ECHINODERMS OF THE SOUTH EASTERN ARABIAN SEA: SYSTEMATICS & ECOLOGY

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Echinoderms of the south eastern Arabian Sea:
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Ph. D. Thesis in Marine Biology

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Front Cover

Brittle star *Ophiothrix (Acanthophiothrix) purpurea*, collected onboard FORV *Sagar Sampada* from the study area.

CERTIFICATE

This is to certify that the thesis entitled "**Echinoderms of the south eastern Arabian Sea: Systematics & Ecology**" is an authentic record of the research work carried out by Ms. Usha V. Parameswaran (Reg. No.: 4423), 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 "**Echinoderms of the south eastern Arabian Sea: Systematics & Ecology**" 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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Usha

For my father

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LIST OF ACRONYMS & ABBREVIATIONS

ANOVA	Analysis of Variance
ASHSW	Arabian Sea High Saline Water
CMLRE	Centre for Marine Living Resources and Ecology
CTD	Conductivity, Temperature, Depth Profiler
DO	Dissolved Oxygen
EAS	Eastern Arabian Sea
EEZ	Exclusive Economic Zone
FIM	Fall Inter Monsoon
FORVSS	Fishery & Oceanographic Research Vessel *Sagar Sampada*
HSDT	High Speed Demersal Trawl
MANOVA	Multivariate Analysis of Variance
MdZ	Median grain size
NEAS	North Eastern Arabian Sea
OM	Organic Matter
OMZ	Oxygen Minimum Zone
PCA	Principle Component Analysis
PERMANOVA	Permutational Multivariate Analysis of Variance
PRIMER	Plymouth Routines in Multivariate Ecological Research
RIMS	Royal Indian Marine Survey
SEAS	South Eastern Arabian Sea
SIM	Spring Inter Monsoon
SM	Summer Monsoon
SPSS	Statistical Package for the Social Sciences
SST	Sea Surface Temperature
WM	Winter Monsoon
WoRMS	World Register of Marine Species

CHAPTER 1

Introduction

1.1 General Introduction

Echinoderms, such as starfish, brittle stars, sea urchins, sea cucumbers and sea lilies represent a distinct phylum (Phylum Echinodermata) of exclusively marine invertebrates. Most echinoderms have an exoskeleton made of calcite, a dorsoventrally compressed body and have a more or less conspicuous pentamerous radial symmetry. Though adult echinoderms exhibit radial symmetry, their larval forms are bilaterally symmetric, which suggests that echinoderms have evolved from a bilaterally symmetric ancestor. Members of this phylum possess a unique water vascular system of coelomic origin, which supports biological functions such as feeding, locomotion, circulation and respiration. Unlike most coelomate invertebrates which are protostomes (i.e. forms with mouth originating from the embryonic blastopore), members of phylum Echinodermata are deuterostomes (the blastopore forms the anus, and mouth develop from a second opening on the dorsal end of the blastula), which establishes their embryological affinity to Chordates. Echinoderms, owing to their relatively large size among the sea-floor fauna (benthos) and their diverse feeding habits, are important members of marine food webs. Being epifauna (fauna living primarily on the surface of sediments), movement and feeding activities of echinoderms results in mixing, reworking and oxygenation of sediments. This process, known as bioturbation, is of great importance in the remineralization of organic detritus in seafloor sediments by microorganisms. Many echinoderms, especially the holothurians, are detritivores and consume large quantities of organic matter (OM) from marine sediments, and largely prevent development of suboxic or anoxic conditions within the sediments of the seafloor. These distinct features makes the echinoderms, an important group both from an ecological and evolutionary perspective.

The ~7,200 extant species of this phylum fall into five distinct classes: the Crinoidea (sea lilies and feather stars), the Asteroidea (starfishes), the Ophiuroidea (brittle stars, serpent stars and basket stars), the Echinoidea (sea urchins, sand dollars and heart urchins) and the Holothuroidea (sea cucumbers). Representatives of the five classes are found at all ocean depths, from the intertidal zones to deep sea trenches, contributing significantly to the biological diversity of the sea-floor.

Echinoderms are highly vulnerable to natural as well as anthropogenic disturbances such as oxygen depletion, climate variability, bottom trawling and other exploitative activities. The sea cucumbers (holothurians) are the raw materials for producing beche-de-mer, a delicacy in many parts of the world. Over 60 species of holothurians are commercially exploited across the world (Purcell 2010), and 172 species are under the threat of extinction (IUCN Red List) from overexploitation/habitat disturbances. Many species of echinoderms, particularly amongst the sea urchins and brittle stars have appealing ornamentation and brilliant colour patterns and are widely exploited for use in marine aquaria. Echinoderms, along with other invertebrates (corals, sponges etc.) also form major by-catch in bottom trawls (Anderson & Clark 2003). Bio-prospecting of echinoderms for novel bioactive molecules is an emerging threat to echinoderm biodiversity, especially in the Southern Ocean. Climate variability and the increasing spread of hypoxic conditions in near bottom waters also poses serious threats to echinoderms, as they are known to be highly susceptible to oxygen depleted conditions (Gray 1997). Many countries have adopted conservation measures for protection of echinoderms including ban on the trade of holothurian meat (Purcell *et al.* 2012). In India, all species of holothurians are placed under Schedule 1 of Wildlife (Protection) Act, 1972.

Taking these aspects into consideration, much work is being carried out around the world to document the systematics, diversity, distribution and ecology of echinoderms. Despite the fact that over 765 species of echinoderms are known to occur in the Indian EEZ (Goyal & Arora 2009, Wafer *et al.* 2011, Sanjeevan *et al.* 2014, Venkataraman *et al.* 2015), forming a significant portion of the 1300 extant echinoderm species of the Indo-Pacific region, not much research focus has been placed on the echinoderms of this region in recent decades. In the Indian waters, studies on echinoderm diversity are mostly restricted to the shallow inshore waters, up to ~30m depth. For the continental shelves beyond this depth, detailed information on species composition, abundance and diversity of this group are lacking.

The South Eastern Arabian Sea (SEAS), off the south-west coast of India constitutes a distinct ecosystem, with its unique physical, chemical, geological and biological attributes (Madhupratap *et al.* 2001, Sanjeevan *et al.* 2009, Jyotibabu *et al.* 2010). Though the benthos in the continental margin of this region are well studied, quantitative information on the standing stock, species diversity, distribution and abundance are restricted to the infauna with focus on polychaetes and nematodes (Jayaraj *et al.* 2008, Joydas & Damodaran 2009). However, the epifauna are poorly studied, and there is no comprehensive information on the species composition, diversity and distribution of the echinoderms in the SEAS.

The present study aims to provide a baseline information on the diversity and distribution of echinoderms in the SEAS and explain the factors that influence their spatio-temporal variations. A comprehensive baseline data on echinoderms of SEAS is a critical requirement to assess impacts of natural and anthropogenic disturbances on this ecologically important group.

1.2 The Echinoderms

1.2.1 Phylum Echinodermata: definition

Echinodermata is a phylum of enterocoelous coelomates having a pentaradiate body plan, derived from an original bilateral symmetry, without a definite head or brain, with a calcareous endoskeleton of separate plates or pieces, often bearing external spines or protuberances, and with a water vascular system of coelomic origin that sends numerous small projections or podia to the exterior and communicates with the external medium by a pore or cluster of pores, at least in juvenile stages (Hyman 1955).

The word Echinodermata is derived from the Greek words *Echino* meaning ‘spiny’ and *derma*, meaning ‘skin’. The name of the phylum is attributed to Klein (1734), who originally coined the term to refer to sea urchins. Although the aforementioned characteristics are encountered in all members, the overall body plan differs greatly amongst the five classes of echinoderms.

1.2.2 General characteristics

The echinoderms are readily recognised by their distinct radial symmetry, which is nearly always pentamerous and by the absence of a definitive ‘anterior’ or ‘head’ portion. Echinoderms can be easily differentiated from other radially symmetric phyla (Coelenterata and Ctenophora), by the presence of a hollow internal cavity or coelom, and their generally higher grade of organization. Almost all echinoderms are motile, though they are known to have evolved from sessile ancestors. They generally range in size from small forms (~ 1 cm) to very large organisms (Ruppert *et al.* 2004).

The body contour of echinoderms may be simple and often rounded, or star-like in shape, with arms (numbering five or multiples thereof) radiating from a central disc, or they may have branched feather-like arms arising from a central body (Hyman 1955, Ruppert *et al.* 2004). The body surface is rarely smooth, and typically is covered with calcareous projections, that vary from small bumps and bosses to long spines. Most echinoderms have a dosro-ventrally compressed body, differentiated into an oral and aboral surface with calcareous structures present in all classes except the sea cucumbers (class Holothuroidea). In sea cucumbers, the body is elongated along the oral-aboral axis, and additionally the calcareous structures are reduced to microscopic spicules embedded in soft skin. The starfish (class Asteroidea), brittle stars (class Ophiuroidea) and sea urchins (class Echinoidea) creep with their oral surface applied to the substrate, the sea cucumbers lie upon one side of the body and members of class Crinoidea (sea lilies and feather stars) keep their aboral surface against the substrate and oral surface directed upwards.

The body wall of echinoderms is made of an outer epidermis, a middle dermis, and an inner layer of coelomic epithelium called the peritoneum. The calcareous skeleton of echinoderms are produced and contained within the middle dermis layer. This endoskeleton can be of various forms – it may consist of closely fitted plates forming a shell known as a test or theca, or it may be composed of small isolated pieces known as ossicles, or may be present only as microscopic spicules strewn within the dermis. The externally projecting spines and tubercles are also of dermal origin, and are covered over by the epidermis. Beneath the dermis, musculature of the body wall may be present with varying degrees of development (Hyman 1955, Pechenik 2014). The most unique and distinctive character of echinoderms is the water vascular system, which is essentially a hydraulic system of fluid-filled tubes, present along the ambulacra, from the mouth to their tips (Figure 1.1). A ring canal which encircles the oesophagus connects to five radial canals, which run along the inner surface of each ambulacrum. A series of podia or tube feet branch out from the radial canals – as hollow external projections used for locomotion, food gathering and sensory mechanisms. At the base of the podia, a sac-like ampulla may be present, which maintains hydraulic pressure. From the ring canal, a stone canal connects the water vascular system to the exterior, via a single opening, known as the hydropore. In the classes Asteroidea, Ophiuroidea and Echinoidea, the stone canal is usually split up at its outer edge into numerous channels, which pass through a specialized dermal plate known as the madreporite. In the Holothuroidea and Crinoidea, the stone canal opens freely into the coelom, and the hydropore is absent in adults (Hyman 1955, Ruppert *et al.* 2004).

A 'true' coelom is present in Echinoderms. A coelom is defined as a 'space in the ento-mesoderm, separating the body wall - typically composed of epidermal, connective and muscular layers - from the digestive tract composed of digestive epithelium, along with muscular and connective layers'. The coelom is lined on all surfaces by a peritoneum of mesodermal origin, and all internal organs are suspended within the coelom. In higher phyla (Hemichordata and Chordata), the organs are suspended in the coelom by means of a mesentery, but this is lacking in adult echinoderms (Hyman 1955, Ruppert *et al.* 2004, Pechenik 2014).

The interior of the echinoderm body is occupied largely by the digestive and reproductive systems. The digestive tract is usually simple, extending from the mouth on the oral surface to the anus on the aboral surface of the body, and may be more or less coiled or may possess pronounced sac-

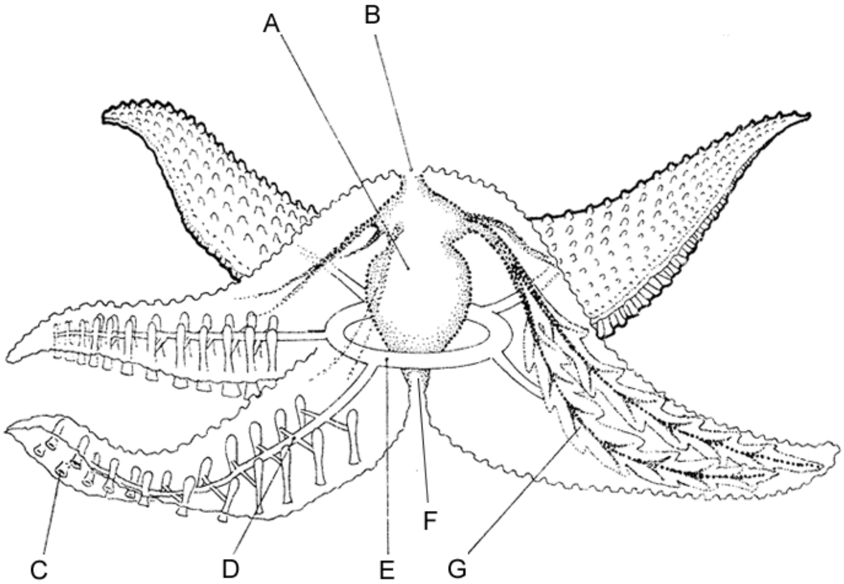

Figure 1.1 General internal anatomy of a starfish (class Asteroidea). A, stomach. B, anus. C, tube feed or podia. D, radial canal. E, ring canal. F, Mouth .G, gastric diverticulum.
[Image source: http://www.biologycorner.com]

like diverticula. The reproductive system of echinoderms is of the simplest form, composed of either a single or radially symmetric gonads, located in the inter-radii and opening by a gonopore within the same interradii. The circulatory system is represented by a simple blood lacunar or haemal system, whose channels are not definitive vessels. Respiratory and excretory activities in echinoderms are mediated by the water vascular system, and separate organs for these functions are lacking. The nervous system is primitive, consisting of networks of ganglionated nerve cords, which follow the general radial pattern. Sensory organs are poorly developed in this phylum (Hyman 1955, Ruppert *et al.* 2004, Pechenik 2014). The internal anatomy of an echinoderm, as present in class Asteroidea is illustrated in Figure 1.2.

1.2.3 Evolutionary position

The unique evolutionary position of echinoderms is illustrated by two important features in their embryological development. In invertebrates such as annelids and arthropods, the origin of the adult mouth is traced to the embryonic blastopore, which represents the first embryonic pore to develop during the blastula stage. In other words, the lower invertebrates are protostomes (meaning 'first mouth'). In contrast, the embryonic blastopore of echinoderms, hemichordates and chordates develops into the adult anus, while the mouth in these phyla develops rather from a secondary opening in later stages of embryonic development. These phyla are therefore referred to as the deuterostomes (meaning 'second mouth'). Secondly, the larvae of echinoderms possess bilateral symmetry, which is replaced by the characteristic radial symmetry in adults. This indicates that this group evolved from bilaterally symmetric ancestors (Hyman 1955, Smith 1997, Clarkson 2009), and that its radial symmetry is a derived character.

Echinodermata are the only extant deuterostome phylum other than Hemichordata and Chordata, with a radial symmetry that evolved separately, from bilaterally symmetric ancestors. This makes the echinoderms truly distinct from the remaining invertebrate phyla. The splitting of echinoderms from other deuterostome groups is estimated to have occurred around 570 million years ago, in the Palaeozoic era (Pawson 2007). Detailed analysis of complete mitochondrial genomes and nuclear 18S rRNA gives strong evidence for a hemichordate-echinoderm clade (Bromham & Degnan 1999, Furlong & Holland 2002). Cameron *et al.* (2000) proved the monophyly of each of the deuterostome taxa, the Chordata (Vertebrata and Cephalochordata), Urochordata, Hemichordata and Echinodermata.

1.2.4 Systematics & diversity

The echinoderms are common and conspicuous marine animals that have been reported since ancient times. All invertebrates except insects, were classified into class 'Vermes' by Linnaeus (1758) in his Systema Naturae. Within this class, Linnaeus placed the then recognized echinoderms – Asterias, Echinus and Holothuria – into the group Mollusca, along with several other marine invertebrates such as naked molluscs, polychaetes, coelenterates and ctenophores. Later, the name Echinodermata was revived by Bruguière (1792), when he divided Linnaeus' class Vermes into six orders: Infusoria, Intetina, Mollusca, Echinodermata, Testacea and Zoophyta. This was the first time that echinoderms were recognized as a distinct group from other invertebrates. Bruguière improved the knowledge and understanding of the various groups of echinoderms viz. asteroids, ophiuroids, echinoids etc. Lamarck (1801) carried out much work on the classification of invertebrates, and in 1801 recognized seven classes of invertebrates, amongst which the Radiata included both the echinoderms (asteroids, echinoids and holothurians) and the coelenterates. Though Lamarck asserted that the echinoderms were closely related to coelenterates, he was the first to rightly place the holothurians with the other echinoderms. Cuvier (1817) recognized the higher organization of the echinoderms, but he did not remove them from the class Radiata. The misplaced classification of Lamarck and Cuvier was followed until Frey & Leuckhart (1847) separated the Echinodermata as a group coordinate with other major invertebrates. Their revision was based on the understanding that the grade of structure of the echinoderms was obviously higher than the coelenterates. Since this time, the Echinoderms have been regarded as a separate invertebrate phylum.

The knowledge of echinoderm diversity and higher classification has been growing steadily over the last 160 years, the most comprehensive and authoritative summaries being provided by Ludwig (1889-1907), Bather (1900), Cuénot (1948) and Hyman (1955). Much was added to the knowledge of echinoderm diversity and classification through the collections of various oceanographic expeditions such as the *Galathea* (1845-47), H.M.S. *Challenger* (1872-76), R.I.M.S. *Investigator* (1888-1892), U.S.S. *Albatross* (1888-1907), *Siboga* (1899-1900), *Mabahiss* (1933-34) etc. The echinoderms collected during these cruises were carefully analysed and described (Agassiz 1881, Carpenter

1884, Verrill 1885, Lyman 1879, 1882, Sladen 1889, Théel 1882, de Meijere 1904, Rathburn 1907, Sluiter 1901, A. H. Clark 1918, 1936, Döderlein 1921, Macan 1938, Mortensen 1939, H. L. Clark 1939 etc.). The voluminous monographic works of A. H. Clark (1915-1967, 5 Volumes) and Mortensen (1928-1951, 5 Volumes) which collated knowledge of all known species of Crinoids and Echinoids respectively, remain important to this day.

In the 1950s and '60s the revision of the major invertebrate groups by various authors in Moore's (1953) comprehensive 'Treatise on Invertebrate Paleontology' resulted in an era of great change in the understanding of this phylum. The advent of molecular techniques in recent decades, to supplement morphological taxonomy, has resulted in the upheaval of classification of many higher taxa (families, orders etc.), and numerous important volumes on living (extant) and fossil (extinct) echinoderms have been published by Smith (1988a, b, 2007), Smith *et al.* (1992, 1995), Mooi & Telford (1998), Candia Carnevali & Bonasoro (2001), Barker (2001), Jangoux & Lawrence (2001), Féral & David (2001), Kasyanov (2001), Heinzeller & Nebelsick (2004) and Matranga (2005).

Five classes are universally recognized among the echinoderms: the Crinoidea (sea lilies and feather stars), the Asteroidea (starfishes), the Ophiuroidea (brittle stars, serpent stars and basket stars), the Echinoidea (sea urchins, sand dollars and heart urchins) and the Holothuroidea (sea cucumbers). Based on phylogenetic analysis of fossil evidence, Smith (1988a, b) suggested that divergence of these five modern classes occurred about 450-590 million years ago. In some works, these classes have been grouped into supra-classes, E.g. Asterozoa (Asteroidea & Ophiuroidea), Echinozoa (Echinoidea & Holothuroidea), Crinozoa (fossil and recent Crinoidea), Eleutherozoa (Asteroidea, Ophiuroidea, Echinoidea & Holothuroidea). However, these are used more as informal and convenient terms to collectively refer to forms having similar life habits, body forms etc., rather than being of any taxonomic importance (Pawson 2007). The interrelationship among classes (Figure 1.2) was resolved using phylogenomic analysis by Telford *et al.* (2014).

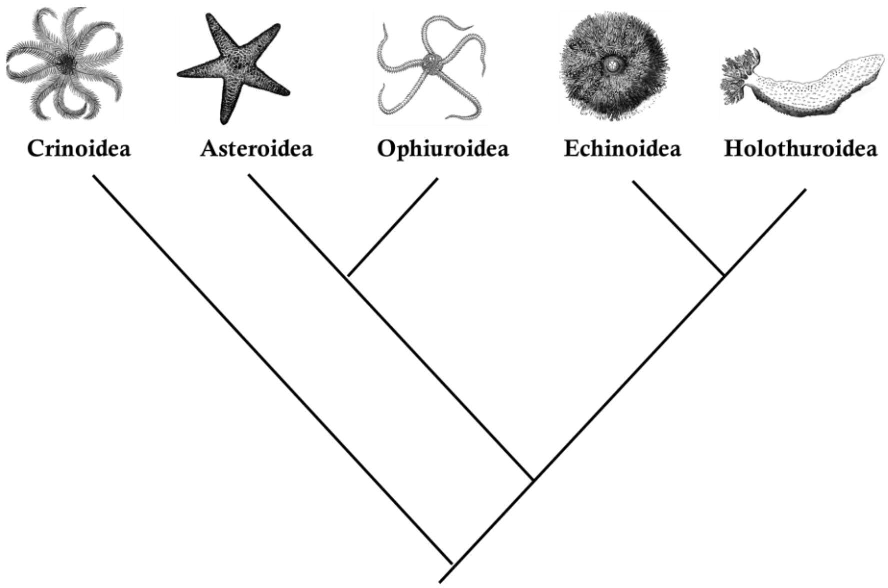

Figure 1.2 Phylogeny of the five classes of echinoderms, adapted from Telford *et al.* (2014)
[Image source: http://etc.usf.edu/]

1.2.4.1 Class Asteroidea

Class Asteroidea comprises of starfishes, all of which possess the same body plan – with a central disc and radiating arms, numbering 5 or multiples thereof – resulting in a pentagonal or stellate shape (Figure 1.3). The exoskeleton is made of interlocking or networking plates, which may either be rigid or loose and flexible. The plates often bear granules, spines or other structures derived from these. Each arm of asteroids possess a ventral groove called the ambulacrum, which lead to the mouth (Figure 1.3). The tube-feet of the water-vascular system project from this groove, and are used extensively for locomotion, burrowing, feeding etc. A row of ambulacral and sub-ambulacral spines protect the soft tube feet from damage. The characters of taxonomic importance in starfishes include the nature of skeletal plating,

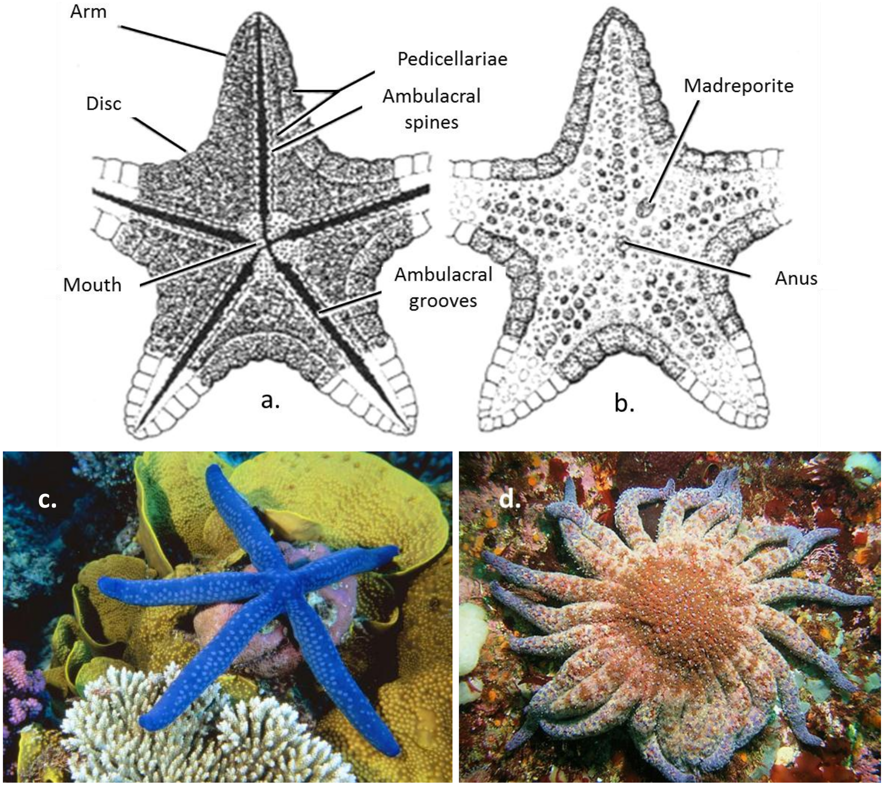

Figure 1.3 Class Asteroidea. a. general body plan, oral side, b. general body plan, aboral side, c. & d. examples of starfishes
[Image sources: http://www.geo.arizona.edu/, http://www.flickr.com/]

the spines, granules or other structures present on them, the forms of the ambulacra and associated structures, the number and length of arms etc. Many starfishes are active predators on soft and hard-bodied benthos, and many forms also graze on algae, corals, sponges etc. Some starfish are also detritivorous, and feed by ingesting sediments as a whole, then digesting the organic matter present in them and egesting the undigested sediments (Hyman 1955, Mah 2016).

The systematics and classification of genera and families within this class have been greatly debated over the last few decades (Blake 1987, 1989, Gale 1987, Clark & Downey 1992, Lafay *et al.* 1995, Mooi & David 2001 etc.). A broad framework for resolving these issues was provided by

Lafay *et al.* (1995) who combined molecular and morphological studies. Many works were carried out on selected families (Blake 2000, Blake *et al.* 2000, Mooi & David 2000, Hotchkiss 2000, Vickery & McClintock 2000, Hrincevich *et al.* 2000, Mah 2000, Knott & Wray 2000) and it has been generally agreed by all workers that supplementation of classical taxonomy with molecular techniques is desirable to resolve taxonomic uncertainties, particularly at family levels. Over 1800 species of extant starfishes are recorded, falling in 36 families (Pawson 2007, Mah 2016), of which about 160 species have been recorded in Indian waters (Sastry 2007).

1.2.4.2 Class Ophiuroidea

The class Ophiuroidea is composed of the brittle stars and basket stars. The body the ophiuroids consists of a central disc, with five (sometimes 6-7) radiating arms. The dorsal and ventral surfaces of the disc are covered by skin, usually embedded with thick plates. The mouth is ventral and armed with five jaws, each with different kinds of shields, plates, papillae and teeth (Figure 1.4). The arms are covered by a series of dorsal, ventral and lateral plates, which have arm spines and series of tube-feet projecting from them. The basket-stars (Figure 1.4.c) are distinguished by their characteristic branching arms, while brittle stars have simple arms. The structure of the jaw apparatus, the nature of the plates on the disc and arms as well as the numbers and shapes of the arm spines are the key taxonomic characters among the Ophiuroidea (Fell 1960). Ophiuroids are diverse in their feeding modes – from active predation and scavenging, to detritivory and suspension feeding (Hyman 1955).

The state of knowledge of ophiuroid classification based on cladistic analysis of morphological data was summarized by Smith *et al.* (1995). Some evolutionary pathways were proposed by Cisternas *et al.* (2004), after studying development patterns of 23 species. More recently, some new morphological characteristics, particularly the articulation sockets of the arm

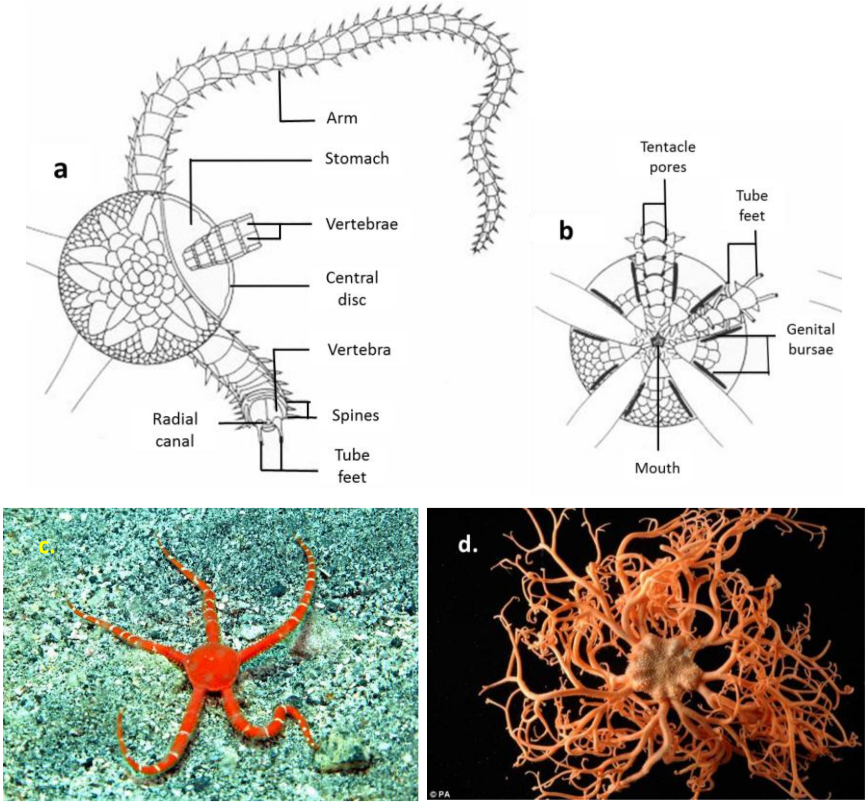

Figure 1.4 Class Ophiuroidea. a. general body plan, oral side, b. general body plan, aboral side, c. brittle star, d. basket star

[Image sources: http://www.geo.arizona.edu/, http://islandtimedivers.blogspot.in/, https://thetruthbehindthescenes.wordpress.com/]

spines on the lateral arm plates, are being used as key characters at family levels (Martynov 2010, Thuy & Stöhr 2011) which have helped to resolve some taxonomic uncertainties (E.g. O'Hara & Stöhr 2006, Thuy & Meyer 2013). Over 2100 species of ophiuroids, falling in 17 families are currently recorded (Pawson 2007, Stöhr *et al.* 2012a, 2016), out of which about 160 species are reported from India (Sastry 2007).

1.2.4.3 Class Echinoidea

The Echinoidea includes the sea urchins, heart urchins, cake urchins and sand dollars (Figure 2.6). The common feature within this class

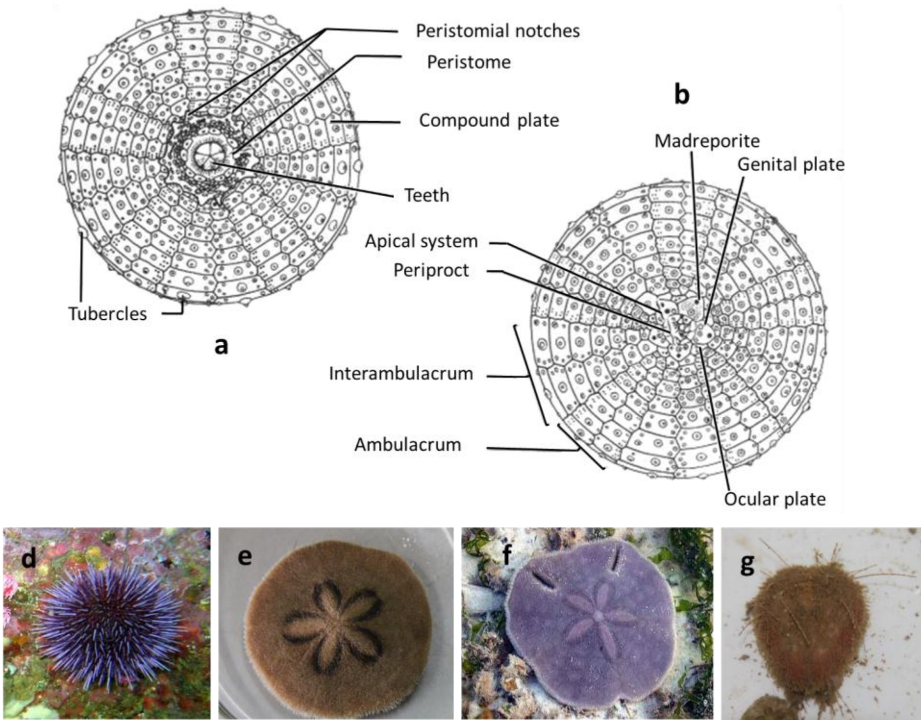

Figure 1.5 Class Echinoidea. a. general body plan, oral side, b. general body plan, aboral side, c. sea urchin, d. sand dollar, e. cake urchin, f. heart urchin.

[Image source: http://www.geo.arizona.edu/, https://www.butterflies.org/, http://www.personal.psu.edu/]

is the occurrence of a thick test made of interlocking plates, which bears numerous spines of varying size and shape. Apart from the spines, stalked and multi-valved pincer-like pedicellariae are also encountered in most echinoids. In the sea urchins or regular urchins, the test is spherical or nearly so, and the spines are usually long and stout (Figure 1.5a, b). The heart urchins (Figure 1.6c), with ovoid tests, along with the cake urchins and sand dollars (Figure 1.6d, e), which have flattened tests are collectively called the irregular urchins. The mouth is ventral in all echinoids, while the anus, which is located within a structure known as the periproct, may be mid-dorsal (regular urchins), posteriorly displaced (heart urchins) or even ventral (sand dollars & cake urchins). The mouth of regular urchins is armed with a unique pentamerous jaw apparatus, known as the Aristotle's Lantern, which is suspended from within the test, and projects out of the mouth. Though the characters of taxonomic value are different in regular and irregular urchins, but the nature of the spines and pedicellariae are important in all groups. Echinoids may be active predators, grazers or detritivores (Hyman 1955).

Echinoids have an excellent fossil record, owing to the strong calcified test. As a result, the echinoids have been subjected to a great number and variety of studies – from palaeontology, biology and ecology to developmental biology (Emlet 1988, Bosch *et al.* 1987, Sameoto 2010). The systematics of higher taxa have been analysed by several workers, based on morphological (test & spine morphology, structure of Aristotle's lantern, pedicellariae, larval development) and molecular data (Smith 1988b, Smith *et al.* 1992, Littlewood & Smith 1995, Lee 2003, Stockley *et al.* 2005, Smith *et al.* 2006, Smith 2007, Solovjev & Markov 2004). As the echinoid gonads are edible and have commercial value, considerable work has also been done in the field of aquaculture (reviewed in Yokota *et al.* 2002). Around 800 species of extant echinoids have been recorded around the world, belonging to 22 families (Pawson 2007, Kroh & Smith 2010, Kroh & Mooi 2016). Of these, about 110 species have been reported from around India (Sastry 2007).

1.2.4.4 Class Holothuroidea

The Holothuroidea or sea cucumbers are the only class to have outgrown the pentamerous symmetry which is characteristic of echinoderms, and have developed secondary bilateral symmetry (Figure 1.6). The calcareous skeleton is greatly reduced, being represented only by microscopic spicules embedded in the more or less thick skin. They possess a crown of tentacles, which can be retracted into the mouth and is supported by a calcareous ring of plates. In many forms, the five rows of tube-feet are still distinguishable along the length of the body (Figure 1.6). Taxonomic identification of holothurians is based on the number and shape of the

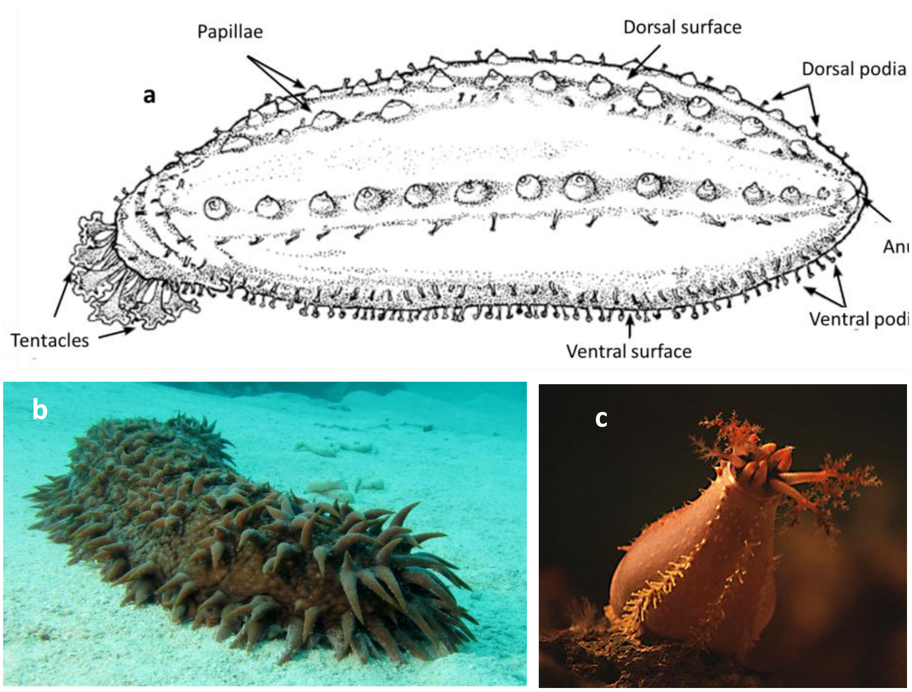

Figure 1.6 Class Holothuroidea. a. general body plan, b. & c. examples of sea cucumbers.

[Image sources: Purcell (2010), http://archaeologynewsnetwork.blogspot.in/, http://www.geol.umd.edu/]

tentacles, the morphology of the collar ring and most importantly, the shape, size and placement of the calcareous spicules in the skin. Holothurians are chiefly detritivorous, either ingesting and digesting organic matter directly from sediments, or undertake suspension feeding using their tentacles (Hyman 1955, Purcell 2010).

Some species of sea cucumbers are consumed raw, cooked, pickled or in dried form in Asian and European cuisines. Referred to as Beche-de-mer, Hoi Sam or Trepang, these products have high export value, particularly to East Asian countries, and it is reported by that over 60 species are commercially exploited across the world (Purcell 2010). Owing to their economic value, taxonomy and systematics of the holothurians are of great importance, as is the understanding of their distribution and biology. Overfishing and unmanaged harvesting are reported from several regions, leading to decline in stocks. There is an urgent need to implement strict conservation measures for all the commercially important species of holothurians (Purcell 2010, Purcell *et al.* 2012). The holothurians are placed under Schedule-I of the Indian Wildlife (Protection) Act (1972), which prohibits any collection, possession or trade of sea cucumbers or products derived from them.

Higher classification of holothurians has been relatively stable, with only a few discrepancies in distinction among orders (reviewed in Pawson & Fell 1965, Kerr & Kim 2001). Morphological and molecular approaches have been employed to elucidate interrelationships between families and within families (Smirnov 1998, Kerr & Kim 1999, 2001, Kerr 2001, Kerr *et al.* 2005, Lacey *et al.* 2005). Approximately 1400 species of holothurians are recorded in the world oceans (Pawson 2007, Paulay & Hansson 2016). Of these, about 150 species have been reported from India (Sastry 2007).

1.2.4.5 Class Crinoidea

The class Crinoidea comprises the un-stalked 'feather stars' and stalked 'sea lilies'. The body is typically a cup-shaped calyx with a central mouth surrounded by crown of arms, each of which bears branching pinnules, resembling a feather (Figure 1.7). The exoskeleton is composed of numerous ossicles, which articulate end-to-end. While the feather stars are capable of active swimming, they are usually found attached to the sea bed by means of cirri. In contrast, the sea lilies are predominantly sessile (Hyman 1955). Ossicles of the pinnules, arms, calyx, stalk etc. have distinct characteristics and modes of articulation, which are of much taxonomic importance. The crinoids use their arms and pinnules to filter suspended organic matter from the near-bottom water, which are carried to the mouth by ciliary currents (Hyman 1955).

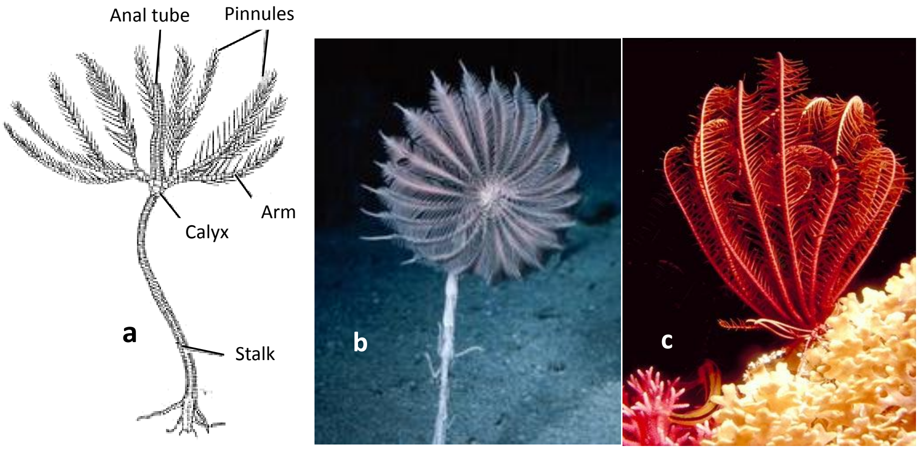

Figure 1.7 Class Crinoidea. a. general body plan, b. sea lily, c. feather star
[Image sources: http://www.geo.arizona.edu/, http://cnso.nova.edu/messing/crinoids/index.html, http://www.teara.govt.nz/]

A complete monographic work on the Crinoidea was published by A. H. Clark (1915, 1921, 1937, 1941, 1947, 1950) and A. H. Clark & A. M. Clark (1967). The work of Messing (1997) provides a comprehensive review of the classification, ecology and other aspects of the un-stalked crinoids (or Comatulids). The classification of the stalked crinoids was summarized by Roux *et al.* (2002), who provided a key to genera along with a comprehensive checklist. A few detailed revisions of selected taxa and regional works are also published (E.g. David *et al.* 2006, Messing 2007). Research on systematics is also being carried out by complementing morphological analyses with molecular approaches (E.g. Cohen *et al.* 2004). There are approximately 650 extant species of crinoids, represented by about 100 sea lilies (in 11 families) and about 550 feather stars (in 20 families) (Pawson 2007, Messing 2016). About 60 species of crinoids are reported from Indian waters (Sastry 2007).

1.2.5 Ecological roles

With the exception of a few species of swimming abyssal sea cucumbers, all adult echinoderms are benthic organisms, i.e. they live in or on the sea-floor. While some groups (particularly the Crinoidea) may exist by attaching themselves to the sediments via stalks or cirri, none of the echinoderms are completely sessile, and most are actively motile (Hyman 1955). Mode of feeding (reviewed in Meyer 1982, Massin 1982, De Ridder & Lawrence 1982, Jangoux 1982, Warner 1982) include active filter feeding from the water column (Crinoidea, Holothuroidea and Ophiuroidea), selective and non-selective detritivory (Asteroidea, Ophiuroidea, Holothuroidea and Echinoidea), and active predation on other benthic fauna (Asteroidea and Ophiuroidea). The role of the detritivorous echinoderms such as the holothurians is of direct importance in the reworking of marine sediments and remineralization of organic matter in the sea floor sediments. Many forms, particularly echinoids and asteroids are apex predators and occupy keystone position in some ecosystems. Echinoderms, in general, are important components in the food-webs of the sea-floor.

Through their locomotion and feeding activities on the seafloor, echinoderms play a vital role in mixing and reworking of sediments, a process known as bioturbation. By this process, they incorporate organic matter and oxygen into deeper layers of sediments and thereby enhance remineralization processes which occur there. Many echinoderms also interact with other organisms such as sponges, gorgonids and also other echinoderms to form various obligatory and facultative associations. Ophiuroids, in particularly, are known to be epizoic on gorgonids (E.g. Fujita 2001, A. M. Clark 1976), sponges (Caspers 1985) and echinoids (reviewed in Kroh & Thuy 2013), and are also known to be endosymbionts on jellyfish (Fujita & Namikawa 2006). Polychaetes are known commensals in the ambulacral grooves of starfishes (Jones 1964), while polychaetes, crustaceans, fishes etc. are known to be commensals or parasites in the cloaca of sea cucumbers (Jones & Mahadevan 1965, Smith & Tyler 1969, Britayev & Zamishliak 1996 etc.). James (1995a) provided a review of associations of echinoderms known from Indian waters.

Sexes are separate in all echinoderms, but conspicuous external sexual dimorphism is very rare (Mortensen 1933, Stöhr 2001, Parameswaran *et al.* 2013). Fertilization occurs externally after broadcast spawning, and the resulting larvae undergo a planktonic phase before settling and transforming into the adult forms (Hyman 1955). Echinoderms, thus, periodically enhance plankton biomass through the supply of larvae. However, some echinoderms are known to brood juveniles (Mooi & David 1993, Hamel & Mercier 1995, Sponer & Roy 2002, Hunter & Halanych 2008 etc.). Occasionally, echinoderm larvae form sizeable components in the planktonic biomass (Thorson 1950).

1.2.6 Global diversity & distribution

In the last decade, inventory on marine biodiversity over wide geographic ranges have been carried out through International efforts such as Census of Marine Life (CoML), Ocean Biogeographic Information System (OBIS), World Register of Marine Species (WoRMS) and Marine Barcode of Life (MarBOL). The Centre for Marine Living Resources and Ecology, Kochi is the nodal agency for CoML and OBIS in the northern Indian Ocean region. These initiatives aim to assess the diversity, distribution and abundance of marine life on a global scale, and make information available on their taxonomy and distribution available to the public through searchable interfaces. Further, these efforts also aim to enhance global capacity to identify marine organisms using DNA Barcodes. From the species distribution records in the aforementioned databases, preliminary assessments of the global distribution patterns of many taxonomic groups have become possible (E.g. Stöhr *et al.* 2012a, Mah & Blake 2012, Cairns 2011, Williams 2011, Van Soest *et al.* 2012).

Among the echinoderms, the global distribution patterns of the Ophiuroidea (Stöhr *et al.* 2012a) have been examined. The largest families amongst the Ophiuroidea were found to be Amphiuridae (467 species), Ophiuridae (344) and Ophiacanthidae (319). Biogeographic analysis revealed the presence of nearly equal numbers of species in the continental shelves (1313 species) and bathyal depths (1297 species). The Indo-Pacific region was found to harbour highest species richness (825 species) at all depths. Adjacent oceans were also relatively species rich, including the North Pacific (398), South Pacific (355) and Indian (316) due to the presence of many Indo-Pacific species that partially extended into these regions. Regions of relatively low species richness included the Arctic (73 species), East Atlantic (118), South America (124) and Antarctic (126) (Stöhr *et al.*, 2012).

Mah & Blake (2012) carried out similar analyses on the distribution as well as phylogeny of the Asteroidea. The results revealed that the Goniasteridae were the most diverse family in this class (256 species), followed by Astropectinidae (243) and Asteriidae (178). Of the 36 families of extant Asteroidea, 23 were found to occur either exclusively or primarily in cold-water settings, 6 families occurred in temperate environments and 7 were present primarily or exclusively in tropical water habitats. The work also summarized the present knowledge on phylogeny of this class, building on the works of Blake (1987), Janies (2001), and Mah & Foltz (2011a, b).

In general, the Indo-west Pacific region is an area of high species diversity, particularly in the case of Asteroidea, Ophiuroidea and Holothuroidea (Mah & Blake 2012, Stöhr *et al.* 2012a, Pawson 1995). A comprehensive monograph and taxonomic key on the Shallow-water Indo-West Pacific Echinoderms was published by Clark & Rowe (1971) which dealt with all five classes and provided distributional ranges of the species. Only about 345 species were reported from Indian waters in this work (Clark & Rowe 1971).

1.3 Echinoderms of Indian waters: status of knowledge

The first report on echinoderms in India is that of Plancus & Gaultire who described and illustrated a large multi-armed starfish from the coast of Goa. This species was formally described and given the name *Asterias planci* by Linnaeus (1758), when he implemented the system of Binomial Nomenclature. The species, currently known by *Acanthaster planci* (or Crown of Thorns starfish), is among the most well-known starfishes, mainly due to its notoriety as a coral-devouring species (Birkeland & Lucas 1990).

Most of our knowledge on the species diversity of echinoderms in the Indian Seas comes from the surveys of the Royal Indian Marine Survey Ship (R.I.M.S.) *Investigator*, under the leadership of Dr. Alfred William Alcock. The Investigator surveys, which were carried out between 1888 and 1892, collected samples using Agassiz trawls from between ~30 and ~4000 m depths in the Arabian Sea, Bay of Bengal, Laccadive Sea, Gulf of Mannar and Andaman Sea. Over the following years, the biological samples collected during these surveys were examined and described by taxonomic experts. Amongst these, the echinoderms were described in a series of publications titled "Echinoderma of the Indian Museum", in which the shallow and deep-sea asteroids (Alcock 1893a, b, Koehler 1909), ophiuroids (Koehler 1897, 1898, 1899), echinoids (Anderson 1894, Koehler 1914, 1922, 1927) and holothurians (Koehler & Vaney 1905, 1908, 1910, Walsh 1891) were dealt with separately. The crinoid fauna from the Expedition were described by A. H. Clark (1912a, b, 1932). A few other collections from R.I.M.S. *Investigator* were also described by other workers (Wood-Mason & Alcock 1891, Alcock 1894, Bell 1887a, b, Koehler 1910, Bomford 1913). Apart from the *Investigator* collections, a few other regional works were also carried out around India, particularly in near-shore and intertidal areas in the late 18th and early 19th Century (Duncan 1887, Bell 1888, 1902, Döderlein 1888, Gravely 1927, 1941). The John Murray Expedition, which was carried out along the Arabian

Sea made substantial collections of bottom fauna in 1933-34. Echinoderms from these collections were described by A. H. Clark (1936), Macan (1938), H. L. Clark (1939) and Mortensen (1939).

In the second half of the 20th century, studies on echinoderm diversity on a localized and regional scale were carried out along the east and west coast of India as well as Lakshadweep, Andaman & Nicobar Islands. P. N. Ganapathi and C. V. Kurian, who are among the pioneers of benthic studies in India, have also recorded echinoderm fauna in their works along the northeast and southwest coasts of the peninsula respectively (Ganapathi & Rao 1962a, b, Radhakrishna & Ganapathi 1969, Ganapathi & Sastry 1970, 1972, Kurian 1953, 1969).

Relatively more work has been carried out around the Andaman & Nicobar Islands. The starfish species *Culcita novaegiuneae* was first reported in Indian waters by Haldar & Chakrapani (1976), from the Middle Andaman Island. The shallow water Asteroidea of the region was studied by Julka & Das (1978), who reported 19 species. Rao published some works on interstitial holothurians and their juveniles from Andaman & Nicobar Islands (Rao 1973, 1975). Much work on the echinoderms of the Islands was carried out by Sastry, who recorded over 30 species for the first time from the region (Sastry 1977a, b, 1981a, b, c, 1987, 1997, 1998a, 1999a, b, 2001b, 2002, Soota & Sastry 1979). James has recorded several species of brittle stars and holothurians from the region, including the new species *Ophioneris andamanensis* (James 1968a, 1986a, b, 1987a, b, c, 1988, 1991). Sastry (1996, 1998a, 1999a, 2005) and James (1991) have published inventories and checklists of the echinoderms of the Andaman & Nicobar. Another deep-sea survey in the Andaman Back-Arc Basin (Andaman Sea) yielded two new species and four new records of rare deep-sea Ophiuroids (Stöhr *et al.* 2012b). A rare deep-sea taxon, *Ophiomyces delata* (Ophiohelidae) was recorded from an unusually shallow depth in the Duncan Passage, Andaman Islands (Parameswaran *et al.* 2016).

Less work has been published on echinoderms of the Lakshadweep Archipelago. Bell (1902) reported on a collection of crinoids, asteroids, echinoids and ophiuroids made by Stanley Gardiner in the Lakshadweep and Maldives. The results of an ecological survey in the Minicoy Atoll recorded several species of echinoderms (Nagabhusaham & Rao 1972). Several workers reported on the holothurian fauna of the archipelago (Mukhopadhyay & Samanta 1983, Sastry 1991a, b, Deepa & Bijukumar 2010, 2011). James (1989) summarized the knowledge on diversity of echinoderms and recoded 76 species in the Lakshadweep.

Amongst the earliest records of echinoderms in the east coast of India are those of Thurston (1895a, b), who reported over 50 species from the littoral areas of the Gulf of Mannar. Following a long gap, a new species of apodous holothurian, *Chondrocloeca varians* was described by Nair (1946), from the Madras Harbour. Another new species of holothurian was discovered in the beach sands of Vishakhapatnam by Rao, who named it *Psamothuria ganapathi* (Rao 1968). Some crinoid associated fauna from the Andhra coast were discussed in the works of Rao & Sowbhagyavathi (1972). James (1987d) recorded a new species of holothurian, *Psolus mannarensis* from the Gulf of Mannar, and also inventoried the echinoderm fauna of the region (James 1985a). Sastry (1995, 1998b, 2001a) provided inventories of echinoderm species for several parts of the east coast of India. In the continental shelf (30-200m) off the north east coast of India (Paradip to Divi Point), Damodaran (2010) reported 7 species of echinoderms.

On the west coast, marine fauna of the Karwar coast were studied through a survey, and the echinoderms collected therein were recorded by Patil (1953). A few common species from below the 15 fathom line off the

Travancore coast were reported by Kurian (1953). Gideon *et al.* (1957) conducted a preliminary survey of marine fauna of the Gulf of Kutch and recorded several species of echinoderms. Later, a few more species were reported from the region by Gopalakrishnan (1969). Sane & Chhapgar (1962) inventoried the intertidal echinoderms off Bombay, recording about 12 species. James (1971) discussed the taxonomy and systematics of the ophiuroid genus *Amphioplus* (Amphiuridae) off the southwest coast. A few species were mentioned by Ranade (1979) from off Ratnagiri and Parulekar (1981) from Malvan. Echinoderms collected during benthic surveys since then have been reported at the genus level (Prabhu *et al.* 1993, Joydas & Damodaran 2009 etc.). Sastry (2004) provided a checklist of echinoderms on the Gujarat coast. One new species of Ophiuroid, *Asteroschema sampadae* was reported from bathyal depths off the southern tip of India (Parameswaran & Abdul Jaleel 2012). The rare sexually dimorphic and epizoic brittle star, *Ophiodaphne scripta* was reported for the first time from the southwest coast (Parameswaran *et al.* 2013). One species of echinoid (Hegde & Rivonkar 2013) and one holothurian (Deshmukh *et al.* 2015) were reported from the inshore areas of Goa, which were new records in Indian waters.

Based on shallow-water collections across the Indian waters, James has reviewed the existing knowledge of several families of ophiuroids and holothurians (James 1967, 1968b, 1971, 1973, 1976, 1985b, 1987e, f, g, 1995b, 1997, 1998), and the status of knowledge on echinoderms in Indian seas (James 2008). The holothurian resources of the Indian waters were also detailed by James (1983, 1994). At present, the exploitation and trade of holothurians is banned in India. As an alternative, some research is being carried out on their hatchery production and sea ranching at the CMFRI, Tuticorin (James & James 1993, James 1994, Asha & Muthiah 2002 etc.). James & Lal Mohan (1969) compiled a consolidated bibliography on the Echinoderms of the Indian Ocean.

A comprehensive checklist of echinoderm reported from the Indian Seas was published by Sastry (2007) under the auspices of the Zoological Survey of India, which listed 651 species. More recent works place the total number of echinoderms in Indian waters at 765 species (Wafer *et al.* 2011, Sanjeevan *et al.* 2014) and 777 species (Venkatraman *et al.* 2015). Nearly all studies on diversity of echinoderms in the last 60 years have been based on intertidal and shallow water regions. The present literature survey reveals a dearth of detailed information on diversity and distribution of echinoderms in the Indian waters beyond the depth of ~25 m.

1.4 Echinoderms of the south eastern Arabian Sea: relevance of present study

Within the northern Indian Ocean, the South Eastern Arabian Sea (SEAS) is a region with distinctive oceanographic and biological features (Madhupratap *et al.* 2001, Luis and Kawamura 2004, Smitha *et al.* 2008, Sanjeevan *et al*. 2009, Jyothibabu *et al.* 2010) within the northern Indian Ocean. It represents a typical Eastern Boundary Upwelling System (EBUS), with moderate to intense coastal upwelling and enhanced biological production (Banse 1959, 1968, Smitha *et al.* 2008) during the Summer Monsoon (SM) season (June to September). The environmental conditions and biological processes in the region are reviewed in Chapter 2 (section 2.1). The species diversity of polychaetes and nematodes, which are numerically the dominant components of macro and meiofauna respectively, are well studied (Jayaraj *et al.* 2008, Joydas & Damodaran 2009, 2014, Sajan *et al.* 2010a, b). However, there is no similar comprehensive information on the species composition, diversity and distribution of the echinoderms in the SEAS.

The SEAS is known to harbour relatively high benthic biomass (Joydas & Damodaran 2009, Damodaran 2010, Abdul Jaleel 2012), but the contribution of echinoderms to this high biomass is not properly quantified.

Intense sub-surface hypoxia is reported in the SEAS during the SM (Naqvi *et al.* 2000, 2006, 2009, Abdul Jaleel *et al.* 2015, Gupta *et al.* 2016). The echinoderms are amongst the most sensitive groups to hypoxia and may show stress, avoidance, mortality or complete absence from hypoxic waters (Rosenberg *et al.* 1991, Diaz & Rosenberg 1995, Gray *et al.* 2002, Hunter *et al.* 2011), but the response of this group to the seasonal hypoxia in the SEAS is not known. The high biological production during the monsoon supports an enhanced fishery of finfishes and crustaceans. Bottom trawling activities are practiced in the SEAS throughout the year (Silas 1977, James 1981, 1987), except during the monsoon trawl-ban period. Large scale trawling and dredging are known to cause extreme changes in benthic assemblages (Hall & Harding 1997, Lindegarth *et al.* 2000 etc.). Despite being a non-target group, echinoderms are often caught in large numbers in the bottom trawls in the SEAS, and constitute about 0.8-4.5 % of total non-edible annual discards (Kurup 2004). From the Kochi Metropolitan area alone, a vast quantity of untreated domestic (0.26 x 103 m^3d^{-1}) and industrial (0.104 x 106 m^3d^{-1}) waste is discharged into the Cochin Estuary which is transported to the adjacent continental shelf (CPCB 1996, Balachandran *et al.* 2006). Assessment of the multiple impacts of such anthropogenic influences (trawling, pollution etc.) is not possible without high resolution baseline data with seasonal coverage.

Echinoderms often occupy key ecological niches in marine sediments. Apart from being important members of the food web, they play significant roles in the process of bioturbation of sediments, and also contribute to pelagic standing stock through their larvae. A clear understanding of the ecological role of all constituent taxonomic and functional groups is a prerequisite for providing a synthesis on the marine benthic ecology of the region.

1.5 Objectives

Taking the above into account, the present study aims to:

i. Create a baseline inventory on the taxonomy, systematics, diversity, distribution and abundance of echinoderms in the SEAS

ii. To delineate factors influencing distribution of echinoderms in the region and to study the impacts of natural events (hypoxia) as well as anthropogenic activities (bottom trawling).

iii. To examine the interrelationship of echinoderms with associated benthic fauna in the SEAS.

1.6 Outline of the thesis

The thesis is divided into five chapters, as below:

Chapter 1 provides a general introduction to the research topic. The definition, key characteristics, systematic position, evolutionary and ecological importance as well as higher level classification of Phylum Echinodermata are provided in this chapter. The key features including characters relevant to taxonomic identification of each Class is briefly outlined, along with the status of knowledge of its diversity globally and in the Indian waters. A review of literature on Indian Echinoderms is provided, which reveals that this phylum has not been sampled beyond near shore areas (i.e. beyond 25 m depth) since the surveys of RIMS Investigator (1888-1892). The relevance of studying the echinoderms in the SEAS and the objectives of the thesis are provided.

In Chapter 2, the environmental settings of the study area, the South Eastern Arabian Sea (SEAS) between 7°-15° N and 73°-78° E (20-1500m depths) are reviewed, briefly outlining the geomorphology and surficial sediment nature, hydrography and biological processes in the water column as well as status of knowledge on benthic fauna in the region. The sampling strategy adopted and the rationale behind it are outlined. Methods adopted in analysis of samples and data are explained.

Chapter 3 describes the species diversity (species count) of the phylum in the continental shelf and slope of the SEAS and are revalidates and the echinoderm species diversity of the region. A brief systematic account of the species collected in the present study is provided. The chapter also contains updated checklists for each class of echinoderms. A total of 76 species belonging to 36 families, and representing all five classes of echinoderms were recorded from the SEAS in the present study, of which 46 species are newly recorded from the region and one species is new to science. With the addition of new records, the total number of echinoderm species known from the SEAS is revalidated to 256 species.

The terms 'systematics' and 'taxonomy' are often used interchangeably, with overlapping, or exactly similar meanings. While taxonomy may be defined as "the theory and practice of classifying organisms" (Mayr & Ashlock 1991), it was originally coined for the theory of plant classification (de Candolle 1813). The term 'systematics' is derived from the term for the system of classification developed by early naturalists (Linnaeus 1758). 'Systematics' was defined by Simpson (1961) as "the scientific study of the kinds and diversity of organisms and of any or all relationships between them". Mayr & Ashlock (1991) suggest a broad interpretation of the word 'relationship' in the above definition, rather than the narrow 'phylogenetic sense' alone. Michener (1970) defined systematics as "the field that (a) provides scientific names to organisms, (b) describes them, (c) preserves their collections in form of voucher specimens, (d) provides classifications for the organisms, keys to their identification, and data on their distributions, (e) investigates their evolutionary histories, and (f) considers their environmental adaptations". This definition is adopted in Chapter 2 which deals with aspects (a) to (d) given above, for the echinoderms of the SEAS.

In Chapter 4, the abundance, composition and distribution of echinoderms in the SEAS shelf is described. The distribution patterns of echinoderms are examined in relation to the spatio-temporal variations in bottom water and sediment characteristics, which are known to influence the distribution of benthic fauna.

The salient findings of the study are summarized in Chapter 5 and conclusions are outlined.

