary production promotes secondary (Haridas *et al.* 1980; Madhupratap *et al.* 1990) as well as tertiary production, under favorable environmental conditions (Madhupratap *et al.* 2001) in most parts of the upwelling zones of SEAS.



a) Summer Monsoon b) Fall Inter Monsoon c) Winter Monsoon d) Spring Inter Monsoon

Figure 6.5. Showing the spatio-temporal variation in primary production in the west coast of India (Source: Nair *et al.* 2010)

The offshore extent of primary production in ToT far exceeds other areas of SEAS both during the SM and the FIM seasons. Outside the near coast, the highest SM values in surface and column primary production (12.5 mg C/m^3/d and 900 mg C/m^2/d respectively) are recorded in the ATTC of which the ToT is a part. The values of Surface and Column Primary production of ToT area are more than two fold the values recorded for areas adjacent the ATTC (Figure 6.5) implying that the ToT/ ATTC is the most productive area of SEAS.

During the WM, the southward flowing EICC carries the low saline Bay of Bengal waters to the SEAS. The low saline oligotrophic waters from Bay Bengal occupy the surface layers and play a vital role in altering the physical and biological properties of SEAS (Prasannakumar *et al.* 2004). Water column stratification and oligotrophic conditions significantly reduce the primary production. The average primary production in the coastal and oceanic regions of SEAS gets reduced to 272 mg C/m^2/day and 209 mg C/m^2/day.

6.5 EXPORT FLUX TO DEEP-SEA

On an average, only 4.3–8.2% of the carbon fixed by primary producers is exported to the deep Arabian Sea (Lee *et al.* 1998; Nair *et al.* 1989). Sediment trap studies yielded sinking carbon fluxes of 18, and 27 mg C/m^{-2}/d at 130 m, during the during winter monsoon and summer monsoon seasons, respectively for the eastern Arabian Sea (Sarma *et al.* 2003). However, such a low rates of export flux cannot sustain an unusually high megafaunal standing stock (2,556 and 21,535 kg/km^2 during the SM and WM, respectively).

As noted in the previous para, both the surface and column productivity of the ATTC (ToT) area during SM season is more than double that of adjacent areas. However, there is no proportionate increase in the number of copepods (primary grazers) in the mixed layers of ToT during SM (< 150 copepods per 1000m^3) as compared to the adjacent Kochi transect (> 200 copepods per 1000 m^3). Since primary production is more than double that of the adjacent areas and grazing potential is relatively low compared to other areas, large scale export flux is to be expected in the ToT area. Other forcing mechanisms such as seasonally reversing eddies (LH and LL) prevailing in this area and the meandering of WICC might have a strong influence in the export flux of the region. The anti-cyclonic warm-core eddy (LH) during the WM and cyclonic cold-core eddy (LL) during SM coincide with the peak and low megafaunal standing stock seasons, respectively. In the open ocean areas of the SEAS, the anti-cyclonic LH during winter season produce oceanic downwelling (Kurian and Vinayachandran 2006) which may excerpt a strong funneling action to drive the organic matter to the depths of ToT. However, there is no quantitative evidences to substantiate the export flux to the deep-sea, mediated by such hydrographic process.

Trawl operations in the ToT often recovered relatively fresh terrigenous debris, such as green grass, leaves, twigs, pieces of wood etc., which showed very little signs of decay (Figure 6.6). The freshness of the grass and leaves indicate that these materials were deposited rather recently, which is suggestive of the strong siphoning mechanisms that deliver such fresh deposits to the deep-sea floor. Additionally, wide verities of allochthonous, anthropogenic debris, such as plastic bags, PVC pipes, bottles, oil-drums, filled garbage bags, clothes, shoes, tyres etc. were retrieved from trawled stations. All these evidences indicate that most of terrigenous debris reaching the ocean are deposited in an offshore area like the ToT. Bulk deposition of terrigenous debris in ToT, bypassing the shelf margins indicate downslope slumping of debris by turbidity currents to this site. Such processes which provide terrigenous sediments to the abyssal plains are known from the North Atlantic Ocean and off the Indian Ocean on either side of India (Davies and Gorsline 1976).

Figure 6.6. Marine debris deposits recovered in the trawl catches from ToT, collection locations are: a. sea anemone attached to a PVC pipe, b oil drum, c. bottle, d. garbage bag, e. banana palm, f. green grass, h. clothes and tooth paste, i & j. coconut husk, k. plastic bags.

Studies conducted in a similar bathyal deep-sea habitat which shows an unusual deep-sea megafaunal standing stock off Cape Hatteras in the North Atlantic experienced atypically high organic carbon flux. This is caused by a unique combination of enhanced surface production associated with Gulf Stream induced upwelling, out welling of nutrients from nearby coastal bays, and rapid topographic funneling across the narrow shelf and down the steep incised slope (Schaff *et al.* 1992; Blake and Diaz 1994; Rhoads and Hecker 1994).

6.6 SEDIMENTATION ON CONTINENTAL MARGIN OF SEAS

Various physical, chemical and geological processes control the sedimentation regime in the SEAS. The continental margin of western India is composed of a complex variety of sedimentary environments. The SEAS shelf receives fluvial input from rivers which originate in the Western Ghats. Studies carried out on the sediment characteristics of the shelf region off the southwest coast of India (Nair and Pylee 1968; Nair 1975; Hashimi and Nair 1981; Paropkari *et al.* 1987; Narayana and Prabhu 1993; Chauhan and Gujar 1996; Jayaraj *et al.* 2007; Joydas and Damodaran 2009) have revealed that sand is the dominant sediment fraction in the whole shelf region. However, the shelf region south of Kollam markedly differs from its northern side, as this part is completely devoid of fine sediment fractions i.e. ‘no clay zone’ (Figure 6.7).

Studies conducted along the continental margin (200 -1000m) of the SEAS (Chauhan and Gujar 1996; Abdul Jaleel 2012) showed that sand was the dominant component of shelf edge sediments (200 m), but the silt content in these sediments was also high. Sediments of deeper sites (500 and 1000 m) were dominated by finer fractions (silt and clay), in the entire SEAS (Figure 6.7). Organic matter content was comparatively low on the shelf edge and increased significantly down the slope (Figure 6.8). Sediment sample collected from ToT (at Stn. 31602, depth 1,350 m), showed a dominance of Silt (84%) followed by Clay (12%) and sand (4%) with OM content of 6%.

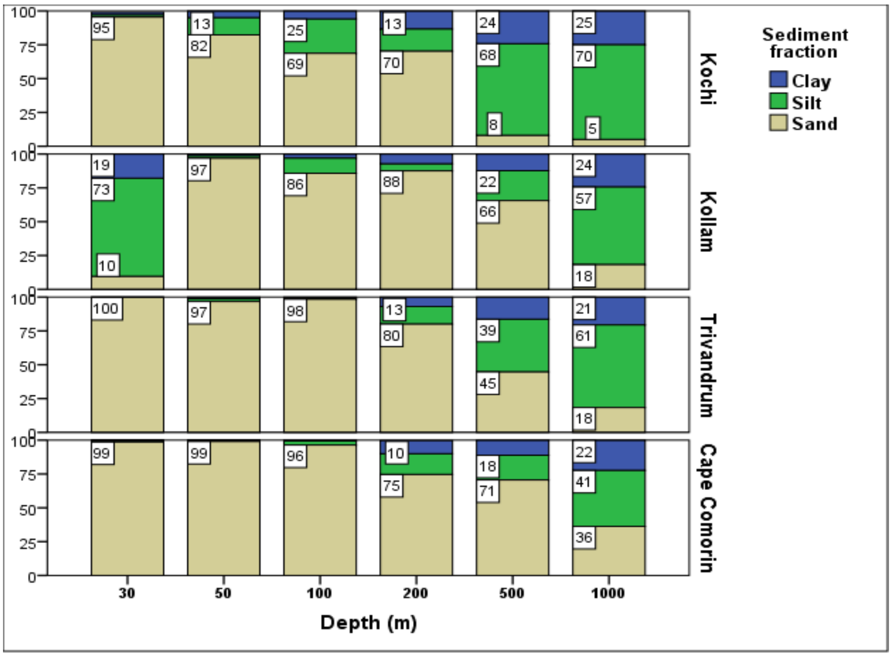


Figure 6.7. Sediment texture composition of 6 depths along four transects of SEAS (data source: Damodaran 2010; Abdul Jaleel 2012)

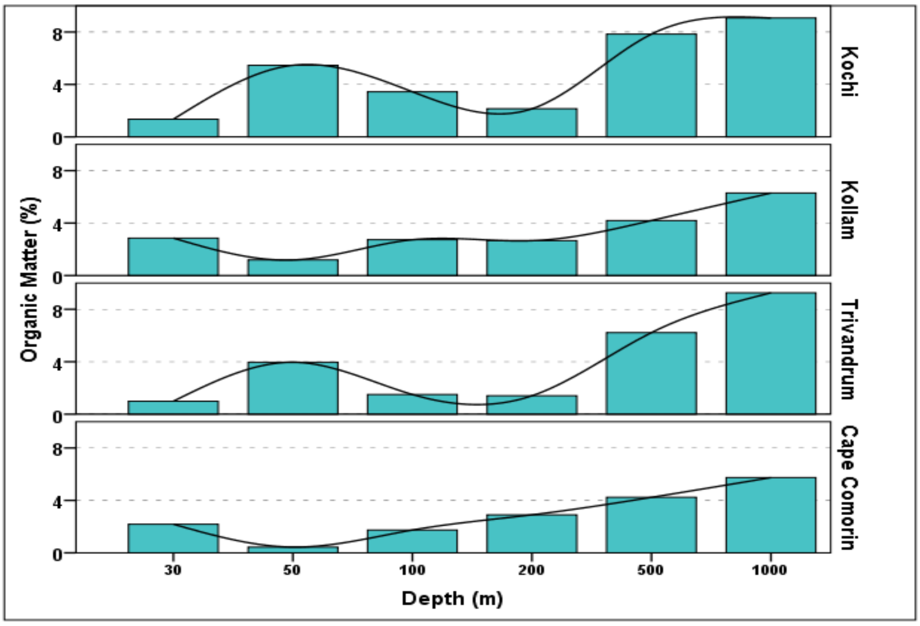


Figure 6.8. Sediment organic matter content at 6 depths along four transects of SEAS (data source: Damodararn 2010;Abdul Jaleel *et al.*2014)

Hydrodynamic conditions of the SEAS have a profound influence on spatial and temporal variability in the primary production and the vertical export flux of organic matter and sediments (Nair *et al.* 1989). The settlement and transport of organic matter and sediments to the sea floor is more influenced by hydrodynamic processes than the geomorphological features (Goldberg and Griffin 1970; Kolla *et al.* 1981). Gyres and eddies in the Arabian Sea are known to transport sediments to great depths, and are responsible for shaping geomorphology of the region (Das *et al.* 1980). Particularly in SEAS, sedimentation over the continental shelf region south of Kollam is hindered by the seasonally reversing ocean currents and subsurface currents (Smitha *et al.* 2008, Damodaran 2010), producing a ‘no clay zone’ (Chauhan and Gujar 1996; Rao and Wagle 1997; Abdul Jaleel *et al.* 2015). The ‘no clay zone’ most probably could be the ‘catchment area’ for the ‘statistical funnel’ of the seasonally reversing eddies prevailing in the region. Increase of finer sediment fractions (clay and silt) and organic matter towards the deeper continental slope of SEAS (Naidu 1993; Abdul Jaleel *et al.* 2014), underline the fact that the settlement and deposition zone lies in the deeper zones, i.e. bathyal ToT.