CHAPTER 2

Study area, Sampling design & Analysis

2.1 The south eastern Arabian Sea

The study area is located on the continental margin (20 to ~1500m depth zone) off the southwest coast of India (7°-15° N, 73° -78° E), in the South Eastern Arabian Sea (SEAS). The SEAS is essentially an Eastern Boundary Upwelling System (EBUS), with distinct oceanographic and biological features (Madhupratap *et al.* 2001, Luis and Kawamura 2004, Smitha *et al.* 2008, Sanjeevan *et al.* 2009, Jyothibabu *et al.* 2010) within the northern Indian Ocean. The bathymetric contours in the SEAS are depicted in Figure 2.1.

2.1.1 Geomorphology & sediment nature

The continental margin of the west coast of India is an Atlantic type passive or stable margin (Biswas 1989, Rao & Wagle 1997). The shelf basins evolved since the Palaeocene epoch, following the stabilization of Indian plate after its collision with the Eurasian plate. The margin is characterized by a wide continental shelf in the north, which gradually narrows to the south (Rao *et al.* 1983). In contrast, the continental slope is narrow in the north and wider to the south, where the topography is also gentler, particularly between Ratnagiri and Mangalore and south of Kochi (Rao & Wagle 1997). The continental shelf towards the south (SEAS) has a width of ~60-120 km, and shelf break occurs around 80-220 m at various regions (Nair 1975, Naini 1980, Rao & Wagle 1997). The topography of the mid shelf is smooth, whereas the outer shelf is rugged and made up of ridges and depressions of around 6 m (Rao & Wagle 1997).

Various climatic, geological and hydrodynamic processes control sediment deposition and nature of bottom in the SEAS. The region receives freshwater inputs from over 20 rivers and discharge from two major estuarine systems (Cochin & Ashtamudi), with terrestrial discharge being higher during the southwest monsoon season (Hashimi & Nair 1981). Studies have revealed that sand is the dominant sediment type in the shelf off the west coast of India as a whole (Nair & Pylee 1968, Nair 1975, Hashimi *et al.* 1978, Narayana & Prabhu 1993).

Up to a depth of 10-12m, terrigenous sediments occur in the form of sands (including heavy metals), followed by a zone of silty clay in the areas north of Kollam (Rao & Wagle 1997, Jayaraj *et al.* 2008). The trapping of coarser sediments within the estuaries and backwaters of Kochi and Kollam, and flocculation at the discharge sites where freshwater and seawater mixes, result in the discharge and deposition of finer clay fractions around these areas (Hashimi *et al.* 1981, Rao & Wagle 1997, Damodaran 2010). It is likely that similar processes come into play at other river mouths north of Kochi (e.g. Beypore, Kannur, Mangalore, and Bhatkal). Such finer deposits have been reported within the 15-50m depth contours (~40 km from the coast), in these regions (Damodaran 1973, Hashimi & Nair 1981, Jayaraj *et al.* 2008, Ingole *et al.* 2010).

In the areas beyond the influence of these estuaries (i.e. south of Kollam), the sediments of the continental shelf (up to ~100m) are found to be predominantly biogenic calcareous sand (Rao & Wagle 1997), interspersed with rocky outcrops, particularly off the southern tip of the peninsula (Jayaraj *et al.* 2008, Damodaran 2010). The quantum of river discharge between Kollam and Cape Comorin is less, and it is drained through hard Precambrian Khrondalite formations known to occur in this belt, very close to the coast (Krishnan 1968, Rao & Wagle 1997). Additionally, the orientation of the coast changes from N70° W to N10° W just south of Kollam, which, under the influence of the southwest monsoon results in the alongshore transport of sediments southwards, away from the coast. The reduced sediment supply possibly favours growth of corals (Rao & Wagle 1997).

The middle shelf region (50-100m), north of Mangalore, is characterized by calcareous sands (Rao & Wagle 1997, Jayaraj *et al.* 2008, Damodaran 2010), which is considered to be a southward extension of the unique carbonate platform off the Saurasthra coast, knows as the Fifty Fathom Flat (Rao & Wagle 1997). Between Kochi and Kollam, the sediments between 50-100m are predominantly terrigenous sands (Rao & Wagle 1997). Winnowing activity by internal waves and shelf waves in the outer continental shelf and shelf edge (100-200m), result in the retention of sandy sediments (Narayana & Prabhu 1993, Jayaraj *et al.* 2008, Damodaran 2010), mostly of relict nature (Hashimi *et al.* 1981, Rao & Wagle 1997). Beyond 200m, the sediment texture gradually shifts from sandy to silt dominated sediments (Ingole *et al.* 2010, Abdul Jaleel *et al.* 2014).

A study conducted by Paropkari *et al.* (1992) reported a continuous band of organic rich sediments along the west coast of India (from Bombay to Cape Comorin). Damodaran (2010) recorded Organic matter (OM) content of 0.2-6.7% along the entire western continental shelf (Dwaraka to Cape Comorin). The OM content was found to be high in the mid-shelf region (4-7.56%) in the SEAS (Jayaraj *et al.* 2008). The OM value increases towards the north, in the fine grained sediments (2.17-7.56%), when compared to the southern (0.21-3.0%) SEAS (Jayaraj *et al.* 2008, Abdul Jaleel *et al.* 2015).

2.1.2 Hydrography & biological processes

The SEAS is subjected to seasonal wind reversal associated with the southwest (June-September) and northeast (November to February) monsoons, which influences the hydrography and oceanography of the upper water column (Sharma 1966, Johannessen *et al.* 1981, Smitha *et al.* 2008). The southward flowing coastal current (West India Coastal Current, WICC) initiates in March, reaches its peak strength in July, and vanishes in October (Cutler & Swallow 1984, Shetye & Shenoi 1988, Shankar *et al.* 2002). During the southwest monsoon, moderate to intense coastal upwelling occurs (Banse 1959), with isotherms tilting upwards from around April (Gupta *et al.* 2016), and a pole-ward undercurrent is indicated (Antony 1990, Smitha *et al.* 2008). The coastal upwelling causes nutrient enrichment in the upper water column which results in enhanced biological production in the euphotic column (Habeebrehman *et al.* 2008, Thomas *et al.* 2013). The high production and subsequent degradation of organic matter causes rapid utilization of dissolved oxygen from the upwelled waters, which are oxygen-poor to begin with. The formation of a low-saline film at the surface during the monsoon prevents oxygen penetration to the sub-surface waters, and results in formation of intense seasonal sub-surface hypoxia over the continental shelf of the SEAS during this season (Naqvi *et al.* 2000, 2006, 2009, Abdul Jaleel *et al.* 2015, Gupta *et al.* 2016). The Sea Surface Temperature (SST) falls to ~25° C in this season, and the mixed layer is relatively shallow (8-20m). The presence of Arabian Sea High Saline Water mass (ASHSW, salinity >36) in the sub-surface waters (up to 150m) and Persian Gulf Water (PGW) at 200-400m depth in the northern parts of the SEAS are recorded during the summer monsoon (Shenoi *et al.* 2005).

During the winter monsoon season (November-February), the region is characterized by warm (SST >28° C) and low saline (<34.8) waters at the surface, owing to the intrusion of Bay of Bengal water, carried poleward by the northward flowing WICC (Prasannakumar *et al.* 2004), and a southward undercurrent is noted. The upper water column is less dynamic, highly stratified and turns oligotrophic in nature. In the spring inter-monsoon period (March to May), the weak winds and increased solar radiation further intensify surface stratification and oligotrophic conditions. Surface waters are warmest during this season (>31.5° C) and is referred as the Arabian Sea Warm Pool (Sabu & Revichandran 2011). The conditions in the SEAS during this season are ideal for proliferation of the filamentous algae of genus *Trichodesmium* (Sellner 1997) and the occurrence of blooms of *T. erythraeum* and *T. thiebautii* are well documented in the SEAS in the spring inter-monsoon (Devassy *et al.* 1978, Jyothibabu *et al.* 2003, Padmakumar *et al.* 2010). The presence of ASHSW is observed in the SEAS during the winter monsoon as well as the spring inter-monsoon.

The hydrographic properties of bottom water are found to show considerable bathymetric and latitudinal variations over the western continental shelf (Damodaran 2010). The temperature (range 12.9-29.4° C) and dissolved oxygen (0.02-3.7 mll^{-1}) values decrease with increasing depth. Salinity over the region ranged from 26.26-37.32 psu, and is considerably higher towards the north. Temperature also increased from south to north, while DO decreased (Damodaran 2010, Joydas & Damodaran 2014).

2.1.3 Benthos of the SEAS

Qualitative and quantitative aspects of benthos of the west coast of India have been studied by Kurian (1953, 1967, 1971), Seshappa (1953), Damodaran (1973), Parulekar & Wagh (1975), Ansari *et al.* (1977, 1996), Harkantra *et al.* (1980) and Sarladevi *et al.* (1991, 1996). As part of the Marine

Living Resources Programme of the Ministry of Earth Sciences, detailed investigations on standing stock and composition of benthos along the east and west coast of India have been carried out between 1997 and 2002 (results published in Damodaran 2010). The study found that the mean abundance and biomass of macrofauna was higher in the south west coast of India when compared to the northwest, northeast and southeast coasts (Ganesh & Raman 2007, Joydas & Damodaran 2009, Damodaran 2010). Both in the east and west coast, the density and biomass decreased with increasing depth and the group that contributed most to density was the polychaetes, followed by crustaceans and molluscs (Ganesh & Raman 2007, Jayaraj *et al.* 2008, Joydas & Damodaran 2009, Damodaran 2010, Musale & Desai 2010, Smitha 2011, Abdul Jaleel *et al.* 2015). This pattern is observed even beyond 200m in the SEAS (Abdul Jaleel 2012). The study by Ingole *et al.* (2010) along one transect in the SEAS (14° N) revealed relatively high macrofaunal biomass in the mid-shelf region.

The abundance, diversity, distribution and community structure of macrobenthic (benthic fauna >500 μ size) polychaetes of the SEAS margin and the environmental influences on them are described by various workers (Jayaraj *et al.* 2008, Joydas & Damodaran 2009, Musale & Desai 2010, Smitha 2011). The meiofaunal nematodes of the region are also well documented (Sajan *et al.* 2010a, b). Only a limited number of workers have studied the biological implications of oxygen depletion in the SEAS margin (Ingole *et al.* 2010, Joydas & Damodaran 2014, Abdul Jaleel *et al.* 2015) as well as the impacts of bottom trawling and effectiveness of the trawl-ban (Kurup 2004), most of which pertain to infaunal polychaetes (Abdul Jaleel *et al.* et al. 2015). An assessment of changes in macrofaunal standing stock across the 45-day monsoon trawl ban in the southern SEAS, during which the region is also influenced by seasonal hypoxia, revealed an overall increase in standing stock, particularly of polychaetes. Echinoderms, which form a part of both infauna and epifauna, have been poorly studied in the SEAS as compared to other taxa.

2.2 Sampling design

The most notable characteristic of benthic fauna is that they are extremely patchy in distribution even within the range of suitable habitat conditions. This is primarily due to unpredictable and variable patterns in recruitment and also a result of interactions within assemblages at various spatial scales (Thrush 1999, Eleftheriou & McIntyre 2005). Therefore, considerations should be made for such patchiness while sampling marine benthos and spatial replication is a mandatory requirement for any benthic study (Eleftheriou & McIntyre 2005). Replicates are to be made for each region, depth-class, sediment type and season (Underwood 2000, Glasby & Underwood 1996). Data collected in such a systematic manner can then be used for a hierarchal or spatially nested analysis, in order to test whether differences among assemblages are significant with respect to differences in environmental factors (Morrisey 1992, Underwood 1997). Data on abundance of faunal groups or species are often expressed in terms of density (i.e. number of individuals in a standard surface area of sediment, such as no. m^{-2} or no. per haul). However, owing to the patchy nature of benthic faunal distribution, the size of the sampling unit is very important in identifying patterns of distribution. In general, a uniform sample unit size is recommended (Eleftheriou & McIntyre, 2005).

A number of reviews are published on the equipment and techniques used for sampling of benthos (E.g. Gray *et al.* 1991, Elliott *et al.* 1993, Bakus 2003, Eleftheriou & McIntyre 2005). Echinoderms usually range from approximately 1cm to very large organisms, and collectively may be considered as 'megafauna'. They may occur above the sediments (epifauna) or found burrowing within the sediments (infauna). A combination of different techniques and the use of different samplers are ideal for obtaining reliable data and meaningful synthesis of community structure (Eleftheriou & McIntyre 2005).

For the qualitative sampling of epifauna, dredges, otter trawls, beam trawls, sledges or Agassiz trawls may be used. Dredges are among the most useful equipment for exploratory purposes, as they can be towed to obtain samples from a variety of grounds. The common dredge, known as the Naturalist dredge, has a heavy metal frame, and is designed to break off pieces of rock, scraping organisms off hard surfaces and for limited penetration of soft bottoms. They can therefore be used for the collection of infauna and epifauna simultaneously, depending on the net mesh size. The net is usually about half as deep as it is wide with a mesh size of about 10-12 mm (Eleftheriou & McIntyre 2005). Standardization of trawling conditions and duration of tow can be employed to estimate population density of epifauna (i.e. quantitative or semi-quantitative studies), which is of great value for comparative purposes. Such methods are often used in studying epifaunal and megafaunal communities (Ganesh & Raman 2007).

In the case of infauna, the vast majority of organisms are reported to inhabit the top 5-10 cm of soft sediments, with only some forms burrowing deeper (Barnett & Hardy 1967, Thayer 1975). The Smith-McIntyre grab (Smith & McIntyre 1954) is ideal for firm and uniform penetration of soft sediments, and is preferred by most workers at shelf depths (Eleftheriou & McIntyre 2005). The grab has hinged buckets, mounted within a stabilized framework, and is equipped with powerful springs which assist in penetration. Trigger plates on the sides of the stabilization frame ensure that the grab is resting flat on the bottom before the springs are released (Smith & McIntyre 1954). The standard bite area of a Smith-McIntyre grab is $0.1m^2$, but $0.2m^2$ variants are also used (Abdul Jaleel *et al.* 2014).

Depending on their life habits and feeding modes, echinoderms show clear affinities to certain environmental conditions. Their diversity and distribution in a region are influenced by factors such as sediment nature, organic matter content, current velocities, benthic standing stock, oxygen availability, temperature etc. (Brown & Gibson 1983, Kaiser & Spencer 1996, Thrush 1999, Freeman *et al.* 2001, Vasquez-Bader *et al.* 2008 etc.). Considerable spatial and temporal variations are known to occur in these hydrographic and sediment characteristics of SEAS. Accordingly, significant bathymetric and latitudinal variations are reported in the standing stock and composition of infauna (macro and meiofauna) as well as in the diversity and community structure of nematodes and polychaetes. In order to check for similar variations in distribution patterns of echinoderms and their structuring factors, stratified sampling was carried out in the SEAS margin, with seasonal collections using the facilities onboard the Fishery Oceanographic Research Vessel (FORV) *Sagar Sampada*.

2.3 Collection of samples & data

Stratified sampling was carried out on-board Fishery Oceanographic Research Vessel (FORV) *Sagar Sampada* (Figure 2.2a). Eight bathymetric transects, approximately 1° apart along the continental shelf region (30 to ~250 m) of the SEAS and located off Cape Comorin (~7°-8° N, T1), Trivandrum (~8°-8° 30' N, T2), Kollam (~8° 40' - 9° 30' N, T3), Kochi (~9° 40' - 10° 30' N, T4), Calicut (10° 30' - 11° 30' N, T5), Kannur (11° 30' - 12° 30' N, T6), Mangalore (12° 30' - 13° 30' N, T7) and Bhatkal (13° 30' - 14° 45' N, T8) were selected for sampling purpose. All transects were perpendicular to the coast, and oriented in the east-west direction, except Cape Comorin transect, where the stations were located

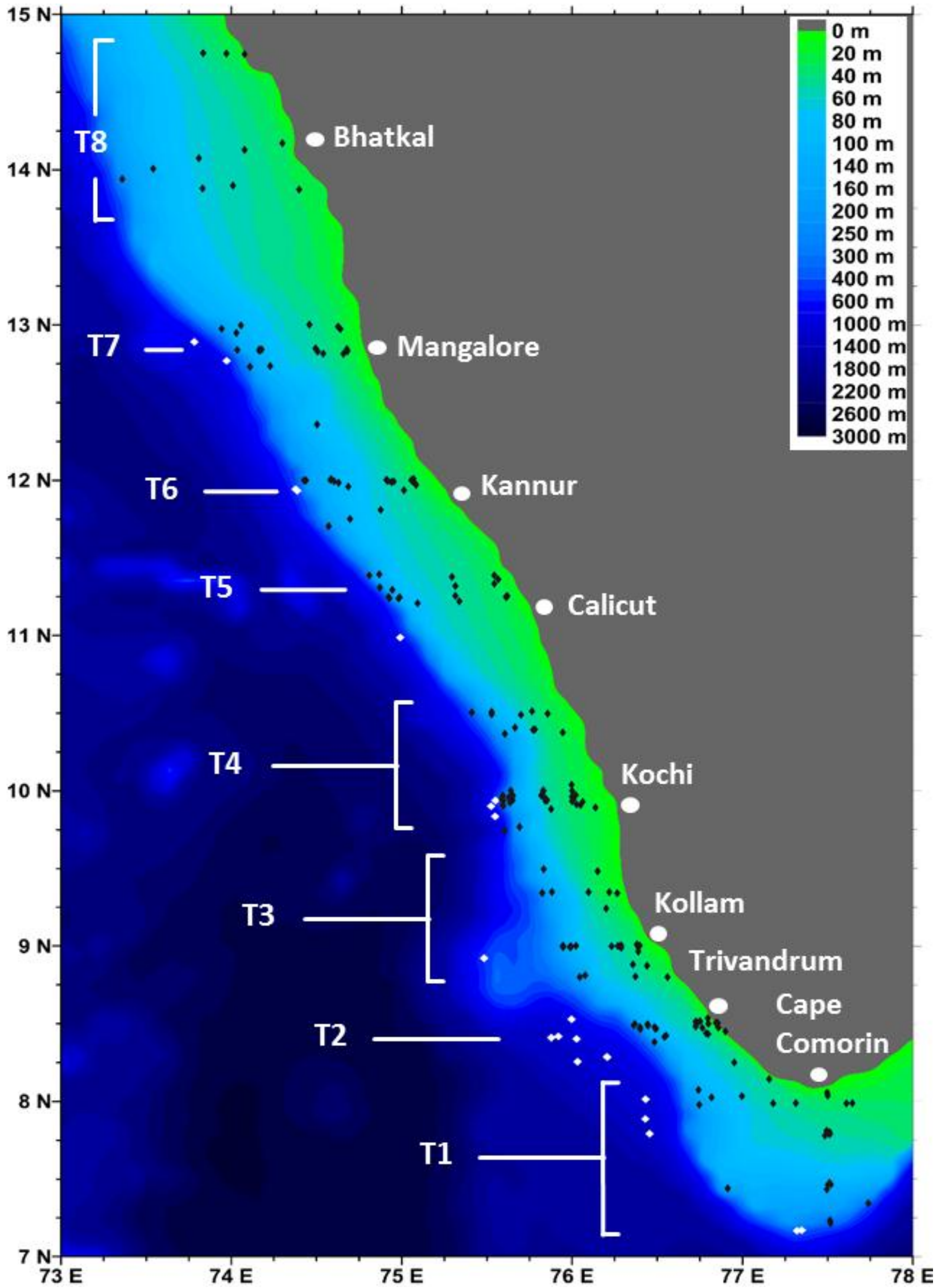

Figure 2.1 Map of the study area showing sampling sites in the shelf (black dots) and slope (white dots)

around the south and west of the cape. The sampling sites represent 32 grids across the SEAS shelf with spatial and depth variability. Sampling was done during the summer monsoon (SM, June-September), fall inter-monsoon

(FIM, October), winter monsoon (WM, November-February) and spring inter-monsoon (SIM, March-May) seasons.

Echinoderms, which constitute both epifauna and infauna, were collected using two sampling gears in the shelf region. Epifauna were collected using a modified naturalist dredge, with a metal frame of length 1 m and height 0.3 m and a nylon net bag of 1 cm mesh size (Figure 2.2). Towing of the dredge was done for 10 minutes at a speed of 2 nautical miles per hour (3.7 km/h), with each haul covering approximately 600-620 m^2 of the seafloor. Faunal groups (live) in the dredge samples were sorted on-board and preserved. The echinoderms were preserved in 70% ethanol,

Figure 2.2 Sampling Platform FORV *Sagar Sampada*, and sampling gears - Naturalist dredge and Smith-McIntyre Grab

since they are primarily identified based on the calcareous plates and spicules on their body, which disintegrate upon prolonged immersion in acidic preservatives like formalin.

Infauna (macro infauna) were separated from sediment samples obtained using a modified Smith-McIntyre grab (Figure 2.2) of 0.1-0.2 m^2 bite area, by on-board sieving using a 0.5 mm mesh test sieve. Samples were preserved in 8% buffered formaldehyde solution. Additionally, echinoderms were also collected from eight operations of deep-sea demersal trawls (High Speed Demersal Trawl, HSDT) and seven dredge operations in the continental slope (200-1500 m). Operations of the naturalist dredge and demersal trawls were done after scanning for suitable grounds using the on-board Echo sounder (SIMRAD EK-60).

Relevant data on environmental parameters were collected from all stations in the continental shelf to elucidate the influence of environment on echinoderm distribution. Data on salinity, temperature and dissolved oxygen concentration of bottom water were collected using the on-board conductivity temperature depth (CTD) profiler (Model SBE-911). CTD data on dissolved oxygen was cross-checked at a few sites with data from the Winkler Method following Strickland and Parsons (1972). Sub-samples for analysis of sediment characteristics were taken from the grab samples. During the study, 241 sites were covered in the continental shelf, through 112 dredge operations and 410 grab operations. In addition, 22 sites in the continental slope were also sampled (Figure 2.1, Table 2.2).

2.4 Analysis

2.4.1 Analysis of biological samples

2.4.1.1 Epifauna

Faunal groups collected in the dredge hauls included echinoderms, molluscs (chiefly gastropods, cephalopods and bivalves), crustaceans (chiefly brachyuran crabs, prawns, hermit crabs and stomatopods), fishes, echiuroids, nemertines, sponges and coelenterates. The samples in each taxonomic group was enumerated and expressed in individuals per haul (ind./haul). Owing to the nature of the sampling gear, the abundance data from dredge collections were considered as semi-quantitative. Out of the 123 dredge hauls, 112 were considered for quantitative analysis, while 11 were omitted since the operations did not meet the requisite standards.

2.4.1.2 Infauna

Sediment samples collected using the grab were sieved again in the shore lab (0.5 mm test sieve) and sorted into major taxonomic groups, viz. polychaetes, crustaceans, molluscs, echinoderms and other groups, each group was enumerated and wet-weight was taken. After sorting, the echinoderms were preserved in 70% ethanol. Density and biomass of these groups were expressed as individuals and grams per square meter (ind. m^{-2} and g m^{-2}), in order to quantify the contribution of echinoderms to infaunal standing stock.

2.4.1.3 Taxonomic identification of echinoderms

Taxonomic identification of the shallow-water (up to ~200 m) echinoderms was carried out primarily using the key of Clark & Rowe (1971). Other relevant taxonomic publications such as Koehler (1898, 1910), Koehler & Vaney (1905), H. L. Clark (1909), A. H. Clark (1912a, b), Fell (1960), James (1968b, 1971, 1987d, 1997), A. M. Clark (1970) and Cherbonnier & Guille (1978) were also used. Deep-sea echinoderms were identified by following the results of the RIMS Investigator expeditions (Alcock 1893b, Wood-Mason & Alcock 1891, Anderson 1894, Walsh 1891, Koehler 1897, 1909, 1914, 1922, Koehler & Vaney 1905, 1927) and more recent taxonomic works (Madsen 1961, Mah 2007, O'Hara & Stöhr 2006 etc.). The status and validity of all taxa were checked and updated using the World Register of Marine Species (WoRMS Editorial Board 2016). Data on presence and absence of echinoderm species collected using various gears from the 241 sites of the continental shelf were pooled together in order to examine their distribution patterns in the SEAS shelf as a whole (Chapter 4).

2.4.2 Sediment characteristics

Sediment texture analysis was done using a CILAS 1180 particle size analyser, and data on percentage composition of sand, silt and clay was taken along with median and mean grain size. Samples which were coarser in nature, and therefore not suitable for analysis through the particle size analyser, were subjected to serial sieving (at half Φ intervals) and data on sediment texture was extracted using GRADISTAT v8 software. Organic matter (OM) content of the sediments was estimated following the wet-oxidation method of El-Wakeel & Riley (1957) and expressed as percentage dry weight of sediments. The sediment

2.4.3 Data analysis

The number of species collected in each sample was used as a direct measure of diversity in the present study. A diagrammatic method for estimating species richness was also adopted, by using a species-area curve or species accumulation curve (Clarke & Warwick 2001), which depicts the cumulative number of species observed as each sample is added. The plot reaches its upper asymptote when a majority of the species in a community have been obtained, and is therefore also used to test sampling sufficiency (Clarke & Warwick 2001, Khan 2006). Accumulation curves indicate the rate at which species are added (Magurran 2013). Several methods have been developed to extrapolate the actual species accumulation curves to estimate total species richness, of which Chao 2 as well as Jacknife estimators (1 & 2) have been used in the present study. The Chao's (1984) estimators are based on the numbers of rare species, of which Chao-2, is modified for use with presence-absence data (Colwell & Coddington 1994).

$$S_{Chaos2} = S_{Obs} + \frac{Q_1^2}{2Q_2}$$

Where S_{Obs} indicates the number of observed species, Q_1 is the number of species that occur only in one sample and Q_2 is the number of species that occur in exactly two samples.

In general, Chao's estimators provide minimum estimates of species richness, and assume homogeneity among samples (Magurran 2013). Jacknife estimators also predict species richness on the basis of presence-absence data and place emphasis on rare species. The first order estimator (Jacknife-1) employs the number of species that occur only in one sample, while the second order estimator (Jacknife-2) also takes into account species that occur in exactly two samples (Burnham & Overton 1978, Heltshe & Forrester 1983).

$$S_{Jack1} = S_{Obs} + Q_1\left(\frac{m-1}{m}\right)$$

$$S_{Jack2} = S_{Obs} + \left[\frac{Q_1(2m-3)}{m} - \frac{Q_2(m-2)^2}{m(m-1)}\right]$$

Where S_{Obs} indicates the number of observed species, Q_1 is the number of species that occur only in one sample, Q_2 is the number of species that occur in exactly two samples and m is the total number of samples.

The species accumulation curve was plotted and estimators were calculated using PRIMER-6 package (Clarke & Gorley 2006).

To elucidate the distribution patterns of echinoderms across the SEAS shelf, the data on distribution of epifauna, infauna and echinoderm species was subjected to multivariate analyses using the PRIMER 6 package. In the case of epifaunal and infaunal abundance, Bray-Curtis similarity was calculated based on square-root transformed data. Since multiple sampling gears were used in the present study, the species distribution data was taken as presence or absence, rather than quantitative data. The degree of similarity between stations on the basis of species occurrence was calculated using the Kulczynski index (Kulczynski 1927, Clarke & Warwick 2001), which is ideal for elucidating ecological patterns using presence-absence data (Faith *et al.* 1987). Euclidean distance measures among sites were computed based on the measured environmental parameters (log-transformed and normalised data). The spatio-temporal variations in abundance and composition of epifauna, infauna and echinoderms as well as environmental variables were tested using Permutational Multivariate Analysis of Variance (PERMANOVA) in the PERMANOVA+ add-on for PRIMER-6. This method was chosen over the ANOVA and MANOVA procedures, since the latter tests assume normal distribution of data and are to be used only with Euclidean distance measures. The PERMANOVA, on the other hand, is permutation-based, and can be used with any similarity (or distance) measure. Pearson's correlation coefficient (r) was also used (IBM SPSS 20) to test the strength of relationship between environmental variables (temperature, salinity, DO, OM, sand, silt and clay content, median and mean grain size), depth and latitude.

In an ecosystem, environmental factors act in combination to affect patterns of distribution of organisms. A Principal Component Analysis (PCA) was carried out on log-transformed and normalised environmental data (using PRIMER-6), which resolved the set of covariate or correlated environmental parameters into linearly un-correlated variables known as Principal Components, such that the first principal component explains maximum variability among samples or sites. The PCA scatterplot gives an ordination of the sites, such that those with similar environmental conditions fall closer together. The PCA plot, therefore, was useful to analyse and visualise the overall variations in all environmental parameters across the study area.

Echinoderm species were classified based on the feeding modes, such as detritivores, grazers, predators and suspension feeders (Meyer 1982, Massin 1982, De Ridder & Lawrence 1982, Jangoux 1982, Warner 1982). A PCA of environmental parameters, as well as abundance of macro infauna (which constitute main prey for predators) was plotted and the number of species of each feeding type was superimposed as a bubble on the PCA (of environmental data). The habitat preferences of echinoderm species in the SEAS could thus be visualised.

Table 2.1 Location of sampling sites on the continental shelf

No.	Cruise/ Station	Lat. (N)	Long. (E)	Transect	Depth (m)	Date	Season	Grab	Dredge
1	236/9	9° 57.00'	75° 58.80'	T4	30	03.08.'05	SM	+	
2	236/10	9° 52.20'	75° 51.00'	T4	48	03.08.'05	SM	+	+
3	236/11	9° 45.00'	75° 40.20'	T4	113	03.08.'05	SM	+	
4	236/13	9° 00.00'	76° 22.80'	T3	33	04.08.'05	SM	+	
5	236/14	8° 58.20'	76° 16.80'	T3	52	04.08.'05	SM	+	
6	236/15	8° 55.20'	76° 04.80'	T3	75	04.08.'05	SM	+	
7	236/16	8° 54.00'	76° 01.20'	T3	95	04.08.'05	SM	+	
8	236/18	8° 31.80'	76° 48.00'	T2	37	05.08.'05	SM	+	
9	236/19	8° 25.80'	76° 42.00'	T2	58	05.08.'05	SM	+	
10	236/21	8° 3.00'	77° 21.00'	T1	32	05.08.'05	SM	+	
11	236/22	7° 55.80'	77° 55.80'	T1	50	05.08.'05	SM	+	
12	236/23	7° 19.80'	77° 19.20'	T1	122	06.08.'05	SM	+	
13	260/55	7° 12.94'	77° 31.03'	T1	206	24.12.'08	WM	+	
14	260/56	7° 25.98'	77° 29.68'	T1	108	25.12.'08	WM	+	
15	260/57	7° 46.69'	77° 29.04'	T1	54	25.12.'08	WM	+	
16	260/58	8° 28.89'	76° 43.46'	T2	52	25.12.'08	WM	+	+
17	260/59	8° 29.21'	76° 26.70'	T2	113	25.12.'08	WM	+	
18	260/60	8° 29.41'	76° 21.64'	T2	212	25.12.'08	WM	+	
19	260/61	8° 59.65'	75° 56.93'	T3	205	26.12.'08	WM	+	
20	260/62	8° 59.80'	75° 59.24'	T3	112	26.12.'08	WM	+	
21	260/63	8° 59.79'	76° 16.95'	T3	50	26.12.'08	WM	+	
22	260/64	8° 57.90'	76° 23.33'	T3	32	26.12.'08	WM		+
23	260/65	10° 2.34'	75° 59.77'	T4	32	26.12.'08	WM		+
24	260/66	10° 0.19'	75° 49.74'	T4	51	26.12.'08	WM	+	
25	260/67	9° 57.57'	75° 37.71'	T4	110	26.12.'08	WM	+	
26	260/68	9° 57.63'	75° 35.38'	T4	227	26.12.'08	WM	+	
27	267I/1	7° 59.28'	77° 38.70'	T1	30	30.05.'09	SIM	+	+
28	267I/2	7° 47.64'	77° 30.26'	T1	52	30.05.'09	SIM	+	+
29	267I/3	7° 28.51'	77° 30.64'	T1	99	30.05.'09	SIM	+	+
30	267I/4	8° 30.34'	76° 51.00'	T2	35	31.05.'09	SIM	+	+
31	267I/5	8° 30.04'	76° 43.83'	T2	51	31.05.'09	SIM	+	+
32	267I/6	8° 28.17'	76° 29.60'	T2	101	01.06.'09	SM	+	
33	267I/7	8° 27.90'	76° 24.01'	T2	210	01.06.'09	SM	+	
34	267I/12	9° 00.01'	75° 56.85'	T3	223	03.06.'09	SM	+	
35	267I/13	8° 59.49'	75° 59.33'	T3	100	03.06.'09	SM	+	
36	267I/14	9° 00.03'	76° 17.01'	T3	49	03.06.'09	SM	+	+
37	267I/15	9° 00.08'	76° 23.52'	T3	31	03.06.'09	SM	+	+
38	267I/18	9° 56.44'	75° 35.66'	T4	212	04.06.'09	SM	+	
39	267II/7	11° 14.52'	74° 55.71'	T5	211	08.06.'09	SM	+	
40	267II/8	11° 13.25'	75° 20.30'	T5	50	10.06.'09	SM	+	+
41	267II/9	11° 14.84'	75° 36.80'	T5	32	09.06.'09	SM	+	+
42	267II/10	11° 14.79'	74° 59.30'	T5	101	10.06.'09	SM	+	+
43	267II/12	11° 59.66'	74° 36.15'	T6	97	11.06.'09	SM	+	
44	267II/13	11° 59.79'	74° 55.08'	T6	53	11.06.'09	SM	+	
45	267II/14	12° 00.05'	75° 03.34'	T6	33	11.06.'09	SM	+	+
46	267II/22	9° 56.39'	75° 38.30'	T4	98	13.06.'09	SM	+	+

Table 2.1 Location of sampling sites on the continental shelf cont.

No.	Cruise/ Station	Lat. (N)	Long. (E)	Transect	Depth (m)	Date	Season	Grab	Dredge
47	267II/23	9° 56.33'	75° 51.16'	T4	49	13.06.'09	SM	+	+
48	267II/24	9° 55.78'	76° 03.66'	T4	29	13.06.'09	SM	+	+
49	270I/1	12° 59.33'	74° 37.59'	T7	32	04.08.'09	SM	+	
50	270I/2	13° 00.17'	74° 27.49'	T7	48	05.08.'09	SM	+	
51	270I/3	12° 59.84'	74° 03.35'	T7	101	05.08.'09	SM	+	
52	270I/4	12° 58.58'	73° 56.52'	T7	189	05.08.'09	SM	+	
53	270I/9	12° 00.07'	74° 26.29'	T6	186	06.08.'09	SM	+	
54	270I/10	12° 00.13'	74° 34.85'	T6	108	06.08.'09	SM	+	
55	270I/11	12° 00.18'	74° 54.60'	T6	53	06.08.'09	SM	+	+
56	270I/12	12° 00.56'	75° 04.17'	T6	29	06.08.'09	SM	+	+
57	270I/15	11° 14.96'	74° 55.36'	T5	210	07.08.'09	SM	+	
58	270I/16	11° 14.40'	74° 58.84'	T5	113	07.08.'09	SM	+	
59	270I/17	11° 15.35'	75° 18.88'	T5	53	07.08.'09	SM	+	+
60	270I/18	11° 15.29'	75° 37.19'	T5	30	07.08.'09	SM	+	+
61	270I/21	9° 56.15'	75° 35.77'	T4	201	08.08.'09	SM	+	
62	270I/22	9° 56.68'	75° 38.12'	T4	106	08.08.'09	SM	+	+
63	270I/23	9° 56.18'	75° 50.57'	T4	52	08.08.'09	SM	+	
64	270I/24	9° 55.94'	76° 00.04'	T4	33	08.08.'09	SM	+	+
65	270II/1	9° 00.28'	76° 23.75'	T3	30	14.08.'09	SM	+	+
66	270II/2	9° 00.19'	76° 17.27'	T3	50	14.08.'09	SM	+	+
67	270II/3	8° 59.67'	75° 59.33'	T3	113	14.08.'09	SM	+	+
68	270II/4	8° 59.89'	75° 56.57'	T3	214	14.08.'09	SM	+	
69	270II/9	8° 30.34'	76° 51.25'	T2	31	16.08.'09	SM	+	+
70	270II/10	8° 29.69'	76° 43.68'	T2	53	16.08.'09	SM	+	+
71	270II/11	8° 28.10'	76° 29.31'	T2	108	16.08.'09	SM	+	+
72	270II/12	8° 28.34'	76° 23.84'	T2	198	16.08.'09	SM	+	
73	270II/19	7° 59.26'	77° 36.64'	T1	32	18.08.'09	SM	+	+
74	270II/20	7° 47.42'	77° 30.83'	T1	52	18.08.'09	SM	+	+
75	270II/21	7° 27.83'	77° 30.09'	T1	100	18.08.'09	SM	+	+
76	270II/22	7° 13.98'	77° 30.79'	T1	199	18.08.'09	SM	+	
77	275/1	9° 54.28'	75° 35.74'	T4	231	13.05.'10	SIM	+	+
78	275/2	9° 54.54'	75° 35.49'	T4	116	13.05.'10	SIM	+	+
79	275/3	9° 54.76'	76° 01.61'	T4	50	13.05.'10	SIM	+	
80	275/4	9° 54.56'	76° 02.95'	T4	33	14.05.'10	SIM	+	+
81	275/5	9° 53.55'	76° 08.20'	T4	22	14.05.'10	SIM		
82	275/6	9° 20.54'	75° 49.45'	T3	229	14.05.'10	SIM	+	
83	275/7	9° 20.97'	75° 52.84'	T3	111	14.05.'10	SIM	+	+
84	275/8	9° 20.84'	76° 05.75'	T3	53	14.05.'10	SIM	+	
85	275/9	9° 20.83'	76° 13.08'	T3	30	15.05.'10	SIM	+	
86	275/10	9° 20.48'	76° 15.93'	T3	20	15.05.'10	SIM	+	
87	275/11	8° 28.72'	76° 23.87'	T2	187	15.05.'10	SIM	+	
88	275/12	8° 28.71'	76° 28.99'	T2	102	15.05.'10	SIM	+	+
89	275/13	8° 30.60'	76° 44.02'	T2	50	15.05.'10	SIM	+	
90	275/14	8° 30.19'	76° 50.98'	T2	33	15.05.'10	SIM	+	+
91	275/15	8° 03.41'	77° 29.81'	T1	24	16.05.'10	SIM	+	
92	275/16	8° 02.20'	77° 29.95'	T1	31	16.05.'10	SIM	+	+

Table 2.1 Location of sampling sites on the continental shelf cont.

No.	Cruise/ Station	Lat. (N)	Long. (E)	Transect	Depth (m)	Date	Season	Grab	Dredge
93	275/17	7° 48.58'	77° 29.61'	T1	51	16.05.'10	SIM	+	+
94	275/18	7° 27.92'	77° 31.14'	T1	100	16.05.'10	SIM	+	
95	275/19	7° 20.58'	77° 44.28'	T1	200	16.05.'10	SIM	+	
96	282/7	8° 01.55'	76° 49.14'	T1	86	15.11.'10	WM		+
97	282/8	7° 59.2'	77° 10.76'	T1	49	15.11.'10	WM		+
98	282/10	8° 26.01'	76° 47.94'	T2	53	20.11.'10	WM		+
99	282/12	8° 59.38'	76° 17.33'	T3	49	21.11.'10	WM		+
100	282/27	9° 58.27'	75° 49.11'	T4	55	26.11.'10	WM		+
##	288/1	10° 30.73'	75° 45.85'	T4	41	04.08.'11	SM	+	+
102	288/3	10° 30.53'	75° 31.67'	T4	84	04.08.'11	SM	+	+
103	288/6	11° 12.42'	75° 05.55'	T5	81	07.08.'11	SM	+	+
104	288/8	11° 14.92'	75° 36.71'	T5	33	07.08.'11	SM	+	+
105	288/10	11° 57.52'	74° 41.16'	T6	83	08.08.'11	SM	+	+
106	288/12	11° 58.25'	75° 05.10'	T6	31	08.08.'11	SM	+	+
107	288/14	12° 21.58'	74° 30.13'	T6	87	09.08.'11	SM	+	+
108	289/1	10° 00.08'	75° 59.95'	T4	36	25.08.'11	SM		+
109	289/2	9° 56.54'	75° 51.07'	T4	50	26.08.'11	SM	+	+
110	289/3	9° 55.49'	75° 38.05'	T4	109	26.08.'11	SM	+	+
111	289/4	9° 56.51'	75° 35.14'	T4	196	27.08.'11	SM	+	+
112	289/9	9° 00.12'	75° 56.80'	T3	155	28.08.'11	SM	+	+
113	289/10	9° 00.16'	76° 01.41'	T3	89	28.08.'11	SM	+	
114	289/11	8° 59.92'	76° 13.91'	T3	53	28.08.'11	SM	+	+
115	289/12	8° 59.40'	76° 23.31'	T3	34	28.08.'11	SM	+	
116	289/16	8° 24.98'	76° 32.46'	T2	106	30.08.'11	SM	+	
117	289/17	8° 26.30'	76° 47.16'	T2	52	30.08.'11	SM	+	+
118	289/18	8° 27.05'	76° 53.96'	T2	38	30.08.'11	SM	+	
119	289/19	8° 30.00'	76° 48'.00'	T2	50	31.08.'11	SM	+	
120	289/20	8° 30.00'	76° 48'.00'	T2	50	31.08.'11	SM	+	
121	289/21	8° 30.00'	76° 48'.00'	T2	51	31.08.'11	SM	+	+
122	289/22	8° 30.00'	76° 48'.00'	T2	50	31.08.'11	SM	+	
123	289/25	8° 30.00'	76° 48'.00'	T2	52	01.09.'11	SM	+	
124	289/29	8° 30.00'	76° 48'.00'	T2	51	02.09.'11	SM	+	+
125	289/33	8° 30.00'	76° 48'.00'	T2	52	03.09.'11	SM	+	+
126	289/37	8° 30.00'	76° 48'.00'	T2	52	04.09.'11	SM	+	+
127	289/38	8° 30.00'	76° 48'.00'	T2	51	04.09.'11	SM	+	
128	289/40	8° 30.00'	76° 48'.00'	T2	51	05.09.'11	SM	+	
129	289/41	8° 30.00'	76° 48'.00'	T2	52	05.09.'11	SM	+	+
130	289/44	8° 30.00'	76° 48'.00'	T2	54	06.09.'11	SM	+	
131	289/45	8° 30.00'	76° 48'.00'	T2	52	06.09.'11	SM	+	+
132	289/49	8° 30.00'	76° 48'.00'	T2	52	07.09.'11	SM	+	+
133	289/50	8° 30.00'	76° 48'.00'	T2	51	07.09.'11	SM	+	
134	289/52	8° 30.00'	76° 48'.00'	T2	53	08.09.'11	SM	+	
135	289/53	8° 30.00'	76° 48'.00'	T2	51	08.09.'11	SM		+
136	295/1	11° 18.55'	74° 52.284'	T5	199	22.02.'12	WM	+	
137	295/2	11° 17.64'	74° 56.71'	T5	105	22.02.'12	WM	+	+
138	295/3	11° 19.17'	75° 18.90'	T5	52	22.02.'12	WM	+	+

Table 2.1 Location of sampling sites on the continental shelf cont.

No.	Cruise/ Station	Lat. (N)	Long. (E)	Transect	Depth (m)	Date	Season	Grab	Dredge
139	295/4	11° 21.76'	75° 34.02'	T5	31	22.02.'12	WM	+	
140	295/5	11° 58.31'	75° 04.97'	T6	32	23.02.'12	WM	+	+
141	295/6	11° 56.19'	75° 00.76'	T6	51	23.02.'12	WM	+	+
142	295/7	11° 48.56'	74° 52.62'	T6	65	23.02.'12	WM	+	+
143	295/8	11° 45.04'	74° 41.79'	T6	95	23.02.'12	WM	+	
144	295/9	11° 42.21'	74° 34.25'	T6	207	23.02.'12	WM	+	+
145	295/10	12° 48.91'	74° 39.50'	T7	37	24.02.'12	WM	+	+
146	295/11	12° 48.99'	74° 32.36'	T7	51	24.02.'12	WM	+	+
147	295/12	12° 44.14'	74° 13.63'	T7	105	24.02.'12	WM	+	+
148	295/13	12° 43.91'	74° 06.55'	T7	202	24.02.'12	WM	+	+
149	295/14	14° 10.29'	74° 18.02'	T8	31	25.02.'12	WM	+	+
150	295/15	14° 07.70'	74° 04.66'	T8	54	25.02.'12	WM	+	+
151	295/16	14° 04.50'	73° 48.53'	T8	70	25.02.'12	WM	+	
152	295/17	14° 00.35'	73° 32.49'	T8	101	25.02.'12	WM	+	+
153	295/18	13° 56.35'	73° 21.54'	T8	204	25.02.'12	WM	+	+
154	295/19	9° 44.60'	75° 36.17'	T4	199	27.02.'12	WM	+	+
155	295/20	9° 46.07'	75° 41.43'	T4	98	27.02.'12	WM	+	+
156	295/21	9° 52.96'	75° 52.58'	T4	52	27.02.'12	WM	+	+
157	295/22	9° 56.45'	76° 00.32'	T4	33	27.02.'12	WM	+	+
158	315/6	10° 24.50'	75° 39.90'	T4	60	08.07.'13	SM		+
159	315/9	10° 23.72'	75° 46.88'	T4	30	08.07.'13	SM	+	
160	316/3	8° 32.17'	76° 47.79'	T2	27	16.07.'13	SM	+	
161	316/4	8° 30.91'	76° 45.06'	T2	49	16.07.'13	SM	+	
162	316/5	8° 25.44'	76° 33.08'	T2	84	16.07.'13	SM	+	
163	316/13	8° 52.97'	76° 21.38'	T3	52	18.07.'13	SM	+	
164	316/14	8° 52.41'	76° 26.41'	T3	43	18.07.'13	SM	+	
165	316/17	9° 28.96'	76° 08.94'	T3	32	19.07.'13	SM	+	
166	316/19	9° 29.77'	75° 49.94'	T3	105	19.07.'13	SM	+	
167	316/23	9° 57.83'	75° 38.27'	T4	108	20.07.'13	SM	+	
168	316/24	9° 58.10'	75° 49.62'	T4	55	20.07.'13	SM	+	
169	316/25	9° 58.33'	76° 01.24'	T4	31	20.07.'13	SM	+	
170	317/1	9° 57.89'	76° 00.02'	T4	33	30.07.'13	SM	+	
173	317/2	9° 58.35'	75° 49.66'	T4	54	30.07.'13	SM	+	
172	317/3	9° 58.13'	75° 39.15'	T4	100	31.07.'13	SM	+	
173	317/7	10° 22.02'	75° 36.32'	T4	115	02.08.'13	SM	+	
174	317/8	10° 23.54'	75° 46.31'	T4	50	02.08.'13	SM	+	
175	317/9	10° 22.53'	75° 56.67'	T4	30	02.08.'13	SM	+	
176	317/10	11° 20.06'	75° 32.58'	T5	31	03.08.'13	SM	+	
177	317/13	11° 58.31'	75° 04.97'	T6	30	08.08.'13	SM	+	+
178	317/14	11° 59.40'	74° 56.33'	T6	53	08.08.'13	SM	+	
179	317/15	11° 59.02'	74° 37.77'	T6	95	08.08.'13	SM	+	
180	317/21	12° 50.60'	74° 10.72'	T7	100	10.08.'13	SM	+	+
181	317/22	12° 49.86'	74° 30.22'	T7	53	10.08.'13	SM	+	
182	317/24	12° 58.49'	74° 38.35'	T7	32	14.08.'13	SM	+	
183	317/26	13° 52.39'	74° 23.88'	T8	33	15.08.'13	SM	+	
184	317/27	13° 53.86'	74° 0.60'	T8	52	15.08.'13	SM	+	+

Table 2.1 Location of sampling sites on the continental shelf cont.

No.	Cruise/ Station	Lat. (N)	Long. (E)	Transect	Depth (m)	Date	Season	Grab	Dredge
185	317/28	13° 52.78'	73° 49.83'	T8	65	15.08.'13	SM		+
186	317/41	14° 45.08'	73° 50.11'	T8	52	18.08.'13	SM	+	
187	317/42	14° 44.91'	73° 58.30'	T8	33	18.08.'13	SM	+	
188	317/43	14° 44.68'	74° 04.66'	T8	20	18.08.'13	SM	+	
189	319/1	8° 15.04'	76° 57.08'	T1	51	07.09.'13	SM	+	+
190	319/2	8° 04.48'	76° 44.47'	T1	113	07.09.'13	SM	+	+
191	319/6	7° 48.10'	77° 30.70'	T1	53	08.09.'13	SM	+	
192	319/10	8° 28.56'	76° 51.50'	T2	37	11.09.'13	SM	+	+
193	319/11	8° 28.43'	76° 45.86'	T2	50	11.09.'13	SM	+	
194	319/12	8° 28.33'	76° 29.29'	T2	102	11.09.'13	SM	+	
195	319/18	8° 59.85'	75° 59.69'	T3	108	12.09.'13	SM	+	
196	319/19	9° 00.03'	76° 16.09'	T3	50	12.09.'13	SM	+	+
197	319/20	9° 00.66'	76° 22.78'	T3	33	12.09.'13	SM	+	
198	321/11	7° 26.44'	76° 54.75'	T1	124	08.12.'13	WM		+
199	321/12	7° 59.37'	77° 18.76'	T1	48	09.12.'13	WM	+	+
200	321/13	8° 08.63'	77° 09.40'	T1	49	09.12.'13	WM		+
201	321/14	8° 02.04'	76° 59.83'	T1	56	09.12.'13	WM		+
202	321/15	7° 58.68'	76° 44.80'	T1	144	09.12.'13	WM		+
203	321/19	8° 22.92'	76° 29.02'	T2	221	11.12.'13	WM	+	+
204	321/21	9° 14.52'	76° 12.02'	T3	47	13.12.'13	WM	+	
205	329/31	12° 56.94'	74° 01.81'	T7	152	27.09.'14	SM		+
206	329/32	12° 50.60'	74° 09.86'	T7	103	27.09.'14	SM	+	+
207	329/33	12° 51.02'	74° 29.71'	T7	53	27.09.'14	SM	+	+
208	329/34	12° 50.90'	74° 29.65'	T7	31	27.09.'14	SM	+	
209	330/1	12° 50.68'	74° 40.72'	T7	30	04.10.'14	FIM	+	
210	330/2	12° 50.32'	74° 30.26'	T7	51	04.10.'14	FIM	+	+
211	330/3	12° 50.17'	74° 09.75'	T7	105	04.10.'14	FIM	+	+
212	330/4	12° 50.40'	74° 02.10'	T7	211	05.10.'14	FIM	+	+
213	330/11	11° 59.96'	74° 25.54'	T6	204	08.10.'14	FIM	+	+
214	330/12	12° 0.38'	74° 35.18'	T6	102	08.10.'14	FIM	+	+
215	330/13	11° 59.52'	74° 57.18'	T6	52	08.10.'14	FIM	+	
216	330/14	11° 59.22'	75° 04.21'	T6	32	09.10.'14	FIM	+	
217	330/15	11° 23.25'	75° 32.55'	T5	32	09.10.'14	FIM	+	
218	330/16	11° 22.70'	75° 17.71'	T5	53	09.10.'14	FIM	+	+
219	330/17	11° 23.64'	74° 52.12'	T5	101	09.10.'14	FIM	+	+
220	330/18	11° 23.24'	74° 48.55'	T5	181	09.10.'14	FIM	+	
221	330/25	10° 30.34'	75° 24.69'	T4	188	11.10.'14	FIM	+	
222	330/26	10° 29.57'	75° 31.70'	T4	88	12.10.'14	FIM	+	+
223	330/27	10° 29.33'	75° 41.98'	T4	51	12.10.'14	FIM	+	+
224	330/28	10° 29.82'	75° 51.40'	T4	30	12.10.'14	FIM	+	
225	330/29	9° 57.25'	76° 00.37'	T4	32	13.10.'14	FIM	+	
226	330/30	9° 57.63'	75° 50.12'	T4	51	13.10.'14	FIM	+	
227	330/31	9° 56.40'	75° 39.07'	T4	95	13.10.'14	FIM	+	
228	330/32	9° 58.22'	75° 35.54'	T4	196	13.10.'14	FIM	+	
229	330/75	8° 29.94'	76° 22.13'	T2	195	24.10.'14	FIM	+	
230	330/76	8° 29.88'	76° 26.62'	T2	105	24.10.'14	FIM	+	+

Table 2.1 Location of sampling sites on the continental shelf cont.

No.	Cruise/ Station	Lat. (N)	Long. (E)	Transect	Depth (m)	Date	Season	Grab	Dredge
231	330/77	8° 30.88'	76° 43.50'	T2	50	24.10.'14	FIM	+	+
232	330/78	8° 30.36'	76° 50.62'	T2	34	24.10.'14	FIM	+	+
233	330/79	8° 48.02'	76° 33.58'	T3	33	25.10.'14	FIM	+	+
234	330/80	8° 48.19'	76° 22.33'	T3	52	25.10.'14	FIM	+	+
235	330/81	8° 48.71'	76° 04.57'	T3	96	25.10.'14	FIM	+	+
236	333/1	9° 57.48'	76° 00.12'	T4	33	13.12.'14	WM	+	
237	333/2	10° 00.08'	75° 49.99'	T4	52	13.12.'14	WM	+	+
238	333/3	10° 00.15'	75° 38.43'	T4	102	13.12.'14	WM	+	+
239	333/7	12° 49.91'	74° 40.85'	T7	31	15.12.'14	WM	+	
240	333/8	12° 49.75'	74° 30.35'	T7	52	15.12.'14	WM	+	+
241	333/9	12° 50.21'	74° 09.95'	T7	102	15.12.'14	WM		+

Table 2.2 Location of sampling sites on the continental slope

No.	Cruise/ Station	Lat. (N)	Long. (E)	Transect	Depth (m)	Date	Season	Grab	Dredge	Trawl
1	219/12	9° 50.16'	75° 32.86'	T4	988	19.12.'03	WM	+		
2	219/17	11° 55.93'	74° 23.13'	T6	525	21.12.'03	WM		+	
3	219/21	12° 46.14'	73° 58.39'	T7	991	22.12.'03	WM		+	
4	225/1	7° 10.27'	77° 20.86'	T1	245	14.05.'04	SIM		+	
5	225/8	8° 55.30'	75° 29.03'	T3	454	12.05.'04	SIM		+	
6	233/11	9° 56.28'	75° 82.99'	T4	500	23.04.'05	SIM		+	
7	233/15	10° 59.29'	74° 59.52'	T5	992	14.04.'05	SIM		+	
8	233/17	11° 56.54'	74° 22.66'	T5	523	17.04.'05	SIM		+	
9	233/21	12° 53.45'	73° 47.00'	T5	1000	18.04.'05	SIM		+	
10	254/2	7° 10.02'	77° 19.21'	T1	454	20.05.'07	SIM	+		
11	254/12	9° 50.16'	75° 32.87'	T4	835	03.05.'07	SIM		+	
12	278/2	9° 54.00'	75° 31.44'	T4	1120	08.08.'10	SM			+
13	281/3	8° 24.15'	76° 1.64'	T2	995	12.10.'10	FIM			+
14	305/1	8° 17.13'	76° 12.42'	T2	1069	19.10.'12	FIM			+
15	316/1	8° 17.19'	76° 12.34'	T2	1032	14.07.'13	SM			+
16	316/2	7° 47.48'	76° 27.31'	T1	1324	15.07.'13	SM			+
17	316/9	8° 24.61'	75° 52.71'	T2	1245	17.07.'13	SM			+
18	319/8	7° 53.24'	76° 25.77'	T1	1262	09.08.'13	SM			+
19	319/9	8° 15.28'	76° 01.89'	T2	1338	10.08.'13	SM			+
20	321/16	8° 00.85'	76° 25.91'	T1	1154	10.12.'13	WM			+
21	321/18	8° 25.12'	75° 55.18'	T2	1241	11.12.'13	WM			+
22	321/20	8° 31.78'	75° 59.74'	T2	1047	12.12.'13	WM			+

CHAPTER 3

Echinoderms of the south eastern Arabian Sea: Diversity & systematics

3.1 Introduction

The echinoderms of the South Eastern Arabian Sea (SEAS) continental margin were first recorded through the surveys of the Royal Indian Marine Survey (RIMS) *Investigator* (1888-1892), and subsequently through the works of Kurian (1953), James (1969, 1971), Price & Reid (1985) and Jayakumari (2004). While the *Investigator* surveys covered both the shelf areas (Koehler 1898, 1910, 1914, 1922, 1927, Koehler & Vaney, 1908) and deep-sea (Wood-Mason & Alcock 1891, Walsh 1891, Alcock 1893a, b, Anderson 1894, Koehler 1897, 1899, 1909, 1922, 1927, Koehler & Vaney 1905), the later surveys were restricted to intertidal and near-shore areas (<20 m depth). Further, 93 species of echinoderms have been reported from the Lakshadweep islands (Anderson 1894, Koehler 1898, 1922, 1927, Bell 1902, James 1969, 1989, Mukhopadhyay & Samanta 1983, Mukhopadhyay 1991, Sastry 1991b, 2007), of which 76 are reported exclusively from coral reef habitats of the archipelago, and 17 are common with the mainland coastal species. From the aforementioned surveys, a total of 209 species of echinoderms have been recorded from the SEAS, comprising 54 shallow, 79 deep-sea and 76 reef-associated species. Sastry (2007) provides a bibliographic list of echinoderms known from Indian waters, which includes records from the SEAS.

This chapter aims to document comprehensively the diversity of echinoderms in the 20 to 1500 m depths of the SEAS and revalidate the echinoderm species diversity in the SEAS. With this objective, 22 systematic surveys were carried out on-board FORV *Sagar Sampada* (FORVSS) during the years 2008 to 2014, covering 241 depth-stratified stations (20 m to 200 m/shelf break) along 8 transects in the continental shelf and 22 random stations in the continental slope (200-1500 m). Collections from the shelf were carried out using naturalist dredge and Smith-McIntyre grab, and from the slope using high-speed demersal trawl (HSDT), naturalist dredge and Smith-McIntyre grab. Methodologies and approaches in sampling are outlined in Chapter 2. The findings from the present study are given below, followed by a brief systematic account on the echinoderms of the SEAS continental margin (excluding the Lakshadweep Islands). Species numbers recorded in the present study, previously known species from the region and new records of echinoderms from SEAS are given in (Table 3.1). Tables 3.2 to 3.6 provide updated checklists of species for the five classes of echinoderms found in the SEAS. Echinoderms recorded from the near shore areas of Lakshadweep are given in Table 3.7. The distribution records given in the systematic account as well as Tables 3.2-3.7 also take into the account the annotated list of Sastry (2007). The status and validity of all taxa were checked and updated using the World Register of Marine Species (WoRMS Editorial Board 2016).

3.2 Results & discussion

3.2.1 Diversity of Echinoderms in the south eastern Arabian Sea

A total of 76 species of Echinoderms were recorded in the present study, which include 29 previously known species, 46 new records and 1 new species. From the continental shelf of the SEAS (20-200 m/shelf break), 5477 echinoderms were collected (from 112 dredge hauls and 410 grab operations), and assigned to 54 species under 25 families. Among the shelf echinoderms, echinoids (11 species in 7 families) were the numerically dominant group among the echinoderms, owing to the relatively high density of two species, *Clypeaster rarispinus* (Clypeasteridae) and *Sculpsitechinus auritus* (Astriclypeidae). The ophiuroids were represented by 24 species (6 families), asteroids by 8 species (5 families), holothurians by 5 species (3 families) and crinoids by 6 species (3 families). From the slope region (200-1500 m), 22 species were collected (from 11 HSDTs, 9 dredge hauls and 2 grab operations), representing Asteroidea (10 species), Ophiuroidea (6 species), Echinoidea (2 species), Holothuroidea (3 species) and Crinoidea (1 species). The predominantly deep-sea echinoid species, *Stereocidaris alcocki* (Cidaridae), was recorded at one site in the shelf (at 51 m depth). Apart from this, no other species was found common to the shelf and slope in the SEAS.