Seismic studies in the sub-bottom configuration of ToT (Yatheesh *et al.* 2013) revealed that the slope basement of ToT area was blanketed with a sediment apron of thickness ~1.7 sec TWT (i.e. approximately 1.27 km thick sediment bed). Chauhan and Gujar (1996) has analyzed the surficial clay mineral distribution on the southwestern continental margin of India. Their studies showed, the higher concentration of clay minerals such as kaolinite, smectite, gibbsite, and laterite granules on the slope (ToT area), which is suggestive of contribution from chemically weathered soils of peninsular India (supplied by Karmana, Neyyar and Tambraparni rivers). However, presence of a well-defined ‘no-clay zone’ on the shelf, confirm a cross-shelf sediment movement to the deeper slope areas (ToT). Their study also showed high contents of illite and chlorite (clay minerals which are not abundant in the soils and estuarine sediments of this region) in the slope region (ToT). This indicates to the possibility of sediment contribution from the Bay of Bengal waters, which enter this region during winter monsoon.

6.7 BENTHIC FAUNA

Ecosystem functioning involves several processes, which can be summarized as production, consumption, and transfer to higher trophic levels, decomposition, and nutrient regeneration (Danovaro *et al.* 2008). The present section examines properties of the faunal communities as it reflects and impacts the fate of organic carbon inputs in the SEAS continental margins. Heterogeneity in macrobenthic communities in relation to environmental and geomorphological settings of the continental margin of SEAS was well studied up to 1000 m depth. The studies reveal a decreasing trend in standing crop and diversity of macrobenthos with increasing depth in the SEAS shelf (Joydas and Damodaran 2009; Damodaran 2010). Beyond the shelf break (~200 m) the standing stock showed decreasing trend towards deep, while diversity (and evenness), particularly of polychaetes, increased (Abdul Jaleel *et al.* 2014).

The macrofaunal standing stock and diversity in the SEAS shelf are strongly influenced by the seasonal hypoxia occurring over the shelf (Abdul Jaleel *et al.* 2015) as well as the perennial OMZ impinging on the slope (Ingole *et al.* 2010, Abdul Jaleel *et al.* 2014), which result in decreased richness and high dominance of opportunistic species. Thus, along the SEAS continental margin, the variations in sediment texture and dissolved oxygen of bottom water acting in combination is believed to play a key role in structuring the macrobenthic polychaete communities (Abdul Jaleel *et al.* 2014).

Though summer monsoon is the major fishing season along SEAS, disappearance of demersal fishes from the shelf regions due to hypoxia have also been reported (Banse 1959; Joseph *et al.* 1976; Oommen 1985). A compilation of demersal trawl fishery survey reports of MFV *Matsaya Varshini* during 2005-2013 (Figure 6.9), also showed a marked decrease in demersal fish catch during the summer monsoon season in the 30-500m depth region of SEAS which supports the findings of Banse (1959). While during winter monsoon a distinct revival in demersal fish catch was evident, especially more pronounced in the deeper waters (200-500 m).

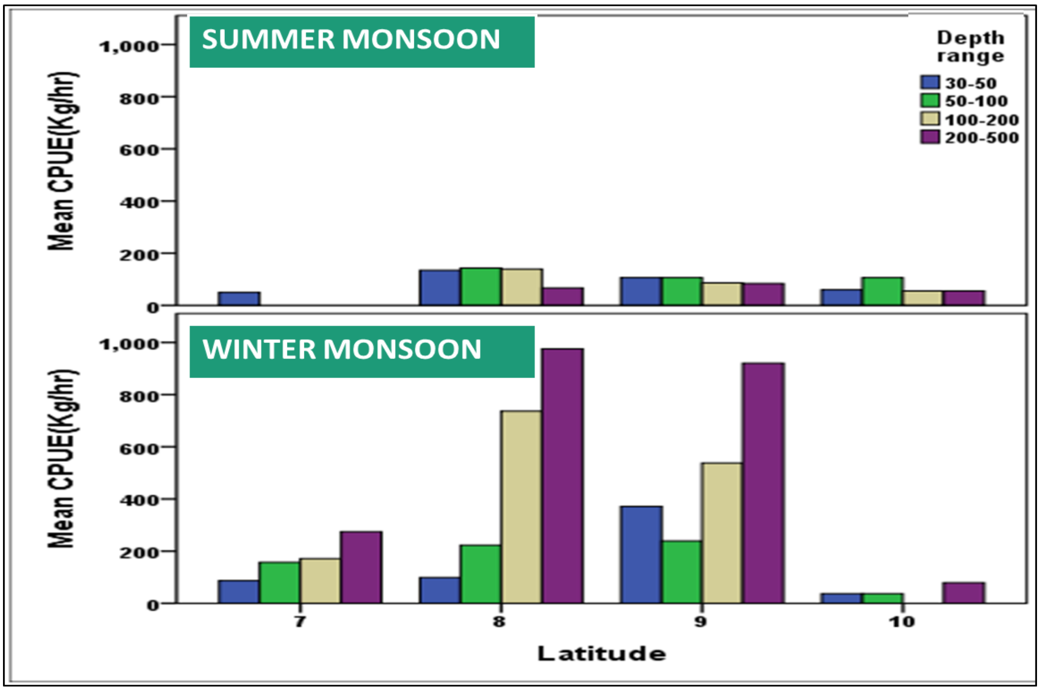


Figure 6.9. Spatio-temporal variations of mean demersal fish catch of MFV *Matsya Varshini* of Fishery Survey of India (Data source: survey reports of MFV *Matsya Varshini* 2005-2013)

The Arabian Sea harbors an oxygen minimum zone (OMZ) at a depth between ~ 150 and 1000 m, below its highly productive surface waters, where the average annual flux of organic matter to the seabed is high (Wyrtki 1973, Helly and Levin 2004). The ecological effects of OMZ on benthic fauna are complex, affecting the faunal diversity, growth and metabolism, standing stock, or can even produce large area of ‘dead zones’ (Diaz and Rosenberg 1995; Levin 2003). The mobile benthic megafauna exhibit avoidance from the core regions of OMZ, with peaks in their abundance and diversity observed along the boundaries of OMZ in the Arabian Sea (Smallwood *et al.* 1999; Murty *et al.* 2009; Hunter *et al.* 2011). An 'edge-effect,' at the boundaries of an OMZ where food rich conditions are exploited by high densities of hypoxia tolerant megafauna is widely reported (Levin 2003). However, the bathyal ToT is located well outside of the realm of influence of the Arabian Sea OMZ, with high dissolved oxygen in the bottom waters year-round. Thus, ToT is a suitable deep-sea habitat, where many megafauna can take refuge.

Survey reports of RV *Varuna* (Silas 1969) revealed an increase in demersal fish catch towards deeper waters up to 500 m, especially off Quilon and Trivandrum. The trend in increase of mean demersal fish biomass towards the deeper regions of SEAS was visible in later surveys also (E.g. Sudarsan *et al.*1988; Somvanshi *et al.* 2009) (Figure 6.10). The decrease in fish catch reported between 500-1100 m depth (Somvanshi *et al.* 2009) could be an artifact of inadequate samplings in that particular depth stratum during their survey. The present study (Figure 6.11) of this depth stratum gives clear indication of its increasing trend towards the deeper depths of SEAS, with the ToT representing a core region of abundance.

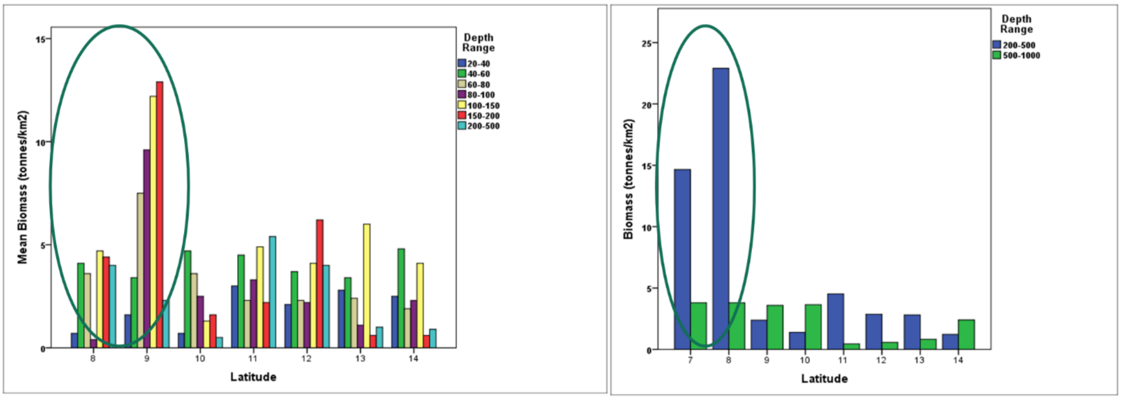


Figure 6.10. Bathymetric and spatial variations in demersal fish biomass in SEAS. (Data Source: Sudarsan *et al.* 1988; Somvanshi *et al.* 2009)

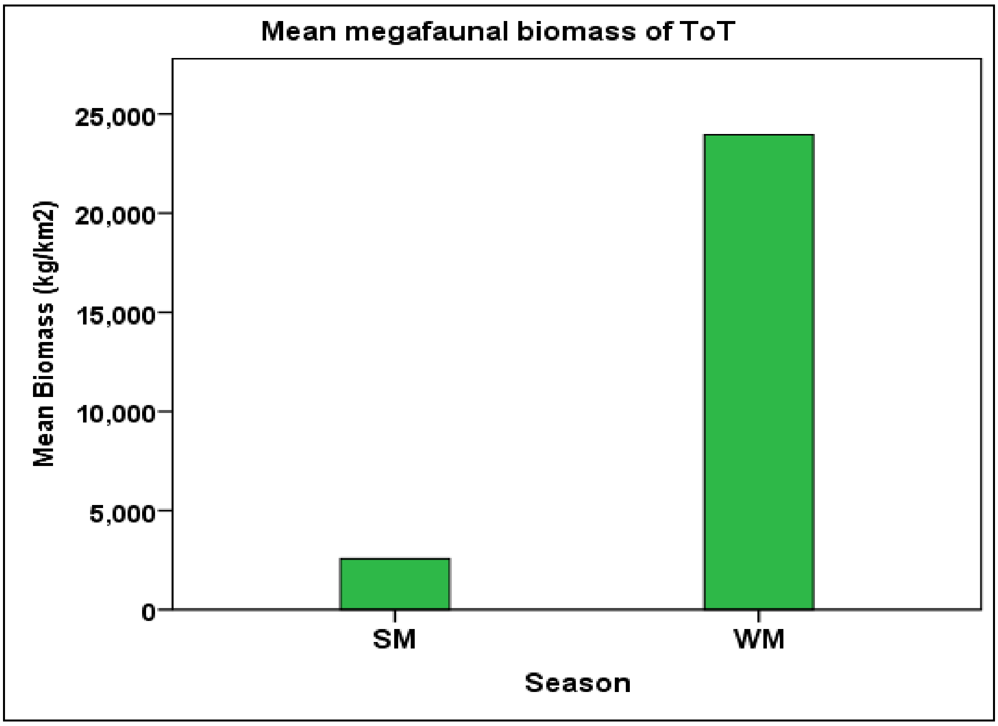


Figure 6.11 Average megafaunal biomass (kg/km^2) of ToT during summer monsoon (SM) and Winter monsoon (WM) seasons.