To test the sufficiency of sampling, species accumulation curves were plotted for the continental shelf and slope, and species estimators were calculated to determine the number of species likely to be encountered in the study area with unlimited sampling (principles detailed in Chapter 2, Section 2.5.3). The species accumulation curve for the continental shelf (Figure 3.1a) did not reach the upper asymptote, and estimators predicted the occurrence of up to 92 species in this region (Chao's 2 estimator: 79±13, Jacknife 1 estimator: 79 & Jacknife 2 estimator: 91 species). The present study (54 species from 241 sites) was able to collect 59% of the highest estimated diversity. An examination of the species distribution in the shelf region (detailed in Chapter 4, Section 4.2.1.3), revealed that the high values of the aforementioned estimators was due to the exceptionally high diversity in the Cape Comorin transect. Though the sampling sufficiency in the present study was almost 100% for transects north of Kochi, the rocky nature of bottom and coarser sediments around the Cape restricted the operations in this region to 28 sites (only 48-72% sampling sufficiency). While previous studies report

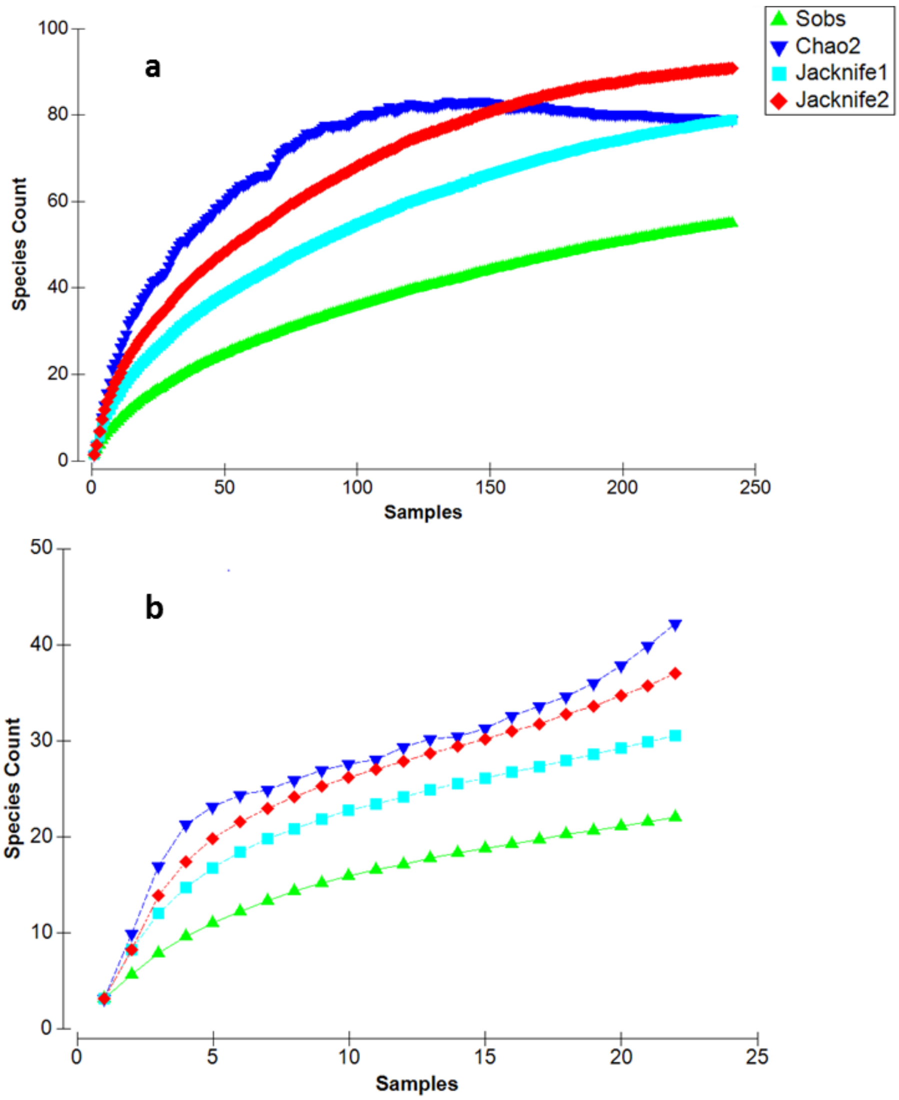

Figure 3.1 Species accumulation curves for echinoderms in the SE Arabian Sea continental shelf (a) and slope (b)

only 55 species from the SEAS continental shelf, the present study provides an additional 41 new records for the region. The species accumulation curve for the slope also did not approach the asymptote (Figure 3.1b). Species estimators predict that as many as 62 species (Chao's 2 estimator: 42±20, Jacknife 1 estimator: 31 & Jacknife 2 estimator: 37 species) may be collected in this region with intensified sampling. The present study, with 22 species (from 22 sites), has recorded only 54% of the highest estimator of species diversity. This may be attributed to the operational limitations of FORV *Sagar Sampada* in sampling the continental slope, which permitted only a limited number of random sample collections. Though 77 species have previously been reported from the slope region of the SEAS through the RIMS *Investigator* surveys, many of these were collected at depths beyond the present study area. In spite of limitations in sampling, the present study was able to discover 6 new records from the slope.

The 47 new records from the present study (Tables 3.2 to 3.6) include one species new to science (*Asteroschema sampadae*, Class Ophiuroidea), one species (*Zoroaster alfredi*, Class Asteroidea) newly recorded from the Arabian Sea, two species (*Ophioconis cupida*, Class Ophiuroidea and *Petasometra helianthoides*, Class Crinoidea) which are new records from the India EEZ, 30 new records from the Eastern Arabian Sea (EAS) and 13 new records from the SEAS. With these new records, the total number of to echinoderm species in the SEAS is now revalidated as 256 (95 species from the continental shelf, 85 species from the slope and 76 coral reef associated species from the Lakshadweep) as against the previous record of 209 species.

3.2.1.1 Class Asteroidea

Out of the 18 species of Class Asteroidea identified in the present study, 8 species were restricted to the continental shelf and 10 species to the slope areas of the SEAS. The 8 shelf species fall under families Astropectinidae (3 species), Luidiidae (2 species), Goniasteridae (1 species), Ophidiasteridae (1 species) and Oreasteridae (1 species). Among these, *Luidia hardwicki* (Family Luidiidae) was the most widely distributed species in the study area (Cape-Kochi, 33-111m depth range). This species is also widely distributed across the Indian Ocean (Clark & Rowe 1971). In the continental slope, class Asteroidea was represented by 10 species under families

Zoroasteridae (3 species), Goniasteridae (3 species), Asterinidae (1 species), Porcellanasteridae (1 species), Astropectinidae (1 species) and Brisingidae (1 species).

A review of literature reveals that 27 species of Asteroidea were known from the SEAS prior to the present study (Table 3.1), of which 5 species were from the shelf, including near shore (<20 m depth) and 22 were from the deep-sea, reported by the RIMS Investigator surveys (1888-1892). Among the 8 shelf species recorded in the present study, 6 are new records. These are *Astropecten hemprichi*, *A. vappa* (Astropectinidae), *Luidia denudata*, *L. hardwicki* (Luidiidae) and *Heteronardoa carinata* (Ophidiasteridae). Therefore, the number of species under class Asteroidea in the SEAS shelf is revalidated as 11 (6 new records + 5 previously known species). The 10 species recorded from the slope during the present study comprised 8 species recorded by earlier surveys and 2 new records. Other deep-sea Asteroidea (14 species) of the RIMS *Investigator* surveys were reported from depths >1500 m. The two new records from the slope are *Johannaster superbus* Koehler, 1909, previously reported only from the NE Arabian Sea and *Zoroaster alfredi* Alcock, 1893, reported from comparable depths in the Bay of Bengal. The updated checklist of Asteroidea from the deep-sea areas of SEAS, therefore, comprises 24 species (22 previously known + 2 new records). No species were found to be common to the shelf and slope among the Asteroidea. With the present observations, the total number of Asteroidea in SEAS is revalidated from 27 species (previous record) to 35 species (Table 3.1 and 3.2).

3.2.1.2 Class Ophiuroidea

In the present study, 30 species of ophiuroids were identified, of which 24 species are from the shelf and 6 species are from the slope region of the SEAS. The brittle stars of the SEAS shelf were represented by 24 species, falling under families Amphiuridae (12 species), Ophiotrichidae (6 species), Ophiodermatidae (2 species), Ophiocomidae (2 species), Ophiuridae (1 species) and Ophiacanthidae (1 species). The species *Ophiura kinbergi* (Family Ophiuridae) was the most widely distributed brittle-star on the SEAS shelf. The 6 species from the slope each belong to families Asteroschematidae, Ophiochitonidae, Ophiodermatidae, Ophiotrichidae, Ophiacanthidae and Ophiuridae.

Previous surveys report a total of 27 ophiuroid species from the SEAS, which includes 7 shelf species and 20 deep-sea species. Among the 30 species recorded in the present study, 20 species from the shelf and 3 species from the slope are new records (Table 3.1 & 3.3). The new records from the shelf include 11 species under family Amphiuridae [*Amphipholis misera*, *Amphiura ambigua*, *A. constricta*, *A. duncani*, *A. micra*, *A. heptacantha*, *A. tenuis*, *A. crispa*, *Dougalopus echinatus*, *Ophiodaphne scripta* (Parameswaran *et al.* 2013, Appendix 2) and *Ophiosphaera insignis*] 4 species under family Ophiotrichidae (*Ophiopteron elegans, Ophiothrix proteus, O. purpurea* and *O. foveolata*), 2 species each under family Ophiocomidae (*Ophiocoma brevipes* and *Ophiopsila pantherina*) and Ophiodermatidae (*Ophiarachnella infernalis* and *Ophioconis cupida*) and one species under family Ophiacanthidae (*Ophiacantha dallasii*). Of the 3 new records from the slope, the species *Asteroschema sampadae* under family Asteroschematidae collected from 450 m depth off Cape Comorin is a species new to science (Parameswaran & Abdul Jaleel 2012, Appendix 1). The other two new records from the slope are *Amphiophiura sordida* (Ophiuridae) and *Ophiothrix aristulata* (Ophiotrichidae). No species were found to be common to the shelf and slope among the Ophiuroidea. With the 23 new records from the present study, the species diversity of Ophiuroidea (Table 3.1 & 3.3) is revalidated to 50 (previously 27).

<u>3.2.1.3 Class Echinoidea</u>

Of the 13 species of Echinoidea identified in the present study, 11 were from the shelf and 2 species were from the slope region. The shelf species fall under family Clypeasteridae and Temnopleuridae (3 species each), Echinoneidae, Astriclypeidae, Echinolampadidae, Loveniidae and Maretiidae (1 species each). Two species, *Clypeaster rarispinus* (Clypeasteridae) and *Sculpsitechinus auritus* (Astriclypeidae) were the numerically dominant echinoderm species in the SEAS shelf. The two slope species belonged to family Cidaridae and Histocidaridae. Additionally, one taxon under Order Echinothurioida was also collected, but could not be identified to species level due to the mutilated condition of the specimen. Though this taxon is included in the systematic account, it is excluded from the comparative table and checklist, since species identity is not confirmed.

Previous surveys have reported 32 species of echinoids from the SEAS, of which 18 were from shelf areas and 14 from the deep-sea. Among the 13 species recorded in the present study, 6 shelf species (*Paratrema doederleini*, *Salmaciella dussumieri*, *Echinoneus cyclostomus*, *Echinolampas alexandri*, *Clypeaster fervens* and *Lovenia elongata*) are new records (Table 3.1 & 3.3). The deep-sea species, *Histocidaris denticulata* Koehler, 1927, was collected for the first time since its original description from the SEAS through the RIMS *Investigator* surveys (1888-1892). The *Stereocidaris alcocki* (Cidaridae), which is a deep-sea species (depth range ~280-1100 m), was also recorded at one site in the continental shelf (Cape Comorin, 51 m), and is the only echinoderm species to be recorded in both the shelf and the slope in the SEAS during the present study. With the 6 new records from the present study, the species diversity of Echinoidea in SEAS (Table 3.1 & 3.4) is revalidated as 43 (previously 37).

3.2.1.4 Class Holothuroidea

In the present study, 8 species of holothurians were identified, of which 5 were from the shelf and 3 were from the slope. The five shelf species from the shelf fall under families Cucumariidae (2 species), Phyllophoridae (2 species) and Synaptidae (1 species). One taxon could not be identified to species level owing to damage of specimen. The latter is included in the systematic account but excluded from the comparative table and checklist, since species identity is not confirmed. The 3 deep-sea species were represented by family Psychropotidae, Synallactidae and Molpadidae (1 species each). The validity of one of these (*Perizona magna* Koehler & Vaney, 1909) was doubted by recent workers (Sastry 2007), but specimens matching well with the original description were collected in the present study.

Previous surveys report a total of 32 species of holothurians, which included 18 from the shelf and 14 deep-sea species. Among the 8 species recorded in the present study, 3 species from the shelf (*Synaptula recta*, *Pseudocnus echinatus*, *Thyone dura*) and 1 species from the slope (*Benthodytes typica*) are new records. No holothurian species were found common to the shelf and slope of the SEAS. With the 4 new records from the present study, the diversity of Holothuroidea in the SEAS (Table 3.1 & 3.5) is revalidated as 36 species (previously 32).

3.2.1.5 Class Crinoidea

In the present study, 7 species of crinoids were recorded in the present study, of which 6 were from the shelf area and 1 was from the slope. The shelf species fell under family Antedonidae, Colobometridae and Himerometridae (2 species each), while the deep-sea species comes under family Cainocrinidae. In general, the crinoids were rare in the SEAS, being represented only at 4 stations in the shelf which were all confined to the Cape Comorin shelf region, and 1 station in the slope (991 m) off Mangalore.

Previous surveys report 10 species of Crinoidea from the SEAS, comprising 3 species from the shelf and 7 species from the slope. In the shelf area of SEAS, the present study revealed 6 new records, of which 2 species (*Antedon parviflora* and *Heterometra africana*) are newly reported from SEAS and the remaining 4 species (*Mastigometra micropoda*, *Cenometra bella*, *Petasometra helianthoides* and *Himerometra robustipinna*) are new for the entire eastern Arabian Sea & Gulf of Mannar. With the 6 new records from the present study, the species diversity of Crinoidea in the SEAS (Table 3.1 & 3.6) is revalidated as 16 species (previously 10).

3.2.2 Systematic account of Echinoderms of the south eastern Arabian Sea continental margin

Class Asteroidea de Blainville, 1830

Class Asteroidea comprises 1836 extant species, which fall under 40 families in 8 orders. In Indian waters, 161 species (under 83 genera and 20 families) and representing all 8 orders have been reported. In the SEAS continental margin, Order Paxillosida (Family Astropectinidae, Luidiidae, Porcellanasteridae & Pseudarchasteridae), Notomyotida (Benthopectinidae), Valvatida (Asterinidae, Goniasteridae, Ophidiasteridae & Oreasteridae), Forcipulatida (Zoroasteridae) and Brisingida (Brisingidae) are reported, with 35 species in 21 genera. Order Notomyotida, is known from depths >1500 m in the SEAS through RIMS *Investigator* surveys (Table 3.2, Nos. 15-18).

Order Paxillosida Perrier, 1884

Family Astropectinidae Gray, 1840

Genus *Astropecten* Gray, 1840

Astropecten polyacanthus Müller & Troschel, 1842

PL. I, Fig. 1-3

Collection locations: **Cape Comorin-Trivandrum, 51-52 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). – 8° 15.041' N, 76° 57.085' E, 51 m, 7.9.2013 (FORVSS 319, St. 1). TRIVANDRUM – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00073

Diagnosis: Major radius 5 cm, minor radius 1 cm. Paxillae with 2-6 central granules and 7-10 short, stout, peripheral spines. First supero-marginal on each arm with a very long, conical spine, subsequent two lacking spines; remaining with spines along the centre or adradial edge. A transverse series of stout, conical spines across the infero-marginals, of which the upper (lateral) most is the longest. Cream colour with dark brown patches in the disc and basal parts of the arm, brown mottles on the distal part of arms; supero-marginal and main infero-marginal spines conspicuous, bright orange in colour.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (Thurston 1895b, James 1969, 1985a, 1988), SW Bay of Bengal (Karuppaiyan 2007), and Andaman & Nicobar Islands (Bell 1887a, Koehler 1910, Julka & Das 1978, James 1983, 2005).

Astropecten vappa Müller & Troschel, 1843

PL. I, Fig. 4-6

Collection locations: **Cape Comorin-Mangalore, 24-116 m.** CAPE COMORIN – 8° 3.411' N, 77° 29.811' E, 24 m, 16.5.2010 (FORVSS 275, St. 15). – 7° 59.373' N, 77° 18.765' E, 48 m, 9.12.2013 (FORVSS 321, St. 12). TRIVANDRUM – 8° 28.896' N, 76° 43.461' E, 52 m, 25.12.2008 (FORVSS 260, St. 58). – 8° 30.345' N, 76° 51.251' E, 31 m, 16.8.2009 (FORVSS 270II, St. 9). – 8° 28.71' N, 76° 28.998' E, 102 m, 15.5.2010 (FORVSS 275, St. 12). – 8° 30.88' N, 76° 43.5' E, 50 m, 24.10.2014 (FORVSS 330, St. 77). KOCHI – 9° 56.331' N, 75° 51.169' E, 49 m, 13.6.2009 (FORVSS 267II, St. 23). – 9° 56.189' N, 75° 50.576' E, 52 m, 8.8.2009 (FORVSS 270I, St. 23). – 9° 54.546' N, 75° 35.493' E, 116 m, 13.5.2010 (FORVSS 275, St. 2). – 9° 46.075' N, 75° 41.438' E, 98 m, 27.2.2012 (FORVSS 295, St. 20). – 10° 0.08' N, 75° 49.99' E, 52 m, 13.12.2014 (FORVSS 333, St. 2). Naturalist dredge.

Voucher specimen No.: IO/SS/ECD/00074

Diagnosis: Major radius 3-4 cm, minor radius 1 cm. Central paxillae with 2-4 short central spines and about 10 peripheral spines; fewer spines in peripheral paxillae. Proximal supero-marginals with a single large spine along their inner margins; spines smaller in distal supero-marginals, positioned in the middle or outer part of the plate. Infero-marginals with one large spine at the outer distal edge, and two markedly dissimilar spines immediately below it – one much larger than the other; rest of the plate covered by small, somewhat flattened (but not scale-like) spines. Furrow spines numbering 3. Light cream colour with brown marking along the centre of each arm, and along inner margin of supero-marginal plates; some supero-marginals along the middle of arm with a brown marking across their width.

Distribution: Continental and insular shelves of the north-western and central Indo-Pacific. Indian waters – NE Arabian Sea (Sastry 2004), SE Arabian Sea (present study), SW Bay of Bengal (Koehler 1910), Andaman & Nicobar Islands (Koehler 1910, James 1983, Sastry 2005).

Remarks: *Astropecten zebra* Koehler, 1910, reported from Indian waters is a synonym (Shepherd 1968, A. M. Clark 1989).

Astropecten hemprichi Müller & Troschel, 1842

Collection locations: **Cape Comorin, 52 m.** CAPE COMORIN – 7° 47.428' N, 77° 30.835' E, 52 m, 18.8.2009 (FORVSS 270II, St. 20). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/0007

Diagnosis: Major radius 6 cm, minor radius 1 cm. Paxillae with 2-4 central granules and 7-10 short, stout, peripheral spines. Supero-marginals extending well onto the dorsal side of the disc, narrow and numerous, at least 35 on each side. Supero-marginal spines positioned centrally at the arm base and adradially towards the arm tip; none conspicuously larger than others, with a gradual reduction towards the arm tip. Infero-marginals with numerous thin spines and scales across the surface. Cream colour with dark brown patches in the disc and basal parts of the arm.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (James 1985a, 1988, Satyamurti 1976), and NW Bay of Bengal (Sastry 2001a).

Genus *Persephonaster* Wood-Mason & Alcock, 1891

Persephonaster rhodopeplus Wood-Mason & Alcock, 1891

Collection locations: **Cape Comorin-Trivandrum, 995-1338 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). TRIVANDRUM – 8° 24.153' N, 76° 1.64' E, 995 m, 12.10.2010 (FORVSS 281, St. 3). – 8° 15.283' N, 76° 1.886' E, 1338 m, 10.8.2013 (FORVSS 319, St. 9). Demersal trawls.

Diagnosis: Damaged specimens, with major radius about 7 cm and minor radius about 3.5 cm. Aboral side set closely with paxillae which bear numerous equal sized granules. Supero and infero-marginals relatively narrow and granule covered; the latter bearing a set of needle-like median spines of which the abactinal is the longest. Adambulacral armament in three longitudinal rows; composed of short, truncated spines. Colour brown with purple to reddish tinges on the marginal plates and infero-marginal spines.

Distribution: Continental slope. Indian waters – SE Arabian Sea (Wood-Mason & Alcock 1891, Alcock 1893b, present study), and Gulf of Mannar (Wood-Mason & Alcock 1891, Alcock 1893b).

Family Luidiidae Sladen, 1889

Genus *Luidia* Forbes, 1839

Luidia denudata Koehler, 1910

PL. I, Fig. 7-9

Collection locations: **Cape Comorin, 53-113 m.** CAPE COMORIN – 8° 4.48’ N, 76° 44.47’ E, 113 m, 7.9.2013 (FORVSS 319, St. 2). – 7° 48.108’ N, 77° 30.703’ E, 53 m, 8.9.2013 (FORVSS 319, St. 6). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00077

Diagnosis: Major radius 4-5 cm, minor radius 1.5 cm; arms number 9-10, delicate and most broken or separated from the disc. Abactinal armaments are paxillae bearing one (sometimes 2-3) central stout spines along with a circlet of 10-12, long, slender spines; uniform across the arms and much of the disc, though paxillae at the centre of the disc are smaller and closer together. Colour in life brownish-gray throughout, lacking any bold colour patterns.

Distribution: Continental and insular shelves of the north-western and central Indo-Pacific. Indian waters – SE Arabian Sea (present study), and SW Bay of Bengal (Koehler 1910).

Luidia hardwicki (Gray, 1840)

PL. I, Fig. 10-11

Collection locations: **Cape Comorin-Mangalore, 33-111 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). – 7° 48.582' N, 77° 29.613' E, 51 m, 16.5.2010 (FORVSS 275, St. 17). – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). – 8° 15.041' N, 76° 57.085' E, 51 m, 7.9.2013 (FORVSS 319, St. 1). – 8° 2.041' N, 76° 59.838' E, 56 m, 9.12.2013 (FORVSS 321, St. 14). TRIVANDRUM – 8° 26.303' N, 76° 47.163' E, 52 m, 30.8.2011 (FORVSS 289, St. 17). – 8° 27.052' N, 76° 53.967' E, 38 m, 30.8.2011 (FORVSS 289, St. 18). – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). – 8° 30' N, 76° 48' E, 52 m, 4.9.2011 (FORVSS 289, St. 37). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). – 8° 30.88' N, 76° 43.5' E, 50 m, 24.10.2014 (FORVSS 330, St. 77). KOLLAM – 9° 20.971' N, 75° 52.841' E, 111 m, 14.5.2010 (FORVSS 275, St. 7). KOCHI – 9° 52.2' N, 75° 51' E, 48 m, 3.8.2005 (FORVSS 236, St. 10). – 10° 30.535' N, 75° 31.676' E, 84 m, 4.8.2011 (FORVSS 288, St. 3). – 9° 46.075' N, 75° 41.438' E, 98 m, 27.2.2012 (FORVSS 295, St. 20). – 10° 24.5' N, 75° 39.9' E, 60 m, 8.7.2013 (FORVSS 315, St. 6). – 9° 58.353' N, 75° 49.661' E, 54 m, 30.7.2013 (FORVSS 317, St. 2). CALICUT – 11° 15.352' N, 75° 18.882' E, 53 m, 7.8.2009 (FORVSS 270I, St. 17). – 11° 12.421' N, 75° 5.558' E, 81 m, 7.8.2011 (FORVSS 288, St. 6). KANNUR – 11° 57.521' N, 74° 41.169' E, 83 m, 8.8.2011 (FORVSS 288, St. 10). MANGALORE – 9° 57.48' N, 76° 0.12' E, 33 m, 13.12.2014 (FORVSS 333, St. 1). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00076

Diagnosis: Major radius up to 6 cm, minor radius up to 1 cm; disc small, 5 relatively long, gradually tapering arms; arms often found in various stages of regeneration. A row of marginal spines along the edge of the arm. Dorsal side of disc covered in paxillae, which bear 1-2 central and 6-7 lateral, thorny spines, which are all of the same size. Some adambulacral plates with long, slender pedicellariae. Colour in life brownish-gray throughout, lacking any bold colour patterns.

Distribution: Continental and insular shelves of the north-western and central Indo-Pacific. Indian waters – NE Arabian Sea (James 1969), SE Arabian Sea (present study), Gulf of Mannar (Bell 1888, Thurston 1895b), SW Bay of Bengal (James 1987g), and NW Bay of Bengal (Sastry 1995, 1998b).

Family Porcellanasteridae Sladen, 1883

Genus *Sidonaster* Koehler, 1909

Sidonaster vaneyi Koehler, 1909

PL. I, Fig. 12

Collection locations: **Cape Comorin-Kochi, 988-1245 m.** CAPE COMORIN – 8° 0.845' N, 76° 25.91' E, 1154 m, 10.12.2013 (FORVSS 321, St. 16). TRIVANDRUM – 8° 24.61' N, 75° 52.714' E, 1245 m, 17.7.2013 (FORVSS 316, St. 9). KOCHI – 9° 50.16' N, 75° 32.86' E, 988 m, 19.12.2003 (FORVSS 219, St. 12). – 9° 54' N, 75° 31.44' E, 1120 m, 8.8.2010 (FORVSS 278, St. 2). Demersal trawl, Smith-McIntyre grab and naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00013

Diagnosis: Major radius 2-3 cm and minor radius about 1 cm. A row of thin marginal plates, of which the basal ones are characterized by the cribriform organs with thick spines; supero-marginals of either side separated throughout, and bearing two spines on the adoral side; adoral side characterized by a thin skin which bears felt-like covering of needle-like spines. Epiproctal cone very distinct dorsally. Actinal area covered by a delicate membrane Adambulacral plates with a protruding adoral part, on which 2-3 spines are confined. Oral spine from either side of jaw joined to form a single mouth spine.

Distribution: Continental slope regions of the western and central Indo-Pacific. Indian waters – SE Arabian Sea (Koehler 1909, present study), and Andaman & Nicobar Islands (Koehler 1909, James 1983, Sastry 2005).

Remarks: *Sidonaster batheri* Koehler, 1909, reported from Indian waters, is synonymised (A. M. Clark 1989).

Family Pseudarchasteridae is known from depths >1500 m in the SEAS through RIMS Investigator surveys (Table 3.2, Nos. 13-14) and was not represented in the present collections.

Order Valvatida Perrier, 1884

Family Asterinidae Gray, 1840

Genus *Anseropoda* Nardo, 1834

Anseropoda ludovici (Koehler, 1909)

Collection locations: **Kollam, 454 m.** KOLLAM – 8° 55.3' N, 75° 29.03' E, 454 m, 12.5.2004 (FORVSS 225, St. 8). Naturalist dredge.

Diagnosis: Major radius about 10 cm; body profile pentagonal with excavated sides, form thin, flattened and membranous, semi-transparent and webbed. Adoral side paved with series of rhomboid plates which decrease in size from the disc to the margin; papular pores numerous and set in longitudinal as well as transverse rows.

Distribution: Continental slope. Indian waters – SE Arabian Sea (Koehler 1909, present study).

Remarks: Damaged specimen with only one arm and the disc intact and the plates dissolved.

Family Goniasteridae Forbes, 1841

Genus *Ceramaster* Verrill, 1899

Ceramaster cuenoti (Koehler, 1909)

PL. I, Fig. 13-15

Collection locations: **Cape Comorin-Trivandrum, 995-1324 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). – 7° 53.24' N, 76° 25.768' E, 1262 m, 9.8.2013 (FORVSS 319, St. 8). – 8° 0.845' N, 76° 25.91' E, 1154 m, 10.12.2013 (FORVSS 321, St. 16). TRIVANDRUM – 8° 24.153' N, 76° 1.64' E, 995 m, 12.10.2010 (FORVSS 281, St. 3). – 8° 17.13' N, 76° 12.42' E, 1069 m, 19.10.20012 (FORVSS 305, St. 1). – 8° 17.19' N, 76° 12.34' E, 1032 m, 14.7.2013 (FORVSS 316, St. 1). – 8° 24.61' N, 75° 52.714' E, 1245 m, 17.7.2013 (FORVSS 316, St. 9). – 8° 25.107' N, 75° 55.18' E, 1241 m, 11.12.2013 (FORVSS 321, St. 18). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00080

Diagnosis: Sub-pentagonal form with strongly excavate arms; major radius up to 8 cm, minor radius up to 4 cm; ends of arms fairly narrow. Adoral plates rounded, unequal and covered uniformly with stout, rounded granules; about 5-7 on each plate; madreporite small but distinct. Radial areas with numerous papular pores, and distinct alveolar pedicellariae which stand above the general armament. Supero-marginals wider than long, with a curved dorsal surface; much of their surface is bare, with large rounded granules around their periphery. Actinal inter-radii with granule-covered rhomboid plates, of which a row of wide plates parallel to the adambulacrals is distinguishable. Adambulacral plates with two rows of blunt, short spines. Colour uniformly bright orange.

Distribution: Continental slope. Indian waters – SE Arabian Sea (Koehler 1909, present study).

Johannaster **Koehler, 1909**

Johannaster superbus Koehler, 1909

PL. II, Fig. 1-3

Collection locations: **Cape Comorin-Trivandrum, 1241-1338 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). TRIVANDRUM – 8° 15.283' N, 76° 1.886' E, 1338 m, 10.8.2013 (FORVSS 319, St. 9). – 8° 25.107' N, 75° 55.18' E, 1241 m, 11.12.2013 (FORVSS 321, St. 18). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/0079

Diagnosis: Stellate form with strongly excavate arms; major radius up to 18 cm, minor radius up to 6 cm; arms uniformly tapering to acute tips, inter-radii excavate. Adoral plates more or less hexagonal, larger in the radial areas than the inter-radii, and covered uniformly with rounded granules; madreporite prominent. Radial areas with very numerous single papulae and flattened, elongate alveolar pedicellariae scattered throughout. Supero-marginals narrow, covered with large rounded granules all. Actinal plates rhomboid and granule-covered, the row adjacent to the adambulacrals broad and arranged in a longitudinal series and bearing alveolar pedicellariae; the remainder of actinal plates smaller and irregular in arrangement. Adambulacral plates with two rows of blunt, short spines. Colour uniformly dull orange.

Distribution: Continental slope regions across Indo-Pacific. Indian waters – SE Arabian Sea (Koehler 1909, present study), and SW Bay of Bengal (Koehler 1909).

Genus *Nymphaster* Sladen, 1889

Nymphaster moebii (Studer, 1884)

PL. II, Fig. 4-5

Collection locations: **Cape Comorin-Trivandrum, 1241-1324 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). TRIVANDRUM – 8° 24.61' N, 75° 52.714' E, 1245 m, 17.7.2013 (FORVSS 316, St. 9). – 8° 25.107' N, 75° 55.18' E, 1241 m, 11.12.2013 (FORVSS 321, St. 18). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00081

Diagnosis: Major radius up to 14 cm, minor radius 5-6 cm, arms usually all broken at the base or middle. Dorsal disc plates irregularly polygonal, larger in the radial areas; all covered by large, rounded granules; madreporite conspicuous, rounded. Marginal plates conspicuous but not occupying much of the dorsal surface; plates of either side joining beyond the fifth or sixth; covered in small rounded granules, rarely alveolar pedicellariae. The marginal plates of the arms wider than long and decreasing in width from base to tip of the arms. Ventral interradial plates large, polygonal with large, spaced granules on the surface; adambulacral plate with a single row of 8-10 blunt spines, and several large rounded granules abradially. Colour light or bright orange dorsally, pale ventrally.

Distribution: Continental slope regions of the Indian Ocean. Indian waters – SE Arabian Sea (Alcock 1893b, Koehler 1909, present study), Gulf of Mannar (Alcock 1893b, Koehler 1909), and Andaman & Nicobar Islands (Alcock 1893b, Koehler 1909, James 1983, Sastry 2005).

Remarks: *Nymphaster basilicus* Alcock, 1893, *Nymphaster protentus* Alcock, 1893, *Dorigona belli* Koehler, 1909, *Dorigona ludwigi* Koehler, 1909, and *Dorigona ternalis* Koehler, 1909, reported from Indian waters are considered as synonyms (Macan 1938).

Genus *Stellaster* Gray, 1840

Stellaster childreni Gray, 1840

PL. II, Fig. 6-7

Collection locations: **Cape Comorin-Calicut, 32-101 m.** CAPE COMORIN – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). – 8° 2.041' N, 76° 59.838' E, 56 m, 9.12.2013 (FORVSS 321, St. 14). TRIVANDRUM – 8° 26.303' N, 76° 47.163' E, 52 m, 30.8.2011 (FORVSS 289, St. 17). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). – 8° 30.88' N, 76° 43.5' E, 50 m, 24.10.2014 (FORVSS 330, St. 77). CALICUT – 11° 14.846' N, 75° 36.808' E, 32 m, 9.6.2009 (FORVSS 267II, St. 9). – 11° 14.792' N, 74° 59.302' E, 101 m, 10.6.2009 (FORVSS 267II, St. 10). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00004

Diagnosis: Major radius 8 cm, minor radius 5-6 cm. Body arched towards the centre of the disc with wide inter-radial areas, paved with rounded to hexagonal skin-covered plates. A single short, blunt (squared off) spine at the aboral margin of each infero-marginal plate. Colour mottled dark brown and maroon colour, some plates on actinal sides coloured dark brown.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (James 1985a, 1988), SW Bay of Bengal (James 1987g, 1997, Karuppaiyan 2007), NW Bay of Bengal (Koehler 1910, Sastry 1998b), and Andaman & Nicobar Islands (Koehler 1910, Sastry 2005).

Remarks: *Stellaster equestris* Gray, 1805 and *Stellaster incei* Gray, 1847 reported from Indian waters are synonyms (Döderlein 1935).

Family Ophidiasteridae Verrill, 1870

Genus *Heteronardoa* Hayashi, 1973

Heteronardoa carinata (Koehler, 1910)

Collection locations: **Kochi, 50 m.** KOCHI – 9° 56.548' N, 75° 51.075' E, 50 m, 26.8.2011 (FORVSS 289, St. 2). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/0082

Diagnosis: Major radius 4 cm, minor radius 0.5 cm; body form stellate, disc very small and arms cylindrical and tapering; body composed of tessellate, granule covered rounded plates, of which proximal ones tend to form longitudinal and transverse rows. Papular pores single; granulation coarser in the papular areas, which are present only on the adambulacral side. Adambulacral spines short, stout and prismatic, in 2 rows. Colour orange.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (Jayakumari 2004, present study), and Andaman & Nicobar Islands (Koehler 1910, James 1983, Sastry 2005).

Remarks: *Nardoa squamulosa* Koehler, 1910 reported from Indian waters is a synonym (Rowe 1976).

Family Oreasteridae Fisher, 1911

Genus *Goniodiscaster* H.L. Clark, 1909

Goniodiscaster forficulatus (Perrier, 1875)

PL. II, Fig. 8-9

Collection locations: **Cape Comorin-Trivandrum, 52-124 m.** CAPE COMORIN – 7° 26.443' N, 76° 54.754' E, 124 m, 8.12.2013 (FORVSS 321, St. 11). TRIVANDRUM – 8° 28.896' N, 76° 43.461' E, 52 m, 25.12.2008 (FORVSS 260, St. 58). – 8° 28.71' N, 76° 28.998' E, 102 m, 15.5.2010 (FORVSS 275, St. 12). – 8° 30.88' N, 76° 43.5' E, 50 m, 24.10.2014 (FORVSS 330, St. 77). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00083

Diagnosis: Major radius up to 4 cm, minor radius 1-1.5 cm; body flatenned, form stellate with broad, round-tipped arms. Abactinal plates tessellate, oval, convex and bearing spaced, sub-conical granules of various sizes in addition to alveolar pedicellariae; some pates with a single short, conical spine; papular in groups. Sub-ambulacral armaments composed of short, stout spines in longitudinal rows. Colour dark brown dorsally and light cream ventrally.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – SE Arabian Sea (Jayakumari 2004, present study), Gulf of Mannar (James 1969), and SW & NW Bay of Bengal (Koehler 1910).

Order Forcipulatida Perrier, 1884

Family Zoroasteridae Sladen, 1889

Genus *Cnemidaster* Sladen, 1889

Cnemidaster zea (Alcock, 1893b)

PL. II, Fig. 10-11

Collection locations: **Cape Comorin-Trivandrum, 995-1338 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). – 7° 53.24' N, 76° 25.768' E, 1262 m, 9.8.2013 (FORVSS 319, St. 8). TRIVANDRUM – 8° 24.153' N, 76° 1.64' E, 995 m, 12.10.2010 (FORVSS 281, St. 3). – 8° 17.13' N, 76° 12.42' E, 1069 m, 19.10.20012 (FORVSS 305, St. 1). – 8° 17.19' N, 76° 12.34' E, 1032 m, 14.7.2013 (FORVSS 316, St. 1). – 8° 24.61' N, 75° 52.714' E, 1245 m, 17.7.2013 (FORVSS 316, St. 9). – 8° 15.283' N, 76° 1.886' E, 1338 m, 10.8.2013 (FORVSS 319, St. 9). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00084

Diagnosis: Arms 12 cm in length; disc raised well above arms. Disc demarcated by large, tumid, oval plates, which are smooth and membrane clad; madreporite well distinguished among these plates; papulae distinct between plates. Arms sub-cylindrical and tapering, with corn-like rows of oblong, membrane clad plates in 13 rows; small pedicellariae and prominent papulae in the junction of these plates. Adambulacral armature composed of flat, foliaceous spinelets, and furrow spines bearing numerous small pedicellariae, in addition to one larger one. Colour deep orange to brown.

Distribution: Continental slope. Indian waters – SE Arabian Sea (Alcock 1893b, present study), and Gulf of Mannar (Alcock 1893b).

Genus *Zoroaster* Thomson, 1873

Zoroaster alfredi Alcock, 1893b

PL. II, Fig. 12-14

Collection locations: **Cape Comorin-Trivandrum, 1032-1324 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). – 8° 0.845' N, 76° 25.91' E, 1154 m, 10.12.2013 (FORVSS 321, St. 16). TRIVANDRUM – 8° 17.13' N, 76° 12.42' E, 1069 m, 19.10.20012 (FORVSS 305, St. 1). – 8° 17.19' N, 76° 12.34' E, 1032 m, 14.7.2013 (FORVSS 316, St. 1). – 8° 24.61' N, 75° 52.714' E, 1245 m, 17.7.2013 (FORVSS 316, St. 9). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00085

Diagnosis: Arms 18-22 mm; disc raised above the tumid arms, overall form rigid. Disc covered with large stellate plates which are covered in membrane-clad spinelets; space between plates with papulae, and pedicellariae, of which one is prominent. Arms, rectangular in cross section; with 13 rows of plats, of which the central is prominent, sub-hexagonal. All are covered with needle-like spinelets and minute pedicellariae, in addition to a short, stout spine at the centre of each plate. Spaces between plates bearing numerous small pedicellariae and one large one. 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.

Distribution: Continental slope. Indian waters – SE Arabian Sea (present study), and NW Bay of Bengal (Alcock 1893b).

Zoroaster planus Alcock, 1893b

PL. II, Fig. 15

Collection locations: **Cape Comorin-Calicut, 1000-1338 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). – 7° 53.24' N, 76° 25.768' E, 1262 m, 9.8.2013 (FORVSS 319, St. 8). TRIVANDRUM – 8° 17.13' N, 76° 12.42' E, 1069 m, 19.10.20012 (FORVSS 305, St. 1). – 8° 17.19' N, 76° 12.34' E, 1032 m, 14.7.2013 (FORVSS 316, St. 1). – 8° 24.61' N, 75° 52.714' E, 1245 m, 17.7.2013 (FORVSS 316, St. 9). – 8° 15.283' N, 76° 1.886' E, 1338 m, 10.8.2013 (FORVSS 319, St. 9). CALICUT – 10° 59.29' N, 74° 59.52' E, 1000 m, 14.4.2005 (FORVSS 233, St. 15). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00086

Diagnosis: Arms 13-15 cm long, disc moderately high, overall form delicate and easily damaged. Disc high, comprising rounded, tumid plates, all covered with capillary spinelets, and most with a central, stout, conical spine (most of which are broken off, but the tubercle is distinct). Arms with 13 rows of sub-hexagonal plates, all bearing a central conical stout spine and numerous smaller capillary spinelets; the plates of the central row distinctly larger and decreasing towards either side; the spaces between plates occupied by a single papula and a pedicellaria. Colour pale salmon.

Distribution: Continental slope. Indian waters – SE Arabian Sea (Alcock 1893b, present study), and Gulf of Mannar (Alcock 1893b).

Order Brisingida Fisher, 1928

Family Brisingidae G.O. Sars, 1875

Genus *Brisinga* Asbjørnsen, 1856

Brisinga ?insularum Wood-Mason & Alcock, 1891

Collection locations: **Cape Comorin, 1324 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). Demersal trawl.

Voucher specimen No.: CMLRE IO/SS/ECD/00087

Diagnosis: Disc 4 cm, all arms broken. Disc with well-defined, vertical edge; aboral side of disc covered with an opaque membrane which is densely invested with minute granules that bear small spinelets. Arms with numerous skin covered, transverse ridges on the dorsal side, which are invested with numerous microscopic pedicellariae. A fluted spine at the margin of the arms, which is mostly broken but clearly very long; a similar but shorter spines just ventral to it; two spines on each plate of the furrow margin and one furrow spine – all these spines being hyaline, fluted and covered in a membranous sac, closely felted with pedicellariae. Colour fleshy, orange to brown.

Distribution: Continental slope. Indian waters – SE Arabian Sea (Wood-Mason & Alcock, 1891, Alcock 1893b, present study).

Remarks: The specimen was collected from demersal trawls and hence heavily damaged. The observable characters indicate to *Brisinga insularum*, but this could not be confirmed conclusively.

Class Ophiuroidea Gray, 1840

Class Ophiuroidea is comprises 2076 extant species, falling under 17 families in 2 orders (Euryalida and Ophiurida). In Indian waters, 163 species (under 74 genera) are reported, representing 16 families. In the SEAS, 50 species (under 29 genera), representing order Euryalida (Asteronychidae and Asteroschematidae) and Ophiurida (Amphiuridae, Ophiacanthidae, Ophiactidae, Ophiochitonidae, Ophiocomidae, Ophiodermatidae, Ophiolepididae, Ophiotrichidae and Ophiuridae) are now known (Table 3.3).

Order Euryalida Lamarck, 1816

Family Asteroschematidae Verrill, 1899

Genus *Asteroschema* Oerstedt & Lütken, 1856

Asteroschema sampadae Parameswaran & Jaleel, 2012

PL. III, Fig. 1-2

Collection locations: **Cape Comorin, 545 m.** CAPE COMORIN – 7° 10.02' N, 77° 19.21' E, 454 m, 20.5.2007 (FORVSS 254, St. 1). Smith-McIntyre Grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00021

Diagnosis: Disc diameter 2 cm, arms about 38-45 mm (21-23 times disc diameter). Disc and arms covered by skin with small, scattered, distinctly conical epidermal ossicles on aboral side and minute spherical granular ossicles on oral side. Conical ossicles bearing a crown of minute spinous terminal projections. Dorsal ornamentation not closely packed anywhere on the body so that large parts of the disc and arms are overlaid by naked skin; but epidermal ossicles somewhat more dense on radial shields and at base of arms. Two arm spines from fourth arm segment; inner spine larger and approximately one third of the arm segment length, becoming twice the length of the arm segment and bearing distinct thorny projections on the inner edge. Arm spines at the distal end of the arm are represented as small hook-shaped spines. Colour light fawn.

Distribution: Continental slope. Indian waters – *Type locality*, SE Arabian Sea (Parameswaran & Jaleel 2012).

Remarks: Species described as part of the present study (Full paper: Appendix 1). Specimens were collected in association with a gorgonid of family Primnoidae.

Order Ophiurida Müller & Troschel, 1840

Family Amphiuridae Ljungman, 1867

Genus *Amphioplus* Verrill, 1899

Amphioplus (Lymanella) depressus (Ljungman, 1867)

PL. III, Fig. 4-6

Collection locations: **Cape Comorin-Mangalore, 24-100 m.** CAPE COMORIN – 8° 3.411' N, 77° 29.811' E, 24 m, 16.5.2010 (FORVSS 275, St. 15). – 7° 48.582' N, 77°

29.613' E, 51 m, 16.5.2010 (FORVSS 275, St. 17). – 7° 48.108' N, 77° 30.703' E, 53 m, 8.9.2013 (FORVSS 319, St. 6). TRIVANDRUM – 8° 30' N, 76° 48' E, 50 m, 31.8.2011 (FORVSS 289, St. 20). – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). – 8° 25.448' N, 76° 33.084' E, 84 m, 16.7.2013 (FORVSS 316, St. 5). – 8° 28.562' N, 76° 51.5' E, 37 m, 11.9.2013 (FORVSS 319, St. 10). KOLLAM – 8° 48.02' N, 76° 33.58' E, 33 m, 25.10.2014 (FORVSS 330, St. 79). – 8° 48.19' N, 76° 22.33' E, 52 m, 25.10.2014 (FORVSS 330, St. 80). KOCHI – 9° 56.395' N, 75° 38.305' E, 98 m, 13.6.2009 (FORVSS 267II, St. 22). – 9° 58.353' N, 75° 49.661' E, 54 m, 30.7.2013 (FORVSS 317, St. 2). – 9° 58.138' N, 75° 39.155' E, 100 m, 31.7.2013 (FORVSS 317, St. 3). – 10° 22.53' N, 75° 56.676' E, 30 m, 2.8.2013 (FORVSS 317, St. 9). – 10° 29.82' N, 75° 51.4' E, 30 m, 12.10.2014 (FORVSS 330, St. 28). – 12° 49.75' N, 74° 30.35' E, 52 m, 15.12.2014 (FORVSS 333, St. 8). CALICUT – 11° 22.7' N, 75° 17.71' E, 53 m, 9.10.2014 (FORVSS 330, St. 16). KANNUR – 11° 59.407' N, 74° 56.339' E, 53 m, 8.8.2013 (FORVSS 317, St. 14). – 11° 59.52' N, 74° 57.18' E, 52 m, 8.10.2014 (FORVSS 330, St. 13). MANGALORE – 12° 51.02' N, 74° 29.71' E, 53 m, 27.9.2014 (FORVSS 329, St. 33). – 12° 50.32' N, 47° 30.26' E, 51 m, 4.10.2014 (FORVSS 330, St. 2). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00088

Diagnosis: Disc diameter 3-5 mm, arms about 10 times this length. Disc covered uniformly with small scales on dorsal and ventral side, primary rosette discernable in some smaller (juvenile) specimens; a well demarcated marginal row of scales thickened scales around the disc, though not conspicuously projecting; radial shields contiguous except at the proximal end, just longer than wide, less than half the disc radius. Oral shield diamond shaped; four contiguous, scale-like oral papillae, capable of closing over the jaw completely, the third one the largest. Two tentacle scales, three arm spines throughout. Colour white.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (James 1969, present study), NW Bay of Bengal (Koehler 1898, Sastry 2007, Rao *et al.* 2009), and Andaman & Nicobar Islands (James 1971, Sastry 2005).

Remarks: *Amphiura relicta* Koehler, 1898 reported from Indian waters is a synonym (Liao, 2004).

Genus *Amphipholis* Ljungman, 1866

Amphipholis misera (Koehler, 1899)

PL. III, Fig. 7-8

Collection locations: **Cape Comorin-Kochi, 51-116 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). TRIVANDRUM – 8° 30' N, 76° 48' E, 51 m, 4.9.2011 (FORVSS 289, St. 38). – 8° 30' N, 76° 48' E, 53 m, 8.9.2011 (FORVSS 289, St. 52). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). KOCHI – 9° 54.546' N, 75° 35.493' E, 116 m, 13.5.2010 (FORVSS 275, St. 2). – 10° 29.57' N, 75° 31.7' E, 88 m, 12.10.2014 (FORVSS 330, St. 26). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00089

Diagnosis: Disc diameter 2-4 mm, composed of small plates, primary rosette always distinct. Oral shields spear-head shaped, longer than wide, 3 contiguous oral papillae, outer-most operculiform, about twice as wide as the second. Two flat tentacle scales. Colour white.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – SE Arabian Sea (present study), and Andaman & Nicobar Islands (Koehler 1899, James 1983, Sastry 2005).

Genus *Amphiura* Forbes, 1843

Amphiura (Amphiura) ambigua Koehler, 1905

PL. III, Fig. 9-11

Collection locations: **Cape Comorin, 32-100 m.** CAPE COMORIN – 8° 3' N, 77° 21' E, 32 m, 5.8.2005 (FORVSS 236, St. 21). – 7° 59.264' N, 77° 36.646' E, 32 m, 18.8.2009 (FORVSS 270II, St. 19). – 7° 27.925' N, 77° 31.141' E, 100 m, 16.5.2010 (FORVSS 275, St. 18). Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00090

Diagnosis: Disc diameter 2-4 mm, arms about 7-8 times this length, disc covered entirely with imbricating scales; radial shields 2-3 times as long as wide, separated proximally and just meeting at the distal edge; primary rosettes distinct. Oral papillae spear-head shaped with a rounded distal edge, one distal oral papilla on each side. Two tentacle scale. About 6-8 arm spines, the middle ones squared off, with distally directed hooks.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – NE Arabian Sea (Sastry 2004), and SE Arabian Sea (present study).

Amphiura (Amphiura) constricta Lyman, 1879

PL. III, Fig. 12

Collection locations: **Trivandrum-Kannur, 52-106 m.** TRIVANDRUM – 8° 24.983' N, 76° 32.466' E, 106 m, 30.8.2011 (FORVSS 289, St. 16). KANNUR – 11° 59.52' N, 74° 57.18' E, 52 m, 8.10.2014 (FORVSS 330, St. 13). Naturalist dredge and Smith-McIntyre grab.

Diagnosis: Disc diameter 3-5 mm, arms about 7-8 times this length, disc covered entirely with small imbricating scales; radial shields narrow, elongate, over thrice as long as wide; primary rosettes distinct. Oral shields spear-head shaped, with a small distal prolongation; one, long, spine-like distal oral papilla on each side. One tentacle scale. Six arm spines at the base of the arm, the second ventral most spine with a small, glassy, distally directed hook; dorsal spine larger than the rest. Colour white.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – SE Arabian Sea (present study).

Amphiura (Amphiura) duncani Lyman, 1882

Collection locations: **Kochi-Calicut, 52-109 m.** KOCHI – 9° 55.492' N, 75° 38.056' E, 109 m, 26.8.2011 (FORVSS 289, St. 3). – 9° 58.138' N, 75° 39.155' E, 100 m, 31.7.2013 (FORVSS 317, St. 3). CALICUT – 11° 19.179' N, 75° 18.903' E, 52 m, 22.2.2012 (FORVSS 295, St. 3). Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00091

Diagnosis: Disc diameter 2-3 mm; arm always broken; disc covered above and below by small but thick imbricating scales; primary rosette indistinct; radial shields about half of disc radius, meeting distally. Oral shields rhombic, much broader than long; infra-dental papillae large and prominent on the oral plates; one leaf-shaped distal oral papilla. One rounded tentacle scale. Usually 4-5 arm spines, of which the ventral-most is distinctly longer, about 1.45 times the corresponding segment. Colour white.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study).

Amphiura (Amphiura) micra H.L. Clark, 1938

PL. III, Fig. 13

Collection locations: **Cape Comorin, 24 m.** CAPE COMORIN – 8° 3.411' N, 77° 29.811' E, 24 m, 16.5.2010 (FORVSS 275, St. 15). Smith-McIntyre grab.

Diagnosis: Disc diameter 2 mm, arms about 7-8 times this length, disc covered entirely with small imbricating scales; radial shields short, wide, about twice as long as wide and meeting only at the distal edge; primary rosettes distinct. Oral shields triangular, with a rounded distal edge; one distal scale like oral papilla on each side, which is longer than wide. One tentacle scale. Six arm spines at the base of the arm, the second ventral most spine with a small, glassy, distally directed hook; dorsal spine larger than the rest. Colour white.

Distribution: Continental and insular shelves of the Indian Ocean. Indian waters – SE Arabian Sea (present study), and SW Bay of Bengal (Karuppaiyan 2007).

Amphiura (Fellaria) heptacantha (Mortensen, 1940)

PL. III, Fig. 14-15

Collection locations: **Cape Comorin, 31 m.** CAPE COMORIN – 8° 2.207' N, 77° 29.956' E, 31 m, 16.5.2010 (FORVSS 275, St. 16). Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00093

Diagnosis: Disc diameter 2 mm; scales present only around the radial shields, which are long and bar-like, with a small gap between them, rest of the disc naked, highly contorted; arms very long, all broken. Distal oral papillae not present on all jaws (possibly lost), scale-like with a rounded distal edge. Tentacle scales absent. Arm spines number 7, all flattened, and most with a very rugose tip. Colour white.

Distribution: Continental and insular shelves of the Indian Ocean. Indian waters – SE Arabian Sea (present study).

Amphiura (Ophiopeltis) tenuis (H.L. Clark, 1938)

Collection locations: **Cape Comorin, 24-53 m.** CAPE COMORIN – 8° 3.411' N, 77° 29.811' E, 24 m, 16.5.2010 (FORVSS 275, St. 15). – 7° 48.108' N, 77° 30.703' E, 53 m, 8.9.2013 (FORVSS 319, St. 6). Naturalist dredge and Smith-McIntyre grab. Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00092

Diagnosis: Disc diameter 3 mm; scales present only around the radial shields, which are long and bar-like, apparently in contact for most of their length, rest of the disc naked; arms very long, all broken. Distal oral papillae very small, but always present. Tentacle scales absent. Arm spines number 4-5, the second with prominently rugose tips. Colour white.

Distribution: Continental and insular shelves of the Indian Ocean. Indian waters – SE Arabian Sea (present study), and NW Bay of Bengal (Sastry 1995, 1998b).

Amphuira crispa Mortensen, 1940

Collection locations: **Cape Comorin, 24 m.** CAPE COMORIN – 8° 3.411' N, 77° 29.811' E, 24 m, 16.5.2010 (FORVSS 275, St. 15). Smith-McIntyre grab.

Diagnosis: Disc diameter 2 mm, arms about 8 times this length, disc covered with small imbricating scales on the dorsal side, but naked on proximal part of ventral inter-radii; radial shields short, wide, about twice as long as wide and meeting only at the distal edge; primary rosettes distinct. Oral shields with a rounded distal edge; one distal scale like oral papilla on each side. One tentacle scale. Colour white.

Distribution: Continental and insular shelves of the western and northern Indian Ocean. Indian waters – SE Arabian Sea (present study).

Genus *Dougalopus* A. M. Clark, 1970

Dougalopus echinatus (Ljungman, 1867)

Collection locations: **Trivandrum, 49 m.** TRIVANDRUM – 8° 30.914' N, 76° 45.067' E, 49 m, 16.7.2013 (FORVSS 316, St. 4). Smith-McIntyre grab.

Diagnosis: Disc diameter 5 mm, with spines on the dorsal side, damaged; arms broken, but more than 5 times this length. Oral shield with an acute proximal edge and rounded distal edge, three oral papillae, the third one largest. Dorsal arm plates fan shaped and carinate; three to four arm spines. Colour white.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (James 1969, 1985, 1988), and NW Bay of Bengal (Koehler 1898).

Genus *Ophiodaphne* Koehler, 1930

Ophiodaphne scripta (Koehler, 1904)

PL. IV, Fig. 1-7

Collection locations: **Cape Comorin-Kollam, 38-111 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). TRIVANDRUM – 8° 26.014' N, 76° 47.946' E, 53 m, 20.11.2010 (FORVSS 282, St. 10). – 8° 27.052' N, 76° 53.967' E, 38 m, 30.8.2011 (FORVSS 289, St. 18). – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). – 8° 30' N, 76° 48' E, 52 m, 4.9.2011 (FORVSS 289, St. 37). – 8° 30' N, 76° 48' E, 51 m, 4.9.2011 (FORVSS 289, St. 38). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 9° 20.971' N, 75° 52.841' E, 111 m, 14.5.2010 (FORVSS 275, St. 7). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00071

Diagnosis: Species showing prominent sexual dimorphism – with dwarf males being attached to the ventral side of the disc of the female, which is much larger.

Female – Disc diameter up to 4 mm and arms about 1.5 to 2 times this length. Disc covered above and below with small imbricating scales, with primary rosette and radial shields clearly distinguished. Radial shields about one half of disc radius, contiguous along most of their length and separated by a few small scaled; transverse parallel grooves along inner edge or across entire surface of radial shields. Small grooves also visible on remaining dorsal disc scales of most specimens. Oral shields small and rhomboid with a rounded distal edge; adoral shields large; oral plates distinct. Infradental papillae extremely small and poorly distinguished; oral papillae more or less fused together, forming a continuous row along the sides of jaws; provided with numerous minute thorns on their edge. Oral and adoral shields along with sunken oral plates, bearing minute inwardly directed spinules. Teeth conspicuous, rounded and conical structures, 4-5 in a vertical row. Dorsal arm plates pentagonal with rounded distal edges, just contiguous proximally, becoming fan-shaped and separated distally; ventral arm plates more or less square, contiguous proximally, reducing in size and becoming separated distally. Five rounded conical arm spines at the arm base; 4 arm spines distally, of which the two dorsal-most are transformed into hooks; and last few segments bearing only two hook-shaped arm spines. A single leaf-like tentacle scale present throughout the arm. Colour white.

Male – Disc diameter up to 1 mm, arms about 4-5 times this length; slightly tumid in inter-radii. Dorsal disc completely covered by large rounded primary rosette plates; ventral side of disc paved by small imbricating scales. Genital slits and jaw structures minute and poorly developed. As in females, a continuous row of fused, thorny oral papillae present, bearing minute thorns. Teeth rounded and conical. Dorsal arm plates fan-shaped and separated throughout arm; ventral arm plates pentagonal and separated throughout arm. Tentacle scales absent; 3 short cylindrical arm spines at the arm base; two in number and sometimes ending in glassy thorns; transformed into curved hooks at the distal arm. Colour white.

Sexual dimorphism – Apart from the obvious distinctions in size, the males and females differ significantly in skeletal elements, chiefly the number, disposition and ornamentation of dorsal disc scales; and numbers and shape of arm spines, which are described above. Tentacles scales and genital slits are altogether absent in males but present in females.

Distribution: Continental and insular shelves of the western and north western Indian Ocean. Indian waters – SE Arabian Sea (Parameswaran *et al.* 2013, present study), and SW Bay of Bengal (Parameswaran *et al.* 2013). Also recorded from Bay of Bengal based on specimen at the British Museum of Natural History (Clark & Rowe 1971), exact location not known.

Remarks: Collected as epibiont on *Sculpsitechinus auritus* (Leske, 1778). This rare, sexually dimorphic species represents a new record from the Indian waters, and was published along with notes on systematics of *Ophiodaphne* and the adaptations for its unique life habit (Parameswaran *et al.* 2013, Appendix 2).

Notes on adaptations & habit**:** The males are attached mouth-to-mouth, to the ventral side of the females with the arms of the male fitting into the interradii of the female, in such a way that they cover over the jaw structures of the latter. The specialized structures which facilitate pairing in this species include (a) the distal hooked arm spines of the males and (b) the sunken nature of the jaw structure of the female and the thorns present on it (Mortensen 1933, Parameswaran *et al.* 2013). No males were obtained without female 'hosts', and so the possibility that the male might be parasitic on the female cannot be ruled out (Mortensen 1933, Parameswaran *et al.* 2013). The distal, hooked arm spines of the female enable its attachment to the host (Mortensen 1933, Parameswaran *et al.* 2013), most likely by hooking on to the miliary spines of the latter. The females, with or without paired males, attached themselves with their aboral side adpressed to the oral side of *S. auritus*. The attachment is not a fixed one, and the females can be observed actively moving across the host test. *Ophiodaphne scripta* is believed to feed on detritus that passes through the mouth (of both the male and female), due to ciliary currents of the host echinoid (Mortensen 1933, Parameswaran *et al.* 2013).

Genus *Ophiosphaera* Brock, 1888

Ophiosphaera insignis Brock, 1888

PL. IV, Fig. 8-10

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00094

Diagnosis: Disc diameter 2-3 mm, arms about 2-3 times this length. Disc distinctly domed and composed of a mosaic of small, hard scale-like plates; radial shields small, twice as long as wide, contiguous; outer edge of disc demarcated by a row of erect scales. Oral apparatus small; three glassy apical oral papillae, separated from two minute scale-like distal oral papillae by a wide diastema. Arm spines number 3 at the base of the arm, increasing to 6 at segment 4-5, decreasing beyond proximal part of the arm; lowermost arm spine conspicuously enlarged, about two times corresponding segment length, club-like and hollow, spines decreasing in length towards the dorsal side. Colour cream.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study).

Remarks: Specimen was collected in association with echinoid *Salmaciella dussumieri* L. Agassiz in L. Agassiz & Desor, 1846 and is known to be epibiont on echinoids (Koehler 1930, Cherbonnier & Guille 1978 etc.). This species is also known to show sexual dimorphism; with a dwarf male being attached to the oral side of a larger female (Koehler 1930). Only two females were collected during the present study, without any epibiont males.

Family Ophiacanthidae Ljungman, 1867

Genus *Ophiacantha* Müller & Troschel, 1842

Ophiacantha dallasii Duncan, 1879

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). Naturalist dredge.

Diagnosis: Small epibionts, disc diameter 3 mm, disc covered above and below by short trifid stumps, more or less obscuring radial shields. Oral shields roughly triangular with a rounded distal margin; adoral shields larger than oral shields, with distal prolongations which extend beyond the lateral margins of the oral shields; three oral papillae on each side, the outer one larger, but less than twice as wide as long. Arm distinctly moniliform. Small spiniform tentacle scales on basal arm segments. Up to 7 arm spines; on the second free arm segment, spines from either side contiguous, and dorsal row of spines more than twice as long as other spines. Colour greyish white.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study). Also collected from Andaman & Nicobar Islands during FORVSS surveys (unpublished).

Remarks: Specimens collected in association with a gorgonid.

Genus *Ophiomoeris* Koehler, 1904

Ophiomoeris tenara (Koehler, 1897)

Collection locations: **Cape Comorin-Trivandrum, 1241-1154 m.** CAPE COMORIN – 8° 0.845' N, 76° 25.91' E, 1154 m, 10.12.2013 (FORVSS 321, St. 16). TRIVANDRUM – 8° 25.107' N, 75° 55.18' E, 1241 m, 11.12.2013 (FORVSS 321, St. 18). Naturalist dredge and demersal trawl.

Voucher specimen No.: CMLRE IO/SS/ECD/00095

Diagnosis: Disc diameter 6-8 mm, arms about 2-3 times this length; disc intended inter-radially, and covered with rounded tumid plates. Of these, the radial shields are the largest (more than half disc radius), elliptical and protruding at the periphery of the disc; they are well separated radially by a row three plates, of which the distal one is very broad; inter-radially, they are closer together, being separated by a single narrow elongate plate. Ventral inter-radii occupied by a few small plates; oral shields small and triangular; adoral shields very large, thick and crescent shaped; oral papillae large and wide, numbering 3 on each side, besides a single conical oral papilla. First dorsal arm plate twice as wide as long, subsequent ones triangular. One rounded tentacle scale; three arm spines, which are just shorter than the corresponding segments. Colour white.