Significant increase in megafaunal standing stock during WM in the ToT, was due to a marked increase in organic deposit feeders (here, the primary consumers), suggesting that faunal production trends at this depth is mediated by a heavy influx of organic deposits. The marked increase in megafaunal standing stock was synchronized with the downwelling anticyclonic eddy (LH) prevailing during the WM but not with the peak in surface primary productivity, which occurs during SM. The anticyclonic downwelling eddy (LH) may be pumping a huge proportion of the unused organic matter produced during the SM to the depths of ToT. Increased load of terrigenous debris in ToT and disappearance of finer fraction of sediment in the highly productive shelf region of SEAS also supports the hypothesis of cross shelf movement of sediments and deposition to the bathyal areas of ToT. The seasonal changes in the surface primary production and prevailing hydrodynamic conditions of the water column in the SEAS have a combined influence on the export flux of POC and DOC into the deep-sea, thereby fueling megafaunal communities living in association with the sea-floor of the ToT.

The Canonical Correspondence Analysis (CCA) was carried out to elucidate the influence of environmental factors on the distribution of selected megafaunal species (Figure 6.12). A total of 23 megafaunal species were selected based on SIMPER result (Chapter 4, Table 4.9) which cumulatively contributes 50% dissimilarity between depth zones. The CCA axis 1 (Eigen value 0.009) explained the 100% variability in the data. Depth and depth related factors (Temperature, Salinity and Dissolved Oxygen) explains the variability of CCA axis. As discussed earlier, the above parameters do not show much spatial or temporal variations along isobaths above 750 m. CCA plot clearly indicates that species assemblage in ToT are controlled more by depth related factors than seasonal changes (elucidated in Chapter 4). Species assemblage in the lower right quadrant of CCA plot (dominated by *Aristaeopsis edwardsiana, Benthobatis moresbyi, Bathyuroconger vicinus, Coryphaenoides macrolophus, Hoplostethus melanopus, Roulena squamilatera)* occupy shallow depth with relatively higher temperature, high salinity and low dissolved oxygen. Species assemblage in the upper left quadrant of CCA plot (dominated by *Alepocephalus longiceps, Coryphaenoides hextii, Dicrolene introniger*, *Roulena guentheri)* occupy the deep waters having relatively low temperature, low salinity and higher dissolved oxygen values. Rest of the species in the CCA analysis such as (*Alepocephalus blanfordii*, *Coryphaenoides woodmasoni*, *Lamprogrammus niger*, *Pseudaristeus crassipes*, *Caryophyllia communis* etc.) occupy intermediate depth levels.

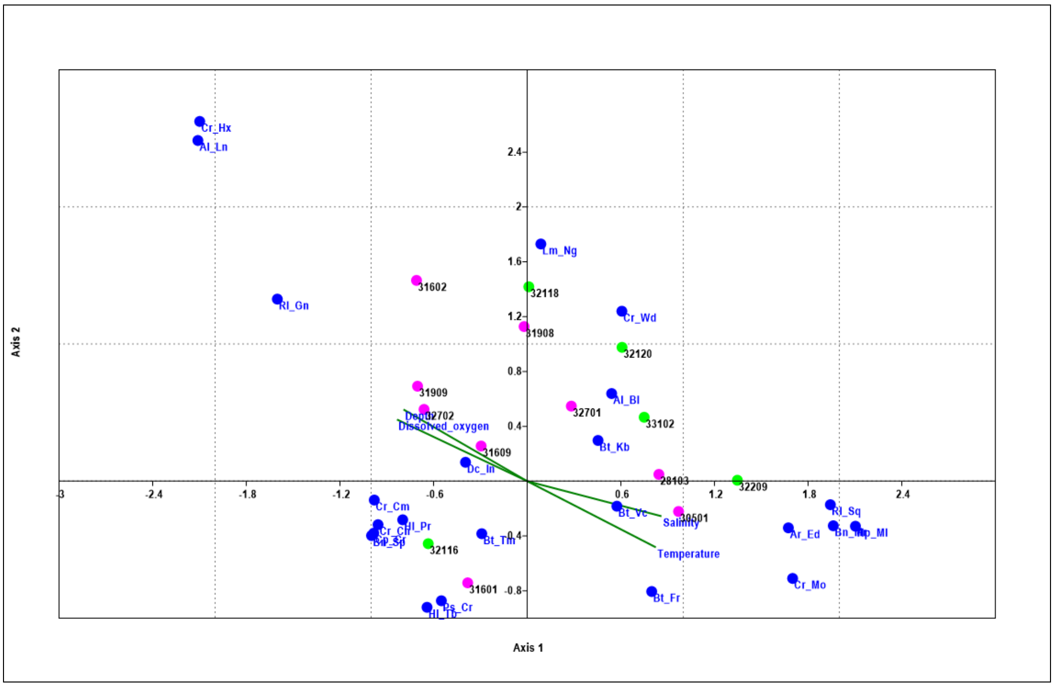


Figure 6.12 Canonical Correspondence Analysis (CCA) plot showing scatter plot of 23 selected species in the study area with respect to its environmental variables.
Abbreviations:- Al Bl: *Alepocephalus blanfordii*, Al Ln: *Alepocephalus longiceps*, Ar Ed: *Aristaeopsis edwardsiana*, Bn Mr: *Benthobatis moresbyi*, Bn Sp: *Benthodytes* sp, Bt Fr: *Bathygadus furvescens*, Bt Kb: *Bathynomus keablei*, Bt Tm: *Bathytroctes squamosus*, Bt Vc: *Bathyuroconger vicinus*, Cp Cr: *Cephea coerulea*, Cr Cm: *Caryophyllia communis*, Cr Cn: *Ceramaster cuenoti*, Cr Hx: *Coryphaenoides hextii*, Cr Mo: *Coryphaenoides macrolophus*, Cr Wd: *Coryphaenoides woodmasoni*, Dc In: *Dicrolene introniger*, Hl Pr: *Halosaurus parvipennis*, Hl Tb: *Haliporus taprobanensis*, Hp Ml: *Hoplostethus melanopus*, Lm Ng: *Lamprogrammus niger*, Ps Cr: *Pseudaristeus crassipes*, Rl Gn: *Rouleina guentheri*, Rl Sq: *Rouleina squamilatera.*