Distribution: Continental slope regions of the Indo-Pacific. Indian waters – SE Arabian Sea (Koehler 1897, 1899, present study), and Andaman & Nicobar Islands (Koehler 1897, 1899, James 1983, Sastry 2005).

Family Ophiochitonidae Matsumoto, 1915

Genus *Ophiochiton* Lyman, 1878

Ophiochiton ambulator Koehler, 1897

Collection locations: **Cape Comorin-Kannur, 523-1241 m.** CAPE COMORIN – 8° 0.845' N, 76° 25.91' E, 1154 m, 10.12.2013 (FORVSS 321, St. 16). TRIVANDRUM – 8° 25.107' N, 75° 55.18' E, 1241 m, 11.12.2013 (FORVSS 321, St. 18). CALICUT – 10° 59.29' N, 74° 59.52' E, 992 m, 14.4.2005 (FORVSS 233, St. 15). – 11° 56.54' N, 74° 22.66' E, 523 m, 17.4.2005 (FORVSS 233, St. 17). – 12° 53.45' N, 73° 47' E, 1000 m, 18.4.2005 (FORVSS 233, St. 21). KANNUR – 11° 55.93' N, 74° 23.13' E, 525 m, 21.12.2003 (FORVSS 219, St. 17). Demersal trawl & naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00096

Diagnosis: Disc diameter up to 2.5 cm, arms about 8-10 times this length; disc usually clearly incised, covered with small imbricating scales, among which the primary rosette is usually distinguishable. Radial shields long and triangular, about half disc radius; separated on their distal edge by a row of wide scales. Oral shield nearly triangular, 5-6 conical oral papillae. Arms prominently keeled above and below, two tentacle scales of which the outer one is larger; 3 long conical arm spines, as long as two arm segments. Colour cream.

Distribution: Continental slope regions of the northern Indian Ocean. Indian waters – SE Arabian Sea (Koehler 1897, 1899, present study), and SW Bay of Bengal (Koehler 1897, 1899).

Family Ophiocomidae Ljungman, 1867

Genus *Ophiocoma* L. Agassiz, 1835

Ophiocoma (Breviturma) brevipes Peters, 1851

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00097

Diagnosis: Disc diameter 12 mm; arms about 5 times this length; disc covered with rounded granules above and below. Apical tooth papillae forming a cluster at the apex of the jaw, and oral papillae present along the jaw angle. Tentacle scales 2. Arm spines hollow, shorter than the width of corresponding arm segment. Colour of disc pale green, arms lightly banded.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – Lakshadweep Islands (Koehler 1898, James 1969, 1987e, Sastry 1991b), SE Arabian Sea (present study), Gulf of Mannar (Bell 1888) and Andaman & Nicobar Islands (Koehler 1898, James 1969, 1983, 1987e, Sastry 1999a, 2001b, 2005).

Genus *Ophiopsila* Forbes, 1843

Ophiopsila pantherina Koehler, 1898

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). Naturalist dredge.

Diagnosis: Disc diameter 3 mm; arms broken; disc covered by small scales. Two tentacle scales, of which the outer is rounded, and the inner is much elongate, crossing the corresponding scale of the other side – the two scales resembling a pair of crossed swords. Arms spines numbering 7-9, short, stout and hollow. Colour grey.

Distribution: Indian waters – SE Arabian Sea (present study), and Andaman & Nicobar Islands (Koehler 1898, James 1983, Sastry 2005).

Family Ophiodermatidae Ljungman, 1867

Genus *Bathypectinura* H.L. Clark, 1909

Bathypectinura heros (Lyman, 1879)

PL. IV, Fig. 11-12

Collection locations: **Trivandrum-Kochi, 835-1241 m.** TRIVANDRUM – 8° 25.107' N, 75° 55.18' E, 1241 m, 11.12.2013 (FORVSS 321, St. 18). KOCHI – 9° 50.16' N, 75° 32.87' E, 835 m, 3.5.2007 (FORVSS 254, St. 12). – 9° 54' N, 75° 31.44' E, 1120 m, 8.8.2010 (FORVSS 278, St. 2). Naturalist dredge and demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00098

Diagnosis: Disc diameter 2-3.5 cm, arms about 2-3 times this length; disc covered above and below by fine granulation, with only the distal ends of the radial shields exposed. Oral shields large and bare, triangular with a rounded distal edge; adoral shields and oral plates obscured by granulation, similar to the disc; a single conical apical oral papilla and 7 papillae along the inner side of the, which increase in size from the proximal to the distal-most one. Arms strongly carinate dorsally, dorsal arm plates twice as wide as long; usually 4 arm spines which are shorter than the corresponding arm segments and adpressed to it. Tentacle scales very large and rounded. Colour bright orange.

Distribution: Continental slope regions of the Indo-Pacific and Atlantic Ocean. Indian waters – SE Arabian Sea (Koehler, 1897, 1899, present study), and NW Bay of Bengal (Koehler 1897, 1899).

Remarks: *Pectinura conspicua* Koehler, 1897 reported from Indian waters is a synonym (Madsen 1973).

Genus *Ophiarachnella* Ljungman, 1872

Ophiarachnella infernalis (Müller & Troschel, 1842)

PL. IV, Fig. 13-15

Collection locations: **Cape Comorin, 51 m.** CAPE COMORIN – 8° 15.041' N, 76° 57.085' E, 51 m, 7.9.2013 (FORVSS 319, St. 1). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00099

Diagnosis: Disc diameter 2 cm; arms about 4-5 times this length; disc covered above and below by rounded granulation, but with several bare, flat-topped plates along the periphery, including the radial shields which are small, elliptical and set widely apart. Oral plates free bare, triangular, and with a partially exposed supplementary oral shield just distal to it; adoral shields and oral plates covered by granulation; 6-7 oral papillae on each side, apart from the apical one; proximal papillae conical, while the distal ones somewhat scale like. Doral and ventral arm plates fan-shaped; arm spines 7 in number; shorter than the corresponding segment, and adpressed. Two tentacle scales, of which the inner one is bigger and rounded, outer scale smaller and overlapping the base of the ventral-most arm spine.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (Thurston 1895b) and Andaman & Nicobar Islands (James 1983, Sastry 1999a, 2005).

Genus *Ophioconis* Lütken, 1869

Ophioconis cupida Koehler, 1905

PL. V, Fig. 1-2

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00100

Diagnosis: Disc diameter 5 mm, arms 2-3 times this length; disc with a well-defined dorsolateral margin, and wholly covered with uniform rounded granulation, though these are dislodged rather easily to reveal very thin imbricating scales underneath; radial shields indistinct. Oral shields rounded or sub-triangular, covered partly by granulation, as are the adoral shield and oral plates; apical oral papillae indistinguishable from these granules; a row of 3 oral papillae along the edge of jaw. Teeth extremely wide, with a rounded, hyaline edge. Arm spines numbering 7-9, flattened, as long as the corresponding segment. Colour white light grey with dark mottling.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study).

Family Ophiotrichidae Ljungman, 1867

Genus *Ophiocnemis* Müller & Troschel, 1842

Ophiocnemis marmorata (Lamarck, 1816)

PL. V, Fig. 3-4

Collection locations: **Cape Comorin-Trivandrum, 49-52 m.** CAPE COMORIN – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). TRIVANDRUM – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00101

Diagnosis: Disc diameter 1 cm, arms about 3 times this length. Disc dominated on the dorsal side by the large radial shields, which are flat, triangular and bare, separated by narrow bands of plates covered with prominent, rounded granules; equidistant inter-radially and radially. Ventral side of the disc covered by thin skin. Oral shields triangular with a wide, rounded distal edge; a cluster of small tooth papillae at the jaw apex. Tentacle scales lacking. Colour light with greyish-green mottling.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (Jayakumari 2004, present study), Gulf of Mannar (Bell 1888, Koehler 1898, James 1985a, 1988, Venkatraman *et al.* 2013), SW Bay of Bengal (Gravely 1941, Satyamurti 1976, James 1987g, Karuppaiyan

2007), NW Bay of Bengal (Sastry 1995, 1998b, Rao *et al.* 2009), and Andaman & Nicobar Islands (Sastry 2005).

Genus *Ophiopteron* Ludwig, 1888

Ophiopteron elegans Ludwig, 1888

PL. V, Fig. 5

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00102

Diagnosis: Disc diameter 1 mm, arms about 5-6 mm. Disc covered with spaced, short stumps; radial shields not distinct. A cluster of tooth papillae at the apex of each jaw. Arm spines of each side webbed together throughout the length of the arm, and in the first 2-3 segments, the webs of each side linked dorsally. Colour orange.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), and Andaman & Nicobar Islands (Koehler 1898, James 1983, Sastry 2005).

Genus *Ophiothrix* Müller & Troschel, 1840

Ophiothrix (Acanthophiothrix) proteus Koehler, 1905

PL. V, Fig. 6

Collection locations: **Trivandrum, 52 m.** TRIVANDRUM – 8° 26.303' N, 76° 47.163' E, 52 m, 30.8.2011 (FORVSS 289, St. 17). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00105

Diagnosis: Disc diameter 3 mm; arms broken but more than 4 times this length. Dorsal side of disc covered with short multifid stumps as well as a few very long spines (which are mostly broken); radial shields about two-thirds of the disc radius, bare except for a row of stumps along the adradial margins. Oral apparatus small, with a cluster of tooth papillae at the apex of the jaw. Arm segments attenuated; dorsal arm plates longer than wide, more or less fan-shaped and contiguous throughout; a pale median line along the length of the arm, bordered by two thin dark lines. Ventral arm plates with a straight distal edge. Up to 10 arm spines, of which the dorsal-most is the longest, more than 4 times corresponding arm segment. Colour light cream.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), SW Bay of Bengal (Karuppaiyan 2007), and Andaman & Nicobar Islands (Sastry 2005).

Ophiothrix (Acanthophiothrix) purpurea von Martens, 1867

PL. V, Fig. 7

Collection locations: **Cape Comorin, 51-52 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). – 8° 15.041' N, 76° 57.085' E, 51 m, 7.9.2013 (FORVSS 319, St. 1). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00104

Diagnosis: Disc diameter 4-6 mm; arms broken but more than 3 times this length. Dorsal side of disc dominated by radial shields, which is more than two-thirds of the disc radius and bare, their inter-radial length shorter, so that the radial shield is widest at the middle portion; remainder of the disc covered in short stumps or spines. Oral apparatus small, with a cluster of tooth papillae at the apex of the jaw. Dorsal arm plates longer than wide, more or less fan-shaped and contiguous throughout; a pale median bright red line along the length of the arm, bordered by two thin light, yellow lines. Up to 10 arm spines, of which the dorsal-most appear longer, more than 3 times corresponding arm segment, though most spines are broken. Colour white with red and yellow marking across the disc, and longitudinal red line along arm, bordered by yellow lines.

Distribution: Indian waters – Lakshadweep Islands (Koehler 1898, Sastry 1991b), SE Arabian Sea (present study), and Andaman & Nicobar Islands (Koehler 1898, James 1983, Sastry 1997, 2005).

Ophiothrix (Ophiothrix) aristulata Lyman, 1879

PL. V, Fig. 8-12

Collection locations: **Kochi, 500 m.** KOCHI – 9° 56.28' N, 75° 82.99' E, 500 m, 23.4.2005 (FORVSS 233, St. 11). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/000103

Diagnosis: Disc diameter 6-10 mm; arms about 6 times this length. Dorsal side of disc covered with short thorny spines, along with a few shorter multifid stumps at the edge of the disc – which all arise of small scales imbedded in a thin skin; radial shields about two-thirds of the disc radius, bare except for a couple of spines on some. Oral apparatus small, with a cluster of tooth papillae at the apex of the jaw. Dorsal arm plates longer than wide, rhombic and contiguous throughout; a pale median line along the length of the arm, bordered by two thin dark lines. Ventral arm plates with a convexity along the distal edge. Arm spines numbering 10-12, with rows of short thorns along their length, about 3 times corresponding arm segment; ventral-most arm spines transforming to hooks in the distal part of the arms.

Distribution: Continental slope regions and seamounts of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), SW Bay of Bengal (Koehler 1897, 1899), and Andaman & Nicobar Islands (Koehler 1897, 1899, James 1983, Sastry 2005).

Ophiothrix (Ophiothrix) foveolata Marktanner-Turneretscher, 1887

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). Naturalist dredge.

Diagnosis: Disc diameter 4 mm; arms broken but more than 3 times this length. Disc with a few short trifid stumps, but radial shields more or less bare and with a dark line along their inner margins. Dorsal arm plates wider than long; ventral arm plates with a concave distal margin; arm spines numbering 8-10, 3 times corresponding segment length, bearing two rows of prominent thorns along their length. Transverse markings across the dorsal and ventral side of the arms, corresponding to each segment. Colour cream.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – NE Arabian Sea (Sastry 2004), SE Arabian Sea (present study), NW Bay of Bengal (Sastry 2007), and Andaman & Nicobar Islands (Koehler 1898, Sastry 2005).

Remarks: *Ophiothrix insidiosa* Koehler, 1898 reported from Indian waters, is a synonym (Koehler 1905).

Ophiothrix (Ophiothrix) savignyi (Müller & Troschel, 1842)

Collection locations: **Cape Comorin, 31-52 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). – 8° 2.207' N, 77° 29.956' E, 31 m, 16.5.2010 (FORVSS 275, St. 16). Naturalist dredge.

Diagnosis: Disc diameter 3-5 mm; arms broken. Disc covered with short trifid stumps, which also obscure radial shields which are small and separated. Dorsal arm plates wider than long; ventral arm plates with a concave distal margin, the proximal ones with some stumps, similar to that of the disc; arm spines numbering 8-10, 3 times corresponding segment length, bearing two rows of prominent thorns along their length. Colour cream.

Distribution: Continental and insular shelves of the western and north western Indian Ocean. Indian waters – SE Arabian Sea (Koehler 1898, present study).

Remarks: *Ophiothrix otiosa* Koehler, 1898 reported from Indian waters, is a synonym (Koehler 1905).

Family Ophiuridae Müller & Troschel, 1840

Genus *Amphiophiura* Matsumoto, 1915

Amphiophiura sordida (Koehler, 1897)

Collection locations: **Kochi, 988 m.** KOCHI – 9° 50.16' N, 75° 32.86' E, 988 m, 19.12.2003 (FORVSS 219, St. 12). Smith-McIntyre grab.

Diagnosis: Disc diameter 1 cm, arms about 1.5 cm long; disc margin raised slightly above the arms. Dorsal side of disc demarcated by a ring of peripheral plates – five pairs of large, pentagonal radial shields, and five large inter-radial plates; this encloses a slightly sunken region, occupied by numerous thin, imbricating plates, amongst which a central plate is distinguishable. Radial shields contiguous except for the proximal end, where a triangular plate separates them. Arm combs distinct, with around 10 long, thin teeth, which continue on the ventral side as small genital papillae. The lateral margins of the disc is wide, on occupied by a single rectangular plate, which is bordered dorsally by the inter-radial plate and ventrally by the oral shield. Oral shield is large and occupies the ventral inter-radius completely; adoral papillae large and oblong; oral papillae six in number, apical ones conical and the others short and square. Arms robust; 4-5 tentacle scales basally, their number decreasing and disappearing by the fourth or fifth segment; three extremely short arm spines, arranged equidistantly on the lateral arm plates. Colour white.

Distribution: Indian waters – SE Arabian Sea (present study), and Andaman & Nicobar Islands (Koehler 1897, Koehler 1899, James 1983, Sastry 2005).

Genus *Ophiura* Lamarck, 1801

Ophiura kinbergi Ljungman, 1866

PL. V, Fig. 13-15

Collection locations: **Cape Comorin-Mangalore, 30-155 m.** CAPE COMORIN – 7° 59.285' N, 77° 38.709' E, 30 m, 30.5.2009 (FORVSS 267I, St. 1). – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). – 8° 3' N, 77° 21' E, 32 m, 5.8.2005 (FORVSS 236, St. 21). – 7° 27.837' N, 77° 30.099' E, 100 m, 18.8.2009 (FORVSS 270II, St. 21). – 8° 2.207' N, 77° 29.956' E, 31 m, 16.5.2010 (FORVSS 275, St. 16). – 7° 48.582' N, 77° 29.613' E, 51 m, 16.5.2010 (FORVSS 275, St. 17). – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). – 8° 15.041' N, 76° 57.085' E, 51 m, 7.9.2013 (FORVSS 319, St. 1). – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). – 8° 2.041' N, 76° 59.838' E, 56 m, 9.12.2013 (FORVSS 321, St. 14). – 7° 59.373' N, 77° 18.765' E, 48 m, 9.12.2013 (FORVSS 321, St. 12). TRIVANDRUM – 8° 25.8' N, 76° 42' E, 58 m, 5.8.2005 (FORVSS 236, St. 19). – 8° 28.71' N, 76° 28.998' E, 102 m, 15.5.2010

(FORVSS 275, St. 12). – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). – 8° 30' N, 76° 48' E, 52 m, 3.9.2011 (FORVSS 289, St. 33). – 8° 30' N, 76° 48' E, 52 m, 4.9.2011 (FORVSS 289, St. 37). – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). – 8° 30.88' N, 76° 43.5' E, 50 m, 24.10.2014 (FORVSS 330, St. 77). KOLLAM – 9° 20.971' N, 75° 52.841' E, 111 m, 14.5.2010 (FORVSS 275, St. 7). – 9° 0.127' N, 75° 56.805' E, 155 m, 28.8.2011 (FORVSS 289, St. 9). KOCHI – 10° 2.347' N, 75° 59.773' E, 32 m, 26.12.2008 (FORVSS 260, St. 65). – 9° 56.189' N, 75° 50.576' E, 52 m, 8.8.2009 (FORVSS 270I, St. 23). – 9° 55.94' N, 76° 0.04' E, 33 m, 8.8.2009 (FORVSS 270I, St. 24). – 9° 54.546' N, 75° 35.493' E, 116 m, 13.5.2010 (FORVSS 275, St. 2). – 10° 30.535' N, 75° 31.676' E, 84 m, 4.8.2011 (FORVSS 288, St. 3). – 9° 46.075' N, 75° 41.438' E, 98 m, 27.2.2012 (FORVSS 295, St. 20). – 10° 24.5' N, 75° 39.9' E, 60 m, 8.7.2013 (FORVSS 315, St. 6). – 9° 58.353' N, 75° 49.661' E, 54 m, 30.7.2013 (FORVSS 317, St. 2). – 9° 58.138' N, 75° 39.155' E, 100 m, 31.7.2013 (FORVSS 317, St. 3). – 10° 29.57' N, 75° 31.7' E, 88 m, 12.10.2014 (FORVSS 330, St. 26). – 12° 49.75' N, 74° 30.35' E, 52 m, 15.12.2014 (FORVSS 333, St. 8). CALICUT – 11° 15.293' N, 75° 37.197' E, 30 m, 7.8.2009 (FORVSS 270I, St. 18). – 11° 12.421' N, 75° 5.558' E, 81 m, 7.8.2011 (FORVSS 288, St. 6). – 11° 19.179' N, 75° 18.903' E, 52 m, 22.2.2012 (FORVSS 295, St. 3). KANNUR – 11° 57.521' N, 74° 41.169' E, 83 m, 8.8.2011 (FORVSS 288, St. 10). KANNUR – 11° 56.195' N, 75° 0.762' E, 51 m, 23.2.2012 (FORVSS 295, St. 6). MANGALORE – 10° 0.08' N, 75° 49.99' E, 52 m, 13.12.2014 (FORVSS 333, St. 2). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00022

Diagnosis: Disc diameter up to 1 cm; arms 3-4 times this length. Disc flat, covered dorsally by thin plates and scales, of which the primaries and radial shields are distinct. Radial shields are tear-drop shaped and entirely separated. A pair of prominent arm combs, with long needle-like spines. Oral shield large; adoral shields prominent, 3-4 conical oral papillae on each side. Dorsal arm plates wider at the base and narrowing distally; ventral arm plates reduced; lateral arm plates meeting in the ventral mid line, where an oval depression is present; 8-10 needle-like arm spines, most as long as corresponding segment. First oral tentacle pore opening outside oral slit and surrounded by 5-6 scales; consequent tentacle pores with 2-4 scales, distally one or none. Colour mottled light and dark olive green dorsally, light ventrally.

Distribution: Continental and insular shelves of the Indo-Pacific (also upper slope in these regions). Indian waters – SE Arabian Sea (Koehler 1898, present study), NW Bay of Bengal (Koehler 1898, Sastry 2007), and Andaman & Nicobar Islands (Koehler 1898, James 1983, Sastry 2005).

Remarks: *Ophiuglypha sinensis* Lyman, 1871 reported from Indian waters, is a synonym (Rowe & Gates 1995).

The family Ophiolepididae (Table 3.3, Nos. 32-35) and Ophiactidae (Table 3.3, Nos. 22-25) are known from regions outside the present survey area within SEAS and were not represented in the present surveys.

Class Echinoidea Leske, 1778

The class Echinoidea comprises 1010 extant species under 51 families in 16 orders. In Indian waters, 112 species (under 73 genera, 31 families and 12 orders) have been reported. The echinoids of the SEAS are represented by order Cidaroida (Family Cidaridae & Histocidaridae), Echinothurioida (Echinothuriidae & Phormosomatidae), Camarodonta (Echinometridae, Temnopleuridae & Toxopneustidae), Diadematoida (Diadematidae), Salenoida (Saleniidae), Stomopneustoida (Stomopneustidae), Ecinoneioida (Echinoneidae), Clypeasteroida (Astriclypeidae, Clypeasteridae, Echinocyamidae & Laganidae), Echinolampadoida (Echinolampadidae), Pedinoida (Pedinidae), Spatangoida (Brissidae, Eurypatagidae, Hemiasteridae, Loveniidae, Maretiidae & Schizasteridae), with 43 species in 34 genera (Table 3.4). Order Diadematoida (Table 3.4, No. 18), Salenioida (Table 3.4, No. 19), Stomopneustoida (Table 3.4, No. 20) and Pedinoida (Table 3.4, No. 33) are recorded primarily from outside the present survey depths and were not collected in the present surveys.

Order Cidaroida Claus, 1880

Family Cidaridae Gray, 1825

Genus *Stereocidaris* Pomel, 1883

Stereocidaris alcocki (Anderson, 1894)

PL. VI, Fig. 1

Collection locations: **Cape Comorin, 51-215 m.** CAPE COMORIN – 8° 15.041' N, 76° 57.085' E, 51 m, 7.9.2013 (FORVSS 319, St. 1). – 7° 10.27' N, 77° 20.86' E, 245 m, 14.5.2004 (FORVSS 225, St. 1). Naturalist dredge and demersal trawl.

Voucher specimen No.: CMLRE IO/SS/ECD/00106

Diagnosis: Cidaridae with slightly flattened test; test diameter 5-6 cm, test height 3.5 cm. Oculars just in contact with the periproct; uniform tuberculation on ocular and genital plates. Ambulacra simple, sinuous. Inter-ambulacral primary tubercles perforate and non-crenulate; first 2-3 apical inter-ambulacral plates with rudimentary tubercles only. Scrobicular circle differentiated on the remaining inter-ambulacral plates. Primary spines about 1.5-2 times test height; bearing prominent ridges, of which three often form buttresses in the proximal third of the spine, imparting a concave hexagonal cross section to the spines. Pedicellariae and most primary spines lost in all specimens. Colour white with light pink colour at the tip of spines.

Distribution: Continental slope and shelf regions of the northern Indian Ocean. Indian waters – SE Arabian Sea (Anderson 1894, Koehler 1927, present study), NW Bay of Bengal (Koehler 1927), and Andaman & Nicobar Islands (Koehler 1927, James 1983, Sastry 2005).

Family Histocidaridae Lambert, 1900

Genus *Histocidaris* Mortensen, 1903

Histocidaris denticulata Koehler, 1927

PL. VI, Fig. 2-3

Collection locations: **Trivandrum, 1047 m.** TRIVANDRUM – 8° 31.775' N, 75° 59.74' E, 1047 m, 12.12.2013 (FORVSS 321, St. 20). Demersal trawl.

Voucher specimen No.: CMLRE IO/SS/ECD/00107

Diagnosis: Test large, nearly spherical, distinctly flattened above and below; rounded to sub-pentagonal in circumference; test diameter 7-8 cm, test height 8 cm. Inter-ambulacra very prominent, with up to 12 plates in each series. Areolas much wider than high, more than half of plate width, the proximal 3-5 confluent. Primary tubercles prominent, crenulate and perforate throughout. Scrobicular tubercles well differentiated, noticeably larger than the secondary inter-ambulacral tubercles, which are also quiet numerous. Oculars exclude from the periproct (exert), but also some just in contact. Ocular and genital plates somewhat bare; periproct prominent, pentagonal and densely tuberculate; genital pores prominent, placed close to edge of the plate, but never encroaching out of it. Primary spines long, about 2 times test height, slender, with short and inconspicuous collar, bearing uniform striations and scattered, short, distally directed denticles throughout; lacking apical crown; proximal 3-5 primaries much shorter, modified as oral spines – flattened, with serrations along the lateral edges, reducing in size towards peristome; marginal tubercles large, regular, usually single, rarely with 1-2 small, additional tubercles on few plates; tridentate pedicellariae in two sizes – larger ones found around the periproct & smaller ones with more slender blades scattered all over the test. Colour brown.

Distribution: Continental slope regions of the Northern Indian Ocean. Indian waters – SE Arabian Sea (Koehler 1927, present study), and Bay of Bengal (Koehler 1927, exact location not given). Also collected from around Nicobar Islands (400-700 m) through FORVSS surveys (unpublished).

Order Echinothurioida Bronn, 1860

Echinothuriid sp.

Collection locations: **Cape Comorin-Trivandrum, 1047-1154 m.** CAPE COMORIN – 8° 0.845' N, 76° 25.91' E, 1154 m, 10.12.2013 (FORVSS 321, St. 16).

TRIVANDRUM – 8° 31.775' N, 75° 59.74' E, 1047 m, 12.12.2013 (FORVSS 321, St. 20). Demersal trawls.

Diagnosis: Leathery test, 8-11 cm in diameter; collapsing upon collection. Colour dark purple.

Distribution: Indian waters – Four species of Echinothurioida, viz. *Hygrosoma luculatum* (A. Agassiz, 1897), *Phorosoma bursarium* A. Agassiz, 1881, *Phorosoma verticillatum* Mortensen, 1904 and *Sperosoma biseriatum* Doderlein, 1901 are reported from Continental slope regions of Indian waters.

Remarks: Owing to the gear used (demersal trawls), and their delicate nature, all specimens collected were lacking spines, pedicellariae etc., making generic and species identification impossible. The specimens of the two stations may represent distinct species.

Order Camarodonta Jackson, 1912

Family Temnopleuridae A. Agassiz, 1872

Genus *Paratrema* Koehler, 1927

Paratrema doederleini (Mortensen, 1904)

Collection locations: **Trivandrum, 102 m.** TRIVANDRUM – 8° 28.71' N, 76° 28.998' E, 102 m, 15.5.2010 (FORVSS 275, St. 12). Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00108

Diagnosis: Temnopleurid with test diameter and height 1 cm; only 5 oral plates and their corresponding tube feet. Globiferous pedicellariae with a long unpaired lateral tooth. Colour white.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), and Andaman & Nicobar Islands (Koehler 1927, James 1983, Sastry 2007).

Genus *Salmaciella* Mortensen, 1942

Salmaciella dussumieri L. Agassiz in L. Agassiz & Desor, 1846

PL. VI, Fig. 4

Collection locations: **Cape Comorin-Trivandrum, 34-52 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). TRIVANDRUM – 8° 30.36' N, 76° 50.62' E, 34 m, 24.10.2014 (FORVSS 330, St. 78). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00109

Diagnosis: Regular echinoid with test diameter 5-6 cm and test height 3.5-4 cm; with low conical profile, low ambitus and distinctly concave oral side. Primary tubercles Primary tubercles imperforate and strongly crenulate; only one in every 2 or 3 ambital and aboral ambulacral plates. Spines with greenish brown bands.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (Bell 1888, Thurston 1895b, H. L. Clark 1925, Koehler 1927, James 1969, 1985a, 1988, Satyamurti 1976), SW Bay of Bengal (Anderson 1894, Thurston 1895b, Satyamurti 1976, Karuppaiyan 2007, Sastry 2007), and NW Bay of Bengal (Koehler 1927, Rao *et al.* 2009).

Remarks: One specimen (FORVSS 282 St. 8) with eulimnid gastropods attached to aboral spines, and the other was the basibiont for brittle star *Ophiosphaera insignis* Brock, 1888.

Genus *Salmacis* L. Agassiz, 1841

Salmacis virgulata L. Agassiz in L. Agassiz & Desor, 1846

PL. VI, Fig. 5

Collection locations: **Cape Comorin, 52 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00017

Diagnosis: Regular echinoids with test diameter 3 cm and test height 2 cm; a flat oral surface, low ambitus and a sub-conical profile. Ambulacral and inter-ambulacral tubercles of the same size, all crenulate and imperforate. Spines very short and simple. Aristotle's lantern Camarodonta. Test overall white, spines bright purple.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – Lakshadweep Islands (James 1989, Sastry 1991b), SE Arabian Sea (Jayakumari 2004, present study), Gulf of Mannar (Bell 1888, Thurston 1895b, H. L. Clark 1925, Koehler 1927, James 1969, 1985a, 1988, Venkatraman *et al.* 2013), and SW Bay of Bengal (James 1987g, Karuppaiyan 2007, Sastry 2007), and NW Bay of Bengal (Rao *et al.* 2009).

Family Echinometridae (Table 3.4, Nos. 10-11) and Toxopneustidae (Table 3.4, No. 17) are known from the inshore waters <20 m depth, and were not represented in the present collections.

Order Echinoneioda H. L. Clark, 1925

Family Echinoneidae L. Agassiz & Desor, 1847

Genus *Echinoneus* Leske, 1778

Echinoneus cyclostomus Leske, 1778

Collection locations: **Cape Comorin, 30-51 m.** CAPE COMORIN – 7° 59.285' N, 77° 38.709' E, 30 m, 30.5.2009 (FORVSS 267I, St. 1). – 7° 48.582' N, 77° 29.613' E, 51 m, 16.5.2010 (FORVSS 275, St. 17). Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00987

Diagnosis: Very small irregular echinoids (test length >1 cm, height and width half the length), with ovoid tests, distinctly longer than wide. Ambulacra simple, running parallel in pairs from the apical system to the peristome. Peristome central and slightly depressed; periproct large and longitudinally elongate, located just posteriorly from peristome. Primary tubercles imperforate. Colour white.

Distribution: Continental and insular shelves of the western and central Indo-Pacific as well as Caribbean. Indian waters – Lakshadweep Islands (Anderson 1894, Bell 1902, Koehler 1922, H. L. Clark 1925, Sastry 1991b), SE Arabian

Sea (present study), and Andaman & Nicobar Islands (Bell 1887a, H. L. Clark 1925, Sastry 1999b, 2001b, 2005).

Order Clypeasteroida A. Agassiz, 1872

Family Astriclypeidae Stefanini, 1912

Genus *Sculpsitechinus* Stara & Sanciu, 2014

Sculpsitechinus auritus (Leske, 1778)

PL. VI, Fig. 6

Collection locations: **Cape Comorin-Kollam, 38-95 m.** CAPE COMORIN – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). TRIVANDRUM – 8° 28.896' N, 76° 43.461' E, 52 m, 25.12.2008 (FORVSS 260, St. 58). – 8° 26.014' N, 76° 47.946' E, 53 m, 20.11.2010 (FORVSS 282, St. 10). – 8° 27.052' N, 76° 53.967' E, 38 m, 30.8.2011 (FORVSS 289, St. 18). – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). – 8° 30' N, 76° 48' E, 52 m, 3.9.2011 (FORVSS 289, St. 33). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). KOLLAM – 8° 54' N, 76° 1.2' E, 95 m, 4.8.2005 (FORVSS 236, St. 16). – 8° 59.388' N, 76° 17.33' E, 49 m, 21.11.2010 (FORVSS 282, St. 12). – 8° 48.19' N, 76° 22.33' E, 52 m, 25.10.2014 (FORVSS 330, St. 80). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00012

Diagnosis: Clypeasteroida with a very flat, thin test, perforated by a pair of open lunules, one each in the two posterior inter-ambulacra; test diameter up to 7 cm. Test rounded anteriorly; posteriorly somewhat truncated between the lunules. Petals well developed; posterior petals only slightly smaller than anterior ones. Colour brown.

Distribution: Continental and insular shelves of the western and northern Indian Ocean. Indian waters – SE Arabian Sea (Koehler 1927, Kurian 1953, James 1969, Jayakumari 2004, Parameswaran *et al.* 2013, present study), Gulf of Mannar (Bell 1889, Thurston 1895b, Koehler 1927, James 1969, 1985a, 1988, Satyamurti 1976, Venkatraman *et al.* 2013), SW Bay of Bengal (Koehler 1927, Gravely 1941, Satyamurti 1976, James 1987g, Karuppaiyan 2007), NW Bay of Bengal (Koehler 1927, Radhakrishna & Ganapati 1969, James 1969, Sastry 1995, 1998b, 2007, Rao *et al.* 2009), and Andaman & Nicobar Islands (James 1983, Sastry 2005).

Remarks: This species was referred to Genus *Echinodiscus*, until the recent revision of the family by Stara & Sancui (2014) which led to erection of genus *Sculpsitechinus*, to include *S. auritus* and *S. tenuissiumus* (L. Agassiz & Desor, 1847a). *Sculpsitechinus auritus* forms the host for the ophiuroid epibiont *Ophiodaphne scripta* in the SE Arabian Sea, particularly off Trivandrum.

Family Clypeasteridae L. Agassiz, 1835

Genus *Clypeaster* Lamarck, 1801

Clypeaster fervens Koehler, 1922

Collection locations: **Cape Comorin, 52 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00014

Diagnosis: Clypeastid with distinctly pentagonal test, longer than broad; length 2.5 cm and width 1.5-2 cm; sloping evenly to the edge. Petals large, anterior petal open distally. Oral surface concave. Colour brown.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (Koehler 1922, Mortensen 1948), and SW Bay of Bengal (Mortensen 1948).

Clypeaster rarispinus de Meijere, 1903

PL. VI, Fig. 7

Collection locations: **Cape Comorin-Mangalore, 32-111 m.** CAPE COMORIN – 8° 3' N, 77° 21' E, 32 m, 5.8.2005 (FORVSS 236, St. 21). – 7° 48.582' N, 77° 29.613' E, 51 m, 16.5.2010 (FORVSS 275, St. 17). – 8° 1.553' N, 76° 49.144' E, 86 m, 15.11.2010 (FORVSS 282, St. 7). – 7° 48.108' N, 77° 30.703' E, 53 m, 8.9.2013 (FORVSS 319, St. 6). – 7° 59.373' N, 77° 18.765' E, 48 m, 9.12.2013 (FORVSS 321, St. 12). – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). TRIVANDRUM – 8° 28.896' N, 76° 43.461' E, 52 m, 25.12.2008 (FORVSS 260, St. 58). – 8° 29.698' N, 76° 43.68' E, 53 m, 16.8.2009 (FORVSS 270II, St. 10). – 8° 28.71' N, 76° 28.998' E, 102 m, 15.5.2010

(FORVSS 275, St. 12). – 8° 26.014' N, 76° 47.946' E, 53 m, 20.11.2010 (FORVSS 282, St. 10). – 8° 24.983' N, 76° 32.466' E, 106 m, 30.8.2011 (FORVSS 289, St. 16). – 8° 26.303' N, 76° 47.163' E, 52 m, 30.8.2011 (FORVSS 289, St. 17). – 8° 27.052' N, 76° 53.967' E, 38 m, 30.8.2011 (FORVSS 289, St. 18). – 8° 30' N, 76° 48' E, 50 m, 31.8.2011 (FORVSS 289, St. 20). – 8° 30' N, 76° 48' E, 51 m, 31.8.2011 (FORVSS 289, St. 21). – 8° 30' N, 76° 48' E, 50 m, 31.8.2011 (FORVSS 289, St. 22). – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). – 8° 30' N, 76° 48' E, 52 m, 3.9.2011 (FORVSS 289, St. 33). – 8° 30' N, 76° 48' E, 52 m, 4.9.2011 (FORVSS 289, St. 37). – 8° 30' N, 76° 48' E, 51 m, 4.9.2011 (FORVSS 289, St. 38). – 8° 30' N, 76° 48' E, 51 m, 5.9.2011 (FORVSS 289, St. 40). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 54 m, 6.9.2011 (FORVSS 289, St. 44). – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 8° 30' N, 76° 48' E, 51 m, 7.9.2011 (FORVSS 289, St. 50). – 8° 30' N, 76° 48' E, 53 m, 8.9.2011 (FORVSS 289, St. 52). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). – 8° 28.436' N, 76° 45.866' E, 50 m, 11.9.2013 (FORVSS 319, St. 11). KOLLAM – 8° 57.907' N, 76° 23.335' E, 32 m, 26.12.2008 (FORVSS 260, St. 64). – 9° 20.971' N, 75° 52.841' E, 111 m, 14.5.2010 (FORVSS 275, St. 7). – 9° 20.846' N, 76° 5.751' E, 53 m, 14.5.2010 (FORVSS 275, St. 8). – 8° 59.388' N, 76° 17.33' E, 49 m, 21.11.2010 (FORVSS 282, St. 12). – 8° 59.92' N, 76° 13.912' E, 53 m, 28.8.2011 (FORVSS 289, St. 11). – 8° 48.19' N, 76° 22.33' E, 52 m, 25.10.2014 (FORVSS 330, St. 80). – 8° 48.71' N, 76° 4.57' E, 96 m, 25.10.2014 (FORVSS 330, St. 81). KOCHI – 9° 52.2' N, 75° 51' E, 48 m, 3.8.2005 (FORVSS 236, St. 10). – 10° 2.347' N, 75° 59.773' E, 32 m, 26.12.2008 (FORVSS 260, St. 65). – 9° 56.68' N, 75° 38.129' E, 106 m, 8.8.2009 (FORVSS 270I, St. 22). – 9° 54.568' N, 76° 2.953' E, 33 m, 14.5.2010 (FORVSS 275, St. 4). – 10° 30.733' N, 75° 45.853' E, 41 m, 4.8.2011 (FORVSS 288, St. 1). – 9° 46.075' N, 75° 41.438' E, 98 m, 27.2.2012 (FORVSS 295, St. 20). – 10° 24.5' N, 75° 39.9' E, 60 m, 8.7.2013 (FORVSS 315, St. 6). – 9° 58.353' N, 75° 49.661' E, 54 m, 30.7.2013 (FORVSS 317, St. 2). – 10° 29.57' N, 75° 31.7' E, 88 m, 12.10.2014 (FORVSS 330, St. 26). – 10° 29.33' N, 75° 41.98' E, 51 m, 12.10.2014 (FORVSS 330, St. 27). – 9° 57.63' N, 75° 50.12' E, 51 m, 13.10.2014 (FORVSS 330, St. 30). CALICUT – 11° 13.256' N, 75° 20.304' E, 50 m, 10.6.2009 (FORVSS 267II, St. 8). – 11° 15.352' N, 75° 18.882' E, 53 m, 7.8.2009 (FORVSS 270I, St. 17). MANGALORE – 12° 51.02' N, 74° 29.71' E, 53 m, 27.9.2014 (FORVSS 329, St. 33). – 12° 50.32' N, 47° 30.26' E, 51 m, 4.10.2014 (FORVSS 330, St. 2). – 9° 57.48' N, 76° 0.12' E, 33 m, 13.12.2014 (FORVSS 333, St. 1). – 10° 0.08' N, 75° 49.99' E, 52 m, 13.12.2014 (FORVSS 333, St. 2). Naturalist dredge and Smith-McIntyre Grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00042

Diagnosis: Clypeastid with pentagonal test, hardly longer than broad; test diameter about 4-5 cm (specimen from FORVSS 295, St. 20 with diameter of 7 cm). Sutures of the aboral side visible as a darker reticulum on the light olive-green test. A slight but distinct bulge in the posterior inter-ambulacrum, corresponding to the location of the periproct on the oral surface. Colour brown.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – NE Arabian Sea (Sastry 2004), Lakshadweep Islands (Kohler 1922, Sastry 1991b), SE Arabian Sea (Kohler 1922, Sastry 2007, Jayakumari 2004, present study), Gulf of Mannar (Venkatraman *et al.* 2013), SW Bay of Bengal (Kohler 1922, Gravely 1941, Satyamurti 1976, Parameswaran *et al.* 2013), and NW Bay of Bengal (Kohler 1922, Ganapati & Rao 1962b, Satyamurti 1976, Sastry 1995, 1998b, 2007, Rao *et al.* 2009).

Remarks: *Laganum mirabile* H. L. Clark, 1925, reported from Indian waters, is a subjective synonym (WoRMS Editorial Board, 2016).

Clypeaster reticulatus (Linnaeus, 1758)

Collection locations: **Cape Comorin, 52 m.** CAPE COMORIN – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00019

Diagnosis: Clypeastid with oval (nearly) sub-pentagonal test, distinctly longer than wide; length 2.5 cm and width 1.5-2 cm; very thick and rounded at the distal edge and domed centre. Oral face of the test uniformly concave. Colour brown.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – Lakshadweep Islands (Koehler 1922, James 1989, Sastry 1991b), SE Arabian Sea (Koehler 1922, present study), Gulf of Mannar (Venkatraman *et* *al.* 2013), and Andaman & Nicobar Islands (Koehler 1922, James 1983, Sastry 2005).

Family Echinocyamidae and Laganidae (Table 3.4, Nos. 29-31) are recorded in the SEAS from depths >30 m and were not collected in the present surveys.

Order Echinolampadoida Kroh & Smith, 2010

Family Echinolampadidae Gray, 1851

Genus *Echinolampas* Gray, 1825

Echinolampas alexandri de Loriol, 1876

PL. VI, Fig. 9

Collection locations: **Cape Comorin-Trivandrum, 30-50 m.** CAPE COMORIN – 7° 59.285' N, 77° 38.709' E, 30 m, 30.5.2009 (FORVSS 267I, St. 1). TRIVANDRUM – 8° 30.88' N, 76° 43.5' E, 50 m, 24.10.2014 (FORVSS 330, St. 77). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00110

Diagnosis: Irregular echinoids with sub-circular or sub-ovate tests; test length 3 cm. Peristome oval shaped and located slightly anterior to the centre of the oral surface. Petals well developed, open distally. Fascioles absent. Colour white.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – Lakshadweep Islands (James 1989, Sastry 1991b), SE Arabian Sea (present study), Gulf of Mannar (James 1969, 1985a, 1988), and NW Bay of Bengal (Koehler 1922).

Order Spatangoida L. Agassiz, 1840

Family Loveniidae Lambert, 1905

Genus *Lovenia* Desor, in Agassiz & Desor, 1847

Lovenia elongata (Gray, 1845)

PL. VI, Fig. 10

Collection locations: **Cape Comorin-Bhatkal, 33-65 m.** CAPE COMORIN – 7° 55.8' N, 77° 55.8' E, 50 m, 5.8.2005 (FORVSS 236, St. 22). – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). – 8° 15.041' N, 76° 57.085' E, 51 m, 7.9.2013 (FORVSS 319, St. 1). TRIVANDRUM – 8° 30.914' N, 76° 45.067' E, 49 m, 16.7.2013 (FORVSS 316, St. 4). BHATKAL – 13° 52.784' N, 73° 49.836' E, 65 m, 15.8.2013 (FORVSS 317, St. 28). – 14° 44.91' N, 73° 58.309' E, 33 m, 18.8.2013 (FORVSS 317, St. 42). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00016

Diagnosis: Test ovate; about 6 cm in length; with a shallow but distinct anterior sulcus, inner fasciole present within the anterior ambulacrum; peripetalous fasciole absent. Lateral ambulacra with petals widening distally; the columns forming lateral arcs on either side of the test. Scattered primary tubercles scattered among smaller secondary tuberculation in all but the posterior inter-ambulacrum; the corresponding spines very long, slender, banded dark reddish-brown and light brown. Periproct sub-marginal, deeply sunken and with a bilobed sub-anal fasciole. Overall colour light to dark brown. Colour brown.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (Bell 1888, Anderson 1894, Thurston 1895a, b, Herdman & Herdman 1904, Koehler 1914, H. L. Clark 1925, James 1969, 1985, 1988, Satyamurti 1976), SW Bay of Bengal (Anderson 1894, Koehler 1914, Gravely 1941), and Andaman & Nicobar Islands (Sastry 2001, 2005).

Family Maretiidae Lambert, 1905

Genus *Nacospatangus* A. Agassiz, 1873

Nacospatangus alta (A. Agassiz, 1864)

Collection locations: **Cape Comorin, 30-52 m.** CAPE COMORIN – 7° 59.285' N, 77° 38.709' E, 30 m, 30.5.2009 (FORVSS 267I, St. 1). – 7° 47.649' N, 77° 30.26' E, 52 m, 30.5.2009 (FORVSS 267I, St. 2). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00020

Diagnosis: Irregular echinoids with small ovate tests; 2.5-3 cm in length; lacking anterior sulcus; posterior inter-ambulacrum more or less keeled.

Anterior paired petals with pore pairs rudimentary in the proximal part of the anterior column. Peripetalous fasciole absent. Primary aboral tubercles absent or few in number, present only in the poster-lateral pair of inter-ambulacra; other tubercles small and uniform. Labrum elongate and sternal plates with tuberculation only in the posterior part. Periproct sunken; with shield shaped anal fasciole. Sternal plates tuberculate throughout, no bare areas. Colour white.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (Koehler 1914, present study), Gulf of Mannar (H. L. Clark 1925), SW Bay of Bengal (Koehler 1914, Gravely 1941, Satyamurti 1976), NW Bay of Bengal (Anderson 1894, Koehler 1914, Sastry 2007), and Andaman & Nicobar Islands (Koehler 1914, Sastry 2005).

Family Brissidae (Table 3.4, Nos. 34-35), Eurypatagidae (Table 3.4, Nos. 36-38), Hemiasteridae (Table 3.4, Nos. 39) and Schizasteridae (Table 3.4, Nos. 42) are known from SEAS from depths <20 m or >1500 m and were not collected in the present surveys.

Class Holothuroidea

Class Holothuroidea comprises 1693 extant species, falling under 28 families in 5 orders. In Indian waters, 149 species (under 71 genera and 18 families) have been recorded, representing all 5 orders. In the SEAS, the holothurians are represented by order Apodida (Synaptidae), Aspidochirotida (Holothuriidae, Mesothuriidae, Stichopodidae & Synallactidae), Dendrochirotida (Cucumariidae, Phyllophoridae, Psolidae & Yipsilothuriidae) and Elasipodia (Deimatidae, Laetmogonidae & Psychropotidae), with 36 species in 28 genera (Table 3.5).

Holothurian UI

Collection locations: **Trivandrum, 52 m.** TRIVANDRUM – 8° 28.896' N, 76° 43.461' E, 52 m, 25.12.2008 (FORVSS 260, St. 58). – 8° 30' N, 76° 48' E, 52 m, 3.9.2011

(FORVSS 289, St. 33). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). Smith-McIntyre grab.

Remarks: Small (length of preserved specimen ~1 cm), damaged specimens with soft body wall and terminal mouth and anus. Tentacles, calcareous ring, podia etc. not discernable. Spicules: slender tables with large, smooth, rounded holes at the base and well developed spires, which end in a cluster of denticles.

Order Apodida Brandt, 1835

Family Synaptidae Burmeister, 1837

Genus *Synaptula* Örstedt, 1849

Synaptula recta (Sluiter, 1887)

Collection locations: **Trivandrum-Kollam, 31-51 m.** TRIVANDRUM – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). KOLLAM – 9° 0.084' N, 76° 23.524' E, 31 m, 3.6.2009 (FORVSS 267I, St. 15). Smith-McIntyre grab.

Diagnosis: Small Apodida, with elongate body, about 2 cm in length, moth and anus terminal. Calcareous ring weak. Spicules anchors and anchor plates; stock of the anchors not branched, but finely toothed, flukes smooth with minute knobs at the centre; anchor plates oval to sub-rectangular, their holes larger in the centre than edge.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – Lakshadweep Islands (Koehler & Vaney 1908, James 1969, Soota *et al.* 1983, Price & Reid 1985, Mukhopadhyay 1988, Sastry 1991), SE Arabian Sea (present study), Gulf of Mannar (Mukhopadhyay 1988), and Andaman & Nicobar Islands (Koehler & Vaney 1908, James 1969, 1983, 1978, Soota *et al.* 1983, Sastry 2004, 2005).

Order Aspidochirotida Grube, 1840

Family Synallactidae Ludwig, 1894

Genus *Perizona* Koehler & Vaney, 1905

Perizona magna Koehler & Vaney, 1905

Collection locations: **Cape Comorin, 1324 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). Demersal trawl.

Diagnosis: Very large species, of length about 25 cm; body flattened and bordered by a very broad margin, in which the papillae are prominent. The posterior part of the ventrum with a two rows of podia, numbering 5-6. Deposits in the form of thorny, branched rods. Colour light pinkish-purple, with deep purple podia.

Distribution: Continental slope northern Indian Ocean. Indian waters – SE Arabian Sea (Koehler & Vaney 1905, present study).

Remarks: The validity of this taxon is doubted, but three specimens, matching well with the original description were collected during the present study. Unfortunately, owing to the gelatinous nature of the samples and large size, it was poorly preserved and so, voucher specimen is not available.

Family Holothuriidae (Table 4.5, Nos. 2-8), Mesothuriidae (Table 4.5, Nos. 9-10), Stichopodidae (Table 4.5, Nos. 11) are known in the SEAS from samples beyond the present survey area (<20 m or < 1500 m) and were not represented in the present surveys.

Order Dendrochirotida Grube, 1840

Family Cucumariidae Ludwig, 1894

Genus *Leptopentacta* Clark, 1938

Leptopentacta imbricata (Semper, 1867)

PL. VI, Fig. 10

Collection locations: **Cape Comorin-Mangalore, 31-108 m.** CAPE COMORIN – 7° 25.98' N, 77° 29.689' E, 108 m, 25.12.2008 (FORVSS 260, St. 56). – 7° 59.373' N, 77° 18.765' E, 48 m, 9.12.2013 (FORVSS 321, St. 12). TRIVANDRUM – 8° 26.303' N, 76° 47.163' E, 52 m, 30.8.2011 (FORVSS 289, St. 17). – 8° 30' N, 76° 48' E, 51 m, 31.8.2011 (FORVSS 289, St. 21). – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). – 8° 30' N, 76° 48' E, 52 m, 4.9.2011 (FORVSS 289, St. 37). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). KOLLAM – 9° 0.084' N, 76° 23.524' E, 31 m, 3.6.2009 (FORVSS 267I, St. 15). KOCHI – 9° 52.2' N, 75° 51' E, 48 m, 3.8.2005 (FORVSS 236, St. 10). – 9° 58.101' N, 75° 49.62' E, 55 m, 20.7.2013 (FORVSS 316, St. 24). MANGALORE – 12° 51.02' N, 74° 29.71' E, 53 m, 27.9.2014 (FORVSS 329, St. 33). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00078

Diagnosis: Body elongate, up to 2.5 cm in length, slender and curved, moth and anus terminal, with posterior end more tapering than anterior end; form rigid owing to the thick investment of spicules resembling imbricating plates; podia arranged in 5 rows. Tentacles 10 in number, calcareous ring without posterior prolongations. Spicules are smooth buttons with 4 holes. Colour white.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – Lakshadweep Islands (James 1985b), SE Arabian Sea (James 1969, 1987c, Price & Reid 1985, Jayakumari 2004, present study), Gulf of Mannar (Mukhopadhyay 1988), SW Bay of Bengal (Koehler & Vaney 1908, James 1987c), and NW Bay of Bengal (Koehler & Vaney 1908, Mukhopadhyay 1988, Sastry 2007).

Remarks: *Ocnus javanicus* Sluiter, 1880 and *O. typicus* Théel, 1886, reported from Indian waters, are synonyms (WoRMS Editorial Board 2016).

Genus *Pseudocnus* Panning, 1949

Pseudocnus echinatus (von Marenzeller, 1881)

Collection locations: **Cape Comorin, 24 m.** CAPE COMORIN – 8° 3.411' N, 77° 29.811' E, 24 m, 16.5.2010 (FORVSS 275, St. 15). Smith-McIntyre grab.

Diagnosis: Dendrochirotida with 10 tentacles, terminal mouth and anus, tapered body; length up to 1.5 cm; body wall rigid owing to thick investment of spicules. Spicules comprised of fir-cone shaped as well as knobbed buttons.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – SE Arabian Sea (present study), and NW Bay of Bengal (Koehler & Vaney 1908, Sastry 2007).

Family Phyllophoridae Östergren, 1907

Genus *Stolus* Selenka, 1867

Stolus buccalis (Stimpson, 1855)

PL. VI, Fig. 11

Collection locations: **Cape Comorin-Kollam, 30-52 m.** CAPE COMORIN – 7° 59.373' N, 77° 18.765' E, 48 m, 9.12.2013 (FORVSS 321, St. 12). – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). TRIVANDRUM – 8° 26.303' N, 76° 47.163' E, 52 m, 30.8.2011 (FORVSS 289, St. 17). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 6.9.2011 (FORVSS 289, St. 45). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). KOLLAM – 9° 0.281' N, 76° 23.756' E, 30 m, 14.8.2009 (FORVSS 270II, St. 1). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00111

Diagnosis: Dendrochirotid with 10 tentacles, terminal mouth and anus, stiff body wall with podia scattered all over; length up to 3 cm. Calcareous ring short and stout, with bifurcating prolongations, composed of mosaic of plates. Spicules primarily oval smooth, nodose buttons with 12 knobs and 4 holes; some smaller rods with expanded ends and smaller buttons. Colour light with a dark mottling.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – NE Arabian Sea (James 1987c, Sastry 2004), SE Arabian Sea (Jayakumari 2004, present study), Gulf of Mannar (Gravely 1927, James 1968b, 1969, 1985a, 1988, Satyamurti 1976, Mukhopadhyay 1988), SW Bay of Bengal (Gravely 1941, James 1987c) and NW Bay of Bengal (Sastry 2007).

Remarks: *Thyone sacellus* (Selenka, 1967), reported from Indian waters, is a synonym (Thandar 1990).

Genus *Thyone* Oken, 1815

Thyone dura Koehler & Vaney, 1908

PL. VI, Fig. 12

Collection locations: **Cape Comorin-Calicut, 24-109 m.** CAPE COMORIN – 8° 3.411' N, 77° 29.811' E, 24 m, 16.5.2010 (FORVSS 275, St. 15). TRIVANDRUM – 8° 26.303' N, 76° 47.163' E, 52 m, 30.8.2011 (FORVSS 289, St. 17). – 8° 30' N, 76° 48' E, 51 m, 31.8.2011 (FORVSS 289, St. 21). – 8° 30' N, 76° 48' E, 51 m, 2.9.2011 (FORVSS 289, St. 29). – 8° 30' N, 76° 48' E, 52 m, 3.9.2011 (FORVSS 289, St. 33). – 8° 30' N, 76° 48' E, 52 m, 4.9.2011 (FORVSS 289, St. 37). – 8° 30' N, 76° 48' E, 51 m, 4.9.2011 (FORVSS 289, St. 38). – 8° 30' N, 76° 48' E, 51 m, 5.9.2011 (FORVSS 289, St. 40). – 8° 30' N, 76° 48' E, 52 m, 5.9.2011 (FORVSS 289, St. 41). – 8° 30' N, 76° 48' E, 52 m, 7.9.2011 (FORVSS 289, St. 49). – 8° 30' N, 76° 48' E, 51 m, 8.9.2011 (FORVSS 289, St. 53). – 8° 30.914' N, 76° 45.067' E, 49 m, 16.7.2013 (FORVSS 316, St. 4). KOLLAM – 8° 52.971' N, 76° 21.388' E, 52 m, 18.7.2013 (FORVSS 316, St. 13). KOCHI – 9° 55.492' N, 75° 38.056' E, 109 m, 26.8.2011 (FORVSS 289, St. 3). – 9° 58.353' N, 75° 49.661' E, 54 m, 30.7.2013 (FORVSS 317, St. 2). – 10° 29.33' N, 75° 41.98' E, 51 m, 12.10.2014 (FORVSS 330, St. 27). CALICUT – 11° 23.64' N, 74° 52.12' E, 101 m, 9.10.2014 (FORVSS 330, St. 17). Naturalist dredge and Smith-McIntyre grab.

Voucher specimen No.: CMLRE IO/SS/ECD/00112

Diagnosis: Dendrochirotid with 10 tentacles, terminal mouth and anus, stiff body wall with podia scattered all over; length up to 3 cm. Calcareous ring short and stout, with prominent bifurcating prolongations, composed of mosaic of plates. Spicules are tables with 4 smooth holes at the base, and short spires which end in a dense cluster of denticles, no buttons found. Colour white with brown mottling.

Distribution: Continental and insular shelves of the western and central Indo-Pacific. Indian waters – NE Arabian Sea (Koehler & Vaney 1908, Sane & Chhapgar 1962), SE Arabian Sea (present study), and Andaman & Nicobar Islands (James 1983, Sastry 2005).

Family Psolidae and Ypsilpthuriidae (Table 3.5, Nos. 26-29) are reported from depths <20 m or >1000 m in the SEAS, and were not collected in the present surveys.

Order Elasipodida Théel, 1882

Family Psychropotidae Théel, 1882

Genus *Benthodytes* Théel, 1882

Benthodytes typica Théel, 1882

PL. VI, Fig. 13

Collection locations: **Cape Comorin-Kochi, 995-1324 m.** CAPE COMORIN – 7° 47.48' N, 76° 27.31' E, 1324 m, 15.7.2013 (FORVSS 316, St. 2). – 7° 53.24' N, 76° 25.768' E, 1262 m, 9.8.2013 (FORVSS 319, St. 8). – 8° 0.845' N, 76° 25.91' E, 1154 m, 10.12.2013 (FORVSS 321, St. 16). TRIVANDRUM – 8° 24.153' N, 76° 1.64' E, 995 m, 12.10.2010 (FORVSS 281, St. 3). – 8° 17.13' N, 76° 12.42' E, 1069 m, 19.10.20012 (FORVSS 305, St. 1). – 8° 17.19' N, 76° 12.34' E, 1032 m, 14.7.2013 (FORVSS 316, St. 1). – 8° 31.775' N, 75° 59.74' E, 1047 m, 12.12.2013 (FORVSS 321, St. 20). KOCHI – 9° 54' N, 75° 31.44' E, 1120 m, 8.8.2010 (FORVSS 278, St. 2). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00114

Diagnosis: 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.

Distribution: Continental slope regions, ridges and seamounts of the Indian, Pacific and Atlantic Oceans. Indian waters – SE Arabian Sea (present study), and Andaman & Nicobar Islands (Koehler & Vaney 1905, Soota *et al.* 1983, Sastry 2005).

Remarks: *Benthodytes glutinosa* Perrier, 1896, reported from Indian waters, is a synonym (WoRMS Editorial Board 2016).

Family Deimatidae and Laetmogonidae (Table 4.5, Nos. 30-32) are known only from depths >1500 m in the SEAS and were not represented in the present collections.

Order Molpadida Haeckel, 1896

Family Molpadidae Müller, 1850

Genus *Molpadia* Cuvier, 1817

Molpadia musculus Risso, 1826

Collection locations: **Trivandrum-Kochi, 1120-1241 m.** TRIVANDRUM – 8° 25.107' N, 75° 55.18' E, 1241 m, 11.12.2013 (FORVSS 321, St. 18). KOCHI – 9° 54' N, 75° 31.44' E, 1120 m, 8.8.2010 (FORVSS 278, St. 2). Demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00113

Diagnosis: Length up to 7 cm, tumid body with a fusiform tail of about 3 cm, skin thick and appearing spiny and rough. Mouth surrounded by 12-15 digitate tentacles. Ossicles are racquet shaped plates with rounded distal ends and numerous perforations, and anchors which usually have few perforations; fusiform rods with few perforations in the tail. The racquets forming rosettes on the body wall. Colour greyish purple, skin with a deposition of phosphatic deposits.

Distribution: Continental slope regions in the Indian, Pacific, Atlantic and Southern Oceans. Indian waters – SE Arabian Sea (Koehler & Vaney 1905, present study), NW Bay of Bengal (Koehler & Vaney 1905), and Andaman & Nicobar Islands (Koehler & Vaney 1905, James 1983, Soota *et al.* 1983, Sastry 2005).

Family Eupyrgidae (Table 4.5, Nos. 35) is known in the SEAS from depths >1500 m and were not collected in the present surveys.

Class Crinoidea

The Class Crinoidea comprises 659 extant species in falling under 31 families and 4 orders. In Indian waters, a total of 60 species (under 43 genera and 15 families), representing order Isocrinida and Comatulida. The Crinoidea of the SEAS are represented by 16 species (16 genera and 10 families) under the order Isocrinida (Cainocrinidae) and Comatulida (Antedonidae, Charitometridae, Colobometridae, Comatulidae, Himerometridae, Mariametridae, Pentametrocrinidae, Thalassometridae, Tropiometridae).

Order Isocrinida Sieverts-Doreck, 1952

Family Cainocrinidae Simms, 1988

Genus *Teliocrinus* Döderlein, 1912

Teliocrinus springeri springeri (A. H. Clark, 1909)

PL. VI, Fig. 14

Collection locations: **Mangalore, 991 m.** MANGALORE – 12° 46.14' N, 73° 58.39' E, 991 m, 22.12.2003 (FORVSS 219, St. 21). Naturalist dredge and demersal trawls.

Voucher specimen No.: CMLRE IO/SS/ECD/00118

Diagnosis: Isocrinid with IBr series of 2 ossicles, united by syzygy; IIBr series of 4-6 ossicles and IIIBr of 2-4 ossicles. The arms serrated owing to the everted distal aboral edges of the branchials. Stalk comprising cirrus bearing nodals alternating with series of internodals, numbering 10-12; stalk pentagonal in cross section distally, star-shaped nearer to the crown; cirri slender, twice as long as a nodotaxis. Basals triangular, radials rectangular. Colour grey.

Distribution: Continental slope northern Indian Ocean. Indian waters – SE Arabian Sea (A. H. Clark 1909), and Andaman & Nicobar Islands (A. H. Clark 1912a, Sastry 2005).

Remarks: *Hypalocrinus ornatus* A. H. Clark, 1909, reported from Indian waters, is synonymised with *T. springeri* by A. H. Clark (1912a).

Order Comatulida

Family Antedonidae Norman, 1865

Genus *Antedon* de Fréminville, 1811

Antedon ?parviflora (A. H. Clark, 1912)

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). Naturalist dredge.

Diagnosis: Small antedonid with 10 arms; IBr2, first syzygy between fifth and sixth segment. First exterior pinnule larger than second, which is of more or less the same size as the third. Cirri slender, with 12-14 segments that are distinctly longer than broad, and lacking spines or tubercles. Colour white.

Distribution: *A. parviflora* is recorded from the Maldives and the central Indo-Pacific. Indian waters – Though species identity is not confirmed, the present collections provides a positive record of this genus in the SEAS.

Remarks: Number of segments in P1 not clear owing to small size of the specimens. Species identity, therefore is not confirmed.

Genus *Mastigometra* A. H. Clark, 1908

Mastigometra micropoda A. H. Clark, 1909

Collection locations: **Cape Comorin, 51 m.** CAPE COMORIN – 7° 48.582' N, 77° 29.613' E, 51 m, 16.5.2010 (FORVSS 275, St. 17). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00115

Diagnosis: Small Antedonidae with 10 arms; IBr2, basal branchials with ambulacral flanges; first syzygy between segments 3 and 4, second at 9 and 10 or higher; distal branchial segments distinctly wedge shaped. Second outer pinnule larger than third.

Distribution: Continental and insular shelves of the northern Indian Ocean. Indian waters – SE Arabian Sea (present study), and Gulf of Mannar (A. H. Clark 1912b). Type locality given as "India", exact location not known (A. H. Clark 1909).

Family Colobometridae A. H. Clark, 1909

Genus *Cenometra* A. H. Clark, 1911

Cenometra bella (Hartlaub, 1890)

PL. VI, Fig. 15

Collection locations: **Cape Comorin, 51 m.** CAPE COMORIN – 7° 48.582' N, 77° 29.613' E, 51 m, 16.5.2010 (FORVSS 275, St. 17). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00116

Diagnosis: Colobometridae with 10 arms; IBr2, segments of first brachitaxis stout, with ambulacral flanges; first syzygy between segments 3 and 4, second between 13 and 14. Second exterior pinnule stiff and stout, recurved over the calyx, with aboral carination. Cirri with 15 segments, which bear transverse ridges. Colour light with dark striations along the arms.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), Gulf of Mannar (Chadwick 1904, A. H. Clark 1915), and NW Bay of Bengal (A. H. Clark 1909, 1912).

Remarks: *Cenometra herdmani* AH Clark, 1909, reported from Indian waters, is a synonym (WoRMS Editorial Board 2016).

Genus *Petasometra* A. H. Clark, 1912

Petasometra helianthoides **A. H. Clark, 1912**

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). Naturalist dredge.

Diagnosis: Colobometridae with 10 arms; IBr2, first syzygy between segments 3 and 4, second between 9 and 10. Pinnules simple; first inner pinnule lacking; first and second exterior pinnules of the same size. Cirri with 12 segments, bearing aboral transverse ridges on all and an opposing spine on the last. Colour white with dark blotches on the arms.

Distribution: Continental and insular shelves of the Indian Ocean (*P. helianthoides* is known from northern Australia and *Petasometra clarae* is reported from the Malay Archipelago). India – SE Arabian Sea (Present study).

Remarks: Only two species, *P. helianthoides* and *P. clarae* (Hartlaub 1890) are known (both from very few specimens) under this genus and these are suspected to be synonymous (Clark & Rowe 1971). Only character distinguishing the species is the number of arms (10-14 in *P. helianthoides* and 15-31 in *P. clarae*).

Family Himerometridae A. H. Clark, 1907

Genus *Heterometra* A. H. Clark, 1909

Heterometra africana (Hartlaub, 1890)

Collection locations: **Cape Comorin, 49 m.** CAPE COMORIN – 7° 59.26' N, 77° 10.767' E, 49 m, 15.11.2010 (FORVSS 282, St. 8). – 8° 8.634' N, 77° 9.403' E, 49 m, 9.12.2013 (FORVSS 321, St. 13). Naturalist dredge.

Diagnosis: Himerometridae with 11-12 arms; IBr2, IIBr2 (3+4), second syzygy between branchials 9 and 10, branchials wedged shaped in the distal part of the arm. Pinnules simple, with a prominent keel, external ones increasing in size from first to third and subsequently decreasing. Cirri with 22-31 segments, bearing a median aboral spines from segment 7-9. Colour yellowish white and purple.

Distribution: Continental and insular shelves of the western and north western Indian Ocean. Indian waters – NE Arabian Sea (A. H. Clark 1912b), and SE Arabian Sea (present study).

Genus *Himerometra* A. H. Clark, 1907

Himerometra robustipinna (Carpenter, 1881)

Collection locations: **Cape Comorin, 32 m.** CAPE COMORIN – 7° 59.264' N, 77° 36.646' E, 32 m, 18.8.2009 (FORVSS 270II, St. 19). Naturalist dredge.

Voucher specimen No.: CMLRE IO/SS/ECD/00117

Diagnosis: Himerometridae with 11 arms; IBr2, IIBr2 (3+4), second syzygy between branchials 9 and 10; branchials stout, proximal ones with faint ambulacral flanges and distal ones wedged shaped. Pinnules simple, with a prominent keel, external ones decreasing in size from first to third, which is more or less smooth. Cirri with 23 segments, bearing a median aboral spines from segment 8-9. Colour white with black calyx.

Distribution: Continental and insular shelves of the Indo-Pacific. Indian waters – SE Arabian Sea (present study), and Andaman & Nicobar Islands (Sastry 1997, 1998, 2005).

Remarks: *Himerometra magnipinna* A. H. Clark, 1908 and *H. pulcher* A. H. Clark, 1912, reported from Indian waters, are synonyms (WoRMS Editorial Board 2016).

The families Comatulidae (Table 3.6, No. 10), Mariametridae (Table 3.6, No. 13) and Tropiometridae are reported from depths <20 m in the southern part of the SEAS, while Charitometridae (Table 3.6, No. 7), Pentametrocrinidae (Table 3.6, No. 15) and Thalassometridae (Table 3.6, No. 16) are known from depths <1200 m and these families were not collected in the present surveys.

To conclude, the present study describes an echinoderm, *Asteroschema sampadae* new to science and reports on 46 new record of species from the continental margin (20m to 1500 m depths) of SEAS. Results from RIMS *Investigator* surveys, revisited after a span of 120 years, are validated and updated with the present survey results. With this, the Echinoderm diversity in SEAS is revalidated from 209 species to 256 species, which include 180 species from the SEAS continental margin (95 shelf species and 85 deep sea species) and 76 species from the insular shelf of Lakshadweep. Systematic details of all echinoderm species collected in the present surveys together with details of peculiar echinoderm associations (sexually dimorphic brittle star *Ophiodaphne scripta* which is an epibiont on sand dollar *Sculpsitechinus auritus*, the brittle star *Ophiosphaera insignis* which is an epibiont on urchin *Salmaciella dussumieri* and also reported to show dimorphism, and the brittle star *Ophiacantha dallasii* which is an epibiont on gorgonids) are provided.

Table 3.1 Updated species diversity of Echinoderms in the SEAS

		*Previous records from the SEAS**	*Species recorded in the present study*			*Total species recorded from the SEAS (Revalidated)*
			Recorded in present study & previously known from SEAS	*New records for the SEAS*	*Total species recorded during the present study*	
Class Asteroidea	*Shelf*	5 (3)	2	6	8	11
	Slope	22 (14)	8	2	10	24
	Total	**27**	**10**	**8**	**18**	**35**
Class Ophiuroidea	*Shelf*	7 (3)	4	20	24	27
	Slope	20 (17)	3	3	6	21
	Total	**27**	**7**	**23**	**30**	**50**
Class Echinoidea	*Shelf*	21 (6)	5	6	11	27
	Slope	16 (14)	2	0	2	16
	Total	**37**	**7**	**6**	**13**	**43**
Class Holothuroidea	*Shelf*	18 (16)	2	3	5	21
	Slope	14 (12)	2	1	3	15
	Total	**32**	**4**	**4**	**8**	**36**
Class Crinoidea	*Shelf*	3 (3)	0	6	6	9
	Slope	7 (6)	1	0	1	7
	Total	**10**	**1**	**6**	**7**	**16**
Total Echinodermata	*Shelf*	54 (31)	13	41	54	95
	Slope	79 (63)	16	6	22	85
	Total	**133**	**29**	**47**	**76**	**180**

Shallow refers to the continental shelf (including near shore areas), up to 250 m depth
Slope implies the continental slope (and continental rise), at depths from 250 m to ~2200 m
* Number in parenthesis indicates species recorded outside the depth range surveyed in the present study (<20 m or >1500 m)

Table 3.2 Updated checklist of Asteroidea in the SEAS

No.	*Species*	*Region*	*References*	*Remarks*
	Order Paxillosida Perrier, 1884			
	Family Astropectinidae Gray, 1840			
1.	*Astropecten griegi* Koehler, 1909	*Slope*	*Koehler 1909*	
2.	*Astropecten hemprichi* Müller & Troschel, 1842	*Shelf*	*Present study*	*New record from E Arabian Sea*
3.	*Astropecten indicus* Perrier, 1878	*Shelf*	*Koehler 1910, Jayakumari 2004*	
4.	*Astropecten inutilis* Koehler, 1910	*Shelf*	*Kurian 1953*	
5.	*Astropecten polyacanthus* Müller & Troschel, 1842	*Shelf*	*Present study*	*New record from E Arabian Sea*
6.	*Astropecten vappa* Müller & Troschel, 1843	*Shelf*	*Present study*	
7.	*Persephonaster croceus* Wood-Mason & Alcock, 1891	*Slope*	*Wood-Mason & Alcock 1891*	
8.	*Persephonaster rhodopeplus* Wood-Mason & Alcock, 1891	*Slope*	*Wood-Mason & Alcock 1891, Alcock 1893, present study*	
9.	*Psilaster agassizi* (Koehler, 1909)	*Slope*	*Koehler 1909*	
	Family Luidiidae Sladen, 1889			
10.	*Luidia denudata* Koehler 1910	*Shelf*	*Present study*	*New record from E Arabian Sea*
11.	*Luidia hardwicki* (Gray, 1840)	*Shelf*	*Present study*	
	Family Porcellanasteridae Sladen, 1883			
12.	*Sidonaster vaneyi* Koehler, 1909	*Slope*	*Koehler 1909, present study*	
	Family Pseudarchasteridae Sladen, 1889			
13.	*Pseudarchaster jordani* Fisher, 1906	*Slope*	*Koehler 1909*	
14.	*Pseudarchaster roseus* (Alcock, 1893)	*Slope*	*Alcock 1893*	
	Order Notomyotida Ludwig, 1910			
	Family Benthopectinidae Verrill, 1894			
15.	*Benthopecten violaceus* (Alcock, 1893)	*Slope*	*Alcock 1893*	
16.	*Cheiraster (Cheiraster) pilosus* (Alcock, 1893)	*Slope*	*Koehler 1909*	
17.	*Cheiraster cribellum* (Alcock, 1893)	*Slope*	*Alcock 1893*	
18.	*Pectinaster mimicus* (Sladen, 1889)	*Slope*	*Wood-Mason & Alcock 1891, Alcock 1893, Koehler 1909*	
	Order Valvatida Perrier, 1884			
	Family Asterinidae Gray, 1840			
19.	*Anseropoda ludovici* (Koehler, 1909)	*Slope*	*Koehler 1909, present study*	
	Family Goniasteridae Forbes, 1841			
20.	*Astroceramus fisheri* Koehler, 1909	*Slope*	*Koehler 1909*	
21.	*Ceramaster cuenoti (Koehler, 1909)*	*Slope*	*Koehler 1909, present study*	
22.	*Circeaster marcelli* Koehler, 1909	*Slope*	*Koehler 1909*	

Table 3.2 Updated checklist of Asteroidea in the SEAS cont.

No.	*Species*	*Region*	*References*	*Remarks*
23.	*Johannaster superbus* Koehler, 1909	*Slope*	*Present study*	
24.	*Nymphaster moebii* (Studer, 1884)	*Slope*	*Alcock 1893, Koehler 1909, present study*	
25.	*Stellaster childreni* Gray, 1840	*Shelf*	*Jayakumari 2004, present study*	
	Family Ophidiasteridae Verrill, 1870			
26.	*Certonardoa semiregularis* (Muller & Troschel, 1842)	*Shelf*	*Sastry 2007*	
27.	*Heteronardoa carinata* (Koehler, 1910)	*Shelf*	*Present study*	*New record for E Arabian Sea*
	Family Oreasteridae Fisher, 1911			
28.	*Goniodiscaster forficulatus* (Perrier, 1875)	*Shelf*	*Jayakumari 2004, present study*	
	Order Forcipulatida Perrier, 1884			
	Family Zoroasteridae Sladen, 1889			
29.	*Cnemidaster squameus* (Alcock, 1893)	*Slope*	*Alcock 1893*	
30.	*Cnemidaster zea* (Alcock, 1893)	*Slope*	*Alcock 1893, present study*	
31.	*Zoroaster alfredi* Alcock, 1893	*Slope*	*Present study*	*New record from Arabian Sea*
32.	*Zoroaster angulatus* Alcock, 1893	*Slope*	*Alcock 1893*	
33.	*Zoroaster planus* Alcock, 1893	*Slope*	*Alcock 1893, present study*	
	Order Brisingida Fisher, 1928			
	Family Brisingidae G.O. Sars, 1875			
34.	*Brisinga gunnii* Alcock, 1893	*Slope*	*Alcock 1893*	
35.	*Brisinga insularum* Wood-Mason & Alcock, 1891	*Slope*	*Wood-Mason & Alcock 1891, present study*	

Table 3.3 Updated checklist of Ophiuroidea in the SEAS

No.	*Species*	*Region*	*References*	*Remarks*
	Order Euryalida Lamarck, 1816			
	Family Asteronychidae Verrill, 1899			
1.	*Asteronyx loveni* Müller & Troschel, 1842	*Slope*	*Koehler 1897, 1899*	
	Family Asteroschematidae Verrill, 1899			
2.	*Asteroschema sampadae* Parameswaran & Jaleel, 2012	*Slope*	*Parameswaran & Abdul Jaleel 2012 (Present study)*	*New species described through present study*
	Order Ophiurida Müller & Troschel, 1840			
	Family Amphiuridae Ljungman, 1867			
3.	*Amphioplus (Lymanella) depressus* (Ljungman, 1867)	*Shelf*	*James 1969, present study*	
4.	*Amphipholis misera* (Koehler, 1899)	*Shelf*	*Present study*	*New record from E Arabian Sea*
5.	*Amphioplus dispar* (Koehler, 1897)	*Slope*	*Koehler 1897, 1899*	
6.	*Amphiura (Amphiura) ambigua* Koehler, 1905	*Shelf*	*Present study*	
7.	*Amphiura (Amphiura) constricta* Lyman, 1879	*Shelf*	*Present study*	*New record from E Arabian Sea*
8.	*Amphiura (Amphiura) duncani* Lyman, 1882	*Shelf*	*Present study*	*New record from Indian EEZ*
9.	*Amphiura (Amphiura) lorioli* (Koehler, 1897)	*Slope*	*Koehler 1897, 1899*	
10.	*Amphiura (Amphiura) micra* H.L. Clark, 1938	*Shelf*	*Present study*	*New record from E Arabian Sea*
11.	*Amphiura (Fellaria) heptacantha* (Mortensen, 1940)	*Shelf*	*Present study*	*New record from Indian EEZ*
12.	*Amphiura (Ophiopeltis) tenuis* (H.L. Clark, 1938)	*Shelf*	*Present study*	*New record from E Arabian Sea*
13.	*Amphuira crispa* Mortensen, 1940	*Shelf*	*Present study*	*New record from Indian EEZ*
14.	*Histampica duplicata* (Lyman, 1875)	*Slope*	*Koehler 1897, 1899*	
15.	*Dougalopus echinatus* (Ljungman, 1867)	*Shelf*	*Present study*	*New record from E Arabian Sea*
16.	*Ophiodaphne scripta* (Koehler, 1904)	*Shelf*	*Parameswaran et al. 2013 (Present study)*	*New record from Indian EEZ*
17.	*Ophiosphaera insignis* Brock, 1888	*Shelf*	*Present study*	*New record from Indian EEZ*

Table 3.3 Updated checklist of Ophiuroidea in the SEAS contd.

No.	*Species*	*Region*	*References*	*Remarks*
	Family Ophiacanthidae Ljungman, 1867			
18.	*Ophiacantha dallassi* Duncan, 1879	*Shelf*	*Present study*	*New record from Indian EEZ*
19.	*Ophiacantha vorax* Koehler, 1897	*Slope*	*Koehler 1897, 1899*	
20.	*Ophiomoeris tenera* (Koehler, 1897)	*Slope*	*Koehler 1897, 1899, present study*	
21.	*Ophioplinthaca rudis* (Koehler, 1897)	*Slope*	*Koehler 1897, 1899*	
22.	*Ophiotreta matura* (Koehler, 1904)	*Slope*	*Sastry 2007*	
	Family Ophiactidae Matsumoto, 1915			
23.	*Ophiactis flexulosa* Koehler, 1897	*Slope*	*Koehler 1897, 1899*	
24.	*Ophiactis macrolepidota* Marktanner-Turneretscher, 1887	*Shelf*	*Sastry 2007*	
25.	*Ophiactis savignyi* (Müller & Troschel, 1842)	*Shelf*	*Jayakumari 2004*	
	Family Ophiochitonidae Matsumoto, 1915			
26.	*Ophiochiton ambulator* Koehler, 1897	*Slope*	*Koehler 1897, 1899, present study*	
	Family Ophiocomidae Ljungman, 1867			
27.	*Ophiocoma (Breviturma) brevipes* Peters, 1851	*Shelf*	*Present study*	
28.	*Ophiopsila pantherina* Koehler, 1898	*Shelf*	*Present study*	*New record from E Arabian Sea*
	Family Ophiodermatidae Ljungman, 1867			
29.	*Bathypectinura heros* (Lyman, 1879)	*Slope*	*Koehler 1897, 1899, present study*	
30.	*Ophiarachnella infernalis* (Müller & Troschel, 1842)	*Shelf*	*Present study*	*New record from E Arabian Sea*
31.	*Ophioconis cupida* Koehler, 1905	*Shelf*	*Present study*	*New record from Indian EEZ*
	Family Ophiolepididae Ljungman, 1867			
32.	*Ophiomusium familiare* Koehler, 1897	*Slope*	*Koehler 1897, 1899*	
33.	*Ophiosphalma elegans* (Koehler, 1897)	*Slope*	*Koehler 1897, 1899*	
34.	*Ophiotrochus panniculus* Lyman, 1878	*Slope*	*Koehler 1897, 1899*	
35.	*Ophiozonella molesta* (Koehler, 1904)	*Slope*	*Koehler 1897, 1899*	
	Family Ophiotrichidae Ljungman, 1867			
36.	*Macrophiothrix aspidotida* (Müller & Troschel, 1842)	*Shelf*	*Jayakumari 2004*	

Table 3.3 Updated checklist of Ophiuroidea in the SEAS contd.

No.	*Species*	*Region*	*References*	*Remarks*
37.	*Ophiocnemis marmorata* (Lamarck, 1816)	*Shelf*	*Jayakumari 2004, present study*	
38.	*Ophiopteron elegans* Ludwig, 1888	*Shelf*	*Present study*	*New record from E Arabian Sea*
39.	*Ophiothrix (Acanthophiothrix) proteus* Koehler, 1905	*Shelf*	*Present study*	*New record from E Arabian Sea*
40.	*Ophiothrix (Acanthophiothrix) purpurea* von Martens, 1867	*Shelf*	*Present study*	
41.	*Ophiothrix (Ophiothrix) aristulata* Lyman, 1879	*Slope*	*Present study*	*New record from E Arabian Sea*
42.	*Ophiothrix (Ophiothrix) foveolata* Marktanner-Turneretscher, 1887	*Shelf*	*Present study*	
43.	*Ophiothrix (Ophiothrix) savignyi* (Müller & Troschel, 1842)	*Shelf*	*Koehler 1898, Present study*	
	Family Ophiuridae Müller & Troschel, 1840			
44.	*Amphiophiura paupera* (Koehler, 1897)	*Slope*	*Koehler 1897, 1899*	
45.	*Amphiophiura radiata* (Koehler, 1897)	*Slope*	*Koehler 1897, 1899*	
46.	*Amphiophiura sordida* (Koehler, 1897)	*Slope*	*Present study*	*New record from E Arabian Sea*
47.	*Ophiura (Ophiuroglypha) irrorata irrorata* (Lyman, 1878)	*Slope*	*Koehler 1897*	
48.	*Ophiura kinbergi* Ljungman, 1866	*Shelf*	*Koehler 1898, present study*	
49.	*Ophiura aequalis* (Lyman, 1878)	*Slope*	*Koehler 1897, 1899*	
50.	*Ophiura undulata* (Lyman, 1878)	*Slope*	*Koehler 1899*	

Table 3.4 Updated checklist of Echinoidea in the SEAS

No.	*Species*	*Region*	*References*	*Remarks*
	Order Cidaroida Claus, 1880			
	Family Cidaridae Lambert, 1900			
1.	*Phyllacanthus imperialis* (Lamarck, 1816)	*Shelf*	*James 1969*	
2.	*Prionocidaris baculosa* (Lamarck, 1816)	*Shelf*	*Jayakumari 2004*	
3.	*Stereocidaris alcocki* (Anderson, 1894)	*Shelf & Slope*	*Anderson 1894, present study*	
4.	*Stylocidaris tiara* (Anderson, 1894)	*Slope*	*Koehler 1927*	
	Family Histocidaridae Lambert, 1900			
5.	*Histocidaris denticulata* Koehler, 1927	*Slope*	*Koehler 1927, present study*	
	Order Echinothurioida Claus, 1880			
	Family Echinothuriidae Thomson, 1872			
6.	*Sperosoma biseriatum* Döderlein, 1901	*Slope*	*Koehler 1927*	
	Family Phormosomatidae Moretensen, 1934			
7.	*Hygrosoma luculentum* (A. Agassiz, 1879)	*Slope*	*Koehler 1927*	
8.	*Phormosoma bursarium* A. Agassiz, 1881	*Slope*	*Anderson 1894, Koehler 1927*	
9.	*Phormosoma verticillatum* Mortensen, 1904	*Slope*	*Koehler 1927*	
	Order Camarodonta Jackson, 1912			
	Family Echinometridae Gray, 1855			
10.	*Echinometra mathaei* (Blainville, 1852)	*Shelf*	*Jayakumari 2004*	
11.	*Heterocentrotus mamillatus* (Linnaeus, 1758)	*Shelf*	*Jayakumari 2004*	
	Family Temnopleuridae A. Agassiz, 1872			
12.	*Paratrema doederleini* L. Agassiz in L. Agassiz & Desor, 1846	*Shelf*	*Present study*	*New record from E Arabian Sea*
13.	*Salmaciella dussumieri* L. Agassiz in L. Agassiz & Desor, 1846	*Shelf*	*Present study*	*New record from E Arabian Sea*
14.	*Salmacis bicolor* L. Agassiz in L. Agassiz & Desor, 1846	*Shelf*	*Koehler 1927, Sastry 2007, Jayakumari 2004*	
15.	*Salmacis virgulata* Leske, 1778	*Shelf*	*Jayakumari 2004, present study*	
16.	*Temnopleurus toreumaticus* (Leske, 1778)	*Shelf*	*Jayakumari 2004, Sastry 2007*	
	Family Toxopneustidae Troschel, 1872			
17.	*Tripneustes gratilla* (Linnaeus, 1758)	*Shelf*	*Jayakumari 2004*	
	Order Diadematoida Duncan, 1889			
	Family Diadematidae Gray, 1855			
18.	*Echinothrix calamaris* (Pallas, 1774)	*Shelf*	*Jayakumari 2004*	

Table 3.4 Updated checklist of Echinoidea in the SEAS contd.

No.	*Species*	*Region*	*References*	*Remarks*
	Order Salenioida Delage & Hérouard, 1903			
	Family Saleniidae L. Agassiz, 1838			
19.	*Salenocidaris miliaris indica* Mortensen, 1939	*Slope*	*Mortensen 1939*	
	Order Stomopneustoida Kroh & Smith, 2010			
	Family Stomopneustidae Mortensen, 1903			
20.	*Stomopneustes variolaris* (Lamarck, 1816)	*Shelf*	*Jayakumari 2004*	
	Order Echinoneioda H. L. Clark, 1925			
	Family Echinoneidae L. Agassiz & Desor, 1847			
21.	*Echinoneus cyclostomus* (Leske, 1778)	*Shelf*	*Present study*	
	Order Clypeasteroida A. Agassiz, 1872			
	Family Astriclypeidae Stefanini, 1912			
22.	*Sculpsitechinus auritus* (Leske, 1778)	*Shelf*	*Koehler 1922, Kurian 1953, James 1969, Jayakumari 2004, present study*	
	Family Clypeasteridae L. Agassiz, 1835			
23.	*Clypeaster annandalei* Koehler, 1922	*Slope*	*Koehler 1922*	
24.	*Clypeaster fervens* (Linnaeus, 1758)	*Shelf*	*Present study*	*New record from E Arabian Sea*
25.	*Clypeaster humilis* (Leske, 1778)	*Shelf*	*James 1969*	
26.	*Clypeaster rarispinus* de Meijere, 1903	*Shelf*	*Koehler 1922, Sastry 2007, Jayakumari 2004, present study*	
27.	*Clypeaster reticulatus* de Meijere, 1903	*Shelf*	*Koehler 1922, present study*	
	Family Echinocyamidae Lambert & Thiéry, 1914			
28.	*Echinocyamus sollers* Koehler, 1922	*Slope*	*Koehler 1922*	
	Family Laganidae Desor, 1858			
29.	*Jacksonaster depressum* (L. Agassiz, 1841)	*Shelf*	*Kurian 1953*	
30.	*Peronella lesueuri* (L. Agassiz, 1841)	*Shelf*	*Koehler 1922*	
31.	*Peronella macroproctes* Koehler, 1922	*Shelf*	*Koehler 1922, Sastry 2007*	
	Order Echinolampadoida Kroh & Smith, 2010			
	Family Echinolampadidae Gray, 1851			
32.	*Echnolampas alexandri* (Gray, 1845)	*Shelf*	*Present study*	
	Order Pedinoida Mortensen, 1939			
	Family Pedinidae Pomel, 1883			
33.	*Caenopedina depressa* Koehler, 1927	*Slope*	*Koehler 1927*	
	Order Spatangioda L. Agassiz, 1840			
	Family Brissidae Gray 1855			
34.	*Brissopsis luzonica* (Gray, 1851)	*Shelf*	*Koehler 1914*	
35.	*Brissopsis oldhami* Alcock, 1893	*Slope*	*Koehler 1914*	

Table 3.4 Updated checklist of Echinoidea in the SEAS contd.

No.	*Species*	*Region*	*References*	*Remarks*
	Family Eurypatagidae Kroh, 2007			
36.	*Elipneustes denudatus* (Koehler, 1914)	*Shelf*	*Koehler 1914*	
37.	*Elipneustes rubens* (Koehler, 1914)	*Shelf*	*Koehler 1914*	
38.	*Linopnustes spectabilis* (de Meijere, 1904)	*Slope*	*Koehler, 1914*	
	Family Hemiasteridae H. L. Clark, 1917			
39.	*Holanthus vanus* (Koehler, 1914)	*Slope*	*Koehler 1914*	
	Family Loveniidae Lambert, 1905			
40.	*Nacospatangus alta* (A. Agassiz, 1864)	*Shelf*	*Koehler 1914, present study*	
	Family Maretiidae Lambert, 1905			
41.	*Lovenia elongata* (A. Agassiz, 1864)	*Shelf*	*Present study*	*New record from E Arabian Sea*
	Family Schizasteridae Lambert, 1905			
42.	*Hypselaster kempi* (Koehler, 1914)	*Slope*	*Koehler, 1914*	
	Incertia sedis			
43.	*Heterobrissus hemingi* (Anderson, 1902)	*Slope*	*Anderson 1902, Koehler 1914*	

Table 3.5 Updated checklist of Holothuroidea in the SEAS

No.	***Species***	***Region***	***References***	***Remarks***
	Order Apodida Brandt, 1835			
	Family Synaptidae Burmeister, 1837			
1.	*Synaptula recta* (Semper, 1867)	*Shelf*	*Present study*	
	Order Aspidochirotida Grube, 1840			
	Family Holothuriidae Burmeister, 1837			
2.	*Bohadschia ocellata* Jaeger, 1833	*Shelf*	*Koehler & Vaney 1908*	
3.	*Holothuria (Mertensiothuria) leucospilota* (Brandt, 1835)	*Shelf*	*James 1969, Jayakumari 2004*	
4.	*Holothuria (Platyperona) difficilis* Semper, 1868	*Shelf*	*Jayakumari 2004*	
5.	*Holothuria (Selenkothuria) moebii* Ludwig, 1883	*Shelf*	*James 1969*	
6.	*Holothuria (Semperothuria) cinerascens* (Brandt, 1835)	*Shelf*	*James 1969, Jayakumari 2004*	
7.	*Holothuria (Semperothuria) imitans* Ludwig, 1875	*Shelf*	*Jayakumari 2004*	
8.	*Holothuria (Vaneyothuria) integra* Koehler & Vaney, 1908	*Shelf*	*Koehler & Vaney 1908*	
	Family Mesothuriidae Smirnov, 2012			
9.	*Mesothuria incerta* Koehler & Vaney, 1905	*Slope*	*Koehler 1905*	
10.	*Mesothuria multipes* (Ludwig, 1893)	*Slope*	*Koehler 1905*	
	Family Stichopodidae Haeckel, 1896			
11.	*Stichopus herrmanni* Semper, 1868	*Shelf*	*Jayakumari 2004*	
	Family Synallactidae Ludwig, 1894			
12.	*Bathyplotes natans* (M. Sars, 1868)	*Slope*	*Koehler & Vaney 1905*	
13.	*Bathyzona incerta* Koehler & Vaney, 1905	*Slope*	*Koehler & Vaney 1905*	
14.	*Dendrothuria similis* Koehler & Vaney, 1905	*Slope*	*Koehler & Vaney 1905*	
15.	*Perizona magna* Koehler & Vaney, 1905	*Slope*	*Koehler & Vaney 1905, present study*	
	Order Dendrochirotida Grube, 1840			
	Family Cucumariidae Ludwig, 1894			
16.	*Aslia forbesi* (Bell, 1886)	*Shelf*	*Jayakumari 2004*	
17.	*Havelockia ariana* (Koehler & Vaney, 1908)	*Shelf*	*Koehler & Vaney 1908*	
18.	*Leptopentacta imbricata* (Semper, 1867)	*Shelf*	*James 1969, 1983, Price & Reid 1985, Jayakumari 2004, present study*	

Table 3.5 Updated checklist of Holothuroidea in the SEAS contd.

No.	*Species*	*Region*	*References*	*Remarks*
19.	*Pseudocnus echinatus* (Stimpson, 1855)	*Shelf*	*Present study*	*New record from E Arabian Sea*
20.	*Staurothyone rosacea* (Semper, 1869)	*Shelf*	*Jayakumari 2004*	
21.	*Trachasina crucifera* (Semper, 1869)	*Shelf*	*Jayakumari 2004*	
	Family Phyllophoridae Östergren, 1907			
22.	*Neothyonidium intermedium* (Koehler & Vaney, 1908)	*Slope*	*Koehler & Vaney 1905*	
23.	*Phyllophorus (Phyllothuria) cebuensis* (Semper, 1867)	*Shelf*	*Jayakumari 2004*	
24.	*Stolus buccalis* Koehler & Vaney, 1908	*Shelf*	*Jayakumari 2004, Present study*	
25.	*Thyone dura* Koehler & Vaney, 1908	*Shelf*	*Present study*	
	Family Psolidae Koehler & Vaney, 1905			
26.	*Psolidium rugosum* Koehler & Vaney, 1905	*Shelf*	*Koehler & Vaney 1905*	
27.	*Psolus laevis* Koehler & Vaney, 1905	*Shelf*	*Koehler & Vaney 1905*	
28.	*Psolus membranaceus* Koehler & Vaney, 1905	*Shelf*	*Koehler & Vaney 1905*	
	Family Ypsilothuriidae Heding, 1842			
29.	*Ypsilothuria bitentaculata* (Ludwig, 1893)	*Slope*	*Koehler & Vaney 1905*	
	Order Elasipodida Théel, 1882			
	Family Deimatidae Théel, 1882			
30.	*Deima validum validum* Théel, 1879	*Slope*	*Koehler & Vaney 1905*	
31.	*Oneirophanta conservata* Koehler & Vaney, 1905	*Slope*	*Koehler & Vaney 1905*	
	Family Laetmogonidae Ekman, 1926			
32.	*Laetmogone violacea* Théel, 1879	*Slope*	*Koehler & Vaney 1905*	
	Family Psychropotidae Théel, 1882			
33.	*Benthodytes typica* Koehler & Vaney, 1905	*Slope*	*Present study*	*New record from E Arabian Sea*
34.	*Psychropotes minuta* Koehler & Vaney, 1905	*Slope*	*Koehler & Vaney 1905*	
	Order Molpadida Haeckel, 1896			
	Family Eupyrgidae Semper, 1867			
35.	*Eupyrgus scaber* Lütken, 1857	*Slope*	*Walsh 1891*	
	Family Molpadiidae Müller, 1850			
36.	*Molpadia musculus* Risso, 1826	*Slope*	*Koehler & Vaney 1905, present study*	

Table 3.6 Updated checklist of Crinoidea in the SEAS

No.	*Species*	*Region*	*References*	*Remarks*
	Order Isocrinida Sieverts-Doreck, 1952			
	Family Cainocrinidae Simms, 1988			
1.	*Teliocrinus springeri springeri* (A. H. Clark, 1909)	*Slope*	*A. H. Clark 1909, 1912, present study*	
	Order Comatulida			
	Family Antedonidae Norman, 1865			
2.	*Antedon ?parviflora* (A. H. Clark, 1912)	*Shelf*	*Present study*	
3.	*Athrypsometra mira* (A. H. Clark, 1909)	*Slope*	*A. H. Clark 1912*	
4.	*Fariometra obscura* (A. H. Clark, 1909)	*Slope*	*A. H. Clark 1912*	
5.	*Mastigometra micropoda* A. H. Clark, 1909	*Shelf*	*Present study*	*New record from E Arabian Sea*
6.	*Thaumatometra plana* (A. H. Clark, 1912)	*Slope*	*A. H. Clark 1912*	
	Family Charitometridae A. H. Clark, 1909			
7.	*Glyptometra macilenta* (A. H. Clark, 1909)	*Slope*	*A. H. Clark 1909, 1912*	
	Family Colobometridae A. H. Clark, 1909			
8.	*Cenometra bella* (Hartlaub, 1890)	*Shelf*	*Present study*	*New record from E Arabian Sea*
9.	*Petasometra helianthoides* A. H. Clark, 1912	*Shelf*	*Present study*	*New record from Indian EEZ*
	Family Comatulidae Fleming, 1828			
10.	*Comaster schlegeli* (Carpenter, 1881)	*Shelf*	*Jayakumari 2004*	
	Family Himerometridae A. H. Clark, 1907			
11.	*Heterometra africana* (Hartlaub, 1890)	*Shelf*	*Present study*	
12.	*Himerometra robustipinna* (Carpenter, 1881)	*Shelf*	*Present study*	*New record from E Arabian Sea*
	Family Mariametridae A. H. Clark, 1909			
13.	*Lamprometra palmata* Müller, 1841	*Shelf*	*A. H. Clark 1932, Jayakumari 2004*	
	Family Pentametrocrinidae A. H. Clark, 1908			
14.	*Thaumatocrinus investigatoris* AH Clark (in AH Clark & AM Clark, 1967)	*Slope*	*A. H. Clark 1912*	
	Family Thalassometridae A. H. Clark, 1908			
15.	*Stiremetra carinifera* A. H. Clark, 1912	*Slope*	*A. H. Clark 1912*	
	Family Tropiometridae A. H. Clark, 1908			
16.	*Tropiometra carinata* (Lamarck, 1816)	*Shelf*	*A. H. Clark 1932, Jayakumari 2004*	

Table 3.7 List of Echinoderms reported from the Lakshadweep Islands (Shallow water)

1.	*Acanthaster planci* (Linnaeus, 1758)
2.	*Aquilonastra cepheus* (Muller & Troschel, 1842)
3.	*Asteropsis carinifera* (Lamarck, 1816)
4.	*Astropecten tamilicus* Döderlein, 1888
5.	*Cistina columbiae* Gray, 1840
6.	*Cryptasterina pentagona* (Muller & Troschel, 1842)
7.	*Culcita novaeguineae* Müller & Troschel, 1842
8.	*Culcita schmideliana* (Retzius, 1805)
9.	*Dactylosaster cylindricus* (Lamarck, 1816)
10.	*Disasterina ceylanica* Döderlein, 1888
11.	*Fromia indica* (Perrier, 1869)
12.	*Fromia milleporella* (Lamarck, 1816)
13.	*Fromia monilis* (Perrier, 1869)
14.	*Halityle regularis* Fisher, 1913
15.	*Leiaster leachi* (Gray, 1840)
16.	*Linckia guildingi* Gray, 1840
17.	*Linckia laevigata* (Linnaeus, 1758)
18.	*Linckia multifora* (Lamarck, 1816)
19.	*Nardoa novaecaledoniae* (Perrier, 1875)
20.	*Paraferdina laccadivensis* James, 1976
21.	*Pentaceraster regulus* (Müller & Troschel, 1842)
22.	*Siraster tuberculatus* H.L. Clark, 1915
23.	*Tegulaster leptalacantha* (H.L. Clark, 1916)
24.	*Amphipholis squamata* (Delle Chiaje, 1828)
25.	*Macrophiothrix demessa* (Lyman, 1861)
26.	*Macrophiothrix longipeda* (Lamarck, 1816)
27.	*Macrophiothrix nereidina* (Lamarck, 1816)
28.	*Macrophiothrix propinqua* (Lyman, 1861)
29.	*Ophiactis savignyi* (Müller & Troschel, 1842)
30.	*Ophiocoma (Breviturma) brevipes* Peters, 1851
31.	*Ophiocoma (Breviturma) dentata* Müller & Troschel, 1842
32.	*Ophiocoma anaglyptica* Ely, 1944
33.	*Ophiocoma erinaceus* Müller & Troschel, 1842
34.	*Ophiocoma pica* Müller & Troschel, 1842
35.	*Ophiocoma scolopendrina* (Lamarck, 1816)
36.	*Ophiocoma valenciae* Müller & Troschel, 1842
37.	*Ophiocomella sexradia* (Duncan, 1887)
38.	*Ophiolepis cincta cincta* Müller & Troschel, 1842
39.	*Ophiolepis superba* H.L. Clark, 1915
40.	*Ophiomastix annulosa* (Lamarck, 1816)

Table 3.7 List of Echinoderms reported from the Lakshadweep Islands (Shallow water) contd.

41. *Ophiomyxa australis* Lütken, 1869
42. *Ophionereis porrecta* Lyman, 1860
43. *Ophiothrix (Acanthophiothrix) lepidus* de Loriol, 1893
44. *Ophiothrix (Acanthophiothrix) vigelandi* A.M. Clark, 1968
45. *Ophiothrix (Ophiothrix) trilineata* Lütken, 1869
46. *Astropyga radiata* (Leske, 1778)
47. *Brissus latecarinatus* (Leske, 1778)
48. *Clypeaster reticulatus* (Linnaeus, 1758)
49. *Diadema savignyi* (Audouin, 1829)
50. *Diadema setosum* (Leske, 1778)
51. *Echinolampas alexandri* de Loriol, 1876
52. *Echinolampas ovata* (Leske, 1778)
53. *Echinometra mathaei* (Blainville, 1825)
54. *Echinoneus cyclostomus* Leske, 1778
55. *Echinostrephus molaris* (Blainville, 1825)
56. *Echinothrix calamaris* (Pallas, 1774)
57. *Echinothrix diadema* (Linnaeus, 1758)
58. *Eucidaris metularia* (Lamarck, 1816)
59. *Heterocentrotus mamillatus* (Linnaeus, 1758)
60. *Metalia spatagus* (Linnaeus, 1758)
61. *Plococidaris verticillata* (Lamarck, 1816)
62. *Prionocidaris baculosa* (Lamarck, 1816)
63. *Pseudoboletia maculata* Troschel, 1869
64. *Stomopneustes variolaris* (Lamarck, 1816)
65. *Toxopneustes pileolus* (Lamarck, 1816)
66. *Tripneustes gratilla* (Linnaeus, 1758)
67. *Actinopyga echinites* (Jaeger, 1833)
68. *Actinopyga mauritiana* (Quoy & Gaimard, 1834)
69. *Actinopyga miliaris* (Quoy & Gaimard, 1834)
70. *Afrocucumis africana* (Semper, 1867)
71. *Bohadschia argus* Jaeger, 1833
72. *Bohadschia marmorata* Jaeger, 1833
73. *Bohadschia ocellata* Jaeger, 1833
74. *Euapta godeffroyi* (Semper, 1868)
75. *Holothuria (Cystipus) rigida* (Selenka, 1867)
76. *Holothuria (Halodeima) atra* Jaeger, 1833
77. *Holothuria (Lessonothuria) pardalis* Selenka, 1867
78. *Holothuria (Mertensiothuria) hilla* Lesson, 1830
79. *Holothuria (Mertensiothuria) leucospilota* (Brandt, 1835)
80. *Holothuria (Microthele) nobilis* (Selenka, 1867)

Table 3.7 List of Echinoderms reported from the Lakshadweep Islands (Shallow water) contd.

81. *Holothuria (Platyperona) difficilis* Semper, 1868
82. *Holothuria (Stauropora) fuscocinerea* Jaeger, 1833
83. *Holothuria (Stauropora) pervicax* Selenka, 1867
84. *Holothuria (Thymiosycia) arenicola* Semper, 1868
85. *Holothuria (Thymiosycia) impatiens* (Forskål, 1775)
86. *Labidodemas rugosum* (Ludwig, 1875)
87. *Opheodesoma grisea* (Semper, 1867)
88. *Phyrella fragilis* (Mitsukuri & Ohshima in Ohshima, 1912)
89. *Stichopus chloronotus* Brandt, 1835
90. *Stichopus herrmanni* Semper, 1868
91. *Synapta maculata* (Chamisso & Eysenhardt, 1821)
92. *Synaptula recta* (Semper, 1867)
93. *Thelenota ananas* (Jaeger, 1833)

Sources: Anderson (1894), Koehler (1898, 1922, 1927), Bell (1902), James (1969, 1995), Mukhopadhyay & Samanta (1983), Mukhopadhyay (1991), Sastry (1991, 2007).

CHAPTER 4

Distribution & ecology of echinoderms in the south eastern Arabian Sea shelf

4.1 Introduction

Studies on echinoderm distribution in tropical continental margins, at broad or narrow spatial scales are scarce (Lane *et al.* 2001, Entrambasaguas *et al.* 2008, Vasquez-Bader *et al.* 2008, Iken et *al.* 2010, Williams *et al.* 2010 etc.) when compared to other parts of the world oceans (Pawson 1961, Dawson 1970, Tyler & Banner 1977, Sibuet 1977, Ellis *et al.* 2000, O'Hara & Poore 2000, Howell *et al.* 2002, Freeman & Rogers 2003, De Domenico *et al.* 2006 etc.) and other epifaunal taxonomic groups. Under the present scenario of climate change induced acidification (Caldeira & Wickett 2003) and intensification of hypoxia (Diaz & Rosenberg 2008, Stramma *et al.* 2010), habitat fragmentation to which echinoderms are less resilient (Orr *et al.* 2005, Dupont *et al.* 2010, Doney *et al.* 2012, Byrne & Prezslawski 2013), documentation of their distribution and ecology is of critical importance.

Only a few studies have been undertaken on epifaunal or echinoderm distribution and ecology from India. In the continental margins around India, a few studies have been carried out on the distribution of epifauna. Based on surveys along the inner shelf of the north east coast of India (30-200 m), Ganesh & Raman (2007) found that gastropods, bivalves, polychaetes and decapods constituted the bulk of epifauna and that their distribution was influenced by depth, sand, sediment organic matter and sediment mean size. Along the inshore waters (5-25 m depth) off the southeast coast of India, Khan *et al.* (2010) noted that gastropods, bivalves, crustacean and polychaetes were the most abundant and diverse groups and explained the variations in their distribution in relation to the variations in nine environmental variables. Hunter *et al.* (2011) described zonation in epibenthic megafauna along a transect in the continental margin of the Arabian Sea (between 540 and 2000 m depth) and noted high density of ophiuroids at 800 m depth. Joydas & Damodaran (2014) reported a clear decline in standing stock of macro infauna from shallower depths (50 m) to the shelf edge (~200 m) in the eastern Arabian Sea (EAS), with very low contribution from echinoderms, coupled with a decline in species diversity of polychaetes. In the continental slope of the south eastern Arabian Sea (SEAS), Abdul Jaleel *et al.* (2014) noted that polychaete density decreased while diversity increased from the shelf edge (~200 m), which is under influence of the Arabian Sea OMZ, to ~1000 m depth. The SEAS shelf is subjected to intense trawling (Naomi *et al.* 2011), except during the 45-day trawling ban (Vivekanandan *et al.* 2010). Abdul Jaleel *et al.* (2015) reported a clear recovery in standing stock of infauna during this ban period, as a result of recruitment of major polychaete taxa, which coincide their breeding window with the highly productive summer monsoon (SM) season. In this region, echinoderms are reported to form significant portion of trawl by-catch (Kurup *et al.* 2003, Kurup 2004), but no information is available on the density, diversity and distribution of this group.

The distribution of benthic fauna (including echinoderms) are influenced by a wide array of environmental and biotic factors, including temperature, salinity, oxygen availability, current velocities, nature of bottom, habitat heterogeneity, sediment nature, sedimentation rates and food (or prey) availability (Sanders 1958, 1968, Gray 1974, Pearson & Rosenberg 1978, 1987, Levinton 1982, Kinne 1963, Bourget *et al.* 1994, Rosenberg 1995, Snelgrove 1998, Gray & Elliot 2009 etc.). The SEAS is a distinct ecosystem of the eastern Arabian Sea (EAS) with unique physical, chemical and biological attributes (Madhupratap *et al.* 2001, Sanjeevan *et al.* 2009, Jyotibabu *et al.* 2010). This monsoon driven ecosystem experiences two pronounced seasons annually, the Summer Monsoon season (SM) from June to end of September and the Winter Monsoon season (WM) from November to end of February, interspaced by the Fall (October) and Spring (March to end May) Inter-Monsoons (FIM & SIM). The SM season is characterized by strong south-westerly winds that drive an equator ward Western India Coastal Current (WICC), the influence of moderate to intense coastal upwelling and the consequent higher biological production. During the WM season, north-easterly winds drive the Eastern India Coastal Current (EICC) pole ward, leading to the influx and spread of the low saline oligotrophic Bay of Bengal waters over the SEAS which results in reduced biological production. FIM and SIM seasons are quiescent as surface winds are weak and not organized. During the SM & late SIM seasons, hypoxic (DO<0.5ml/l) to suboxic (DO<0.2ml/l) conditions develop in the water column and sea bottom of the SEAS shelf.

The present chapter provides details on the echinoderms in the benthic faunal assemblages of the SEAS shelf and explains the diversity, abundance and distribution of this group in the 20 and ~200 m depths (shelf) based on observed ecological and environmental factors. Methodologies in sampling and data analysis are outlined in Chapter 2.

4.2 Results

4.2.1 Distribution of echinoderms

4.2.1.1 Density & composition of epifauna

Major epifaunal groups represented in the 112 dredge hauls in the SEAS shelf were the echinoderms (Echinoidea, Asteroidea, Ophiuroidea, Holothuroidea & Crinoidea), crustaceans (Decapods such as crabs, hermit crabs and prawns) and molluscs (gastropods, bivalves and cephalopods) and teleost fishes. Other groups included coelenterates, nemertines, sponges, echiuroids and polychaete worms. In the study area as a whole, echinoderms were the dominant group among the epifauna (42% of density), followed by crustaceans (31%), and molluscs (19%), while fishes (4%) and other groups (4%) were least abundant (Figure 4.1).

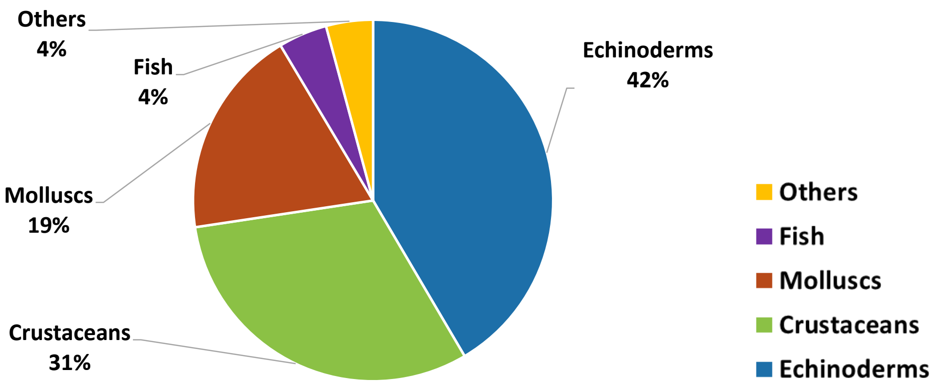

Figure 4.1 Composition of epifauna in the SEAS shelf

Considerable seasonal and latitudinal variations were noted in the density and composition of epifauna (PERMANOVA $p<0.05$), while bathymetric variations were not statistically significant (Table 4.1). In the SEAS shelf as a whole, the mean density of epifauna was 132 ind./haul during Summer Monsoon (SM) season and 120 ind./haul during Winter Monsoon (WM). The statistically significant seasonal variations were a result of the significant differences in relative abundance of faunal groups during

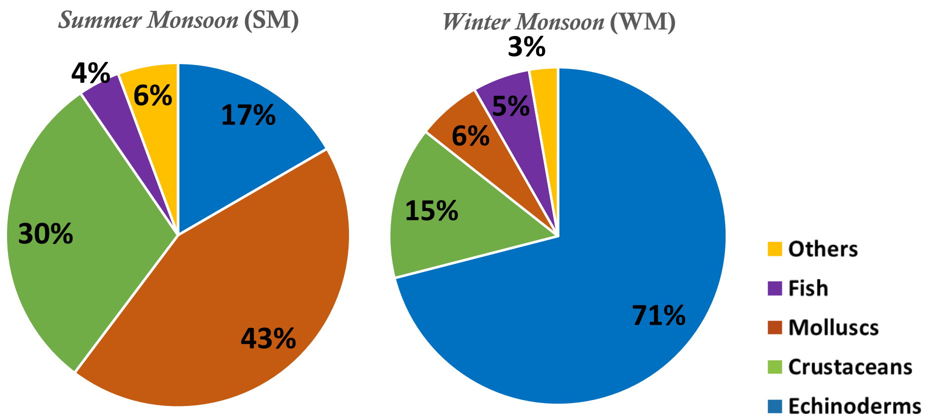

Figure 4.2 Composition of epifauna in the SEAS during summer and winter monsoon (SM & WM)

these two seasons. During SM (Figure 4.2), crustaceans (chiefly prawns and crabs) were the dominant group (43% of epifauna), followed by molluscs (30%) and echinoderms (17%), while fishes and other groups were relatively less abundant (4% and 6% respectively). During WM (Figure 4.2), the relative abundance of echinoderms increased to 71%, and they were the dominant group, while the contribution of crustaceans decreased to 15%. During this season, the molluscs (6%), fishes (5%) and other groups (3%) were relatively less abundant.

Variations in density and composition of epifaunal groups in the four depth strata (20-50 m, 50-80m, 80-150m & 150-250m) of the study area were low and not significant (Table 4.1). Total epifaunal density (Figure 4.3) was 139 ind./haul (20-50 m), 131 ind./haul (50-80 m), 91 ind./haul (80-150 m) and 24 ind./haul (150-250 m). In the 20-50 m depth stratum, molluscs (57 ind./haul, 61% of epifauna) and crustaceans (49 ind./haul, 36%) were the dominant group (Figure 4.4), while echinoderms were dominant in the 50-80 m depth stratum (49 ind./haul, 68%) and crustaceans dominated beyond 80 m (43 ind./haul, 46% at 80-150 m and 17 ind./haul, 70% at 150-250 m depth). Echinoderms were nearly absent in the 150 and 250 m depth stratum, being

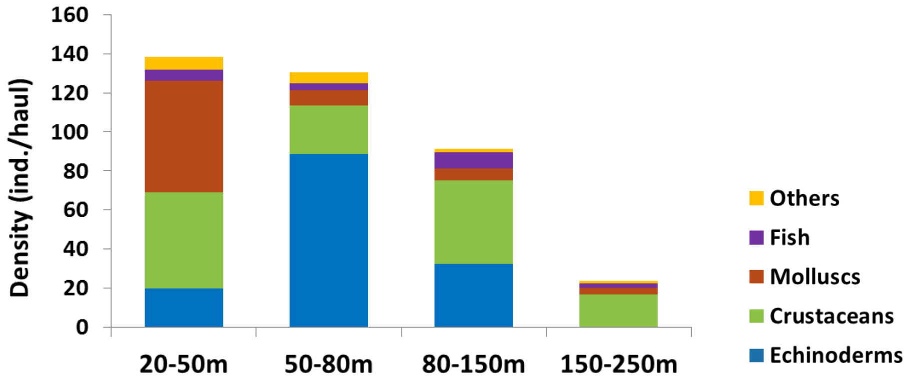

Figure 4.3 Density of epifauna in the four depth strata

represented only by a single sample in Transect 3 (T3). The lack of statistically significant bathymetric variations in epifaunal composition may be attributed to the pronounced latitudinal and seasonal variations, which resulted in wide fluctuations within each depth category. However, mean density decreased by 83% from the shallowest to deepest depth strata.

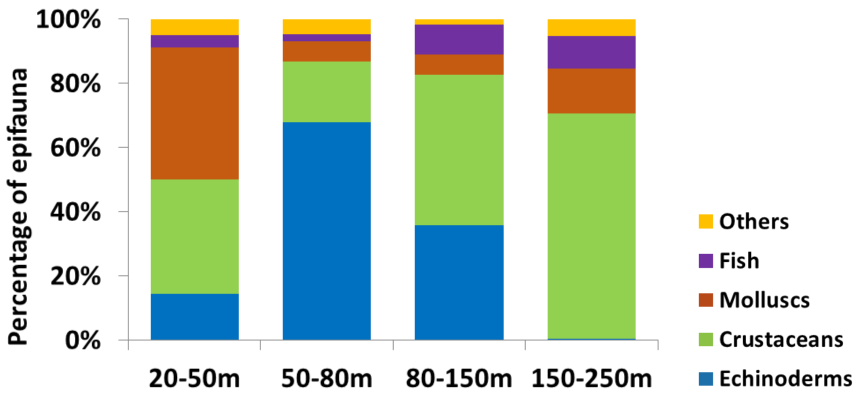

Figure 4.4 Relative abundance of epifaunal groups in the four depth strata

Among the transects (T1-T8), highest density of epifauna (Figure 4.5) was recorded at T3 (267 ind./haul), followed by T2 (137 ind./haul), T6 (124 ind./haul) and T4 (108 ind./haul), while density was low at T1 (40 ind./haul), T5 (58 ind./haul), T7 (44 ind./haul) and T8 (31 ind./haul).

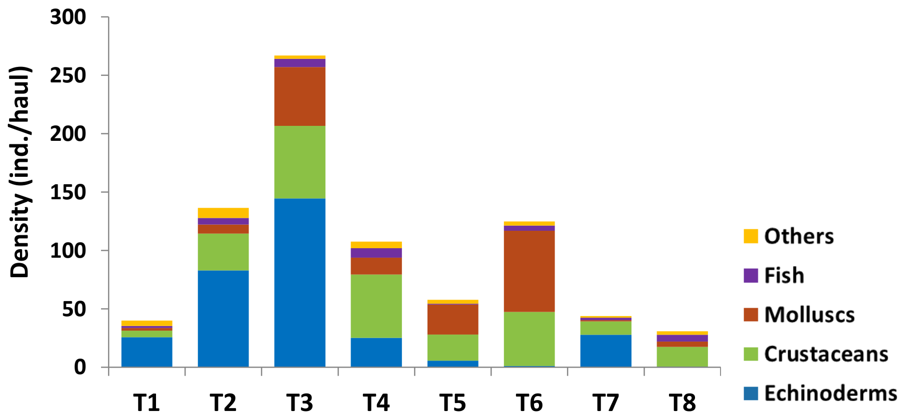

Figure 4.5 Density of epifauna in each transect

Echinoderms were the dominant group among epifauna (Figure 4.6) at T1 (26 ind./haul, 65% of epifauna), T2 (83 ind./haul, 61%), T3 (145 ind./haul, 54%) and T7 (28 ind./haul, 63%), while crustaceans were dominant in T4 (54 ind./haul, 50%) and T8 (17 ind./haul, 55%) and molluscs dominated at T5 (26 ind./haul, 44%) and T6 (70 ind./haul, 56%). A progressive decline in the relative abundance of echinoderms from south to north was noted, from 65% at T1 to 2% at T8, with the notable exception of T7, where echinoderms contributed 63% to mean density. This was accompanied by an overall

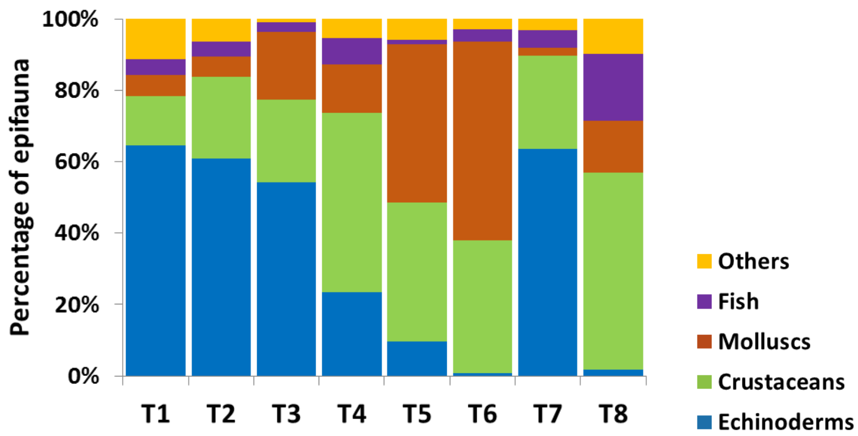

Figure 4.6 Relative abundance of epifaunal groups in each transect

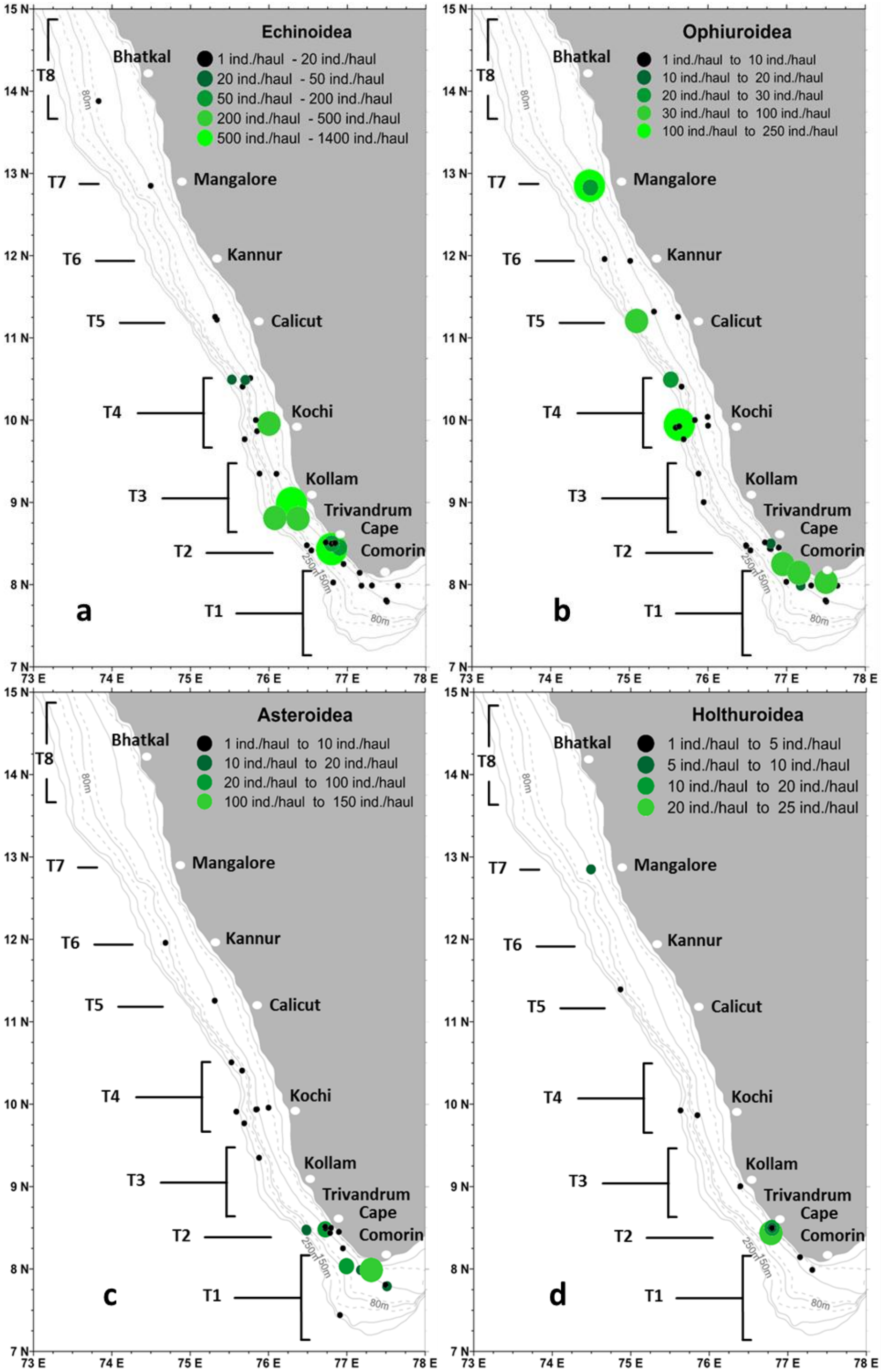

Figure 4.7 Density of Echinoidea (a), Ophiuroidea (b), Asteroidea (c) and Holothuroidea (d) among epifauna in the SEAS shelf

increase in relative abundance of crustaceans (from 13% at T1 to 55% at T8) and molluscs (from 6% at T1 and T2 to 55% at T6).