Biodiversity is often referred to as ‘the health of an ecosystem’. Studies on megafaunal diversity along the SEAS (Silas 1969; Somvanshi *et al.* 2009; Venu 2009; Hashim 2012; Venu 2013) demarcated the deep-sea regions as highly diverse, relative to the shallow areas and nearby localities. The present observation on the megafaunal biodiversity of ToT indicate that the taxonomic richness and diversity indices of SEAS reach their peak at the bathyal depths. The biodiversity of ToT is indicative of the efficiency of the ecosystem, in terms of the ability of the assemblages to exploit the available energy, and thereby maximize production.

A heavy load of organic carbon transported to the deep-sea floor of ToT is recycled within the BBL, through a highly diverse and efficient trophic network by the megafauna. The functionally diverse megafaunal communities within the ToT play a crucial role in the cycling of organic matter. The megafauna depend on a specific resources found at different habitats associated with the seafloor, which enables effective resource partitioning, with minimal conflicts. The distinct morphological and behavioral adaptations of the megafauna within a functional group enable them co-exist by minimizing the competition for food. It is also observed that depth related changes in the species composition do not alter the functional diversity of the region.

Additionally a unique and diverse array of gigantic megafauna were found to inhabit ToT emphasizing that ecological features of this habitat play a crucial role in shaping the diversity and evolution of megafaunal species assemblage of the region. Present results suggest that the conservation measures of ToT will be crucial for the sustainability of the functions of the southeastern Arabian Sea ecosystem. The ecological and biological importance of the deep-sea has often underrepresented in the discussions of the biodiversity and ecosystem functioning of the region. The ongoing international efforts by the Convention on Biological Diversity (CBD) have been serving as a forum for the development of initial criteria to define important and sensitive areas in the deep-seas (Ardron *et al.* 2009).

6.8 ToT: AN ECOLOGICALLY OR BIOLOGICALLY SENSITIVE AREA (EBSA) OF SEAS?

As per the definition adopted by the Convention on Biodiversity (CBD), Ecologically and Biologically Significant Areas (EBSAs) are “geographically or oceanographically discrete areas that provide important services to one or more species/ populations of an ecosystem or to the ecosystem as a whole, compared to other surrounding areas of similar ecological characteristics, or otherwise meet the criteria identified by the Conference of Parties (COP) to CBD”. The COP to CBD have adopted various criteria for identifying EBSAs in need of protection and the scientific guidelines for designing representative networks of Marine Protected Areas (MPAs). Accordingly the CBD passed a resolution that “ the application of the scientific criteria and guidance, based on best available scientific information and applying the precautionary approach and the ecosystem approach, can enable Parties, other Governments and relevant organizations to help halt the rapid loss of marine biodiversity.

The CBD criteria for deep-sea EBSA are based on seven general areas of consideration: 1) Uniqueness or rarity 2) Special importance for the life history of species 3) Importance for threatened, endangered or declining species and or habitats 4) Vulnerability, fragility, sensitivity, slow recovery 5) Biological productivity 6) Biological diversity and 7) Naturalness (Annex 1 of CBD Decision ix/ 20). This section evaluates the ToT megafauna and the ToT ecosystem on the basis of these criteria.

1. **Uniqueness or Rarity:** are areas containing either (i) unique, rare or endemic species, populations or community, and/or (ii) unique, rare or distinct habitats or ecosystems, and/or (iii) unique or unusual geomorphological or oceanographic factors.

   As explained in the previous chapters, the ToT contains unique and rare endemic species of the Northeastern Indian Ocean with a unique and diverse array of gigantic representatives of various taxa. Due to its extraordinary high megafaunal diversity and unusual standing stock as compared to similar deep sea habitats world over the ToT qualifies to be treated as a unique and distinct deep sea ecosystem. Further, the ToT is a unique deep-sea bathyal habitat outside the realm of Arabian Sea OMZ with unique combinations of oceanographical process that funnel organic carbon to the deep waters to fuel the faunal dynamics within the region.

2. **Habitat of special importance for the life history of species:** Areas those are required for a population to survive and thrive. Area containing habitat for the survival and recovery of endangered, threatened, declining species or areas with significant assemblages of such species.

   Abundance of solitary corals such as *Caryophyllia ambrosia*, *C. paradoxus* in the deep-sea beds justify ToT as a special habit for their survival and growth. Ample food supply in the form phytodetritus to the deep habitats of ToT help in the growth and survival of larval forms many megafaunal species. Mass aggregation in this habitat can favor mate selection. ToT as an outside boundary of Arabian Sea OMZ, provide refuge for many mobile megafauna that are displaced from adjacent areas due to bottom suboxia.

3. **Importance for threatened, endangered or declining species and or habitats** ToT is still a pristine area, not subjected to human exploitation. Nevertheless, the present study has identified *Lamprogrammus niger* as a key-stone species in the food-web dynamics of ToT. Since the food web of the area is dominated by this species, any type of resource exploitation should be carried out with utmost caution. Observations from the present study on the accumulation of marine debris along the ToT seabed and its potential to degrade the habitat needs serious consideration. The debris deposit on ToT are suggestive that pollution due to

anthropogenic activities are reaching these habitats in no time which indicate the vulnerability of this habitat.

4. **Vulnerability, fragility, sensitivity, slow recovery:** Areas that contain a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.