Echinoderms were present in 69 of the 112 dredge hauls, representing all five classes. Apart from a single ophiuroid, collected at 155 m depth off T3, echinoderms were altogether absent at the 150-250 m depth category. Significant differences ($p<0.05$) were noted in the density of echinoderms between the SM (mean density: 22 ind./haul) and WM (mean density: 85 ind./haul) seasons.

Among the echinoderms, echinoids were represented in 45 hauls, with higher density at T2-T4 (Figure 4.7a) and maximum density of 1316 ind./haul (T3, 49 m, WM). Ophiuroids were represented in 41 hauls (Figure 4.7b), with high density throughout most of the study area and maximum of 240 ind./haul (T4, 106 m, SM & T7, 53 m, SM). Asteroids were collected in 32 hauls (Figure 4.7c), with relatively high density only at T1 (maximum density 130 ind./haul at T1, 48m, WM) and holothurians were present in 18 hauls (Figure 4.7d), with high density only at T2 (21 ind./haul at 52 m, SM). Class Crinoidea was represented only at 4 sites in T1 (32-51 m), with maximum density of 21 ind./haul (49 m, WM).

4.2.1.2 Density & composition of infauna

Based on 410 grab samples from the SEAS shelf, the polychaetes were found to be the dominant components among infauna (80% of total macrofaunal density), followed by crustaceans, molluscs and echinoderms (Figure 4.8). Other groups represented in very low density included nemertines, sipunculids and hydrozoans. Mean density of echinoderms was 29 ind./m^2 (1% of total macrofaunal density) and mean biomass was 0.79 g/m^2 (9% of total macrofaunal biomass). They were represented by adults of Ophiuroidea and Holothuroidea along with juveniles of certain species of Ophiuroidea (*Ophiura* sp.), Asteroidea (*Astropecten* spp.) and Echinoidea

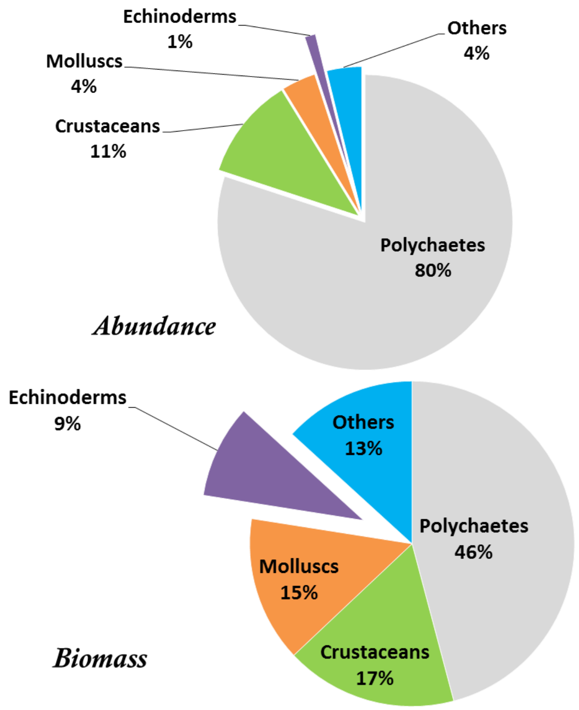

Figure 4.8 Composition of infauna in the SEAS shelf

(*Clypeaster* spp., *Sculpsitechinus* sp.). The occurrence of these juveniles was noted between August and December. Seven species of ophiuroids (all of Family Amphiuridae) and 2 species of holothurians (*Synaptula recta* and *Pseudocnus echinatus*) were represented only among infauna (grab collections).

The standing stock of macro fauna in the SEAS shelf showed significant bathymetric and seasonal variations ($p<0.05$, Table 4.1). Owing to the relative low contribution of echinoderms to macrofaunal standing stock (density and biomass), comparable variations were not discernable in the case of this group. However, echinoderms were notably absent north of T4 during SM, except for *Amphioplus depressus* (Ophiuroidea, Amphiuridae) which occurred in high abundance (20-50 ind./m^2) at two sites in T4 & T7.

4.2.1.3 Species diversity & distribution of echinoderms

In order to analyse the species diversity and distribution of echinoderms in the SEAS shelf, data from the dredge and grab collections were pooled. This provided a presence or absence dataset of the 55 echinoderm species in the 241 sites. The deep-sea species *Stereocidaris alcocki*, which was also collected at 50 m off Cape is considered in this analysis, in addition to the 54 exclusive shelf species detailed in Chapter 3. Owing to the different methodology and sample size of dredge and grab collections, attempts were not made to combine quantitative species distribution data from these two gears. The number of species represented in each site was taken as a direct measure of species diversity. Echinoderms were represented at 106 sites out of 241, with highest diversity of 13 species at 52 m depth in T1 (SIM). With 24 species being identified from the SEAS shelf, the class Ophiuroidea exhibited highest diversity among echinoderms, followed by class Echinoidea (12 species) and Asteroidea (8 species). Holothurians and crinoids in the study area were represented by 5 and 6 species respectively. Bathymetric and latitudinal variations in species distribution were found to be statistically significant ($p<0.05$), while seasonal variations were not significant (Table 4.1).

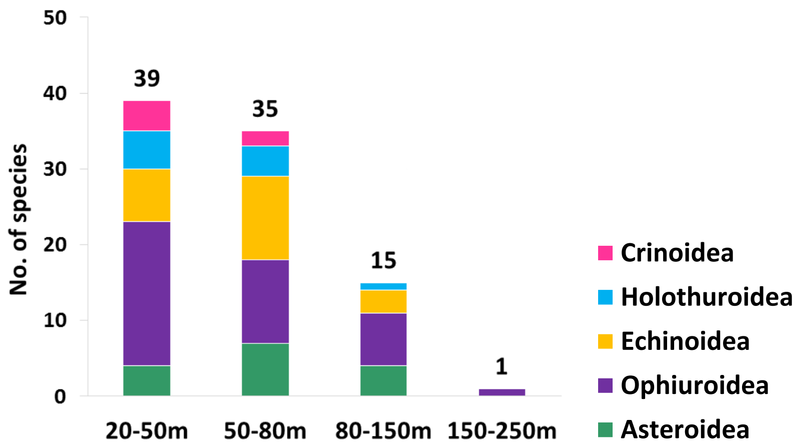

Figure 4.9 Diversity of echinoderm classes in each depth stratum

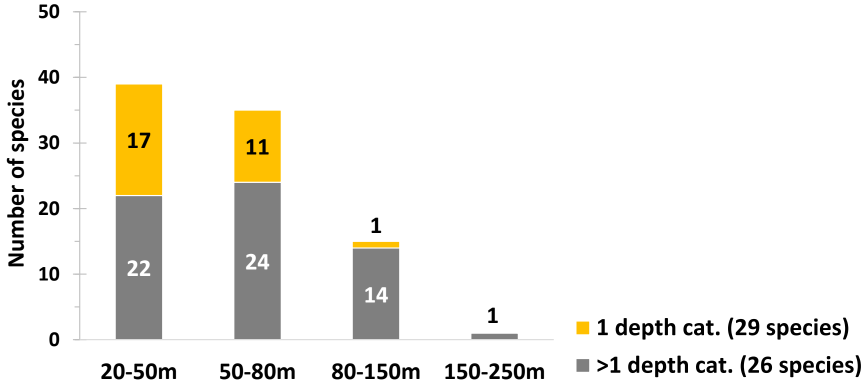

Figure 4.10 Number of species with wide and narrow distribution ranges at each depth stratum

Species diversity was high in the depths between 20 and 80 m (Figure 4.9). Only one species, *Ophiura kinbergi* (Ophiuroidea, Ophiuridae), was represented in the beyond a depth of 124 m (Table 4.2). The Ophiuroidea were the most species rich class between 20 and 50 m depths (19 species), while Asteroidea and Echinoidea were well represented between 50 and 80 m (11 species each). Crinoids were collected only between 20 and 50 m depth, and holothurians showed highest diversity at this depth range. Diversity of all classes decreased beyond 80 m. Based on their distribution in the depth strata, the echinoderm species were classified as those with restricted bathymetric range (recorded only in 1 depth range) and those with wider range (recorded in 2 or more depth ranges). Seventeen species were exclusive to the 20-50 m depth stratum, 11 were found only at 50-80 m depth and 1 species was found to occur only between 80 and 150 m (Figure 4.10); with a total of 29 species having limited bathymetric distribution. The remaining 26 species were recorded at 2 or more depth ranges.

Among the transects, highest species diversity was recorded at T1 (50 species), and crinoids were observed only in this transect (Figure 4.11). Diversity of echinoderms decreased progressively towards the north, particularly in the case of Asteroidea, Ophiuroidea and Echinoidea; and only

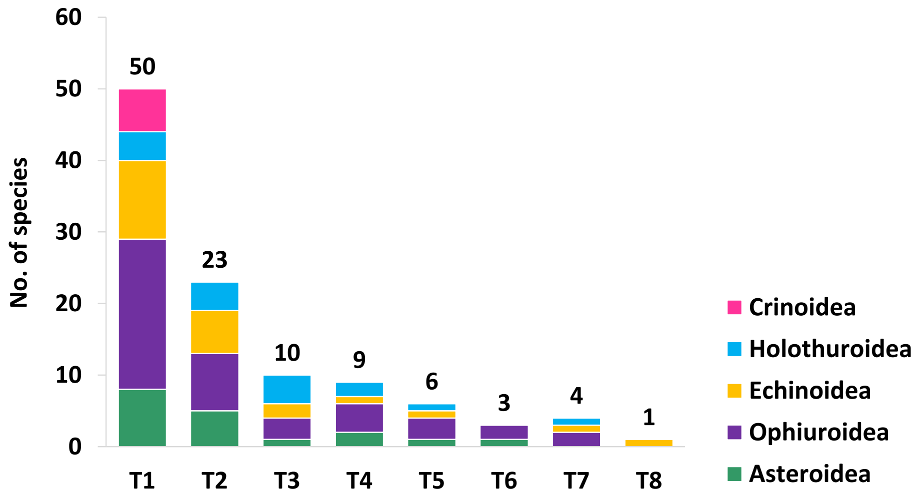

Figure 4.11 Diversity of echinoderm classes in each transect

1 species, *Lovenia elongata* (Echinoidea, Loveniidae), was recorded in T8. Based on their latitudinal distribution (Figure 4.12), species were categorised as those with restricted latitudinal range (recorded only in 1 transect), those with less restricted range (recorded in 2-5 transects) and common species (recorded in 6 or more transects). Thirty four species were found to occur only in one transect, of which 31 were recorded in T1 and 3 in T2. Sixteen species were found to have a less restricted distribution and 4 species occurred nearly

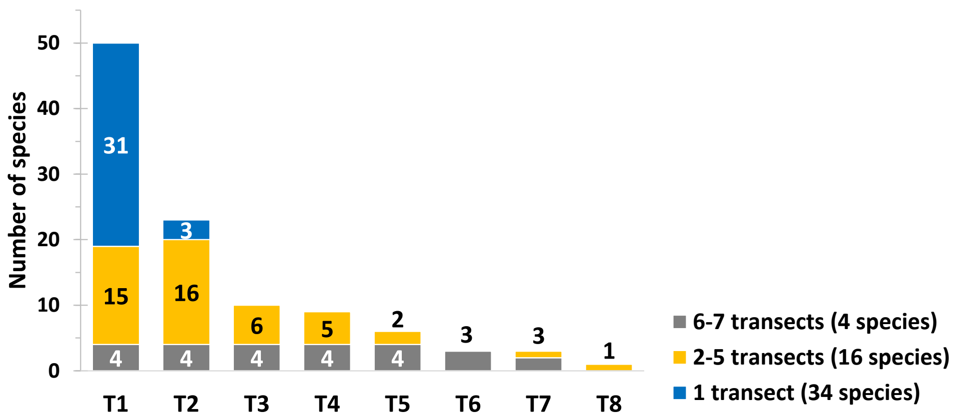

Figure 4.12 Number of species with wide and narrow distribution ranges in each transect

throughout the study area. The results show that, 'unique' or 'characteristic' species were found only in T1 and T2, while species occurring north of T3 were those with relatively wider distribution (Table 4.2).

Out of the 55 species of echinoderms collected in the present study, 24 were from a single sample (rare species), while the remaining 31 species were represented in two or more collections from the study area. The bathymetric and latitudinal ranges of these 31 species were examined in order to further explore distribution patterns of echinoderms in the SEAS shelf (Figures 4.13 & 4.14 respectively). The brittle star *Ophiura kinbergi*, showed widest bathymetric distribution in the SEAS shelf (31-155 m), and 13 other species (*Astropecten vappa*, *Thyone dura*, *Clypeaster rarispinus*, *Luidia hardwicki*, *Amphioplus depressus*, *Goniodiscaster forficulatus*, *Ophiodaphne scripta*, *Amphiura ambigua*, *Amphipholis misera*, *Luidia denudata*, *Amphiura constricta*, *Amphiura duncani* and *Sculpsitechinus auritus*), had a relatively wide distribution range. Ten species (*Lovenia elongata*, *Amphiura tenuis*, *Stellaster childreni*, *Leptopentacta imbricata*, *Nacospatangus alta*, *Stolus buccalis*, *Ophiothrix savignyi*, *Echinoneus cyclostomus*, *Echinolampas alexandri*, *Synaptula recta* and *Salmaciella dussumieri*) showed a somewhat narrower distribution range and 6 species (*Ophiocnemis marmorata*, *Ophioconis cupida*, *Ophiothrix proteus*, *Ophiothrix purpurea*, *Heterometra africana* and *Astropecten polyacanthus*) had a very narrow range in bathymetric distribution range. The most significant bathymetric trend in echinoderm distribution in the SEAS was the absence of all but one species beyond 125 m and the complete absence of the group beyond 155 m in the shelf. This resulted in statistically significant bathymetric distinction ($p<0.05$) in species distribution, despite the lack of bathymetric variations in faunal density. The Figure 4.13 also illustrates that between 20 and 150 m depths, 14 species showed a wider bathymetric distribution range.

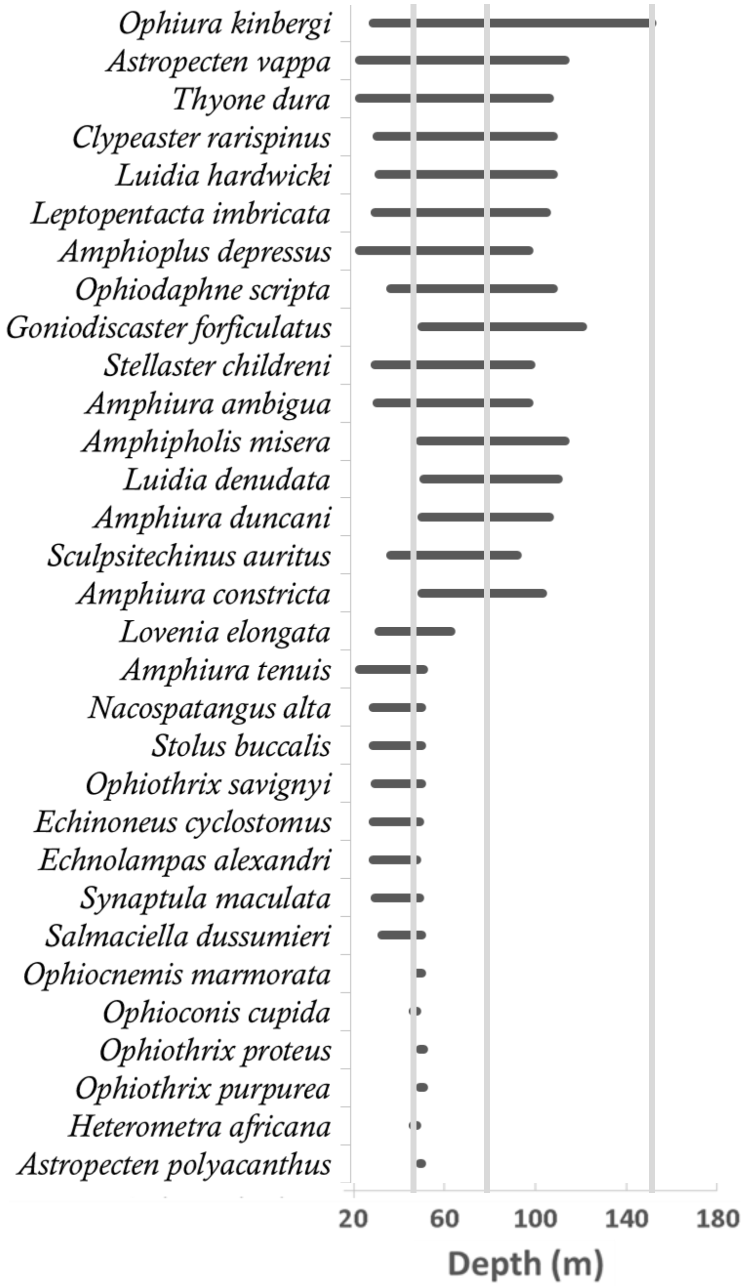

Figure 4.13 Bathymetric distribution ranges of echinoderms in the SEAS shelf

The species having widest latitudinal distribution ranges were *Clypeaster rarispinus*, *Ophiura kinbergi*, *Amphioplus depressus* and *Leptopentacta imbricata* (~7° 45' N to ~12° 49' N, T1-T7). *Luidia hardwicki*, *Thyone dura*,

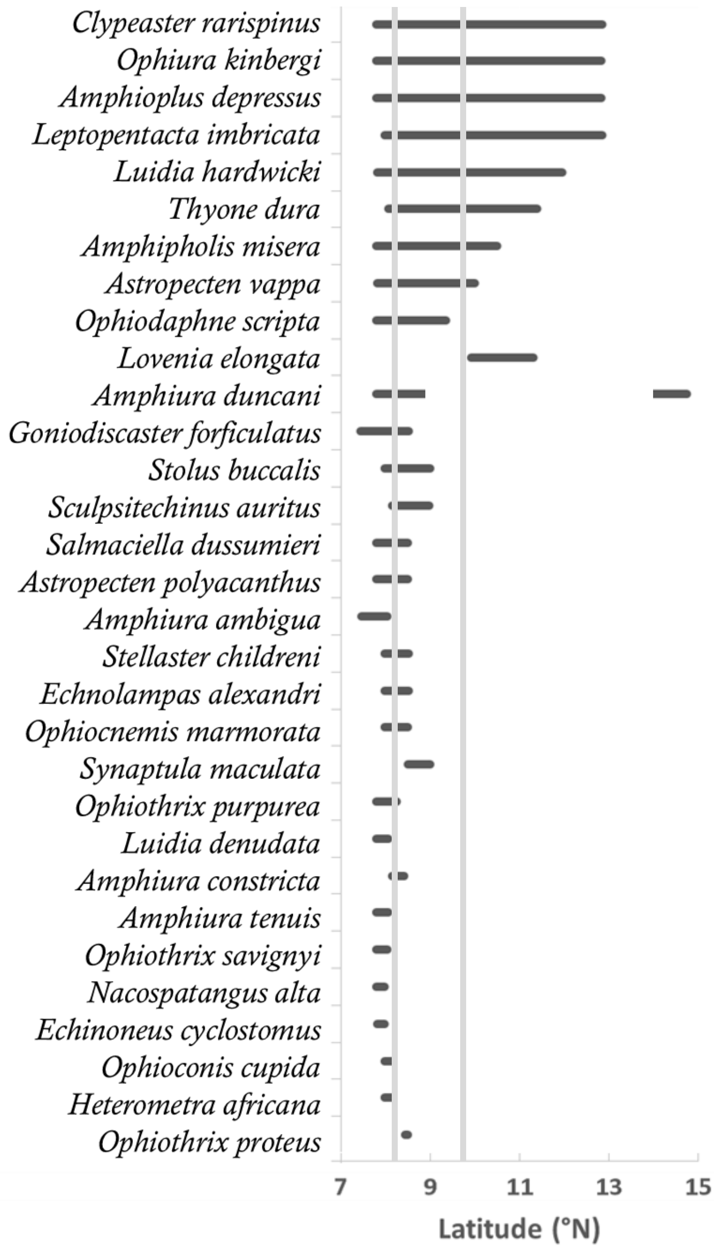

Figure 4.14 Latitudinal distribution ranges of echinoderms in the SEAS shelf

Amphipholis misera and *Astropecten vappa* also showed relatively wide latitudinal range (Figure 4.14, Table 4.2). The aforementioned 8 widely distributed species, were the only echinoderms recorded between T4 and T7 in the present study, along with *Amphiura duncani*, which was only collected at T4 and T5. The echinoid *Lovenia elongata* was observed at T1 and T2, and was the only echinoderm species recorded in T8, but was not recorded between T3-T7. By contrast, 31 species were found to occur only in T1 and 3 species (*Dougalopus echinatus*, *Ophiothrix proteus* and *Synaptula recta*) were represented only in T2. Four species *Ophiodaphne scripta*, *Stolus buccalis*, *Sculpsitechinus auritus* and *Astropecten polyacanthus* were found to occur between T1 and T3, and several others (*Amphipholis misera*, *Lovenia elongata*, *Stellaster childreni*, *Goniodiscaster forficulatus*, *Amphiura constricta*, *Ophiocnemis marmorata*, *Salmaciella dussumieri*, *Echinolampas alexandri*) occurred only at T1 and T2.

The above results show clear latitudinal trends in distribution of species within the 20-150 m depth zone of the SEAS. These variations were analysed and visualised by plotting a non-metric Multi-dimensional scaling (nMDS) ordination based on Kulcsynski resemblance of species incidence data for the 8 transects (Figure 4.15), with similarity contours. The number of

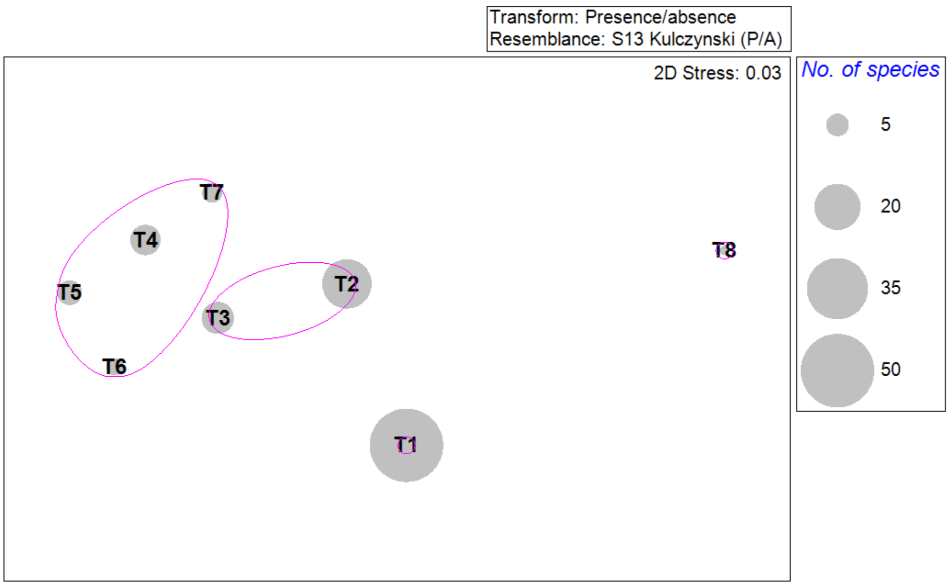

Figure 4.15 nMDS plot showing the grouping of transects based on species occurrence

species recorded in each transect was superimposed as a bubble, to indicate diversity of echinoderms. In the nMDS plot, T8, with only one species (*Lovenia elongata*) being reported, formed an outlier. The rest of the SEAS could be demarcated into three distinct sub-regions, at 65% similarity, based on diversity and species composition. These are:

(i) The Cape Comorin sub-region (T1): characterised by highest diversity in the SEAS shelf (total 50 species), with a large number of unique species, including all 6 crinoids identified in the present study, and 25 other species which were not found anywhere else in the study area.

(ii) The Trivandrum-Kollam sub-region (T2 & T3): characterised by intermediate level of diversity (23 species), including widely distributed species like *Ophiura kinbergi*, *Amphioplus depressus*, *Luidia hardwicki*, *Clypeaster rarispinus*, *Thyone dura* and *Leptopentacta imbricata* of the SEAS shelf as well as those with ranges between T1 and T3.

(iii) The Kochi and Mangalore sub-region (T4-T7): characterised by low diversity (9 species). Apart from *Amphiura duncani*, which was unique to the region and *Amphipholis misera*, which was also recorded in T1 and T2, the 7 species that occurred here (*Ophiura kinbergi*, *Amphioplus depressus*, *Luidia hardwicki*, *Clypeaster rarispinus*, *Thyone dura* and *Leptopentacta imbricata*) were the widely distributed species of the SEAS shelf.

Species estimators (Chaos 2 and Jacknife 1) were employed separately for these three regions in order to test for the number of species likely to be encountered in each region, with intensified sampling. In the Cape Comorin region (T1), only 48-72% of predicted species (Chaos 2: 87±18 andJacknife 1: 80 species) were collected in the present study (Figure 4.16a). The rugged bottom topography and sediment nature around the Cape placed operational limitations on extensive sampling. In the Trivandrum-Kollam region (T2-T3), between 60-100% of predicted number of species (Chaos 2:

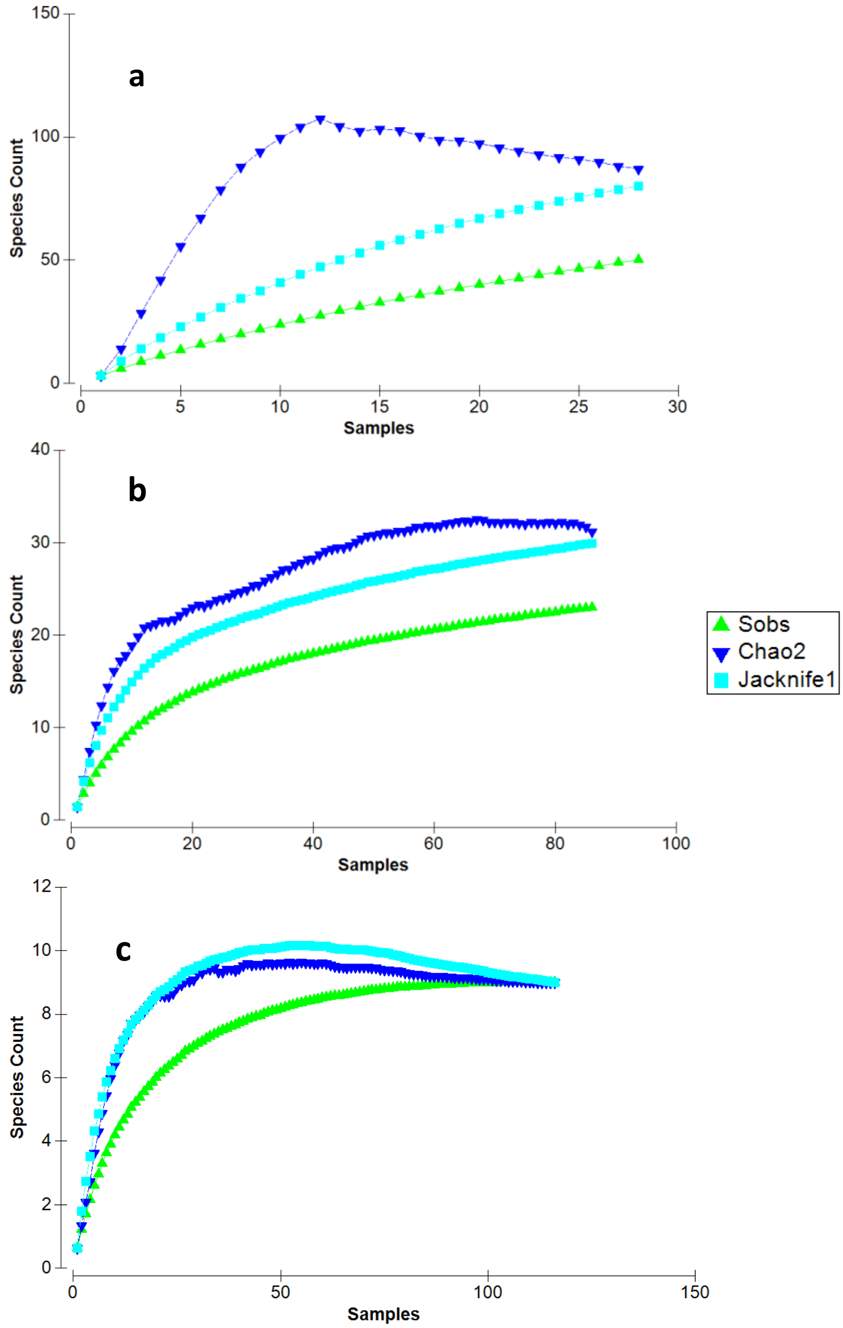

Figure 4.16 Species accumulation curves for the three sub- regions delineated in the SEAS, a. Cape sub-region, b. Trivandrum-Kollam sub-region and c. Kochi-Mangalore sub-region

31±8, Jacknife 1: 30) were obtained through the present study (Figure 4.16b). In the Kochi-Mangalore sector (T4-T7), the estimator values equalled the observed number of species (Figure 4.16c), indicating that all possible species in the region have been collected in the study. The regional species estimators illustrate that despite the possibility of obtaining more species in the Cape transect, this region still exhibited highest species diversity in the SEAS shelf.

4.2.2 Environmental characteristics

A suite of sediment (sediment texture, median and mean grain size and organic matter content of sediments) and hydrographic parameters (salinity, temperature and dissolved oxygen of bottom water) were analysed in order to elucidate the key factors influencing the distribution of echinoderms in the SEAS shelf.

4.2.2.1 Sediment texture and grain size

According to the varying proportion of its constituents (sand, silt and clay), five textural classes could be recognised in the SEAS shelf – sand, silty sand, sandy silt, silt, clayey silt and silty clay, following the classification of Shepard (1954). In general, sand was the dominant component at all depths (Table 4.3), followed by silt, while significant quantities of clay were found to occur only in the 20-50 m depth stratum of northern transects (Figure 4.17). Lowest median grain size (mdZ) of sediments was encountered at 102 m depth in T4 (8.75 μm), while mdZ was largest at 31m depth of T1 (456.15 μm). The composition of sand, silt and clay in sediments as well as mdZ showed significant bathymetric and latitudinal ($p=0.001$) variations (Table 4.1), while significant seasonal variations were not observed. In general, sand content decreased and silt content increased towards the north (Table 4.4), and this trend was most conspicuous between 20 and 50 m depths (sand: $r=-0.723$, $p=0.000$, silt: $r=0.738$, $p=0.000$). The shift in sediment composition was reflected as a reduction in median grain size towards the north ($r=-0.440$,

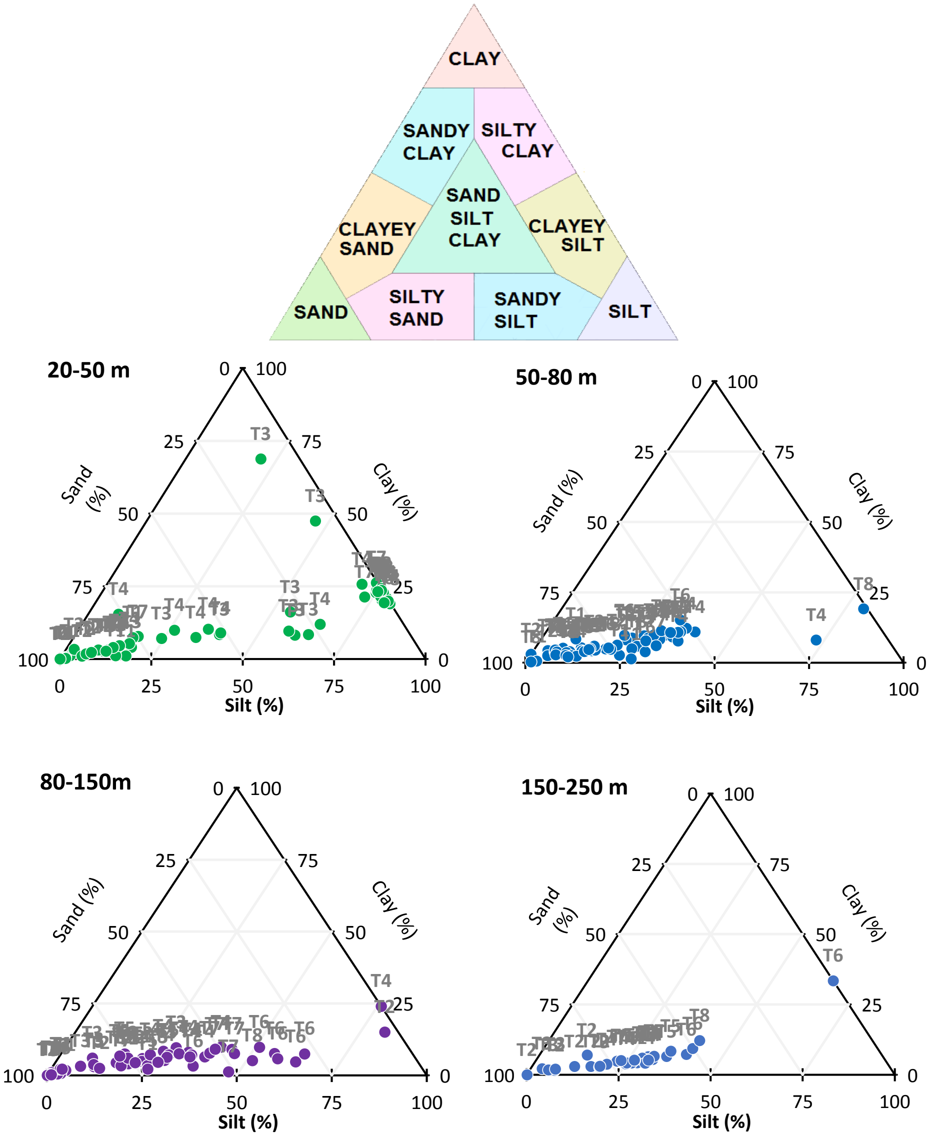

Figure 4.17 Ternary diagrams depicting sediment texture at each site within the depth strata, following the classification of Shepard (1954)

p=0.000). Mean values (±SD) of sediment texture and median grain size of sediments at the four depth strata in each transect are given in Table 4.3 and depicted in Figure 4.18.

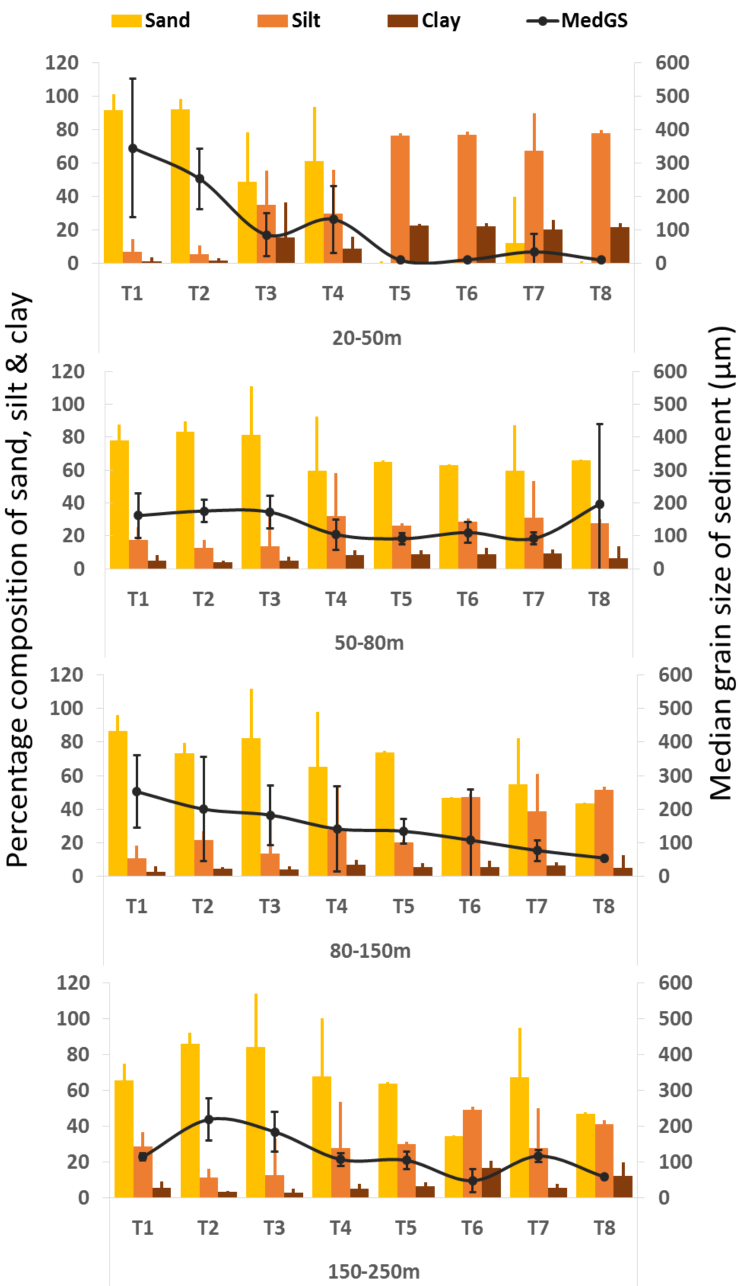

Figure 4.18 Proportion of sand, silt and clay and median grain size (µm) of sediment at each transect within each depth stratum

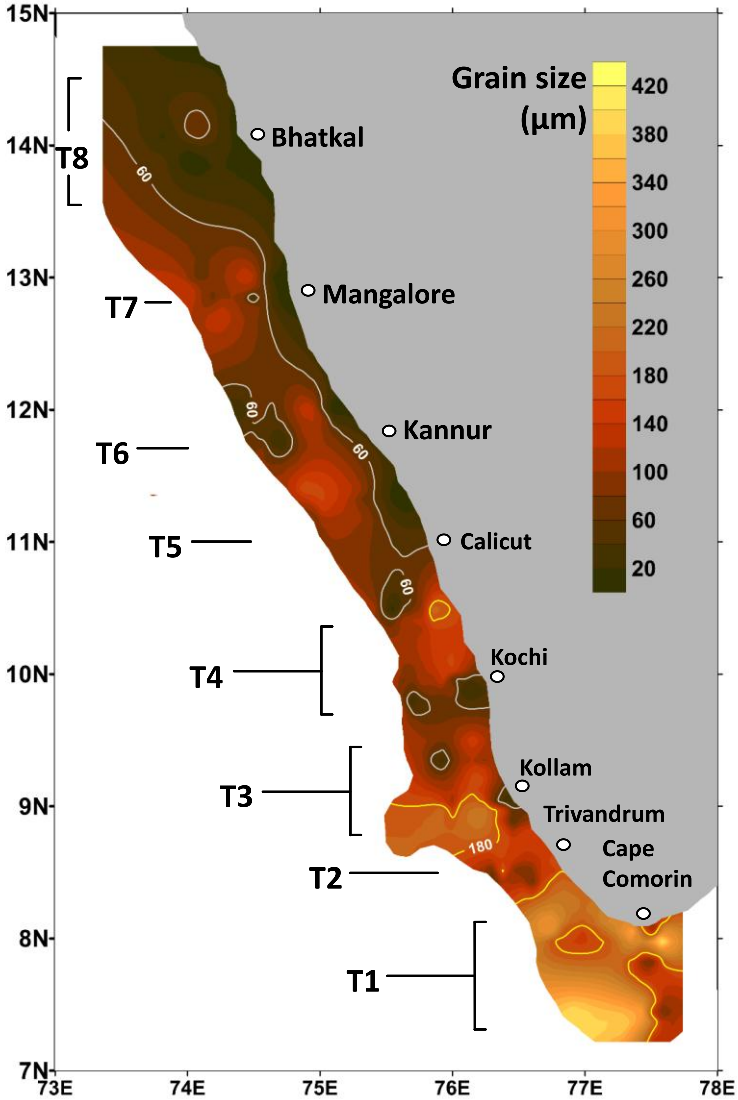

Figure 4.19 Map of the study area showing the mean grain size of sediments in the SEAS shelf

The sediments of the 20-50 m depth stratum were predominantly sandy in the southernmost transects, with coarse biogenic sands at T1 having much higher mdZ than the siliceous sands of T2 (Table 4.3). Along T3 and T4, sand was still the dominant fraction, but with appreciably higher siltcontent. The relative proportion of clay was high at two sites of T3 (both SM 2009). In the northern transects (T5-T8), sediments were predominantly

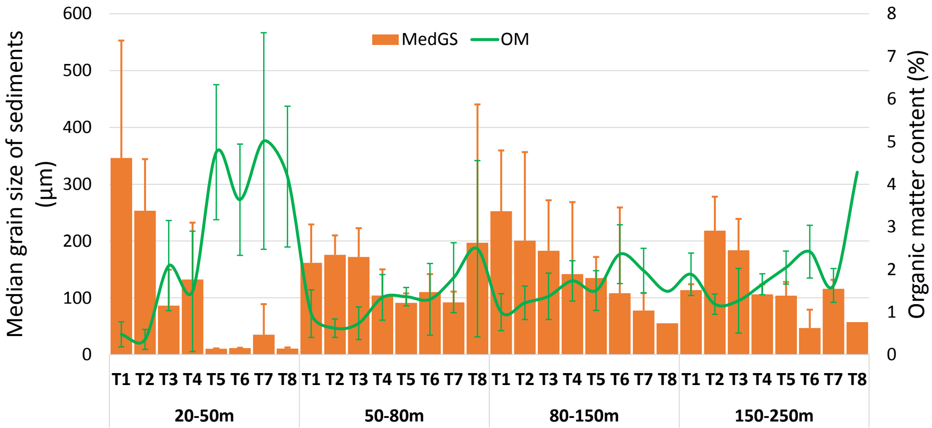

Figure 4.20 Median grain size and organic matter content of sediments in the SEAS shelf

silty, with a low mdZ (silt: 76.6±1.9%, mdZ: 12.07±2.27 µm). In the 50-80 m depth stratum, sediments were sandy in the southern transects (T1-T3, sand: 84.8±6.7%, mdZ: 185.31±45.31 µm), and silty sand in towards the north (T4-T8, sand: 61.5±17.9%, silt: 30.4±15.27%, mdZ: 114.18±98.74 µm). The sediments between 80 and 250 m were heterogeneous, with higher sand content between T1 and T5 (74.9±18.5% sand, 169.86±101.99 µm mdZ) while texture was an admixture of sand and silt between T6 and T8 (50.8±20.2% sand, 41.7±16.1% silt, 89.24±88.65 µm mdZ). The spatial variations in texture in the SEAS shelf is also clearly observed in the map of sediment (mean) grain size (Figure 4.19).

4.2.2.2 Organic matter content of sediments

Organic Matter (OM) content of sediments ranged from 0.20% (T2, 33 m, SIM) to 8.57% (T7, 37 m, WM), with an overall mean of 1.64±1.36% for the entire study area. Sediment OM values showed significant bathymetric ($p=0.001$) and latitudinal ($p=0.001$) variations (Table 4.1). Though seasonal variations were not statistically significant ($p>0.05$), OM was higher during the FIM at most sites (Table 4.5). Highest values of OM were observed (Figure 4.20) in the 20-50 m depth stratum (2.33±2.09%),

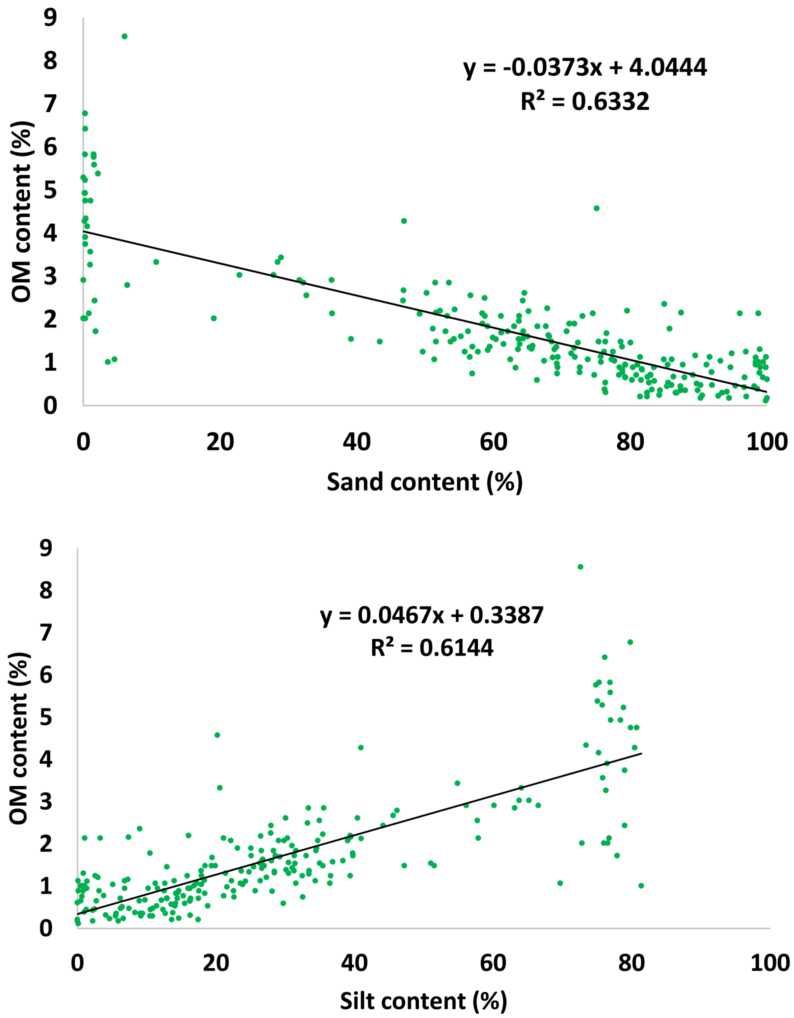

Figure 4.21 Scatter plot of OM with sand content and OM with silt content in the study area

while values were comparably low in the 50-80 m (1.07±0.82%), 80-150 m (1.57±0.63%) and 150-250 m depth strata (1.72±0.71%). A significant increase in OM content was observed with increasing latitude (r=0.544, p=0.000), which could be linked with the increasing proportion of finer sediments (OM & silt: r=0.784, p=0.000) and decreasing median grain size (r=–0.549, p=0.000). Between 20 and 50 m depths, where the latitudinal variation in sediment texture was most pronounced, the decreasing trend of OM towards the north (r=0.674, p=0.000) was also well marked, with relatively high values from T1 to T4 and very high values in the silt-dominated sediments between T5 and T8 (Table 4.3). Between 50 and 80 m depths, the OM content was lower in the southern transects (T1-T3) compared to the northern (T4-T8) transects, while between 80 and 250 m, OM content was the regional distinction was less pronounced. The positive correlation between OM and proportion of silt and the negative correlation between OM and sand content is evident in the respective scatterplots (Figure 4.21).

4.2.2.3 Hydrography of bottom water

In the SEAS shelf, hydrographic parameters of bottom water showed significant spatial and temporal variations. Salinity of bottom water (Figure 4.22a) ranged between 33.254 (T1, 54 m, WM) to 36.353 (T7, 102 m, WM) and showed significant bathymetric, latitudinal and seasonal ($p<0.05$) variations (Table 4.1). Salinity was lowest in the 20-50 m depth category and increased towards the 150-250 m depth category, and this trend was most pronounced during WM (Table 4.5). Lowest salinity was recorded at all depths in T1, and values increased towards the north (Figure 4.22a), reaching highest values at T8. Seasonal variations were not observed between 150 and 250 m, where salinity was observed to increase towards the north.

The temperature of bottom water (Figure 4.22b) in the study area ranged between 12.59°C (T4, 196 m, SM) and 30.85°C (T4, 22 m, SIM), and showed strong bathymetric and seasonal variations ($p=0.001$), while latitudinal variations were less pronounced (Table 4.1). Temperature decreased from the 20-50 m depth stratum to the 150-250 m depth stratum during all seasons (Table 4.5). Between the 20 and 150 m depth zone, bottom water temperature was low during SM and highest during WM, with intermediate values during FIM and SIM. Seasonal variations were not observed in bottom water temperature beyond 150 m depth.

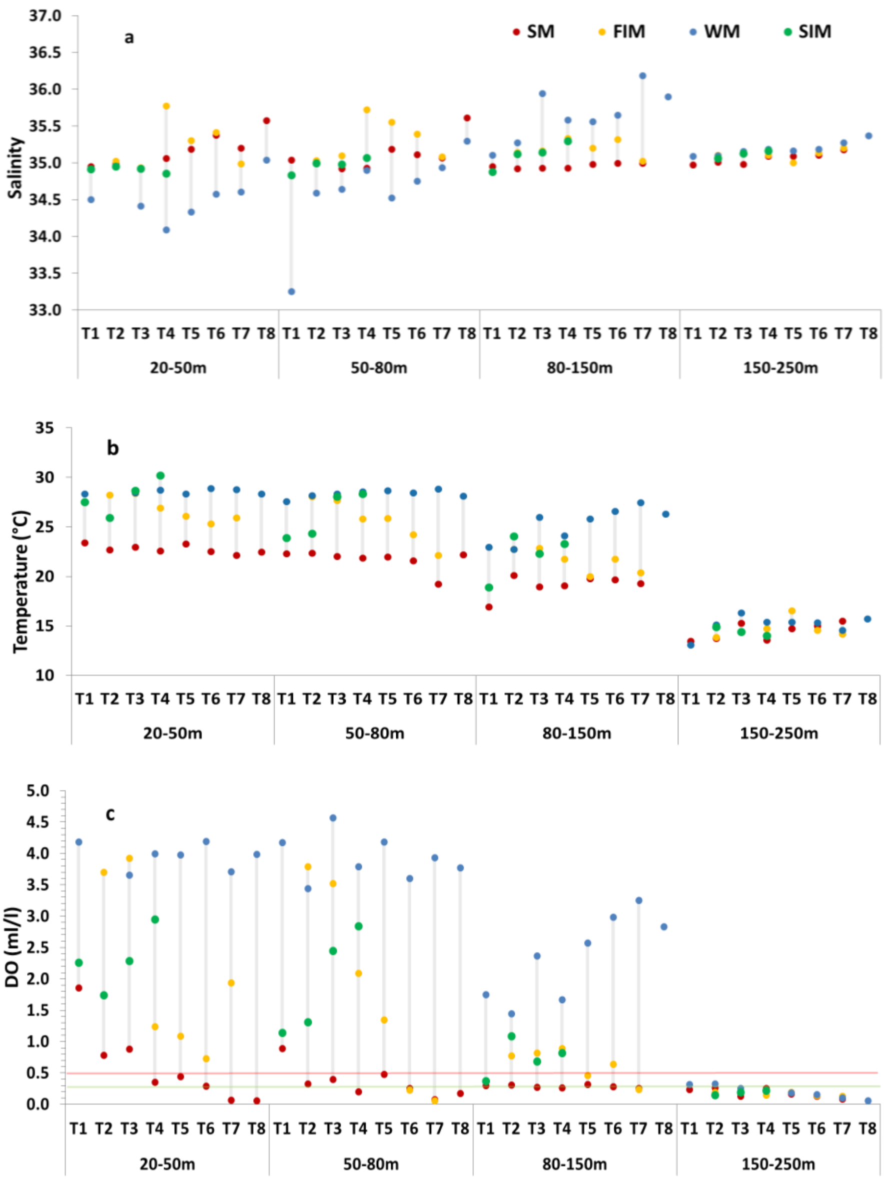

Figure 4.22 Hydrographical parameters of bottom water in the SEAS shelf, a. salinity, b. temperature and c. dissolved oxygen

The DO of bottom water in the study area (Figure 4.22c) ranged between 0.0376 (T4, 36 m, SM) and 4.9849 (T3, 49 m, WM) and displayed significant bathymetric, latitudinal and seasonal (p=0.001) variations during the study (Table 4.1). In general, DO decreased with increasing depth (Table 4.5), most prominently during WM (Table 4.5). In the 20-50, 50-80 and 80-

150 m depth categories, oxygen depleted conditions were observed during SM (0.52±0.61, 0.35±0.27 and 0.28±0.11 ml/l respectively), with DO concentration falling below 0.5 ml/l in the northern and central transects (even below 0.2 ml/l at T7 and T8). Seasonal variations were absent at the 150-250 m depth category, where DO decreased towards the north (Figure 4.22c).

4.2.2.4 Principal component analysis

A Principal Component Analysis (PCA) was carried out in order to analyse and visualize the spatiotemporal variations in the sediment and hydrographical parameters of the study area. The results (Table 4.6, 4.7) revealed that 5 principal components (PCs) were able to explain 91% of variance among the sites. Of these, the PC 1 (Eigenvalue 4.5) and PC 2 (Eigenvalue 2.32), which together explained 68% of the variance among sites, were used to plot a PCA ordination (Figure 4.23). The PC axis 1 separated the stations based on latitudinal variations in sediment characteristics (texture, MdZ and OM), while PC axis 2 separated the stations based on bathymetric and seasonal variations in bottom water parameters (salinity, temperature and DO). In general, sand content and MdZ increased along the PC1 axis, while silt, clay and OM content decreased. Along the PC2 axis, salinity decreased while temperature and DO increased. Thus, the sites in the 20-50 m depth stratum in southern transects, which were characterised by higher sand content and larger grain size ordinated in the upper right quadrant, while those of the northern transects, characterised by high silt content (and smaller MdZ) were positioned in the upper left quadrant. Beyond 50 m depth also, the stations were spread along the PC1 axis based on latitudinal variations in texture; but the sites of the northern transects ordinated closer to the right quadrant, owing to the lower silt content relative to the 20-50 m depth stratum. Within the 20-50 m, 50-80 m and 80-150 m depth strata, the samples of SM season, characterised by relatively low DO

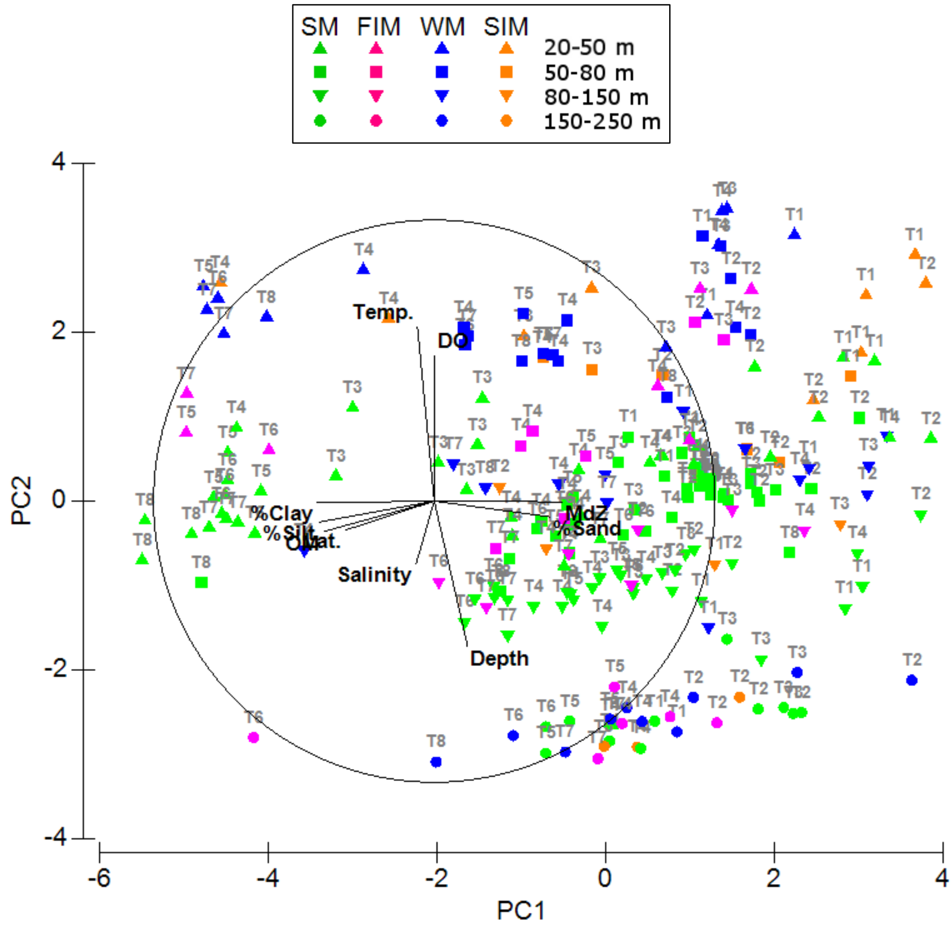

Figure 4.23 Principal Component Analysis (PCA) of environmental variables

and temperature as well as relatively high salinity, were positioned lower along the PC2 axis, compared to the WM, which was characterised by higher temperature and DO (and lower salinity). This seasonal variation was more pronounced in the northern transects (T4-T8) than the south (T1-T3). Owing to the absence of seasonal variations in bottom water salinity, temperature and DO between 150 and 250 m, these sites were not separated along the PC2 axis, but rather only displayed moderate separation along PC1 axis, based on latitudinal variations in sediment texture. The Principal Component Analysis was found to be useful in understanding the overall environmental conditions in the study area, which could be help explain the distribution pattern of the echinoderms in the region.

4.2.3 Linking echinoderm distribution to environmental conditions

In the SEAS shelf, density of echinoderms among the epifauna was correlated positively with bottom water DO ($r=0.311$, $p<0.05$), while that of crustaceans and molluscs showed positive correlation with silt and clay content ($p<0.05$). In order to link the distribution of echinoderm species in the SEAS to the prevailing environmental settings of the SEAS, the number of species collected from each site was superimposed as bubbles on the PCA biplot (Section 4.2.2.6). Species diversity was highest in the upper right quadrant (Figure 4.24a), where the 20-150 m sites of the southern transects (T1-T3) were located, and which were characterised by sandy sediments, high DO content and relatively less seasonal variations in hydrographic conditions. Echinoderm species were poorly represented in the silty sediments of the 20-50 m depth stratum of the northern transects, which were characterised by major seasonal variations in the measured bottom water parameters, most notably the hypoxic conditions during the SM. Intermediate diversity was noted in the relatively sandy sediments of the 80-150 m depth stratum at most transects (particularly T1-T4). Between 150-250 m, echinoderm species were almost absent under the perpetually low oxygen conditions, even though sediments were dominantly sandy.

Similar trends were noted in density of echinoderms among the epifauna (Figure 4.7), with higher density in the sandy sediments between 20 and 80 m in the south (T1-T4), moderate density in the 80-150 m depth category of several transects, and very low density in the silty sediments of the north (T5-T7, 20-50 m), as well as near absence in the perennially oxygen depleted conditions between 150 and 250 m.

The primary feeding modes of the echinoderms collected in the present study were examined, based on literature (Meyer 1982, Massin 1982,

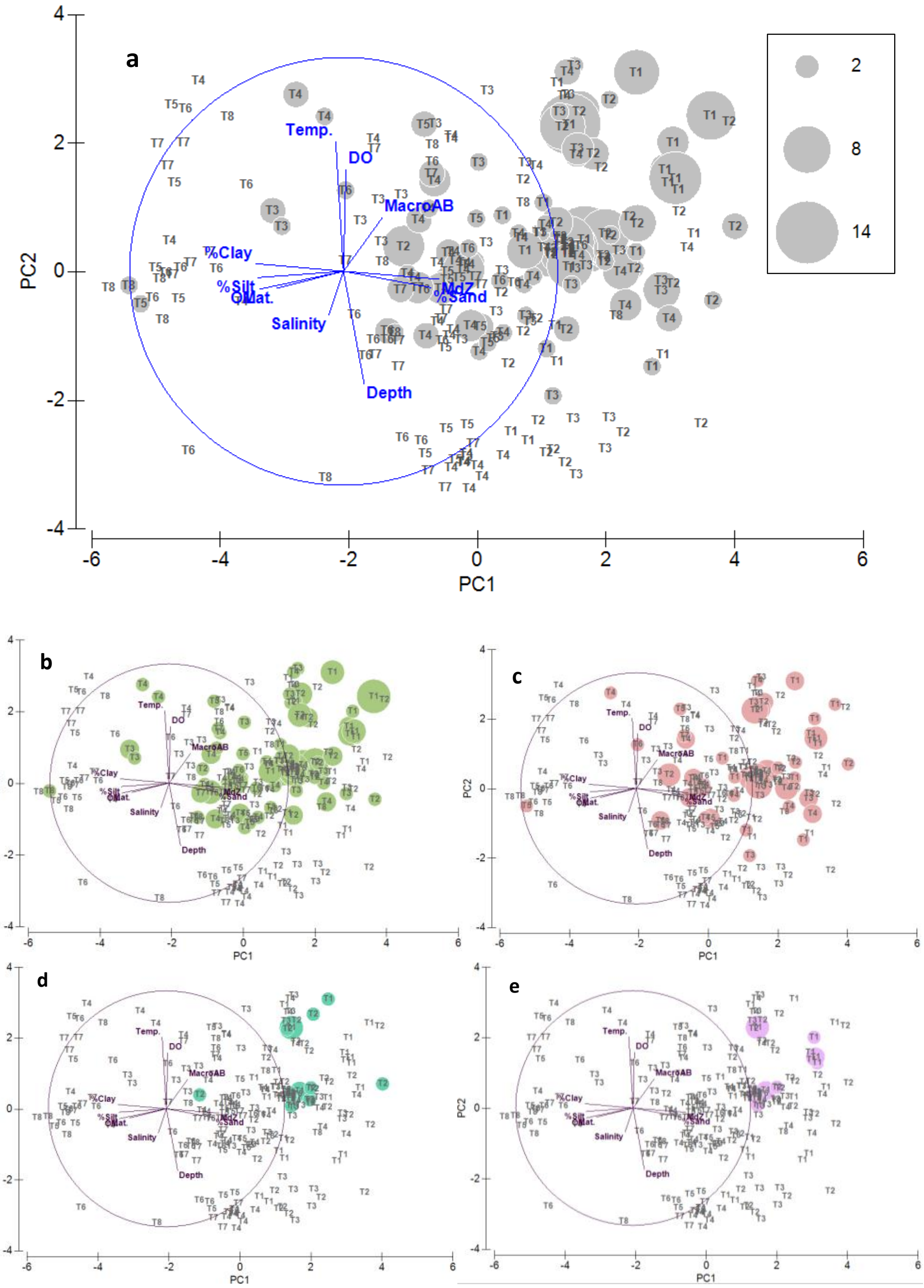

Figure 4.24 Principal Component Analysis (PCA) of environmental variables and macrofaunal standing stock, with superimposed bubbles that indicate diversity of a. total echinoderms, b. deposit feeding echinoderms, c. carnivorous echinoderms, d. grazing echinoderms and e. suspension feeding echinoderms

De Ridder & Lawrence 1982, Jangoux 1982, Warner 1982), in order to elucidate links between observed distribution patterns and main food sources.

The Asteroidea collected in the present study included predators of brittle stars, small molluscs and other invertebrates (Astropectinidae, Luidiidae & Oreasteridae, total 6 species), a mixed grazer, *Stellaster childreni*, which ingests both sedimentary detritus and smaller fauna buried in the substrate and a substrate film feeder, *Heteronardoa carinata*, which is here referred to the broad group of 'deposit feeders'. The Ophiuroidea included partially burrowing deposit feeders of family Amphiuridae (10 species), suspension feeders of family Ophiotrichidae and Ophiocomidae (7 species), and carnivores of family Ophiodermatidae and Ophiuridae (3 species). The complete epibionts, *Ophiodaphne scripta*, *Ophiosphaera insignis* and *Ophiacantha dallasii* were treated separately, since their distribution was linked with that of their hosts and also assuming that they depended partially or wholly on their hosts for feeding. Little is known of the rare genus *Ophiopteron* and its feeding; and since it is suspected to be an epibiont on sponges or gorgonids, *O. elegans* was also treated as an epibiont. The echinoids of the present study were composed of opportunistic grazers (Cidaridae & Temnopleuridae, total 4 species), surface deposit feeders (Clypeasteridae & Echinolampadidae, total 5 species) and burrowing deposit feeders (Astriclypeidae, Echinoneidae, Loveniidae & Maretiidae, total 4 species). All holothurians collected in the present study were small (1-3 cm length), and wholly or partially burrowing forms. Though some of these (Phyllophoridae & Cucumariidae) are traditionally classified as 'suspension feeders', it is surmised that their filter feeding activities are confined to about 1-2 cm above the sediment surface; they are therefore treated as 'interphase feeders', which is taken as a sub-group of deposit feeders.

Though the deposit feeding forms (Figure 4.24b) were widely represented in the study area, most species showed affinity to the sandy sediments between 20-50 m depths in the southern region (T1-T3) and 50-150 m depths in the north, despite the relatively low sedimentary organic matter. A majority of the deposit feeders (clypeasterids echinoids and amphiurids ophiuroids) are considered as surface feeders, depending on freshly deposited OM at the sediment surface, and these included the widely distributed forms such as *Clypeaster rarispinus* and *Amphioplus depressus*. The holothurians were interphase feeders, filtering or collecting food from the sediment-water interphase, and they showed affinity mostly to sandy sediments between T1 and T4 (20-80 m). The spatangoid echinoids, however, are deep-burrowing forms, which ingest subsurface sediments and extract OM from them; and were found to prefer finer sands (MdZ: ~100-200 µm) with some silt content (4-20% silt). In the silty sediments of the northern transects (T4-T8, 20-50 m), a few deposit feeding echinoids were represented (*Lovenia elongata* at 33 m of T8, *Clypeaster rarispinus* at 34 m in T4); and holothurians (*Synaptula recta*, *Stolus buccalis* and *Leptopentacta imbricata*) were also found to occur in relatively silty sediments of T3 (30-32 m, SM).

Carnivorous forms were similarly well represented in sandy sediments (Figure 4.24c), particularly in the southern transects, and in areas with higher macrofaunal density. Two widely distributed echinoderm of the SEAS shelf, *Ophiura kinbergi* and *Luidia hardwicki* are carnivore or scavenger of smaller sized benthic fauna (including other echinoderms). Grazers (regular echinoids) and suspension feeders (crinoids and ophiotrichid ophiuroids) were sparsely represented in the SEAS shelf (Figure 4.24d & e); the former showing affinity to the finer sands of the 20-80 m depths in T2 & T3, and the latter being found only in the coarse coralline sands of T1 (20-80 m).

4.3 Discussion

The echinoderms were found to be a dominant component (42%) among the epifauna in the continental shelf of the south eastern Arabian Sea (SEAS). Echinoderms also contributed to biomass of infauna (10%) in the SEAS shelf, which agrees well with global estimates (Cusson & Bourget 2005). Dominance of echinoderms among epifauna is reported in many parts of the world (Ambrose *et al.* 2001, Hargrave *et al.* 2004, Feder *et al.* 2005, Ruhl, 2007, Bluhm *et al.* 2009, Lebrato *et al.*, 2010).

Based on extensive and seasonally resolved surveys, covering a sizeable area of the SEAS shelf, using multiple gears in order to include both epifauna and infauna, the present study revealed spatio-temporal variations in density and composition of benthic fauna. These variations have been reported in the case of macro infauna in the SEAS shelf (Thomas *et al.* 2006, Damodaran 2010, Abdul Jaleel *et al.* 2015, Sivadas *et al.* 2016), which are relatively well studied. The crustaceans and molluscs also formed important components among benthos, and they dominated among epifauna in some areas. Epifaunal density decreased with depth, and were dominated by molluscs between 20 and 50 m and echinoderms between 50 and 80 m, while the crustaceans dominated in the 80-250 m depth strata. The density of epifauna was highest off Kollam (T3), chiefly owing to high density of echinoderms, while density decreased towards the Cape (T1) and Bhatkal (T8). The relative abundance of echinoderms decreased from south to north in the SEAS. Density of epifaunal echinoderms was much higher in the winter monsoon (WM) than the summer monsoon (SM), which resulted in the significant variations observed in overall faunal composition. In the present study, decrease in infaunal echinoderm density was also noted during SM, particularly in the northern part of the study area. A concurrent, marked increase in standing stock of polychaetes (Thomas *et al.* 2006, Sivadas *et al.* 2016), and a decline in crustacean standing stock is reported in the study area (Abdul Jaleel *et al.* 2015).

Ambient hydrographic conditions are known to play important roles in structuring marine benthic communities (Creutzberg *et al.* 1984, Barry 1988, Rosenberg 1995, Nordberg *et al.* 2001). Factors such as temperature and salinity have a greater influence on distribution in areas where these factors fluctuate widely, such as temperate and polar region and areas with heavy freshwater discharge (Turner *et al.* 1995, O'Hara & Poore 2000, Van Hoey *et al.* 2004). In the SEAS shelf, salinity and temperature of bottom water exhibited seasonal and spatial variations during the present study. Coastal upwelling during the SM, brings cold, high-saline, nutrient rich waters on to the shelf (Banse 1973, Smitha *et al.* 2008) which resulted in lower bottom water temperature up to ~150 m. By contrast, bottom temperature was highest during the WM. A consistent decrease in bottom water temperature with increasing depth is well reported in the EAS shelf (Jayaraj *et al.* 2008, Joydas & Damodaran 2009, Damodaran 2010, Abdul Jaleel *et al.* 2015). Apart from the coastal upwelling, bottom water salinity was also influenced by intrusion of water masses from adjacent areas. The Arabian Sea High Saline Water (ASHSW), which forms in the landlocked, northern Arabian Sea during the WM as a result of wind-induced evaporation (Rochford 1964, Prasannakumar and Prasad 1996) subducts and spreads southwards at ~50-150 m depth (Luis & Kawamura 2004). This southward flow is known to be intense during the SM season (Luis & Kawamura 2004), below which a counter current of low-saline water is reported from the south (Muraleedharan & Prasannakumar 1996). The southern part of the SEAS is in contact with the equatorial Indian Ocean and Bay of Bengal. During the WM, intrusion of low-saline Bay of Bengal water is reported into the SEAS (Prasannakumar *et al.* 2004). These influences from the northern Arabian Sea and Bay of Bengal created strong latitudinal gradients in bottom water salinity of the SEAS. While seasonal variations were noted in both temperature and salinity, the amplitude of variations were relatively low (~5°C and 0.6, respectively). Patches of high saline water are reported hugging the shelf break and continental slope of EAS (Shenoi *et al.* 2004), without significant seasonal variations (Abdul Jaleel 2012), and similar observations were made in the present study also.

Among hydrographic parameters, the dissolved oxygen of bottom water is known to be an important structuring factor for benthos in tropical continental margins (Levin *et al.* 2002, Neira *et al.* 2001, Levin 2003) and below upwelling areas (Cowie 2005), including the EAS (Ingole *et al.* 2010, Hunter *et al.* 2011, Abdul Jaleel *et al.* 2014, 2015, Joydas & Damodaran 2014). As in the case of salinity and temperature, the greatest variation in bottom water DO was noted between SM & WM. During the WM, a bathymetric gradient of decreasing DO with increasing depth was evident, while during the SM, much of the study area was under moderate to intense hypoxia (DO <0.5 ml/l), more noticeable in the northern transects. Seasonal hypoxia in the bottom water of the SEAS shelf is previously reported (Abdul Jaleel *et al.* 2015), and is attributed to the oxygen-poor nature of upwelled water and formation of film of a low-saline film at the surface which limits ventilation, coupled with high production and subsequent degradation of OM during SM (Banse 1959, Naqvi *et al.* 2006, 2009, Gupta *et al.* 2016). The hypoxic conditions disappear along the shelf during the FIM with the withdrawal of upwelling. A perennial oxygen-deficient condition (<0.2 ml/l north of T4) is noted in bottom water along the shelf edge (Abdul Jaleel 2012), and is attributed to the southward extension of the Arabian Sea OMZ (Vijay 2005, Abdul Jaleel 2012, Abdul Jaleel *et al.* 2014).

Availability of suitable substrates and ample food resources also play key role in determining the distribution of benthic fauna (Sanders 1958, Johnson 1971, Gray 1974, Gray & Elliot 2009); and in soft-bottom benthos, the composition and texture of sediments are of great importance (Jayaraj *et al.* 2008, Biernbaum 1979, Abdul Jaleel *et al.* 2014). Benthic taxa are also known to show selectivity with respect to sediment grain size (Whitlatch 1981, Etter & Grassel 1992, Ellingsen 2002, Gray & Elliot 2009). In the present study, sand was the dominant textural class, which corroborates with previous studies in the region (Nair & Pylee 1968, Nair 1975, Hashimi *et al.* 1978, Narayana & Prabhu 1993). Sediment texture showed significant spatial variations, under the influence of hydrodynamic processes. The northern part of the study area (Calicut to Bhatkal) receives inputs from several rivers and two major estuaries of the west coast of India, the Cochin Estuary and Ashtamudi Lake, are located at Kochi and Kollam, respectively. Terrestrial sediment input from these sources influenced the sediment texture between 20 and 50 m SEAS (Hashimi & Nair 1981). Between Calicut & Bhatkal (T5-T8), silt predominated between 20 and 50 m (median grain size 12.07±2.27 µm) which is in agreement with previous studies (Jayaraj *et al.* 2008, Ingole *et al.* 2010, Damodaran 2010). A mixture of silt and sand was noted off Kochi (T4) and Kollam (T3), with minor seasonal variations. A combination of factors are known to act in estuarine systems, including the trapping of coarser sediments within the estuaries and flocculation around the estuary mouths (Rao & Wagle 1997, Damodaran 2010). Seasonal variations around the estuary mouth may be attributed to the increase in terrestrial discharge during the SM. Towards the south, sediments of the 20-50 m depth zone were terrigeneous sands (median grain size 253.36±90.85 µm) off Trivandrum (T2) and calcareous sand (median grain size 346.00±206.73 µm) around Cape Comorin (T1), with boulders and rocky outcrops. The coastal topography south of Kollam caused offshore transport of sediments away from the coast and the low sedimentation rates causes a 'no-clay zone', which favour growth of corals around the Cape (Rao & Wagle 1997), and contributed biogenic materials such as shells and coral fragments to sediments. Beyond 50 m depth, the texture became progressively sandy throughout the study area, and sediments beyond 150 m were uniformly sandy (median grain size 110-220 µm). Occurrence of sandy sediments at around 50 m depth, as well as presence of relict sands in the between 100 and 200 m depths of the SEAS are widely reported (Narayana & Prabhu 1993, Rao & Wagle 1997, Jayaraj *et al.* 2008, Damodaran 2010, Ingole *et al.* 2010, Abdul Jaleel *et al.* 2014, 2015).

The SEAS is an eastern boundary upwelling system (EBUS), with seasonally high production during SM (Banse 1959, Smitha *et al.* 2008, Habeebrehman *et al.* 2008, Thomas *et al.* 2013, Gupta *et al.* 2016). The supply of OM to the seafloor is governed by the seasonally fluctuating surface production, while OM settlement is strongly influenced by the dynamics of the water column (Calvert 1987). During the present study, OM values did not differ significantly between SM & WM, unlike other seasonally varying factors. Rather, highest OM values were noted during FIM (October), immediately following the highly productive SM. The strong SM circulation may hinder OM flux to the bottom during this high productive season (Abdul Jaleel *et al.* 2015), while the quiescent conditions of the subsequent season (FIM) could favour OM settlement. Following settlement, the retention of OM within sediments is strongly influenced by the texture of sediments. Sorption of OM on finer sediment particles (clay & silt) results in higher retention (Keil & Hedges 1993). Lamination and packing of these finer sediment particles leads to preservation and longer residence time for OM (Cowie 2005). Observations of higher OM in finer sediments is reported in the SEAS (Jayaraj *et al.* 2008, Joydas & Damodaran 2009, Abdul Jaleel *et al.* 2014) and was also clearly observed in the present study, where the bathymetric and latitudinal variations in OM was influenced by the sediment texture.

The distribution of epifauna in the SEAS is found to be influenced by the spatial variations in sediment texture and spatio-temporal variations in DO levels. Highest faunal density was noted in the 20 80 m depth stratum in the present study, owing to the high density of echinoderms in the southern transects (Cape-Kollam) and of crustaceans and molluscs in the northern transects (Kochi-Bhatkal). Under oxygen depleted conditions, epifauna are vulnerable than infauna, and mobile forms more vulnerable than sessile forms (Riedel *et al.* 2013). The sandy sediments in the Cape-Kollam sector harboured good density of echinoderms, most of which are known to prefer sandy sediments (Pomory *et al.* 1995, Ellis *et al.* 2000, Ambrose *et al.* 2001, Freeman & Rogers 2003). Echinoderms are also among the group most sensitive to low-oxygen conditions, and show mortality or avoidance behaviour (Alongi 1990, Rosenberg *et al.* 1991, Diaz & Rosenberg 1995, Gray *et al.* 2002, Ganesh & Raman 2007, Levin *et al.* 2009). In the SEAS, echinoderm density (among epifauna and infauna) was correlated with bottom water DO. The group was nearly absent between Kochi and Bhatkal, under the intense hypoxic conditions, but were relatively well represented in this region during the WM. Comparison of infaunal standing stock between SM & WM in the SEAS revealed similar results (Linda 2016). Echinoderms were absent even in the sandy sediments beyond 150 m, owing to the low DO levels were throughout the year. Complete absence of echinoderms among infauna around 200 m depth has also been reported by Abdul Jaleel (2012) and Joydas & Damodaran (2014). These observations suggest that DO levels play a greater role in determining echinoderm distribution in the SEAS, than the availability of suitable substrates. Crustaceans and molluscs are less vulnerable to low-oxygen related stress (Diaz & Rosenberg 1995, Gray *et al.* 2002), and these groups were capable of withstanding the seasonal shelf hypoxia in the northern transects, and established as the dominant taxa among epifauna in the region. Dominance of these groups is reported among epifauna off the south east coast of India (Khan *et al.* 2010). Moreover, small decapods (prawns and ghost shrimps) dominated among crustaceans in the northern transects; being detritivores, they are ideally placed to utilize the higher OM within the silty sediments in the northern transects. The most hypoxia-tolerant taxon among the benthos are the polychaetes (Diaz & Rosenberg 1995, Gray *et al.* 2002, Abdul Jaleel *et al.* 2014), and this group dominated among the infauna in the present study. The taxonomic and functional diversity of this group among SEAS benthos is well studied (Jayaraj *et al.* 2008, Joydas & Damodaran 2009, 2014, Musale & Desai 2010, Abdul Jaleel *et al.* 2014, 2015).

The SEAS shelf is subjected to anthropogenic disturbance in the form of intense bottom trawling, except the 45 day (June 15th – July 31st) trawl-ban period during the SM (Vivekanandan *et al.* 2010). Around 4000 bottom trawlers are reported to operate in the Kerala coast alone (Naomi *et al.* 2011).

Several scientific studies have raised serious concerns on the damages to benthic habitats by bottom trawling gears (Bergman & Hup 1992, Collie *et al.* 2000, Kaiser *et al.* 2006, Queirós *et al.* 2006, Tillin *et al.* 2006). Direct effects of bottom trawling include scraping and ploughing of the substrate, sediment re-suspension and destruction of benthic assemblages (Jones 1992). Indirect effects include post-fishing mortality of benthos and long-term trawl-induced changes in benthic community structure. Such long term changes may affect food availability for commercially important fishes and may also modify the demersal food webs (Jennings & Kaiser 1998, Jennings & Reynolds 2000, Kaiser *et al.* 2006, Bijukumar & Deepthi 2006, Abdul Jaleel *et al.* 2015). Echinoderms are known to be sensitive to trawling disturbances (Bergman & Hup 1992), and represent a significant portion of trawl by-catch in the SEAS (Menon 1996, Kurup *et al.* 2003, Kurup 2004, Bijukumar & Deepthi 2006). In general, impacts of trawling disturbances are known to depend on the type of trawling gear, intensity of trawling, nature of substrate or habitat and the taxa (Kaiser *et al.* 2006). In sandy sediments, habitat restoration and faunal recovery is known to take place more rapidly than in 'muddy' sediments after trawl cessation (Dernie *et al.* 2003, Kaiser *et al.* 2006). This may be a factor contributing to the dominance of echinoderms (particularly echinoids) in the sandy sediments off Trivandrum and Kollam and their paucity in the relatively silty sediments of the north (Kochi-Bhatkal).

Fast growing and rapidly reproducing faunal groups, most notably polychaetes, are known to quickly recoup after trawling disturbance (Jennings *et al.* 2001, Kaiser *et al.* 2006, Shephard *et al.* 2010). In the SEAS shelf, recovery in polychaete standing stock is reported within the 45-day trawling ban period (Abdul Jaleel *et al.* 2015). Being gonochoric and relatively slow-growing organisms, which often attain sexual maturity after 1-3 years (Kasyanov 2001), echinoderms typically take longer time to recover from trawling disturbances (Sardà *et al.* 2000, Desprez 2000, Smith *et al.* 2000, Jennings *et al.* 2001). Unlike the polychaetes, recovery of echinoderms were not noted in the SEAS across the trawl-ban period. This could be due to the longer generation time of this group and the inhibition of larval settlement under the prevailing hypoxic conditions of the SM. This is supported by the occurrence of juvenile (post-settlement stage) echinoderms during late-SM, FIM & early-WM, following withdrawal of hypoxic conditions. Molluscs, which are equally vulnerable to trawling disturbance owing to their shells (Dimitriadis *et al.* 2014), but are more resilient to low-DO stress also showed signs of recoupment during the trawl-ban (Abdul Jaleel *et al.* 2015). More realistic assessment of the impact of bottom trawling on echinoderms in the SEAS, can be achieved only through comparison of areas free from trawling disturbance (Protected Areas) with those areas subjected to heavy bottom trawling. Taking into consideration the significance of echinoderms with respect to ecology and biodiversity, such studies need to be initiated with top priority.

The SEAS shelf is characterised by the availability of a wide variety of habitats for benthic fauna, which may be expected to harbour distinct faunal assemblages. The taxonomic and functional diversity of echinoderm species in the region were analysed to elucidate distribution patterns. A total of 5477 individuals were collected in the present study, representing 55 species. Highest species diversity was observed off Cape Comorin, which encompassed a large number of rare species, while only one species was found to occur off Bhatkal. Between Trivandrum and Mangalore (T2-T7), intermediate diversity was encountered, with occurrence of some common species and a few rare ones.

In general, distribution of species were linked with the availability of suitable habitats as well as food resources. Among the irregular echinoids, the burrowing deposit feeding cake urchin, *Sculpsitechinus auritus*, and spatangoid heart urchins *Lovenia elongata* and *Nacospatangus alta*, were restricted to the southern part of the SEAS (Cape-Kollam region), preferring to burrow in sandy sediments (Jones *et al.* 1987). *Lovenia elongata* was the only echinoderm occurring in the silty and sandy silt sediments off Bhatkal (20-80 m). Being a deposit feeder that lies completely buried in sediments, this species may be living on the high OM content in this region. The deposit feeding species, *Clypeaster rarispinus* (Echinoidea), *Amphioplus depressus* (Ophiuroidea) and *Leptopentacta imbricata* (Holothuroidea) were among the most widely distributed echinoderms in the study area. They occurred in sandy as well as silty sand sediments between Cape & Mangalore (24-111 m). The consistent occurrence of these species between Kochi and Mangalore, where SM hypoxia is known to be intense (Naqvi *et al.* 2006), indicates that *C. rarispinus*, *A. depressus* and *L. imbricata* were relatively less vulnerable to stress related to oxygen-deficiency, compared to other echinoderms of the SEAS. The interphase feeding holothurians, and deposit feeding clypeasterids and amphiurids of the SEAS possibly take advantage of freshly deposited OM at the sediment surface and the suspended OM at the benthic boundary layer.

The Asteroidea found in the study area were chiefly carnivores (*Astropecten* spp. and *Luidia* spp.), as were the brittle stars of family Ophiodermatidae and Ophiuridae. Amongst these taxa, the ophiodermatids were restricted to the Cape region and *Astropecten* spp. were found between Trivandrum and Kollam. Dense macrofaunal assemblages are reported in this region (Joydas & Damodaran 2014), which would form ideal prey for the aforementioned carnivores. Being actively motile, these species are likely to have higher oxygen demand (Ambrose *et al.* 2001), and therefore occurred in the relatively well-oxygenated southern region. By contrast, the starfish *Luidia hardwicki* (range: Cape-Kannur, 33-111 m) and brittle star *Ophiura kinbergi* (range: Cape-Mangalore, 33-155 m) were widely distributed in the SEAS, occurring in both sandy and silty sediments. Individual of *L. hardwicki* were often collected with one or more arms broken off and in various stages of regeneration. Being among the larger echinoderms occurring in the study area, *L. hardwicki* are most likely to have sustained sub-lethal damage from trawling gear. Large numbers of regenerating individuals are reported among *Luidia* in other widely trawled areas (Pomory & Lares 2000), and they are known to have high regeneration capacity (Lawrence 1991, Lawrence & Vasquez 1996, Pomory & Lares 2000). The occurrence of this species across the intensely trawled SEAS indicates that they may be capable of surviving sub-lethal damages from trawls better than most other echinoderm species. Members of genus *Ophiura* have planktotrophic larvae that can survive up to 10 months in plankton, before settling in suitable habitats (Dahm, 1993). The wide distribution of *O. kinbergi* in the study area may be due to such a reproductive strategy, which enables propagules to avoid hypoxic conditions of the seafloor during SM, and facilitates settlement and development after withdrawal of hypoxia.

The Echinoidea of the SEAS also included a few species of regular sea urchins like *Salmaciella dussumieri* and *Salmacis virgulata*, which were restricted to the sandy sediments off Cape & Trivandrum (20-80 m), having higher DO and less intense hypoxia during SM. Being epifaunal opportunistic grazers, these species may be feeding on the macrofauna, surficial OM or perhaps on organisms encrusting upon hard substrates off the Cape.

Class Crinoidea was represented only in the calcareous sandy sediments of the Cape region. These organisms usually attach themselves on hard substrates (rocks or boulders), and are passive filter feeders. The availability of rocks and boulders for attachment around the Cape (Rao & Wagle 1997, Damodaran 2010), and the relatively dynamic water column, with intrusions from the Indian Ocean and Bay of Bengal (Luis & Kawakura 2004), are ideally suited for the crinoids. Moreover, the topography of the shoreline around the western side of the cape ensures little or no sedimentation near the coast (Rao & Wagle 1997), which would hinder the filter feeding activities of the crinoids. Similarly, filter-feeding brittle stars of family Ophiotrichidae and Ophiocomidae were also restricted to this region.

Ophiotrichids reportedly position themselves with their arms raised upwards and using tube feet for filtering and often form dense aggregations in areas with strong currents (Warner & Woodley 1975, Warner 1979).

Sexual dimorphism is rare in echinoderms, and only four species among the Ophiuroidea, *Ophiodaphne scripta*, *O. formata*, *Ophiosphaera insignis* and *Astrochlamys bruneus*, are known to exhibit conspicuous dimorphism, with respect to size and morphology (Parameswaran *et al.* 2013, see Appendix 2). In all four species, the male is smaller and is an epibiont on the female. Of these, two species – *Ophiodaphne scripta* and *Ophiosphaera insignis* were recorded in the present study between Cape and Kollam, the latter being represented by a single female individual. Both these species are reported widely to be epibionts on sea urchins (Mortensen 1933, Cherbonnier and Guille 1978, Guille 1981, Irimura 1981, Kroh & Thuy 2013, Parameswaran *et al.* 2013). The brittle stars possibly derive protection among the spines of the echinoids (Mortensen 1933, Kroh & Thuy 2013) and are believed to depend on the ciliary currents of the echinoids for nutrition (Mortensen 1933, Parameswaran *et al.* 2013). The sexual dimorphism in these species may be linked to their epibiotic habit, having evolved to overcome reproductive barrier that arises when the proximity of conspecific individuals is directly dependant on the proximity of host organisms (Mortensen 1933, Parameswaran *et al.* 2013).

Based on the species distribution pattern observed in the present study, three major sub-regions (Cape, Trivandrum-Kollam and Kochi-Mangalore) are delineated within the SEAS shelf, each with distinct species diversity and functional composition of echinoderms. The coarse sands with biogenic materials, and well oxygenated conditions off the Cape harboured highest diversity of echinoderms, a majority of which are unique to this sub-region. This sub-region is characterised by heterogeneous habitats, which could support multiple functional niches (Gooday *et al.* 2010, Levin *et al.*

2010, Williams *et al.* 2010), and all feeding types are well represented here. Intermediate diversity is found between Trivandrum and Kollam, with a few characteristic species and a dominance of sand dollars *Clypeaster rarispinus* and *Echinodiscus auritus* occurring in the finer sands with relatively high DO. The Kochi and Mangalore sub-region is characterised by the occurrence of only 9 species, most of which are the widely distributed species in the study area (E.g. *Ophiura kinbergi*, *Amphioplus depressus* and *Clypeaster rarispinus*). These widely distributed species were the only ones which could withstand the intense hypoxia and trawling in this sub-region, and establish relatively stable populations. Although echinoderms diversity decreased with depth in the shelf, and this group was absent between 155 and ~250 m depth, diversity increased along the continental slope (beyond ~250 m).

Echinoderms are known to play key roles in functioning of marine benthic communities. The present study provides baseline information on echinoderm diversity, distribution and abundance of echinoderms in a poorly studied tropical continental shelf and also gives insights into the major factors influencing their distribution and abundance. A glimpse into the extent to which echinoderms may be vulnerable to natural and anthropogenic disturbances (climate change, intensification of hypoxia, ocean acidification, trawling etc.) is also provided.

Table 4.1 Results of PERMANOVA test of environmental parameters for variations between depth, latitude & season

Factor	Depth category		Latitude		Season	
	Pseudo-F	p	Pseudo-F	p	Pseudo-F	p
Total epifauna	1.190	0.243	**1.842**	**0.005**	**1.9774**	**0.011**
Total infauna	**8.190**	**0.001**	1.417	0.108	**2.114**	**0.025**
Echinoderm species	**1.243**	**0.034**	**2.216**	**0.001**	1.159	0.322
Salinity	**3.996**	**0.023**	**4.385**	**0.002**	**4.522**	**0.013**
Temperature	**350.180**	**0.001**	**4.607**	**0.006**	**97.718**	**0.001**
Dissolved oxygen	**76.117**	**0.001**	**4.530**	**0.001**	**166.990**	**0.001**
Sediment texture	**11.606**	**0.001**	**11.728**	**0.001**	1.595	0.183
Organic matter	**14.037**	**0.001**	**20.298**	**0.001**	1.879	0.148
Median grain size	**19.943**	**0.001**	**17.657**	**0.001**	1.268	0.273

Table 4.2 Region and depth of occurrence of echinoderm species in the SEAS shelf

Species	Region of occurrence								Depth range
	T1	T2	T3	T4	T5	T6	T7	T8	
Astropecten polyacanthus	+	+	–	–	–	–	–	–	50-52 m
Astropecten vappa	+	+	–	+	–	–	–	–	24-116 m
Astropecten hemprichi	+	–	–	–	–	–	–	–	52 m
Luidia denudata	+	–	–	–	–	–	–	–	53-113 m
Luidia hardwicki	+	+	+	+	+	+	–	–	33-111 m
Stellaster childreni	+	+	–	–	–	–	–	–	32-101 m
Heteronardoa carinata	+	–	–	–	–	–	–	–	50 m
Goniodiscaster forficulatus	+	+	–	–	–	–	–	–	52-124 m
Amphioplus depressus	+	+	+	+	+	+	+	–	24-100 m
Amphipholis misera	+	+	–	+	–	–	–	–	51-116 m
Amphiura ambigua	+	–	–	–	–	–	–	–	32-100 m
Amphiura constricta	+	+	–	–	–	–	–	–	52-106 m
Amphiura duncani	–	–	–	+	+	–	–	–	52-109 m
Amphiura micra	+	–	–	–	–	–	–	–	24 m
Amphiura heptacantha	+	–	–	–	–	–	–	–	31 m
Amphiura tenuis	+	–	–	–	–	–	–	–	24-53 m
Amphuira crispa	+	–	–	–	–	–	–	–	24 m
Dougalopus echinatus	–	+	–	–	–	–	–	–	49 m
Ophiodaphne scripta	+	+	+	–	–	–	–	–	38-111 m
Ophiosphaera insignis	+	–	–	–	–	–	–	–	49 m
Ophiacantha dallasi	+	–	–	–	–	–	–	–	49 m
Ophiocoma brevipes	+	–	–	–	–	–	–	–	49 m
Ophiopsila pantherina	+	–	–	–	–	–	–	–	49 m
Ophiarachnella infernalis	+	–	–	–	–	–	–	–	51 m
Ophioconis cupida	+	–	–	–	–	–	–	–	48-50 m

Table 4.2 Region and depth of occurrence of echinoderm species in the SEAS shelf cont.

Species	Region of occurrence								Depth range
	T1	T2	T3	T4	T5	T6	T7	T8	
Ophiocnemis marmorata	+	+	–	–	–	–	–	–	49-52 m
Ophiopteron elegans	+	–	–	–	–	–	–	–	49 m
Ophiothrix proteus	–	+	–	–	–	–	–	–	52 m
Ophiothrix purpurea	+	–	–	–	–	–	–	–	51-52 m
Ophiothrix foveolata	+	–	–	–	–	–	–	–	49 m
Ophiothrix savignyi	+	–	–	–	–	–	–	–	31-52 m
Ophiura kinbergi	+	+	+	+	+	+	+	–	30-155 m
Stereocidaris alcocki	+	–	–	–	–	–	–	–	51 m
Paratrema doederleini	–	+	–	–	–	–	–	–	102 m
Salmaciella dussumieri	+	+	–	–	–	–	–	–	34-52 m
Salmacis virgulata	+	–	–	–	–	–	–	–	52 m
Echinoneus cyclostomus	+	–	–	–	–	–	–	–	30-51 m
Sculpsitechinus auritus	+	+	+	–	–	–	–	–	38-95 m
Clypeaster fervens	+	–	–	–	–	–	–	–	52 m
Clypeaster rarispinus	+	+	+	+	+	–	+	–	32-111 m
Clypeaster reticulatus	+	–	–	–	–	–	–	–	52 m
Echnolampas alexandri	+	+	–	–	–	–	–	–	30-50 m
Lovenia elongata	+	+	–	–	–	–	–	+	33-65 m
Nacospatangus alta	+	–	–	–	–	–	–	–	30-52 m
Synaptula maculata	–	+	+	–	–	–	–	–	31-51 m
Leptopentacta imbricata	+	+	+	+	–	–	+	–	31-108 m
Pseudocnus echinatus	+	–	–	–	–	–	–	–	24 m
Stolus buccalis	+	+	+	–	–	–	–	–	30-52 m
Thyone dura	+	+	+	+	+	–	–	–	24-109 m
Antedon ?parviflora	+	–	–	–	–	–	–	–	49 m
Mastigometra micropoda	+	–	–	–	–	–	–	–	51 m
Cenometra bella	+	–	–	–	–	–	–	–	51 m
Petasometra helianthoides	+	–	–	–	–	–	–	–	49 m
Heterometra africana	+	–	–	–	–	–	–	–	49 m
Himerometra robustipinna	+	–	–	–	–	–	–	–	32 m

Table 4.3 Sediment characteristics in the SEAS shelf (mean±SD)

		Sand (%)	Silt (%)	Clay (%)	Med. grain size (μm)	Mean grain size (μm)	OM (%)
20-50m	**T1**	91.66 ± 9.36	6.85 ± 7.73	1.50 ± 2.39	346.00 ± 206.73	282.15 ± 94.80	0.48 ± 0.29
	T2	92.32 ± 6.19	5.79 ± 4.99	1.89 ± 1.48	253.36 ± 90.85	228.16 ± 99.89	0.36 ± 0.23
	T3	49.03 ± 29.52	35.28 ± 20.48	15.70 ± 20.65	86.22 ± 63.32	94.25 ± 63.56	2.09 ± 1.06
	T4	61.11 ± 32.55	30.09 ± 26.12	8.80 ± 7.30	132.29 ± 100.13	132.27 ± 80.04	1.49 ± 1.41
	T5	0.56 ± 0.76	76.61 ± 1.09	22.83 ± 0.78	10.53 ± 0.60	14.97 ± 1.30	4.75 ± 1.58
	T6	0.97 ± 0.54	76.80 ± 1.84	22.24 ± 1.87	11.54 ± 0.56	16.76 ± 0.98	3.64 ± 1.30
	T7	12.19 ± 27.64	67.43 ± 22.16	20.38 ± 5.88	35.25 ± 53.52	37.72 ± 49.60	5.01 ± 2.54
	T8	0.56 ± 0.83	77.87 ± 2.12	21.57 ± 2.38	10.74 ± 2.10	14.23 ± 3.30	4.18 ± 1.65
50-80m	**T1**	78.04 ± 12.60	17.27 ± 11.18	4.69 ± 3.41	161.55 ± 67.73	187.79 ± 67.67	0.96 ± 0.56
	T2	83.29 ± 5.11	12.64 ± 4.51	4.07 ± 0.80	175.59 ± 34.25	164.85 ± 14.25	0.62 ± 0.21
	T3	81.28 ± 9.67	13.64 ± 7.89	5.08 ± 2.19	172.08 ± 50.37	172.33 ± 48.88	0.74 ± 0.38
	T4	59.72 ± 17.11	31.97 ± 15.48	8.31 ± 2.80	104.01 ± 46.09	112.02 ± 33.99	1.34 ± 0.54
	T5	65.08 ± 8.98	26.33 ± 6.79	8.59 ± 2.38	91.19 ± 16.81	95.31 ± 16.61	1.36 ± 0.21
	T6	62.75 ± 9.34	28.53 ± 6.76	8.72 ± 4.04	110.18 ± 31.48	122.12 ± 17.17	1.30 ± 0.84
	T7	59.71 ± 3.95	30.92 ± 2.90	9.37 ± 2.16	92.04 ± 19.04	99.44 ± 12.95	1.81 ± 0.82
	T8	65.76 ± 38.01	27.77 ± 30.64	6.48 ± 7.37	197.05 ± 243.26	161.78 ± 126.50	2.49 ± 2.07
80-150m	**T1**	86.72 ± 11.62	10.65 ± 10.28	2.63 ± 1.78	252.56 ± 106.92	278.17 ± 97.12	1.00 ± 0.43
	T2	73.38 ± 30.21	21.84 ± 25.56	4.78 ± 4.74	200.60 ± 155.78	176.50 ± 118.07	1.22 ± 0.39
	T3	82.15 ± 14.05	13.76 ± 11.47	4.09 ± 3.01	182.86 ± 88.94	192.25 ± 88.57	1.37 ± 0.54
	T4	65.25 ± 25.04	27.81 ± 19.50	6.94 ± 5.80	141.75 ± 126.74	130.57 ± 100.27	1.73 ± 0.47
	T5	73.78 ± 5.99	20.42 ± 5.89	5.80 ± 1.78	134.87 ± 37.07	139.15 ± 31.25	1.51 ± 0.47
	T6	46.90 ± 23.90	47.50 ± 21.53	5.60 ± 3.05	108.25 ± 150.78	90.34 ± 83.10	2.36 ± 0.69
	T7	54.72 ± 12.09	38.94 ± 10.80	6.34 ± 3.29	77.63 ± 30.94	83.76 ± 31.89	1.97 ± 0.52
	T8	43.36	51.52	5.12	55.25	58.47	1.49
150-250m	**T1**	65.72 ± 2.05	28.74 ± 0.99	5.54 ± 1.15	113.55 ± 10.31	132.74 ± 5.34	1.89 ± 0.50
	T2	86.10 ± 8.23	10.98 ± 6.63	2.92 ± 2.33	218.37 ± 59.72	209.50 ± 80.01	1.19 ± 0.24
	T3	84.48 ± 12.79	12.70 ± 11.37	2.82 ± 1.50	183.63 ± 55.31	182.24 ± 52.79	1.27 ± 0.76
	T4	67.79 ± 4.69	27.49 ± 4.04	4.72 ± 0.83	106.22 ± 17.43	111.99 ± 15.27	1.65 ± 0.24
	T5	63.80 ± 7.29	29.90 ± 5.91	6.31 ± 1.56	103.71 ± 24.31	109.32 ± 18.99	2.04 ± 0.39
	T6	34.40 ± 29.82	48.93 ± 15.26	16.67 ± 14.57	47.00 ± 32.12	56.45 ± 40.32	2.42 ± 0.62
	T7	67.20 ± 4.95	27.59 ± 4.21	5.21 ± 1.03	115.91 ± 15.83	122.15 ± 13.42	1.62 ± 0.39
	T8	46.91	40.95	12.14	57.43	78.06	4.28

Table 4.4 Pearson's Correlation Coefficients of sediment parameters in relation to depth and latitude

Variable		Depth	Latitude
Organic matter	*Pearson's Correl.*	-0.042	**0.544**
	Significance	0.515	**0.000**
Sand content	*Pearson's Correl.*	**0.165**	**-0.550**
	Significance	**0.010**	**0.000**
Silt content	*Pearson's Correl.*	**-0.134**	**0.566**
	Significance	**0.038**	**0.000**
Clay content	*Pearson's Correl.*	**-0.220**	**0.383**
	Significance	**0.001**	**0.000**
Median grain size	*Pearson's Correl.*	0.009	**-0.440**
	Significance	0.889	**0.000**

Table 4.5 Hydrographic parameters during the four seasons in the SEAS shelf (mean±SD)

	Season	Salinity (psu)	Temperature (˚C)	Dissolved Oxygen (ml/l)	Organic matter (%)
20-50m	**SM**	35.12 ± 0.29	22.70 ± 0.82	0.52 ± 0.61	2.39 ± 1.75
	FIM	35.32 ± 0.36	26.83 ± 1.15	1.98 ± 1.37	2.68 ± 2.76
	WM	34.44 ± 0.58	28.56 ± 0.33	3.94 ± 0.37	2.46 ± 2.92
	SIM	34.91 ± 0.05	28.03 ± 2.36	2.31 ± 0.70	1.57 ± 1.68
50-80m	**SM**	35.04 ± 0.20	22.05 ± 0.96	0.35 ± 0.27	0.97 ± 0.87
	FIM	35.37 ± 0.30	25.66 ± 2.03	1.88 ± 1.46	1.41 ± 0.48
	WM	34.73 ± 0.69	28.39 ± 0.42	3.89 ± 0.51	1.32 ± 0.82
	SIM	34.95 ± 0.11	25.49 ± 2.93	1.70 ± 0.88	0.83 ± 0.48
80-150m	**SM**	34.95 ± 0.07	19.20 ± 1.42	0.28 ± 0.11	1.50 ± 0.63
	FIM	35.22 ± 0.12	21.62 ± 1.09	0.67 ± 0.26	2.04 ± 0.74
	WM	35.56 ± 0.41	24.76 ± 2.78	2.19 ± 0.93	1.60 ± 0.49
	SIM	35.11 ± 0.17	22.15 ± 2.29	0.74 ± 0.30	1.30 ± 0.67
150-250m	**SM**	35.05 ± 0.08	14.42 ± 1.26	0.19 ± 0.09	1.52 ± 0.54
	FIM	35.11 ± 0.06	14.78 ± 0.94	0.16 ± 0.03	1.91 ± 0.55
	WM	35.18 ± 0.09	15.15 ± 0.93	0.22 ± 0.10	1.90 ± 0.98
	SIM	35.12 ± 0.05	14.45 ± 0.45	0.19 ± 0.04	1.70 ± 0.73

Table 4.6 Results of Principal Component Analysis (PCA) - Eigenvalues of principal components

Principal Component	Eigenvalues	Percentage of Variation explained	Cumulative % of variation explained
1	4.53	45.30	45.30
2	2.30	23.00	68.30
3	1.08	10.80	79.10
4	0.74	7.40	86.50
5	0.50	5.00	91.40

Table 4.7 Results of Principal Component Analysis (PCA) - Eigenvector values for Principal Components 1 & 2

Variable	Code	PC1	PC2
Depth	**Depth**	0.119	**0.519**
Latitude	**Lat.**	**-0.314**	0.103
Salinity	**Salinity**	-0.065	**0.223**
Temperature	**Temp.**	-0.060	**-0.619**
Dissolved oxygen	**DO**	0.001	**-0.517**
Sand (%)	**%Sand**	**0.413**	0.056
Silt (%)	**%Silt**	**-0.409**	0.074
Clay (%)	**%Clay**	**-0.422**	0.006
Organic matter	**OM**	**-0.395**	0.109
Median grain size	**MdZ**	**0.456**	0.003

CHAPTER 5

Summary & Conclusion

The present work provides a comprehensive overview on species diversity, distribution and abundance of echinoderms in the South Eastern Arabian Sea (SEAS), 120 years after the R.I.M.S. Investigator Surveys (1888 – 1892). Observed spatio-temporal variations in echinoderm diversity and its contribution to the benthic fauna are explained on the basis of sediment characteristics and dissolved oxygen (DO) levels of bottom water, the two key factors identified from Principal Component Analysis.

Results of the present study are based on extensive field surveys carried out onboard FORV *Sagar Sampada* during the years 2008 to 2014, encompassing 8 transects, 263 stations and 537 sampling operations, spread over the SM, FIM, WM and SIM seasons in the SEAS.

Echinoderm species diversity in SEAS is revalidated to 256 species from the previous record of 209 species. The revalidated list include 95 species from the shelf and 85 species from the slope areas of the continental margin and 76 reef associated species from the insular shelf of Lakshadweep. Species estimators (Chaos 2 and Jacknife 1) indicate that the possibility of encountering additional records from the study area are restricted to the areas south of Kollam, especially the Cape Comorin sector.

Species diversity is maximum in the Cape Comorin transect, but decreases progressively towards the northern transects. Likewise the species diversity of echinoderms in the shelf decreases with depth. In the 150-250 m depth stratum, echinoderms are nearly absent, being represented only by a single specimen (*Ophiura kinbergi*) in the present study, which was collected from off Kollam (Transect 3). However, species diversity was found to be high in the continental slope of SEAS, beyond ~250 m. The 50-80 m depth stratum harbours maximum echinoderm density.

The study reports on 47 new records of echinoderm species from SEAS. These include a species new to science (*Asteroschema sampadae*, Class Ophiuroidea), a new record (*Zoroaster alfredi*, Class Asteroidea) for the Arabian Sea, 2 new records from the Indian EEZ (*Ophioconis cupida*, Class Ophiuroidea and *Petasometra helianthoides*, Class Crinoidea), 30 first time reports from the eastern Arabian Sea (EAS) and 13 new records from SEAS.

The echinoderms, on an annual average, form the dominant group (42%) among the epifauna in the SEAS shelf. Relative abundance of echinoderms in the epifauna of the SEAS shelf was maximum during the WM season (71%), whereas it was only 17% during SM. Echinoderms were notably absent north of Kochi (Transects 4 to 8), except for *Amphioplus depressus* (Ophiuroidea) which occurred in higher abundance in the 20-50 m depth stratum off Kochi (T4) and Mangalore (T7).

Within the infauna of the SEAS, the mean density of echinoderms was 29 ind./m^2 (1% of macrofaunal density). Seven species of ophiuroids (Family Amphiuridae) and 2 species of holothurians (*Synaptula maculata* & *Pseudocnus echinatus*) were represented only among the infauna. Juveniles of

Ophiura spp., *Astropecten* spp. and *Clypeaster* spp. were found in the infaunal assemblages between August and December.

Analysis of the latitudinal trends in species distribution of echinoderms in the 20 to 150 m depths of SEAS by the non-metric Multi Dimensional Scaling (nMDS) ordination reveal the existence of 3 distinct sub-regions within the study area. These are identified, delineated and designated as the Cape Comorin (T1), the Trivandrum-Kollam (T2 & T3) and the Kochi-Mangalore (T4 to T7) sub-regions.

The Cape Comorin sub-region (T1) is characterised by highest echinoderm diversity in the SEAS shelf. Out of the 50 species represented here, 31 species (including all 6 crinoids collected in the present study) were exclusive to this sub-region and not found anywhere else in the study area. The coarse coralline sands provide high habitat heterogeneity, which supported the high diversity in this sub-region. The physical settings of the Cape region are distinct from the rest of the SEAS, and both natural and anthropogenic disturbances (hypoxia and trawling) are relatively low or absent. Many of these species are also reported in the Gulf of Mannar, indicating the southward extent of the diverse fauna of the Gulf.

The Trivandrum-Kollam sub-region (T2 & T3) is characterised by intermediate level of diversity (24 species), including widely distributed species of the SEAS shelf (*Ophiura kinbergi*, *Amphioplus depressus*, *Luidia hardwicki*, *Clypeaster rarispinus*, *Thyone dura* and *Leptopentacta imbricata*), species with ranges between T1 and T3, as well as 4 species which were unique to this sub-region (*Dougalopus echinatus*, *Ophiothrix proteus*, *Paratrema doederleini*, *Synaptula maculata*). The SM hypoxia is relatively mild in this region and well oxygenated conditions prevail throughout the rest of the year. The finer sands of this sub-region support a high density of echinoids *Clypeaster rarispinus* and *Sculpsitechinus auritus*.

The Kochi-Mangalore sub-region (T4-T7) is characterised by low diversity (9 species). Apart from two amphiurid ophiuroids (*Amphiura duncani* and *Amphipholis misera*), the 7 species that occurred here (*Ophiura kinbergi*, *Amphioplus depressus*, *Luidia hardwicki*, *Clypeaster rarispinus*, *Thyone dura* and *Leptopentacta imbricata*) were the widely distributed species of the SEAS shelf. This sub-region is characterised by relatively silty sediments with higher OM content, and experience to pronounce seasonal fluctuations in bottom water DO, as a result of intense SM hypoxia. Only the widely distributed species, were able to overcome the periodic stress of SM hypoxia coupled with the physical disturbances of trawling, so as to establish themselves in this sub-region.

In the present study, DO levels of bottom water as well as sediment texture are identified as the principal factors regulating the diversity, composition and abundance of echinoderms in SEAS. Highest diversity was noted in the 20-80m depth stratum, with high density of echinoderms in the Cape, Trivandrum and Kollam transects which were replaced by the crustaceans and molluscs in the northern transects (Kochi to Bhatkal).

Though echinoderms prefer sandy sediments, they are most sensitive to low oxygen conditions and show mortality or avoidance behaviour in oxygen deficient environments. This is reflected in the fact that echinoderms were nearly absent in the northern transects during the SM season, but were relatively well represented during the WM season. Similarly, echinoderms avoid the sandy sediments beyond 150 m depths of SEAS shelf, as DO levels of bottom waters here are hypoxic throughout the year. On the other hand crustaceans and molluscs, which are relatively less vulnerable to low oxygen related stress, are capable of withstanding the seasonal shelf hypoxia in the northern transects of SEAS.

Echinoderms in the SEAS shelf are under serious threat from the combined impacts of heavy bottom trawling and the spread & intensification of hypoxia; and therefore, need to be conserved and protected. Detailed investigations on direct impacts of bottom trawling and hypoxia on the echinoderms need to be initiated, on priority.

References

Abdul Jaleel KU. 2012. Macrobenthos of the continental margin (200-1000m) of South Eastern Arabian Sea with special reference to Polychaetes. Ph. D. Thesis in Marine Biology. Cochin University of Science and Technology, Kochi: 238 pages.

Abdul Jaleel KU, Anil Kumar PR, Nousher Khan K, Correya NS, Jacob J, Philip R, Damodaran R. 2014. Polychaete community structure in the south eastern Arabian Sea continental margin (200–1000m). Deep Sea Research Part I: Oceanographic Research Papers 93: 60-71.

Abdul Jaleel KU, Parameswaran UV, Gopal A, Chippy K, Shunmugaraj T, Sanjeevan VN, Anil Kumar V, Gupta GVM. 2015. An evaluation of changes in benthic standing stock and community structure off the south eastern coast Arabian Sea during the monsoon trawl-ban. Continental Shelf Research 102: 9-18.

Agassiz A. 1881. Report on the Echinoidea dredged by H.M.S. Challenger, during the years 1873-1876. Longmans & Co.: 321 pages. 66 Pls.

Alcock A. 1893a. Natural history notes from H.M. Indian Marine Survey steamer Investigator, Commander CF Oldham, RN, commanding. Series 2, No 9. An account of the deep-sea collection made during the season of 1892–93. Journal of the Asiatic Society of Bengal 62(2, 4): 169–184. Pls: 8–9.

Alcock A. 1893b. Natural History notes from the HM Indian Marine Survey Steamer Investigator.7. An account of the collection of deep-sea Asteroidea. Annals of the Magazine of Natural History 11(6): 73-121.

Alcock A. 1894. Echinoderma of the Indian Museum. Part I. Illustrations of Zoology of RIMS Investigator, Echinoderma. Pls: 1-3.

Alongi DM. 1990. The ecology of tropical soft-bottom benthic ecosystems. Oceanography and Marine Biology: An Annual Review 28(3): 381-496.

Ambrose W, Clough L, Tilney P, Beer L. 2001. Role of echinoderms in benthic remineralization in the Chukchi Sea. Marine Biology 139(5): 937-949.

Anderson ARS. 1894. On the Echinoidea collected during the season 1893-1894. The journal of the Asiatic Society of Bengal. 63: 188-195.

Anderson OF, Clark MR. 2003. Analysis of bycatch in the fishery for orange roughy, Hoplostethus atlanticus, on the South Tasman Rise. Marine and Freshwater Research 54(5): 643-652.

Ansari ZA, Parulekar AH, Harkantra SN, Nair A. 1977. Shallow water macrobenthos along the central west coast of India. Mahasagar 10(3-4): 123-127.

Ansari ZA, Ingole BS, Parulekar AH. 1996. Benthos of the EEZ of India. In: India's Exclusive Economic Zone- Resource Exploitation, Management (Eds. Qasim SZ, Roonwal GS). Omega Scientific Publications, New Delhi: 74-86.

Antony MK. 1990. Northward undercurrent along west coast of India during upwelling – Some inferences. Indian Journal of Marine Science 19: 95–101.

Asha PS, Muthiah P. 2002. Spawning and larval rearing of sea cucumber: *Holothuria (Theelothuria) spinifera* Theel. SPC Beche de mer Information Bulletin 16: 11-15.

Bakus GJ. 2007. Quantitative analysis of marine biological communities: field biology and environment. John Wiley & Sons: 435 pages.

Balachandran KK, Laluraj CM, Martin GD, Srinivas K, Venugopal P. 2006. Environmental analysis of heavy metal deposition in a flow-restricted tropical estuary and its adjacent shelf. Environmental Forensics 7(4): 345-351.

Banse K. 1959. On upwelling and bottom-trawling off the southwest coast of India. Journal of Marine Biological Association of India 1: 33–49.

Banse K. 1968. Hydrography of the Arabian Sea shelf of India and Pakistan and effects on demersal fishes. Deep-sea Research 15: 45-79.

Barker M. 2001. Echinoderms 2000. Balkema, Lisse: 590 pages.

Barnett PR, Hardy BL. 1967. A diver-operated quantitative bottom sampler for sand macrofaunas. Helgoländer Wissenschaftliche Meeresuntersuchungen 15(1-4): 390-398.

Barry JP. 1988. Hydrographic patterns in McMurdo Sound, Antarctica and their relationship to local benthic communities. Polar Biology 8(5): 377-391.

Bather FA. 1900. The Echinoderma Part III. In: A Treatise on Zoology (Ed. Lankester ER) Adam & Charles Black, London: 1–344.

Bell FJ. 1887a. Report on a Collection of Echinodermata from the Andaman Islands. PZS: 139-145.

Bell FJ. 1887b. The echinoderm fauna of the island of Ceylon. The Scientific Transactions of the Royal Dublin Society 3: 643-658. Pls: 39-40.

Bell FJ. 1888. Report on a Collection of echinoderms made at Tuticorin, Madras by E Thurston. Proceedings of the Zoological Society of London 1888: 383-289.

Bell FJ. 1889. Additions to the echinoderms fauna of Bay of Bengal. Proceedings of the Zoological Society of London 1889: 6-7.

Bell FJ. 1902. The actinogonidiate echinoderms of the Maldive and Laccadive Islands. In: The Fauna and Geography of the Maldive and Laccadive Archipelagoes (Ed. Gardiner JS) 1(16): 223-233.

Bergman MJN, Hup M. 1992. Direct effects of beam trawling on macrofauna in a sandy sediment in the southern North Sea. ICES Journal of Marine Science 49: 5–11.

Biernbaum CK. 1979. Influence of sedimentary factors on the distribution of benthic amphipods of Fishers Island Sound, Connecticut. Journal of Experimental Marine Biology and Ecology 38(3): 201-223.

Bijukumar A, Deepthi GR. 2006. Trawling and by-catch: Implications on marine ecosystem. Current Science 90(8): 922-931.

Birkeland C. Lucas JS. 1990. *Acanthaster planci*: Major management problem on coral reefs. CRC Press, Boca Raton: 257 pages.

Biswas SK. 1989. Hydrocarbon exploration in western offshore basins of India. Geological Survey of India Publication 24: 185-194.

Blake DB. 1987. A classification and phylogeny of post-Paleozoic sea stars (Asteroidea: Echinodermata). Journal of Natural History 21: 481–528.

Blake DB. 1989. Asteroidea: functional morphology, classification and phylogeny. In: Echinoderm Studies 3 (Eds. Jangoux M, Lawrence JM) Balkema, Rotterdam: 179–233.

Blake DB. 2000. The Class Asteroidea (Echinodermata): fossils and the base crown group. American Zoologist 40: 316–325.

Blake DB, Janies DA, Mooi R. 2000. Evolution of starfishes: morphology, molecules, development, and paleobiology. Introduction to the symposium. American Zoologist 40: 311–315.

Bluhm BA, Iken K, Hardy SM, Sirenko BI, Holladay BA. 2009. Community structure of epibenthic megafauna in the Chukchi Sea. Aquatic Biology 7(3): 269-293.

Bomford TL. 1913. A note on certain ophiuroids in the Indian Museum. Records of the Indian Museum 9: 219-225.

Bosch I, Beauchamp K, Steele M, Pearse J. 1987. Development, metamorphosis, and seasonal abundance of embryos and larvae of the Antarctic sea urchin *Sterechinus neumayeri*. The Biological Bulletin 173(1): 126 pages.

Bourget E, DeGuise J, Daigle G. 1994. Scales of substratum heterogeneity, structural complexity, and the early establishment of a marine epibenthic community. Journal of Experimental Marine Biology and Ecology 181(1): 31-51.

Britayev TA, Zamishliak EA. 1996. Association of the commensal scaleworm *Gastrolepidia clavigera* (Polychaeta: Polynoidae) with holothurians near the coast of South Vietnam. Ophelia 45(3): 175-190.

Bromham LD and Degnan BM. 1999. Hemichordates and deuterostome evolution: robust molecular phylogenetic support for a hemichordate + echinoderm clade. Evolution & Development 1: 166–171.

Brown JH, Gibson AC. 1983. Biogeography. St Louis: C.V. Mosby Co: 654 pages.

Bruguiere JG. 1792. Encyclopédie méthodique: Histoire naturelle des vers. Volume 1. chez Panckoucke: 767 pages.

Burnham KP, Overton WS. 1978. Estimation of the size of a closed population when capture probabilities vary among animals. Biometrika 65(3): 625-633.

Byrne M, Przeslawski R. 2013. Multistressor impacts of warming and acidification of the ocean on marine invertebrates' life histories. Integrative and Comparative Biology 53(4): 582-596.

CPCB. 1996. Pollution Potential of industries in coastal areas of India. Coastal Pollution Control Series, Central Pollution Control Board Report.

Cairns SD. 2011. Global diversity of the Stylasteridae (Cnidaria: Hydrozoa: Athecatae). PloS one 6(7): e21670.

Caldeira K, Wickett ME. 2003. Oceanography: anthropogenic carbon and ocean pH. Nature 425(6956): 365-365.

Calvert SE. 1987. Oceanographic control on the accumulation of organic matter in marine sediments, in petroleum source rocks. In. Brooks AJ, Fleet J, editors. Oxford: Blackwell Scientific publications. 137-151.

Cameron CB, Garey JR, Swalla BJ. 2000. Evolution of the chordate body plan: new insights from phylogenetic analyses of deuterostome phyla. Proceedings of the National Academy of Sciences 97(9): 4469-4474.

Candia Carnevali MD, Bonasoro F. 2001. Echinoderm Research 1998: proceedings of the Fifth European Conference on Echinoderms, Milan, Italy, 7–12 September 1998. Balkema, Rotterdam: 550 pages.

Carpenter PH. 1884. Report upon the Crinoidea collected during the voyage of HMS Challenger during the years 1873–76. Reports of the Scientific Results of the Exploratory Voyage of HMS Challenger, Zoology 11: 1–442.

Caspers H. 1985. The brittle star, *Ophiactis savignyi* (Müller & Troschel), an inhabitant of a Pacific sponge, *Damiriana hawaiiana* de Laubenfels. In: Proceedings of the Fifth International Echinoderm Conference (Eds. Keegan BF, O'Connor DS). Galway, 24–29 September 1984. Rotterdam, Balkema: 603–609.

Chadwick HC. 1904. On the Crinoidea. In: A report to the Government of Ceylon on Pearl Oyster Fisheries of the Gulf of Mannar (Ed. Herdman WA). London (Royal Society) Suppl. Report 11: 151-158.

Chao A. 1984. Nonparametric estimation of the number of classes in a population. Scandinavian Journal of statistics: 265-270.

Cherbonnier G, Guille A. 1978. Echinodermes: ophiurides. Faune Madagascar 48: 1-272.

Cisternas P, Selvakumaraswamy P, Byrne M. 2004. Evolution of development and the Ophiuroidea – revisited. In: Echinoderms: München (Eds. Heinzeller T, Nebelsick JH). Taylor & Francis, London: 521–526.

Clark AH. 1909. New recent Indian crinoids. Proceedings of the Biological Society of Washington 22: 143-152.