   This EBSA criterion is focused on the inherent sensitivity of species, or habitats, to disruption. The present study has not analyzed the fragility and recovery time of species or ecosystem features themselves in the face of perturbations. Though the biodiversity and ecological linkages of ToT are formed as a result of long time of geological evolution. Many of the deep-sea species such as sharks and roughies are known for their long life span and are extremely vulnerable to fishing. Likewise, the ToT harbors rich resources of Chimeras, which are sought after for extraction of Liver oil and therefore the chimeras of ToT are to be treated as a fragile group.

5. **Biological productivity:** Areas containing species, populations or communities with comparatively higher natural biological productivity. Such areas play an important role in fuelling ecosystems and increasing the growth rates of organisms and their capacity for reproduction.

   A comparison with the global datasets on megafaunal standing stock (Rex *et al.* 2006) clearly indicates ToT as a highly productive deep-sea habitat of the world. Its standing stock far exceeds that of similar habitats elsewhere and is comparable to the most productive shallow waters. A comparison with adjacent shallow counter parts of SEAS (Wadge Bank and Quilon Bank) indicate high megafaunal standing stocks in the bathyal depths of ToT. Seasonality strongly influence the megafaunal standing stock ToT, reaching peak levels during winter monsoon season. This is attributed to the downwelling anticyclonic warm core eddy

(Lakshadweep High) which siphons Particulate Organic Matter from the euphotic zone to the deep depths of ToT, thereby fuelling the high biological productivity in the bottom waters of ToT.

6. **Biological diversity:** Areas containing comparatively higher density of ecosystems, habitats, communities or species or higher genetic diversity. Important for evolution and maintaining the resilience of marine species and ecosystems.

   ToT is highly diverse in terms of its species richness holding 148 megafaunal species of diverse taxa. Quantitative measures of diversity such as ES50, Shannon Weiner index, Pielou's evenness index showed high extremities. Comparison of the ES50 of ToT with that of the 'megafaunal peak diversity zone' of western North Atlantic indicates that the ToT is a much more diverse deep-sea habitat. The highly diverse megafauna of ToT play a key role in effective resource partitioning and efficient carbon cycling within SEAS.

7. **Naturalness:** Areas with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation. It is important to maintain these areas as reference sites.

   As there are no or least human interventions or disturbances in the ToT, the area qualifies this criteria of CBD.

Based on the above evaluation the ToT fully meets the EBSA criteria on Uniqueness and Rarity (Criteria-1), Habitat of special importance for the life history of species (Criteria-2), Vulnerability, fragility, sensitivity, slow recovery criteria (Criteria-4), Biological productivity (Criteria-5), Biological diversity (Criteria-6) and Naturalness (Criteria-7) and partially meets the criteria on Importance for threatened, endangered or declining species and or habitats (Criteria-3). In view of this it is recommended that the Terrace of Trivandrum be declared an Ecologically and Biologically Sensitive Area and to maintain it as a Reference Site.

Chapter - 7

SUMMARY AND CONCLUSION

- Megafaunal diversity of a hitherto uncharted deep-sea habitat “the Terrace of Trivandrum” located off the southern tip of SEAS is described on the basis of extensive surveys undertaken on board FORV *Sagar Sampada* focusing on 14 selected stations within the 900 to 1500 isobaths.
- Exceptional megafaunal diversity, represented by 148 species belonging to 122 genera in 86 families, under 5 phyla, was recorded from the bathyal depths of ToT. The megafaunal diversity of ToT is unique in terms of the high abundance and diversity of sparsely recorded deep-sea endemic species from Indian Ocean such as *Fenestraja mamillidens*, *Coryphaenoides woodmasoni*, *Harpadon squamosus*, *Nezumia brevirostris*, *Dicrolene vaillanti*, *Holcomycteronus pterotus*, *Monomitopus conjugator, Cnemidaster zea, Zoroaster alfredi* etc. The present survey is the first attempt to record, document and archive specimen of these rare and important species after the RIMS *Investigator* surveys conducted over 100 years ago.
- The present survey also adds to the inventory on biodiversity of the SEAS, with 10 new records on *Colossendeis colossea*, *Bathytyphlops marionae, Bufoceratias shaoi, Diceratias trilobus, Mastigopterus imperator, Alepocephalus longiceps, Aphanopus microphthalmus, Deepstaria enigmatica, Apristurus breviventralis* and *Rhinochimaera africana* etc. One species of deep-sea anglerfish (Order Lophiiformes) in the genus *Chaunax* is expected (unpublished) to be a new species discovery.
- Rediscovery of the Gadiform fish *Corphaenoides hextii* after 100 years of its report by Alcock. The species is known only from two specimen records world over. Since the original type material of Alcock housed in the ZSI, Calcutta is reported missing, the voucher specimen (CMLRE 3160108) collected in the present study is the second available type material of the species world over.

- Results from the present study show that the megafauna of ToT is best represented by 4 classes, the Actinopterigii (45%), Malacostraca (20%), Asteroidea (7%) and Elasmobranchii (7%).
- Present study recorded a 10 to 150 fold increase in the abundance of gigantic forms within the ToT compared with similar habitats in the Indian EEZ, which implies that ToT is a core area of abundance for many gigantic deep-sea megafaunal species. The gigantic species recorded from ToT during the present study include the gigantic pycnogonid *Colossendeis colossea*, gigantic isopod *Bathynomus keablei*, deep-sea lobster *Acanthacaris tenuimana*, deep-sea holothurian *Perizona magna*, deep-sea asteroid *Zoroaster alfredi*, Giant squid *Archituethis* cf. *dux*, gigantic chimaera *Rhinochimaera africana*, gigantic skate *Dipturus johannisdavisi*, cusk-eel *Lamprogrammus brunswigi* and the morid cod *Lepidion inosimae*.
- All of these species are gigantic representatives within their respective higher taxa. For instance, *Colossendeis colossea* the largest member of the class Pycnogonida, *Lepidion inosimae* the largest species of cod of the family Moridae and *Lamprogrammus brunswigi* is the largest species within the genus. Many species found inhabiting the ToT are gigantic relatives to their congeners.
- The present study in the bathyal depths of the ToT documented exceptionally high species richness and diversity of deep-sea mega fauna. Biodiversity estimates for the ToT are much higher than world averages including one of the well-studied, highly productive and diverse deep-sea habitats known to science, located off Cape Hatteras (NE Atlantic). The ES50 index for fish in the ToT average 13.6 against the 7.6 for NE Atlantic and for invertebrates the index is 11 for ToT and 8.2 for NE Atlantic.
- Alpha Diversity indices derived in the present study indicate that majority of the ToT species (40 Nos.) are single site observations, whereas two species were

found in 13 stations out of the 14 stations sampled. Only one species *Alepocephalus blanfordii* was ubiquitously present in all the 14 stations.

- Heterogeneity diversity indices varied. Variations observed were (i) Diversity index (H’) varying between 1.6 and 3.4 (ii) Margalef index of species richness (d) varying between 2.1 and 6.2 (iii) Pielou evenness index (J’) varying between 0.41 and 0.92 (iv) Taxonomic distinctiveness (Delta+) varying between 36.8 and 82.5 and (v) total phylogenetic variability (sPhi+) varing between 1052 and 2281.
- Cumulative Dominance Curve for 4 stations out of the 14 stations sampled start very high in the Y-axis indicating that a single species contributed to 60% of numerical abundance and that the cumulative dominance of two species of shrimps, *Pseudaristeus crassipes* and *Haliporus taprobanensis* to the total numerical abundance makes low evenness to these stations. In the remaining 10 stations cumulative dominance curve starts well below 30% indicating high evenness and diversity.
- The bathyal depths ToT was marked by peak megafaunal diversity in the SEAS, relative to shallower areas (< 950 m). Bathymetric variations were observed in the diversity and species composition within the ToT. Though the megafaunal species composition of ToT change gradually as a function of depth, at a depth of 1,150 m species replacement rate change significantly, which act as be arbitrary boundary, dividing the study area into two significantly differing depth zones viz. shallow 950-1,150 m and deep 1,150-1,450 m.Cluster Analysis clearly indicate that these zones are statistically distinct in faunal assembly at 60% dissimilarity (MDS) between them.
- Results from ANOSIM routine reveal significant variations in species composition of ToT for the SM & WM seasons, the average dissimilarity being 74%. Among the 148 species, 41 species were recorded only during SM and 26 species during WM which indicates considerable species replacement or

migration between seasons. The reason for this high species abundance in ToT during the SM season may perhaps be due to the immigration of species from adjacent areas where bottom waters are suboxic (DO<0.2 ml/L)during SM and Fall Inter-monsoon Seasons. Species that are less tolerant to such low levels of DO may take refuge in the TOT, where the bottom DO levels range between 0.8 to 1.2 ml/L.

- Contrary to the megafaunal species composition, a marked, 10 fold increase in standing stock was noted during the winter monsoon (WM), compared to the summer monsoon (SM). The standing stock values during the WM were exceptionally high in comparison to isobathic regions elsewhere. Analysis of the functional 'trophic guilds' of the ToT megafauna revealed that the remarkable increase in standing stock during the WM was a result of many fold increase in standing stock of the primary consumers, i. e. forms that directly consume organic deposit from the sea bottom (such as browsers and grazers). Short lived invertebrates such as shrimps dominate among these, apparently forming the primary consumers of ToT, particularly during WM. The deep-sea cusk eel *Lamprogrammusniger*, which directly grazes on these 'primary consumers', also showed significantly higher standing stock during WM. This was the only species representing this functional guild (Micronekton grazers), and was the single dominant species (representing 45% biomass), indicating its irreplaceability and keystone position in the ToT.
- Analysis of the trophic organization of ToT megafauna as a whole, revealed that the organic matter reaching the seafloor was efficiently utilized by a functionally diverse array of megafauna. These included divergent morphological and behavioral adaptations, habitat partitioning. Despite the existence of distinct species assemblages in the two depth zones of ToT, their functional (feeding guild) composition was more or less similar. Thus, the ToT megafauna as a

whole, were found to interact, compete or share resources that reach the deep-sea floor through a complex network of trophic linkages.

- In deep-sea habitats, faunal standing stock and functional organization is known to be controlled primarily by the availability of food, in the form of organic matter inputs. The average megafaunal biomass of ToT for summer and winter monsoon seasons (including both shallow and deep zones) were 2,558 kg/ km^2 and 23,992 kg/km^2 during SM and WM respectively. Seasonal shift in standing stock and associated changes in trophic organization suggest that the megafaunal trophic guild dynamics of ToT is closely linked to the seasonally varying food supply in the form of organic matter input.
- The peak in standing stock during the WM in the ToT was found to be synchronized with the high POM in the surface waters and the downwelling anti-cyclonic eddy/ies (Lakshadweep High) occurring in the southern part of the south eastern Arabian Sea during this season. These warm-core eddies may help siphon the POM from surface waters of ToT to its deep depths.
- The present study reveals the occurrence of a rich and diverse assemblage of megafauna in the ToT, with distinctive biological attributes. The ecological values of this deep-sea area to the overall functioning of the ecosystem in the SEAS is presently underestimated, especially in terms of biogeochemical processes. The region also support exceptionally high non-conventional fishery resources, that makes this region highly vulnerable to exploitation in the near future. An evaluation of the ToT against the seven point criteria adopted by CBD for delineation of Ecologically and Biologically Sensitive Areas show that the ToT fully complies with six of these criteria’s and partially meets the requirement of one criteria. Therefore the ToT qualifies to be treated as an EBSA and to be maintained as a future reference site.

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