Clark AH. 1912a. The Crinoidea of the Indian Ocean. Echinoderma of the Indian Museum. Indian Museum, Calcutta 7: 1-325.

Clark AH. 1912b. On a small collection of recent crinoids from the Indian Ocean. Records of the Indian Museum 7: 267-271.

Clark AH. 1915. A monograph of the existing crinoids. Volume 1. The comatulids, Pt. 1. United States National Museum Bulletin. Smithsonian Institution Press, Washington, DC 82(1): 406 pages. Pls: 1-17.

Clark AH. 1918. The unstalked crinoids of the Siboga Expedition. Siboga Expedition 42b: 1-300, 28 plates.

Clark AH. 1921. A monograph of the existing crinoids. Volume 1(2). The comatulids, Pt. 2. United States National Museum Bulletin 82(1, 2): 795 pages.

Clark AH. 1931. A monograph of the existing crinoids, Volume 1, The comatulids, Pt. 3. United States National Museum Bulletin 82(8): 816 pages. Pls: 1-82.

Clark AH. 1932. On a collection of recent crinoids from the Indian Ocean and the Bay of Bengal. Records of the Indian Museum 34(4): 551-566.

Clark AH. 1936. Crinoidea. Scientific Reports of the John Murray Expedition 4(4): 87-108. Pl:1.

Clark AH. 1941. A monograph of the existing crinoids, Volume 1, The comatulids, Pt. 4a. United States National Museum Bulletin. Smithsonian Institution Press, Washington, DC 82: 603 pages.

Clark AH. 1947. A monograph of the existing crinoids, Volume 1, The Comatulids, Pt. 4b. United States National Museum Bulletin. Smithsonian Institution Press, Washingto, DC 82: 473 pages. Pls: 1-43.

Clark AH. 1950. A monograph of the existing crinoids, Volume 1, The Comatulids, Pt. 4c. United States National Museum Bulletin. Smithsonian Institution Press, Washington, DC 82: 383 pages. Pls: 1-32.

Clark AH, Clark AM. 1967. A monograph of the existing crinoids. Volume 1(5). The Comatulids, Pt. 5. United States National Museum Bulletin 82: 860 pages.

Clark AM. 1970. Notes on the family Amphiuridae (Ophiuroidea). Bulletin of the British Museum (Natural History) Zoology 19: 1–81.

Clark AM, Rowe FWE. 1971. Monograph of shallow-water Indo-West Pacific echinoderms. British Museum Press: 238 pages.

Clark AM. 1976. Tropical epizoic echinoderms and their distribution. Micronesica 12(1): 111-118.

Clark AM. 1989. An index of names of recent Asteroidea. In: Jangoux, M.; Lawrence, J.M. (Ed.) Echinoderm Studies, volumes 2-6 . Balkema: Rotterdam, The Netherlands.

Clark AM, Downey ME. 1992. Starfishes of the Atlantic. Chapman & Hall, London: 794 pages.

Clark HL. 1909. Notes on some Australian and Indo-Pacific echinoderms. Museum of Comparative Zoology at Harvard College 52(7): 109-350.

Clark HL. 1925. A catalogue of the recent sea-urchins (Echinoidea) in the collection of the British Museum (Natural History). Printed by order of the Trustees of the Museum: 250 pages.

Clark HL. 1939. Ophiuroidea. Scientific Reports of the John Murray Expedition 6: 29-136.

Clarke KR, Warwick RM. 2001. Changes in marine communities: an approach to statistical analysis and interpretation, 2nd edition, PRIMER-E: Plymouth: 144 pages.

Clarke KR, Gorley RN. 2006. PRIMER v6: user manual/tutorial (Plymouth routines in multivariate ecological research). Plymouth: Primer-E Ltd.

Clarkson E. 2009. Invertebrate palaeontology and evolution. John Wiley & Sons: 468 pages.

Cohen BL, Ameziane N, Eleaume M, Richer de Forges B. 2004. Crinoid phylogeny: a preliminary analysis (Echinodermata: Crinoidea). Marine Biology 44(3): 605–617.

Collie JS, Hall SJ, Kaiser MJ, Poiner IR. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69: 785–798.

Colwell RK, Coddington JA. 1994. Estimating terrestrial biodiversity through extrapolation. Philosophical Transactions of the Royal Society of London B: Biological Sciences 345(1311): 101-118.

Cowie GL. 2005. The biogeochemistry of Arabian Sea surficial sediments: a review of recent studies. Progress in Oceanography 65: 260–289.

Creutzberg F, Wapenaar P, Duineveld G, Lopez Lopez N. 1984. Distribution and density of the benthic fauna in the southern North Sea in relation to bottom characteristics and hydrographic conditions. Journal du Conseil Permanent International pour l'Exploration de la Mer. Conseil Permanent International pour l'Exploration de la Mer 183: 101-110.

Cuénot L. 1948. Anatomie, éthologie et systématique des échinodermes. Traité de zoologie 11: 1-363.

Cusson M, Bourget E. 2005. Global patterns of macroinvertebrate production in marine benthic habitats. Marine Ecology Progress Series 297: 1-14.

Cutler AN, Swallow JC. 1984. Surface currents of the Indian Ocean. (To 25°S, 100°E). IOS. Technical Report: 187 pages.

Cuvier G. 1817. Le règne animal distribué d'après son organisation, pour servir de base à l'histoire naturelle des animaux et d'introduction à l'anatomie comparée 4: 1976 pages. 15 Pls.

Dahm C. 1993. Growth, production and ecological significance of *Ophiura albida* and *O. ophiura* (Echinodermata: Ophiuroidea) in the German Bight. Marine Biology 116(3): 431-437.

Damodaran R. 1973. Studies on the benthos of the mud banks of Kerala coast. Bulletin of the Department Of Marine Sciences. University of Cochin 6: 1-126.

Damodaran R. 2010. Marine Manpower Development Programme, MLR Related Research On-board *FORV Sagar Sampada*, Benthic Productivity. Final Report. Department of Marine Biology, Microbiology & Biochemistry, CUSAT: 214 pages.

David J, Roux M, Messing CG, Ameziane N. 2006. Revision of the pentacrinid stalked crinoids of the genus *Endoxocrinus* (Echinodermata, Crinoidea), with a study of environmental control of characters and its consequences for taxonomy. Zootaxa 1156: 1–50.

Dawson EW. 1970. Faunal relationships between the New Zealand plateau and the New Zealand sector of Antarctica based on echinoderm distribution. New Zealand Journal of Marine and Freshwater Research 4(2): 126-140.

De Candolle AP. 1813. Théorie élémentaire de la botanique. Deterviile.

De Domenico, Francesca, Mariachiara Chiantore, Sabrina Buongiovanni, Maria Paola Ferranti, Serena Ghione, Simon Thrush, Vonda Cummings, Judi

Hewitt, Kerstin Kroeger, Riccardo Cattaneo-Vietti. 2006. Latitude versus local effects on echinoderm assemblages along the Victoria Land coast, Ross Sea, Antarctica. Antarctic Science 18(4): 655-662.

De Meijere JCH. 1904. Die Echinoidea der Siboga-expedition. Buchhandlung und druckerei vormals EJ Brill.: 251 pages.

De Ridder C, Lawrence JM. 1982. Food and feeding mechanisms: Echinoidea. In: Echinoderm nutrition (Eds. Jangoux M, Lawrence JM). CRC Press: 57-116.

Deepa RP, Bijukumar A. 2010. New records of the sea cucumbers *Holothuria (Semperothuria) imitans* Ludwig and *Stichopus herrmanni* Semper (Echinodermata: Holothuroidea) from the southwestern coast of India. Journal of Threatened Taxa 2(2): 712–715.

Deepa RP, Bijukumar A. 2011. New records of sea cucumbers *Phyllophorus (Phyllothuria) cebuensis* (Semper) and *Trachasina crucifera* (Semper) from the south-west coast of India. Indian Journal of Fisheries 58(4): 101–104.

Dernie KM, Kaiser MJ, Warwick RM. 2003. Recovery rates of benthic communities following physical disturbance. Journal of Animal Ecology 72(6): 1043-1056.

Deshmukh A, Ingole B, Mukharjee I, Sivdas S. 2015. First record of the synaptid holothurian Protankyra bidentata (Woodward & Barrett, 1858) from the Indian Ocean. Indian Journal of Fisheries 62(3): 157-160.

Desprez M. 2000. Physical and biological impact of marine aggregate extraction along the French coast of the Eastern English Channel: short-and long-term post-dredging restoration. ICES Journal of Marine Science. Journal du Conseil 57(5): 1428-1438.

Devassy VP, Bhattathiri PMA, Qasim SZ. 1978. *Trichodesmium* phenomenon. Indian Journal of Marine Science 73: 168-186.

Diaz RJ, Rosenberg R. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. Oceanography and Marine Biology: Annual Review 33: 245-303.

Diaz RJ, Rosenberg R. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321(5891): 926-929.

Dimitriadis C, Koutsoubas D, Garyfalou Z, Tselepides A. 2014. Benthic molluscan macrofauna structure in heavily trawled sediments (Thermaikos Gulf, North Aegean Sea): spatiotemporal patterns. Journal of Biological Research-Thessaloniki 21(1): 1-10.

Döderlein L. 1888. Echinodermen von Ceylon. Bericht über die von den Herren Dres Sarasin gesammelten Asteroidea, Ophiuroidea und Echinoidea. Zoologische Jahrbücher Systematik 3(1888): 821-846.

Döderlein L. 1921. Die Asteriden der Siboga-Expedition. Discrete Mathematics. EJ Brill. 309: 3385-3392.

Döderlein L. 1935. Die Asteriden der Siboga-Exped. III. Oreasteridae. Siboga-Expedition 46(2): 71-110, pls. 15-20.

Doney SC, Ruckelshaus M, Duffy JE, Barry JP, Chan F, English CA, Galindo HM, Grebmeier JM, Hollowed AB, Knowlton N, Polovina J. 2012. Climate change impacts on marine ecosystems. Annual Review of Marine Science 4: 11-37.

Duncan PM. 1887. On the Ophiuroidea of the Mergui Archipelago, collected for the Trustees of the Indian Museum by Dr. John Anderson. Journal of the Linnaean Society (Zoology) 21: 85-106.

Dupont S, Dorey N, Thorndyke M. 2010. What meta-analysis can tell us about vulnerability of marine biodiversity to ocean acidification?. Estuarine, Coastal and Shelf Science 89(2): 182-185.

El Wakeel SK, Riley JP. 1957. The determination of organic carbon in marine muds. Journal du conseil 22(2): 180-183.

Eleftheriou A, McIntyre A. 2005. Methods for Study of Marine Benthos. 3rd Edition: 409 pages.

Ellingsen K. 2002. Spatial patterns of benthic diversity: is there a latitudinal gradient along the Norwegian continental shelf?. Journal of Animal Ecology 71(3): 373-389.

Elliott JM, Tullett PA, Elliott JA. 1993. A new bibliography of samplers for freshwater benthic invertebrates. Freshwater Biological Association 30: 91 pages.

Ellis J, Rogers S, Freeman S. 2000. Demersal assemblages in the Irish Sea, St George’s Channel and Bristol Channel. Estuarine, Coastal and Shelf Science 51(3): 299–315.

Emlet RB. 1988. Larval form and metamorphosis of a “primitive” sea urchin, *Eucidaris thouarsi* (Echinodermata: Echinoidea: Cidaroida), with implications for developmental and phylogenetic studies. The Biological Bulletin 174(1): 1-4.

Entrambasaguas L, Pérez-Ruzafa Á, García-Charton JA, Stobart B, Bacallado JJ. 2008. Abundance, spatial distribution and habitat relationships of echinoderms in the Cabo Verde Archipelago (eastern Atlantic). Marine and Freshwater Research 59(6): 477-488.

Etter RJ, Grassle JF. 1992. Patterns of species diversity in the deep sea as a function of sediment particle size diversity. Nature 360: 576-678.

Faith DP, Minchin PR, Belbin L. 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetatio 69(1-3): 57-68.

Feder HM, Jewett SC, Blanchard A. 2005. Southeastern Chukchi Sea (Alaska) epibenthos. Polar Biology 28(5): 402-421.

Fell HB. 1960. Synoptic keys to the genera of Ophiuroidea. Zoological Publications of the Victoria University, Wellington 26: 1-44.

Féral JP, David B. 2001. Echinoderm research 2001. Balkema, Rotterdam: 337 pages.

Freeman S, Richardson C, Seed R. 2001. Seasonal abundance, spatial distribution, spawning and growth of *Astropecten irregularis* (Echinodermata: Asteroidea). Estuarine, Coastal and Shelf Science: 39–49.

Freeman S, Rogers S. 2003. A new analytical approach to the characterisation of macro-epibenthic habitats: linking species to the environment. Estuarine, Coastal and Shelf Science 56(3-4): 749–764.

Frey H, Leuckart R. 1847. Beitrage zur Kenntniss wirbelloser Thiere mit besonderer Berucksightigung der Fauna des norddeutschen Meeres. Freidrich Vieweg und Sohn, Braunschweig: 170 pages. Pls: 2.

Fujita T. 2001. Submersible observations on the euryaline brittle star, *Asteronyx loveni* (Echinodermata, Ophiuroidea), living in association with a gorgonacean. In: Echinoderms 2000 – Proceedings of the 10th International Echinoderm Conference (Ed. Barker M). New Zealand 31: 267-272.

Fujita T, Namikawa H. 2006. New Observations of Ophiocnemis marmorata (Echinodermata: Ophiuroidea) associated with Rhopilema esculentum (Cnidaria: Scyphozoa: Rhizostomeae) in the Philippines and Japan. Memoirs of the National Science Museum, Tokyo 44: 3–28.

Furlong RF, Holland PW. 2002. Bayesian phylogenetic analysis supports monophyly of ambulacraria and of cyclostomes. Zoological science 19(5): 593-599.

Gale AS. 1987. Phylogeny and classification of the Asteroidea (Echinodermata). Zoological Journal of the Linnaean Society 89: 107–132.

Ganapathi PN, Rao MVL. 1962a. Preliminary observations on the bottom fauna of the continental shelf of the North-East coast of India. Proceedings of the First All India Congress of Zoology (1959), Jabalpur 1(3): 8-13.

Ganapathi PN, Rao MVL. 1962b. Studies on the ecology of intertidal sands of the Vishakapatnam coast. Proceedings of the First All India Congress of Zoology (1959), Jabalpur 1(3): 14-25.

Ganapathi PN, Sastry DRK. 1970. Recods of *Athanas indicus* (Coutiere) (Decapoda: Alpheidae) associated with *Stomopneustes variolaris* (Echinodermata: Echinoidea) from Vishakapatnam coast. Symposium on Marine Intertidal Ecology, Andhra University, Vishakapatnam. Abstract No. 33: 21 pages.

Ganapathi PN, Sastry DRK. 1972. Recods of Athanas indicus (Coutiere) (Decapoda: Alpheidae) associated with *Stomopneustes variolaris* (Echinodermata: Echinoidea) from Vishakapatnam coast. Proceedings of the Indian National Science Academy 38B (5-6): 367-372.

Ganesh T, Raman AV. 2007. Macrobenthic community structure of the northeast Indian shelf, Bay of Bengal. Marine Ecology Progress Series 341: 59-73.

Gideon PW, Menon PKB, Rao SRV, Jose KV. 1957. on the Marine Fauna of Gulf of Kutch – A preliminary survey. Journal of the Bombay Natural History Society 54(3): 690-706.

Glasby TM, Underwood AJ. 1996. Sampling to differentiate between pulse and press perturbations. Environmental Monitoring and Assessment 42(3): 241-252.

Gooday Andrew J, Brian J, Bett Elva Escobar, Baban Ingole, Lisa A, Levin, Carlos Neira, Raman AV, Javier Sellanes. 2010. Habitat heterogeneity and its influence on benthic biodiversity in oxygen minimum zones. Marine Ecology 31: 125–147.

Gopalakrishnan P. 1969. On the Holothuroidea (Echinodermata) of the Gulf of Kutch. Journal of the Bombay Natural History Society 66(2): 399-400.

Goyal AK, Arora S. (Eds) 2009. India's Fourth National Report to the Convention on Biological Diversity. Ministry of Environment and Forests, Government of India, New Delhi 75: 143 pages.

Gravely S. 1927. The littoral fauna of Krusadai Island in the Tamil Nadu-Gulf of Mannar: Echinodermata. Bulletin of the Madras Government Museum (Natural History) 1(1): 63-173.

Gravely S. 1941. Shells and other animal remains found on the Madras beach. I. Groups other than the snails. Bulletin of the Madras Government Museum (Natural History) 5(1): 1-112.

Gray JS, Calamari D, Duce R, Portmann JE, Wells PG, Windom HL. 1991. Scientifically based strategies for marine environmental protection and management. Marine Pollution Bulletin 22(9): 432-440.

Gray JS. 1974. Animal-sediment relationships. Oceanography and Marine Biology: Annual Review 12: 223-261.

Gray JS. 1997. Marine biodiversity: patterns, threats and conservation needs. Biodiversity & Conservation 6(1): 153-175.

Gray JS, Wu RSS, Or YY. 2002. Effects of hypoxia and organic enrichment on the coastal marine environment. Marine Ecology Progress Series 238: 249-279.

Gray, JS, Elliott M. 2009. Ecology of marine sediments: from science to management. Oxford University Press: 213 pages.

Guille A. 1981. Echinodermes: Ophiurides. Résultats des Campagnes MUSORSTOM. I - Philippines (18-28 March 1976). Memoirs ORSTOM 91: 413-456.

Gupta GVM, Sudheesh V, Sudharma KV, Saravanane N, Dhanya V, Dhanya KR, Lakshmi G, Sudhakar M, Naqvi SWA. 2016. Evolution to decay of upwelling and associated biogeochemistry over the southeastern Arabian Sea shelf, Journal of Geophysical Research. Biogeosciences: 1-121.

Habeebrehman H, Prabhakaran MP, Jacob J, Sabu P, Jayalakshmi KJ, Achuthankutty CT, Revichandran C. 2008. Variability in biological responses influenced by upwelling events in the Eastern Arabian Sea. Journal of Marine Systems 74(1): 545-560.

Haldar BP, Chakrapani S. 1976. *Culcita pentangularis* Gray (Asteroidea: Oreasteridae), a new record from Indian waters. Journal of the Bombay Natural History Society 73(10): 237-238.

Hall SJ, Harding MJ. 1997. Physical disturbance and marine benthic communities: The effects of mechanical harvesting of cockles on non-target benthic infauna. Journal of Applied Ecology 34: 497–517.

Hamel JF Mercier A. 1995. Prespawning behavior, spawning, and development of the brooding starfish *Leptasterias polaris*. The Biological Bulletin 188(1): 32-45.

Hargrave BT, Kostylev VE, Hawkins CM. 2004. Benthic epifauna assemblages, biomass and respiration in The Gully region on the Scotian Shelf, NW Atlantic Ocean. Marine Ecology Progress Series 270: 55-70.

Harkantra SN, Nair A, Ansari ZA, Parulekar AH. 1980. Benthos of the shelf region along the west coast of India. Indian Journal of Marine Sciences 9: 106-110.

Hartlaub C. 1890. Beitrag zur Kenntniss der Comatuliden-Fauna des indischen Archipels. Nachrichten von der Königlichen Gesellschaft der Wissenschaften und der Georgs-August-Universität zu Göttingen 5: 168–187.

Hashimi NH, Kidwai RM, Nair RR. 1978. Grain size and coarse fraction studies of sediments between Vengurla and Mangalore on the western continental shelf of India. Indian Journal of Marine Sciences 7: 231-238.

Hashimi NH, Kidwai RM, Nair RR. 1981. Comparitive study of the topography and sediments of the western and eastern continental shelf around Cape Comorin. Indian Journal of Marine Sciences 10: 45-50.

Hashimi NH & Nair RR. 1981. Surficial sediments of the continental shelf off Karnataka. Journal of Geological Society of India 22: 266-273.

Hegde M, Rivonkar CU. 2013. A new record of *Temnopleurus decipiens* (de Meijere, 1904) (Echinoidea, Temnopleuroida, Temnopleuridae) from Indian waters. Zoosystema 35(1): 97-111.

Heinzeller T, Nebelsick JH. 2004. Echinoderms: München. Balkema, Leiden: 633 pages.

Heltshe JF, Forrester NE. 1983. Estimating species richness using the jackknife procedure. Biometrics: 1-11.

Herdman WA, Herdman JB. 1904. On the Echinoderma. Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Manaar. London (Royal Society) Suppl. Rep: 10, 137-147.

Hotchkiss FHC. 2000. On the number of rays in a starfish. American Zoologist 40: 340–354.

Howell KL, Billett DS, Tyler PA. 2002. Depth-related distribution and abundance of seastars (Echinodermata: Asteroidea) in the Porcupine Seabight and Porcupine Abyssal Plain, NE Atlantic. Deep Sea Research Part I: Oceanographic Research Papers 49(10): 1901-1920.

Hrincevich AW, Axayácatl RO, Foltz DW. 2000. Phylogenetic analysis of molecular lineages in a species-rich subgenus of sea stars (*Leptasterias* subgenus *Hexasterias*). American Zoologist 40: 365–374.

Hunter RL, Halanych KM. 2008. Evaluating connectivity in the brooding brittle star *Astrotoma agassizii* across the Drake Passage in the Southern Ocean. Journal of Heredity 99(2): 137-148.

Hunter WR, Oguri K, Kitazato H, Ansari ZA, Witte U. 2011. Epi-benthic megafaunal zonation across an oxygen minimum zone at the Indian continental margin, Deep Sea Research I 58: 699–710.

Hyman LH. 1955. The invertebrates: Echinodermata. McGraw-Hill, New York: 763 pages.

Iken K, Konar B, Benedetti-Cecchi L, Cruz-Motta JJ, Knowlton A, Pohle G, Mead A, Miloslavich P, Wong M, Trott T, Mieszkowska N, Riosmena-Rodriguez R, Airoldi L, Kimani E, Riosmena-Rodriguez Y, Fraschetti S, Ortiz-Touzet M, Silva A. 2010. Large-scale spatial distribution patterns of echinoderms in nearshore rocky habitats. PloS one 5(11): e13845.

Ingole BS, Sautya S, Sivadas S, Singh R, Nanajkar. 2010. Macrofaunal community structure in the western Indian continental margin including the oxygen minimum zone. Marine Ecology 31: 148–166.

Irimura S. 1981. Ophiurans from Tanabe Bay and its vicinity, with the description of a new species of Ophiocentrus. Publlications of the Seto Marine Biological Laboratory 26: 15–49.

James DB. 1967. *Phyllophorus (Phyllophorella) parvipedes* Clark (Holothuroidea), a new record from Indian Seas. Journal of the Marine Biological Association of India 7: 325-327.

James DB. 1968a. Studies on Indian Echinoderms-1. Re-description of the echinoid *Breynia vredenburgi* Anderson from the Andaman Sea with emended description. Journal of the Marine Biological Association of India 8(2): 76-81.

James DB. 1968b. Studies on Indian Echinoderms-2. The holothurian *Stolus buccalis* (Stimpson) with notes on its systematic position. Fisheries Research 8(2): 285–289.

James DB. 1969. Catalogue of echinoderms in the reference collections of the Central Marine Fisheries Research Institute, Mandapam. Bulletin of the Central Marine Fisheries Research Institute 7: 51-62.

James DB, Lal Mohan RS. 1969. Bibliography of the Echinoderms of the Indian Ocean. CMFRI Bulletin: 15pages.

James DB. 1971. Studies on Indian Echinoderms-4 On the brittle-stars *Amphioplus gravelyi* sp. nov., and *Amphioplus depressus* (Ljungman) from the Indian Coasts. Journal of the Marine Biological Association of India 12: 139–145.

James DB. 1973. Studies on Indian Echinoderms-5 New and little known starfishes from the Indian Seas. Journal of the Marine Biological Association of India 15(2): 556–559.

James DB. 1976. Studies on Indian Echinoderms 6. Re-description of two little known holothurians with a note on an early juvenile of *Holothuria scabra* Jaeger from the Indian Seas. Journal of the Marine Biological Association of India 18(1): 55-61.

James DB. 1983. Sea cucumber and sea urchin resources. CMFRI Bulletin 34: 85-93.

James DB. 1985a. Echinoderm fauna of the proposed National Marine Park in the Tamil Nadu-Gulf of Mannar. Symposium on Endangered Marine Animals and Marine Parks, Cochin 54: 1-7.

James DB. 1985b. Zoogeography of the shallow-water echinoderms of the Indian Seas. In: James PSBR. Recent advances in Marine Biology. Today and Tomorrows Printers and Publishers, New Delhi 569-591.

James DB. 1986a. Studies on Indian Echindoerms-13 *Phyrella fragilis* (Oshima) (Echinodermata: Phyllophoridae), a new record from the Indian Ocean with notes on its habits. Journal of the Marine Biological Association of India 2(1): 37-38.

James DB. 1986b. Studies on Indian Echindoerms-12 *Holothuria (Acanthotrapeza) pyxis* Selenka, an interesting holothurian from the Andamans. Journal of the Andaman Scientific Association 2(1): 34-36.

James DB. 1987a. Studies on Indian Echindoerms-7 On a new family Labidodematidae (Holothurioidea: Aspidochirotida) with a detailed description *of Labidodemas rugosum* (Ludwig) from the Andamans. Journal of the Marine Biological Association of India 23(1&2): 82–85.

James DB. 1987b. Studies on Indian Echindoerms-8 On a new Genus *Ophioelegans* (Ophiuroidea: Ophiuridae) with notes on *Ophiolepis superba* H L Clark, 1938. Journal of the Marine Biological Association of India 23: 15–18.

James DB. 1987c. Studies on Indian echinoderms - 15. On *Psolus mannarensis* sp. nov. and other Dendrochirotids from the Indian Seas. Journal of the Marine Biological Association of India 26(1&2): 109-122.

James DB. 1987d.Studies on Indian Echindoerms-9 *Ophioneris andamanensis* sp. nov. (Ophiuroidea: Ophionereidae) from Port Blair, Andamans. Journal of the Marine Biological Association of India 24: 33–35.

James DB. 1987e. *Ophiocoma anaglyptica* (Ophiuroidea: Ophiocomidae), a new record from the Indian Ocean with notes on other species of *Ophiocoma* from Indian Seas. Journal of the Marine Biological Association of India 24: 36–41.

James DB. 1987f. On *Protankyra tuticorenensis* sp. nov. and other apodous holothurians from the Indian Seas. Journal of the Marine Biological Association of India 24: 92–105.

James DB. 1987g. Research on Indian Echinoderms – a review. Journal of the Marine Biological Association of India 25: 91-108.

James DB. 1988. *Ophiocoma doederleini* Lorioli, a new record of brittle star from the Andamans. Journal of the Andaman Scientific Association 4(2): 139-140.

James DB, James PSBR. 1993. Ecology, breeding, seed production and prospects for farming of sea cucumbers from the seas around India. Fishing Chimes 13(3): 23-24.

James DB. 1991. Echinoderms of the Marine National Park, South Andamans. Journal of the Andaman Scientific Association 7(2): 19-25.

James DB. 1994. Holothurian resources from India and their exploitation. Bulletin of the Central Marine Fisheries Research Institute 46: 27-31.

James DB. 1995a. Animal associations in Echinoderms. Journal of the Marine Biological Association of India 37(1, 2): 272–276.

James DB. 1995b. Echinoderms of Lakshadweep and their zoogepgraphy. Journal of the Bombay Natural History Society. 43: 144-149.

James DB. 1995c. Taxonomic studies on the species of *Holothuria* (Linnaeus, 1767) from the seas around India. Journal of the Bombay Natural History Society 92(2): 190-204.

James DB. 1997. Notes on the family *Goniasteridae* (Echinodermata: Asteroidea) from the Indian Seas. Journal of the Bombay Natural History Society 38: 133-138.

James DB. 1998. On a little known holothurian *Stichopus vastus* Sluiter with notes on other species of *Stichopus* from the seas around India. Marine Fisheries Information Service, Technical and Extension Series 158: 12-15.

James DB. 2008. Indian echinoderms their resources biodiversity zoogeography and conservation. In: Glimpses of Aquatic Biodiversity- Rajiv Gandhi Chair Special Publication. CUSAT, Kochi: 120-132.

James PSBR. 1981. Exploited and potential capture fishery resources in the inshore waters of India. CMFRI Bulletin 30A: 72-82.

James PSBR. 1987. Current knowledge on the offshore fishery resources of India and possibilities of their exploitation. Souvenir: Inauguration of the Fishery Survey of India Office building, Vishakapatnam: 29-34.

Jangoux M. 1982. Food and feeding mechanisms: Asteroidea. In: Echinoderm nutrition (Eds. Jangoux M, Lawrence JM). CRC Press: 117-160.

Jangoux M, Lawrence JM. 2001. Echinoderm Studies 6. Taylor & Francis, London: 285 pages.

Janies D. 2001. Phylogenetic relationships of extant echinoderm classes. Canadian Journal of Zoology 79: 1232–1250.

Jayakumari M. 2004. Studies on the ecophysiology of echinoderms along the coast of Kerala. Ph.D. Thesis submitted to the University of Kerala: 226pp.

Jayaraj KA, Sheeba P, Josia Jacob, Ravichandran C, Arun PK, Praseeda KS, Nisha PA, Rasheed KA. 2008. Response of infaunal macrobenthos to the sediment granulometry in a tropical continental margin – southwest coast of India. Estuarine, Coastal and Shelf Science 77: 743–754.

Jennings S, Kaiser MJ. 1998. The effects of fishing on marine ecosystems. Advances in Marine Biology 34: 201–352.

Jennings S, Reynolds JD. 2000. Impacts of fishing on diversity: from pattern to process. Pages in Kaiser MJ and de Groot SJ, eds. Effects of fishing on non-target species and habitats: biological, conservation, and socio-economic issues. Blackwell Science, Oxford: 235–250 pages.

Jennings S, Pinnegar JK, Polunin NVC, Warr KJ. 2001. Impact of trawling disturbance on the trophic structure of benthic invertebrate communities. Marine Ecology Progress Series 213: 127–142.

Johannessen OM, Subbaraju G, Blindheim J. 1981. Seasonal variation of the Oceanographic condition off the Southwest coast of India during 1971-75. Fiskeridirektoratets Skrifter. Serie Havundersokelser 18: 247-261.

Johnson RG. 1971. Animal-sediment relations in shallow water benthic communities. Marine Geology 11(2): 93-104.

Jones DA, Ghamrawy M, Wahbeh MI. 1987. Littoral and shallow subtidal environments. Red Sea 7: 169 pages.

Jones JB. 1992. Environmental impact of trawling on the seabed: a review. New Zealand Journal of Marine and Freshwater Research 26(1): 59-67.

Jones S, Mahadevan S. 1965. Notes on animal associations. 5. The pea crab *Pinnotheres deccanensis* Chopra inside the respiratory tree of the sea cucumber, *Holothuria scabra* Jager. Journal of the Marine Biological Association of India 7(2): 377-380.

Jones S. 1964. Notes on animal associations. 4. The starfish, *Pentaceros hedemanni* (Lutken) and the Hesionid polychaete, *Podarke angustifrons* (Grube). Journal of the Marine Biological Association of India 6(2): 249-250.

Joydas TV, Damodaran R. 2009. Infaunal macrobenthos along the shelf waters of the west coast of India, Arabian Sea. Indian Journal of Marine Sciences 38: 191–204.

Joydas TV, Damodaran R. 2014. Infaunal macrobenthos of the oxygen minimum zone on the Indian western continental shelf. Marine Ecology 35(1): 22-35.

Julk JM, Das S. 1978. Studies on the shallow water starfishes of the Andaman & Nicobar Islands. Mitteilungen aus dem Zoologischen Museum in Berlin 54: 345-351.

Jyothibabu R, Madhu NV, Habeebrehman H, Jayalakshmy KV, Nair KKC, Achuthankutty CT. 2010. Re-evaluation of 'paradox of mesozooplankton' in the eastern Arabian Sea based on ship and satellite observations. Journal of Marine Systems 81(3): 235-251.

Jyothibabu R, Madhu NV, Murukesh N, Haridas PC, Nair KKC, Venugopal P. 2003. Intense bloom of *Trichodesmium erythraeum* (cyanophyte) in the open waters along east coast of India. Indian Journal of Marine Sciences 32: 165-167.

Kaiser MJ. Spencer BE. 1996. The effects of beam-trawl disturbance on infaunal communities in different habitats. Journal of Animal Ecology 65: 348–358.

Kaiser MJ, Clarke KR, Hinz H, Austen MCV, Somerfield PJ, Karakassis I. 2006. Global analysis of response and recovery of benthic biota to fishing. Marine Ecology Progress Series 311: 1-14.

Karuppaiyan M. 2007. Diversity of Echinoderms along the southeast coast of India. Ph.D. Thesis. Faculty of Marine Sciences, Annamalai University, India: 266 pages.

Kasyanov VL. 2001. Reproductive strategy of marine bivalves and echinoderms. Science Publishers, Enfield, New Hampshire: 240 pages.

Keil R, Hedges J. 1993. Sorption of organic matter to mineral surfaces and preservation of organic matter in coastal marine sediments. Chemical Geology 107: 385-388.

Kerr AM, Kim J. 1999. Bi-penta-bi-decaradial symmetry: a review of evolutionary and developmental trends in Holothuroidea (Echinodermata). Journal of Experimental Zoology 285: 93–103.

Kerr AM, Kim J. 2001. Phylogeny of Holothuroidea (Echinodermata) inferred from morphology. Zoological Journal of the Linnean Society 133: 63–81.

Kerr AM. 2001. Phylogeny of the apodan holothurians (Echinodermata) inferred rom morphology. Zoological Journal of the Linnean Society 133: 53–62.

Kerr AM, Janies DA, Clouse RM, Samyn Y, Kuszak J, Kim J. 2005. Molecular phylogeny of coral reef sea cucumbers (Holothuriidae: Aspidochirotida) based on 16S mitochondrial ribosomal DNA sequence. Marine Biotechnology 7: 53–60.

Khan SA. 2006. Methodology for Assessing Biodiversity. Centre of Advanced Study in Marine Biology, Annamalai University: 12 pages.

Khan SA, Manokaran S, Lyla S, Nazeer Z. 2010. Biodiversity of epibenthic community in the inshore waters of southeast coast of India. Biologia 65(4): 704-713.

Kinne O. 1963. The effects of temperature and salinity or marine and brackish water animals. Oceanography and Marine Biology: Annual Review 1: 301-340.

Klein J. 1734. Naturalis dispositio echinodermatum. Schreiber, Danzig: 79 pages.

Knott KE, Wray GA. 2000. Controversy and consensus in asteroid systematics: new insights to ordinal and familial relationships. American Zoologist 40: 382–392.

Koehler R. 1897. Echinodermes recueillis par “l'Investigator” dans l'Ocean Indien. I. Les Ophiures de mer profonde. Annales des Sciences Naturelles Zoologie series 8(4): 277-372. Pls: 5-9.

Koehler R. 1898. Echinoderms recueillis par l'Investigator dans l'Ocean Indien, II les Opiures littorales. Bulletin scientifique de la France et de la Belgique 31: 55-126. Pls: 2-5.

Koehler R. 1899. An account of the deep-sea Ophiuroidea collected by the Royal Indian Marine Survey Ship Investigator. Trustees of the Indian Museum, Calcutta 1(1): 1-74. Pls: 1-14.

Koehler R. 1905. Ophiures de l'expédition du Siboga. Part 2. Ophiures littorales. Siboga Expeditie: 45b, 1-140.

Koehler R, Vaney C. 1905. Echinodermata of the Indian Museum. Part IV. An account of the deep-sea Holothuroidea collected by the R.I.M.S. Investigator: 55 pages.

Koehler R, Vaney C. 1908. Holothuries recuielles par l'Investigator dans l'Ocean Indien. II. Les Holothuries Littorales. Trustees of the Indian Museum, Calcutta: 54 pages. Pl: 3.

Koehler R. 1909. An Account of the Deep-Sea Asteroidea collected by the Royal Indian Marine Survey Ship Investigator 5: 115-131.

Koehler R. 1910. Description d'Ophiures nouvelles provenant des dernières campagnes de l'Investigator dans l'Océan Indien. Records of the Indian Museum 5(2): 83-88. Pl: 5.

Koehler R, Vaney C. 1910. Description d' Holothuries nouvelles appartenant au Musee Indien. Records of the Indian Museum Calcutta 5: 89-104.

Koehler R. 1914. Echinoderma of the Indian Museum. Part VIII. Echinoidea (I). Printed by order of the Trustees of the Indian Museum: 192 pages.

Koehler R. 1922. Echinoderma of the Indian Museum. Part IX: Echinoidea (II). Echinoidea (II). Trustees of the Indian Museum: 158 pages.

Koehler R. 1927. Echinides du Musée Indien á Calcutta, III: Echinides réguliers. – Echinoderma of the Indian Museum 10: 1-158.

Krishnan MS. 1968. Geology of India & Burma, Higginbothams, Madras: 536 pages.

Kroh A, Smith AB. 2010. The phylogeny and classification of post-Palaeozoic echinoids. - Journal of Systematic Palaeontology 8(2): 147-212.

Kroh A, Thuy B. 2013. A new Philippine ophiuroid symbiotic on a cassiduloid echinoid species. Zoologischer Anzeiger-A Journal of Comparative Zoology 252(3): 279-288.

Kroh A, Mooi R. (Eds) 2016. World Echinoidea Database. Accessed at http://www.marinespecies.org/echinoidea on 2016-09-20.

Kulczynski. 1927. Zespoly roslin w Pieninach. Bulletin International de l'Academie Polonaise Suppl. 2: 57-203.

Kurian CV. 1953. A preliminary survey of the bottom fauna and bottom deposits of the Travancore coast within the 15-fathom line. Proceedings of the National Institute of Sciences of India 19(6): 746-775.

Kurian CV. 1967. Studies of the benthos of the South West Coast of India. Bulletin of National Institute of Sciences of India 38: 649-656.

Kurian CV. 1969. Distribution of benthos on the southwest coast of India. International Symposium on the Fertility of the Sea, Sao Paulo: 225-239.

Kurian CV. 1971. Distribution of benthos on the South West Coast of India. In: Fertility of the sea (Ed. Costlow JD). Gordon and Breach Scientific Publication, New York: 225pages.

Kurup BM, Premlal P, Thomas JV, Anand V. 2003. Bottom trawl discards along Kerala coast: A case study. Journal of Marine Biological Association of India 45(1): 99-107.

Kurup BM. 2004. Impact of bottom trawling on the sea bottom and its living communities along the coastal waters of Kerala. Final Report submitted to Ocean Science and Technology Cell on Marine Benthos (Ministry of Ocean Development): 177pages.

Lacey KMJ, McCormack GP, Keegan BF, Powell R. 2005. Phylogenetic relationships within the class Holothuroidea, inferred from 18S rRNA gene data. Marine Biology 147: 1149–1154.

Lafay B, Smith AB, Christen R. 1995. A combined morphological and molecular approach to the phylogeny of asteroids (Asteroidea: Echinodermata). Systematic Biology 44(2): 190–208.

Lamarck JBPAD. 1801. Système des animaux sans vertèbres; ou, tableau général des classes, des ordres, et des genres de ces animaux: 432 pages.

Lane DJ, Marsh LM, VandenSpiegel D, Rowe FW. 2001. Echinoderm fauna of the South China Sea: an inventory and analysis of distribution patterns. Raffles Bulletin of Zoology 48: 459-494.

Lawrence JM. 1991. Arm loss and regeneration in Asteroidea (Echinodermata). Echinoderm research 1992: 39-52.

Lawrence JM, Vasquez J. 1996. The effect of sublethal predation on the biology of echinoderms. Oceanologica Acta 19(3-4): 431-440.

Lebrato, Mario, Debora Iglesias-Rodriguez, Richard A Feely, Dana Greeley, Daniel OB Jones, Nadia Suarez-Bosche, Richard S Lampitt, Joan E Cartes, Darryl RH Green, Belinda Alker. 2010. Global contribution of echinoderms to the marine carbon cycle: CaCO3 budget and benthic compartments. Ecological Monographs 80(3): 441-467.

Lee Y. 2003. Molecular phylogenies and divergence times of sea urchin species of Strongylocentrotidae, Echinoida. Molecular Biology and Evolution 20(8): 1211–1221.

Levin LA, Gutierrez D, Rathburn A, Neira C, Sellanes J, Munoz P, Salamanca VM. 2002. Benthic processes on the Peru margin: a transect across the oxygen minimum zone during the 1997-98 El Nino. Progress in Oceanography 53: 1-27.

Levin LA. 2003. Oxygen minimum zone benthos: adaptation and community response to hypoxia. Oceanography and Marine Biology: An Annual Review 41: 1–45.

Levin LA, Whitcraft C, Mendoza GF, Gonzales J, Cowie G. 2009. Oxygen and organic matter thresholds for benthic faunal activity on the Pakistan margin oxygen minimum zone (700–1100 m). Deep-Sea Research II 56: 449–471.

Levin L A, Sibuet M, Gooday AJ, Smith CR, Vanreusel A. 2010. The roles of habitat heterogeneity in generating and maintaining biodiversity on continental margins: an introduction. Marine Ecology 31(1): 1-5.

Levinton JS. 1982. Marine Ecology. Prentice-Hall Inc.: New Jersey: 526 pages.

Liao, Y. 2004. Echinodermata: Ophiuroidea. Fauna Sinica. 40, 1-305. pl. I-VI. Science Press: Beijing.

Linda NS. 2016. Macrobenthos along the inner shelf of south eastern Arabian Sea (10-14°N) during summer and winter monsoon. MSc dissertation. Kerala University of Fisheries and Ocean Studies: 64 pages.

Lindegarth M, Valentinsson D, Hansson M, Ulmestrand M. 2000. Effects of trawling disturbances on temporal and spatial structure of benthic soft sediment assemblages in Gullmarsfjorden, Sweden. ICES Journal of Marine Science 57(5): 1369-1376.

Linnaeus C. 1758. Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Editio decima, reformata. Laurentius Salvius: Holmiae 2: 824 pages.

Littlewood DTJ, Smith AB. 1995. A combined morphological and molecular phylogeny for sea urchins (Echinoidea: Echinodermata). Philosophical Transactions of the Royal Society of London. Series B. Biological Sciences 347: 213–234.

Ludwig H. (1889–1907) Echinodermen. In: Klassen und Ordnungen des Tierreichs 2(3) (Ed. Bronn HG). Winter, Leipzig: 1602 pages.

Luis AJ, Kawamura H. 2004. Air-sea interaction, coastal circulation and primary production in the eastern Arabian Sea: a review. Journal of oceanography 60(2): 205-218.

Lyman T. 1879. Ophiuridae and Astrophytidae of the exploring voyage of the HMS "Challenger", Part II. Bulletin of the Museum of Comparative Zoology at Harvard College 6(2): 65–168.

Lyman T. 1882. Report on the Ophiuroidea Dredged by HMS Challenger During the Years 1873-76. Printed for HM Stationary Off: 500 pages.

Macan TT. 1938. Asteroidea. Scientific Reports, John Murray Expedition 1933-1934. 4(9): 323-435. Pls: 1-6.

Madhupratap M, Nair KNV, Gopalakrishnan TC, Haridas P, Nair KKC, Venugopal P, Gauns M. 2001. Arabian Sea oceanography and fisheries of the west coast of India. Current Science 81: 4-25.

Madsen FJ. 1961. The Porcellanasteridae: A monographic revision of an abyssal group of sea-stars. Danish Science Press 4: 33-174.

Madsen FJ. 1973. The Ophiodermatidae. Galathea Report 11: 133-143.

Magurran AE. 2013. Measuring Biological Diversity John Wiley & Sons Publishers: 264 pages.

Mah CL. 2000. Preliminary phylogeny of the forcipulatacean Asteroidea. American Zoologist 40: 375–381.

Mah CL. 2007. Phylogeny of the Zoroasteridae (Zorocallina; Forcipulatida): evolutionary events in deep-sea Asteroidea displaying Palaeozoic features. Zoological Journal of the Linnean Society 150(1): 177–210.

Mah CL, Foltz DW. 2011a. Molecular Phylogeny of the Valvatacea (Asteroidea, Echinodermata). Zoological Journal of the Linnean Society 161: 769–788.

Mah CL, Foltz DW. 2011b. Molecular Phylogeny of the Forcipulatacea (Asteroidea: Echinodermata): Systematics and Biogeography. Zoological Journal of the Linnean Society 162: 646–660.

Mah CL, Blake D. 2012. Global Diversity and Phylogeny of the Asteroidea (Echinodermata). PloS one 7(4): e35644.

Mah CL. (Ed) 2016. World Asteroidea database. Accessed at http://www.marinespecies.org/asteroidea on 2016-09-20

Martynov A. 2010. Reassessment of the classification of the Ophiuroidea (Echinodermata), based on morphological characters. I. General character evaluation and delineation of. Zootaxa 154: 1–154.

Massin C. 1982. Food and feeding mechanisms: Holothuroidea. In: Echinoderm nutrition (Eds. Jangoux M, Lawrence JM). CRC Press: 43-56.

Matranga V. 2005. Echinodermata. Springer-Verlag, Berlin: 277pages.

Mayr E, Ashlock PD. 1991. Principles of Systematic Zoology. Second Edition. McGraw-Hill, Inc, New York: 475 pages.

Menon NG. 1996. Impact of bottom trawling on exploited resources.Marine Biodiversity Conservation and Management. CMFRI, Cochin: 97-102.

Messing CG. 1997. Living comatulids. In: Geobiology of echinoderms (Ed. Waters JA, Maples CG). Paleontological Society papers 3. Paleontological Society, Pittsburgh: 3–30.

Messing CG. 2007. The crinoid fauna (Echinodermata: Crinoidea) of Palau. Pacific Science 61(1): 91–111.

Messing CG. (Eds) 2016. World List of Crinoidea. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=147423 on 2016-09-20

Meyer DL. 1982. Food and feeding mechanisms: Crinozoa. In: Echinoderm nutrition (Eds. Jangoux M, Lawrence JM). CRC Press: 25-42.

Michener CD. 1970. Systematics in support of biological research. National Academies: 25 pages.

Mooi R, David B. 1993. Ontogeny and origin of the brooding system in Antarctic urechinid sea urchins (Echinodermata, Holasteroida). Zoomorphology 113(2): 69-78.

Mooi R, Telford M. 1998. Echinoderms: San Francisco. Balkema, Rotterdam: 923 pages.

Mooi R, David B. 2000. What a new model of skeletal homologies tells us about asteroid evolution. American Zoologist 40: 326–339.

Moore RC. 1953. Treatise on Invertebrate Paleontology. Geological Society of America, Lawrence, Kansas University of Kansas Paleontological Institute.

Morrisey DJ. 1992. Spatial variation in soft-sediment benthos. Marine Ecology Progress Series 81: 197-204.

Mortensen T. 1928. A Monograph of the Echinoidea. I. Cidaroidea. CA Reitzel & Oxford University Press, Copenhagen & London: 551 pages.

Mortensen T. 1933. Papers from Dr. Th. Mortensen's Pacific Expedition 1914–16. 63. Biological observations on ophiurids, with descriptions of two new genera and four new species. Vidensk Medd Dan Nat Hist Foren 93: 171–195.

Mortensen T. 1935. A Monograph of the Echinoidea. II. Bothriocidaroida, Melonechinoida, Lepidocentroida, and Stirodonta. CA Reitzel & Oxford University Press, Copenhagen & London: 647 pages.

Mortensen T. 1939. Report on the Echinoidea of the Murray Expedition. Part I. In: The John Murray Expedition 1933-34, Scientific Reports, Volume VI, No. 1 British Museum (Natural History), London: 1-28.

Mortensen T. 1940. A Monograph of the Echinoidea. III, 1. Aulodonta, with Additions to Vol. II (Lepidocentroida and Stirodonta). CA Reitzel, Copenhagen: 370 pages.

Mortensen T. 1943a. A Monograph of the Echinoidea. III, 2. Camarodonta. I. Orthopsidæ, Glyphocyphidæ, Temnopleuridæ and Toxopneustidæ. CA Reitzel; Copenhagen 7: 553 pages.

Mortensen T. 1943b. A Monograph of the Echinoidea. III, 3. Camarodonta. II. Echinidæ, Strongylocentrotidæ, Parasaleniidæ, Echinometridæ. CA Reitzel, Copenhagen: 446 pages.

Mortensen T. 1948. A Monograph of the Echinoidea. IV, 1 Holectypoida, Cassiduloida. CA Reitzel, Copenhagen: 371 pages.

Mortensen T. 1948. A Monograph of the Echinoidea. IV, 2. Clypeasteroida. Clypeasteridæ, Arachnoidæ, Fibulariidæ, Laganidæ and Scutellidæ. CA Reitzel, Copenhagen: 471 pages.

Mortensen T. 1950. A Monograph of the Echinoidea. V, 1. Spatangoida I. Protosternata, Meridosternata, Amphisternata I. Palæopneustidæ, Palæostomatidæ, Aëropsidæ, Toxasteridæ, Micrasteridæ, Hemiasteridæ. CA Reitzel, Copenhagen: 432 pages.

Mortensen T. 1951. A Monograph of the Echinoidea. V, 2. Spatangoida II. Amphisternata II. Spatangidæ, Loveniidæ, Pericosmidæ, Schizasteridæ, Brissidæ. CA Reitzel, Copenhagen: 593 pages.

Mukhopadhyay SK, Samanta TK. 1983. On a collection of shallow-water holothurians from the Lakshadweep. Records of the Zoological Survey of India 81: 299-314.

Mukhopadhyay SK. 1988. On some Holothurians from the Gulf of Mannar, India. Records of the Zoological Survey of India 85(1): 1-17.

Mukhopadhyay SK. 1991. Echinodermata: Holothuroidea. State fauna Series 2: Fauna of Lakshadweep. Zoological Survey of India, Calcutta: 363-397.

Muraleedharan PM, Prasannakumar S. 1996. Arabian Sea upwelling-A comparison between coastal and open ocean regions: 842-846.

Musale AS, Desai DV. 2010. Distribution and abundance of macrobenthic polychaetes along the South Indian coast. Environmental Monitoring and Assessment 178(1-4): 423-436.

Nagabhusaham R, Rao GC. 1972. An ecological survey of the marine fauna of Minicoy Atoll (Laccadive Archipelago, Arabian Sea). Islands. Mitteilungen aus dem Zoologischen Museum in Berlin 48(2): 265-324.

Naini BR. 1980. A geological and geophysical study of the continental margin of western India, and the adjoining Arabian Sea including the Indus Cone, Doctoral dissertation, Columbia University: 173 pages.

Nair RR, Pylee A. 1968. Size distribution and carbonate content of the sediments of the western continental shelf of India. Bulletin: National Institute of Science, India 38: 411-420.

Nair RR. 1975. On the nature and origin of small scale topographic prominence on the western continental shelf of India. Indian Journal of Marine Sciences 4: 5-29.

Nair RV. 1946. *Chondrocloea varians*, a new apodous holothurian from Madras Harbour. Proceedings National Institute Science, India 12: 361-384.

Naomi TS, George RM, Sreeram MP, Sanil NK, Balachandran K, Thomas VJ, Geetha PM. 2011. Finfish diversity in the trawl fisheries of southern Kerala. Marine Fisheries Information Service 207: 11-21.

Naqvi SWA, Jayakumar DA, Narvekar PV, Naik H, Sarma VVSS, D'Souza W, Joseph S, George MD. 2000. Increased marine production of N2O due to intensifying anoxia on the Indian continental shelf. Nature 408: 346–349.

Naqvi SWA, Bange HW, Gibb SW, Goyet C, Hatton AD, Upstill-Goddard RC. 2006. Biogeochemical ocean-atmosphere transfers in the Arabian Sea. Progress in Oceanography 65: 116–144.

Naqvi SWA, Naik H, Jayakumar A, Pratihary AK, Narvenkar G, Kurian S, Agnihotri R, Shailaja MS, Narvekar PV. 2009. Seasonal anoxia over the western Indian continental shelf. Indian Ocean Biogeochemical Processes and Ecological Variability: 333-345.

Narayana AC, Prabhu V. 1993. Textural and geochemical studies of relict and modern sediments of the continental shelf off Honavar, West Coast of India. Journal Geological Society of India 41: 299-305.

Neira C, Sellanes J, Levin LA, Arntz WE. 2001. Meiofaunal distributions on the Peru margin: relationship to oxygen and organic matter availability. Deep Sea Research I, Oceanographic Research Papers 48(11): 2453-2472.

Nordberg K, Filipsson HL, Gustafsson M, Harland R, Roos P. 2001. Climate, hydrographic variations and marine benthic hypoxia in Koljö Fjord, Sweden. Journal of Sea Research 46(3): 187-200.

O'Hara TD, Poore GC. 2000. Patterns of distribution for southern Australian marine echinoderms and decapods. Journal of Biogeography 27(6): 1321-1335.

O'Hara TD, Stöhr S. 2006. Deep water Ophiuroidea (Echinodermata) of New Caledonia: Ophiacanthidae and Hemieuryalidae. Mémoires du Muséum national d'histoire naturelle 193: 33–141.

Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, Feely RA, Gnanadesigen A, Gruber N, Ishida A, Joof F, Key RM, Lindsay K, Maier-Reimer E, Matear R, Monfary P, Mouchet A, Najjar RG, Plattner G, Rodgers KB, Chris S, Sarmiento JL, Sehlitzer R, Slater RD, Totterdel IJ, Weirig M, Yamanaky, Yool A. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437(7059): 681-686.

Padmakumar KB, Smitha BR, Thomas LC, Fanimol CL, Sreerenjima G, Menon NR, Sanjeevan VN. 2010. Extensive blooms of *Trichodesmium erythraeum* in the South Eastern Arabian Sea during the onset phase of Summer Monsoon 2009. Journal of Ocean Sciences 45(3): 151-157.

Parameswaran UV, Abdul Jaleel KU. 2012. *Asteroschema sampadae* (Ophiuroidea: Asteroschematinae). A new deep-sea brittle star from the continental slope off the southern tip of India, 2012. Zootaxa 3269: 47–56.

Parameswaran UV, Abdul Jaleel KU, Sanjeevan VN. 2013. *Ophiodaphne scripta* (Ophiuroidea: Amphiuridae), a brittle star exhibiting sexual dimorphism and epibiosis: first record from India, with notes on adaptations, systematics and distribution. Marine Biodiversity 43(4): 333-339.

Parameswaran UV, Abdul Jaleel KU, Gopal A, Sanjeevan VN, Anil Kumar V. 2016. On an unusual shallow occurrence of the deep-sea brittle star *Ophiomyces delata* in the Duncan Passage, Andaman Islands (Northern Indian Ocean). Marine Biodiversity 36(1): 151-156.

Paropkari AL, Babu CP, Mascarenhas A. 1992. A critical evaluation of depositional parameters controlling the variability of organic carbon in Arabian Sea sediments. Marine Geology 107: 213-226.

Parulekar AH, Wagh AB. 1975. Quantitative studies on benthic macrofauna of northeastern Arabian Sea shelf. Indian Journal of Marine Science 4: 174- 176.

Parulekar AH. 1981. Marine fauna of Malvan, Central west coast of India. Mahasagar 14: 33-44.

Patil AM. 1953. Study of the marine fauna of the Karwar coast and the neighboring islands, Part IV: Echinodermata and other groups. Journal of the Bombay Natural History Society 51: 429-434.

Paulay G, Hansson H. 2016. Holothuroidea. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails& id=123083 on 2016-09-20

Pawson DL. 1961. Distribution patterns of New Zealand echinoderms. Tuatara 9(1): 9-18.

Pawson DL, Fell HB. 1965. A revised classification of the dendrochirote holothurians. Breviora 214: 1–7.

Pawson DL. 1995. Echinoderms of the tropical island Pacific: status of their sytematics and notes on their ecology and biogeography. In: Marine and coastal biodiversity in the tropical island Pacific region: 171-192.

Pawson DL. 2007. Phylum Echinodermata. Zootaxa 1668: 749–764.

Pearson TH, Rosenberg R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology: an Annual Review 16: 229-311.

Pearson TH, Rosenberg R, 1987. Feast and famine: Structuring factors in marine benthic communities. In: Organization of Communities Past and Present, the 27th symposium of the British Ecological Society: Aberystwyth (Eds. Gee JHR, Giller PS): 373-395.

Pechenik J. 2014. Biology of the Invertebrates 7th Edition. McGraw-Hill Education: 624 pages.

Pomory CM, Robbins BD, Lares MT. 1995. Sediment grain size preference by the sand dollar Mellita tenuis Clark, 1940 (Echinodermata: Echinoidea): a laboratory study. Bulletin of marine science 56(3): 778-783.

Pomory CM, Lares MT. 2000. Rate of regeneration of two arms in the field and its effect on body components in *Luidia clathrata* (Echinodermata: Asteroidea). Journal of experimental marine biology and ecology 254(2): 211-220.

Prabhu HV, Narayana AC, Kalti J. 1993. Macrobenthic fauna in near shore sediments off Gangolli, west coast of India. Indian Journal of Marine Sciences 22: 168-171.

Prasannakumar S, Prasad TG. 1996. Winter cooling in the Arabian Sea, Current Science 71: 834– 841.

Prasannakumar S, Narvekar J, Kumar A, Shaji C, Anand P, Sabu P, Rijomon G, Josia JK, Jayaraj A, Radhika A, Nair KKC. 2004. Intrusion of the Bay of Bengal water into the Arabian Sea during winter monsoon and associated chemical and biological response. Geophysical Research Letters 31: 4 pages.

Price ARG, Reid CE. 1985. Indian Ocean echinoderms collected during the Sindbad Voyage (1980–1981): 1. Holothurioidea. Bulletin of the British Museum of Natural History (Zoology) 48: 1-9.

Purcell SW. 2010. Managing sea cucumber fisheries with an ecosystem approach. Edited/compiled by Lovatelli, A.; M. Vasconcellos and Y. Yimin. FAO Fisheries and Aquaculture Technical Paper No. 520. Rome, FAO: 157 pages.

Purcell SW, Samyn Y, Conand C. 2012. Commercially important sea cucumbers of the world. Food and Agriculture Organization, United Nations: 150 pages.

Queirós AM, Hiddink JG, Kaiser MJ, Hinz H. 2006. Effects of chronic bottom trawling disturbance on benthic biomass, production and size spectra in different habitats. Journal of Experimental Marine Biology and Ecology 335(1): 91-103.

Radhakrishna Y, Ganapthi PN. 1969. Fauna of Kakinada Bay. Bulletin of the National Institute of Science India 38: 689-699.

Ranade MR. 1979. Studies on the marine fauna of Ratnagiri (west coast of India). I. Echinoderms. Bulletin of Fisheries Faculty Konkan Agricultural University India 1(1): 21-26.

Rao GC. 1968. *Psamothuria ganapathi* n. gen., n. sp., an interstitial holothurian from the beach sands of Waltair coast and its autecology. Proceedings of the Indian National Science Academy 67(B): 201-206.

Rao GC. 1973. Occurrence of some juvenile stages referable to the apodous holothurian *Patinapta ooplaxa* (Marenzeller) in the intertidal sands of Andaman Islands, Proceedings of the Indian National Science Academy 37(B): 225-233.

Rao GC. 1975. On a new interstitial species of *Trochodota* (Apodida, Holothuroidea) from Andamans, India. Current Science 44(14): 508-509.

Rao KH, Sowbhagyavathi R. 1972. Observations on the associates of crinoids at the Waltair coast with species reference to myzostomes. Proceedings of the Indian National Science Academy 38B(5-6): 360-366.

Rao MS, Vijaya Bhanu CH, Annapurna C, Sastry DRK, Srinivasa Rao D. 2009. Echinoderms of Nizampatnam Bay, east coast of India. Journal of the Bombay Natural History Society 106(1): 30–37.

Rao VP, Nair RR, Hashimi NH. 1983. Journal of Geological Society of India 24: 540-546.

Rao VP, Wagle BG. 1997. Geomorphology and surficial geology of the western continental shelf and slope of India: A review. Current Science 73(4): 330-350.

Rathbun M. 1907. Reports on the scientific results of the expedition to the tropical Pacific, in charge of Alexander Agassiz, by the US Fish Commission Steamer Albatross, from August, 1899, to March, 1900, Commander Jefferson F. Moser, USN, commanding. XVIII. Ophiuroidea. Memoirs of The Museum of Comparative Zoology, Harvard University: 23–74.

Riedel B, Pados T, Pretterebner K, Schiemer L, Steckbauer A, Haselmair A, Zuschin M, Stachowitsch M. 2013. Effect of hypoxia and anoxia on invertebrate behaviour: ecological perspectives from species to community level. Biogeosciences Discussions 10(8): 14333-14438.

Rochford DJ. 1964. Salinity maxima in the upper 1000m of the north Indian Ocean. Aust. J. Marine and Freshwater Research 15: 1–24.

Rosenberg R, Hellman B, Johansson B. 1991. Hypoxic tolerance of marine benthic fauna. Marine Ecology Progress Series 79: 127–131.

Rosenberg R. 1995. Benthic marine fauna structured by hydrodynamic processes and food availability Netherlands Journal of Sea Research 34(4): 303-317.

Roux M, Messing CG, Améziane N. 2002. Artificial keys to the genera of living stalked crinoids (Echinodermata). Bulletin of Marine Science 70(3): 799–830.

Rowe FWE. 1976. The occurrence of the genus Heteronardoa (Asteroidea: Ophidiasteridae) in the Indian Ocean, with the description of a new species. Records of the Western Australian Museum 4(1):85-100.

Rowe FWE & Gates J. 1995. Echinodermata. In 'Zoological Catalogue of Australia'. 33 (Ed A. Wells.) pp xiii + 510, CSIRO Australia, Melbourne.

Ruhl HA. 2007. Abundance and size distribution dynamics of abyssal epibenthic megafauna in the northeast Pacific. Ecology 88(5): 1250-1262.

Ruppert EE, Fox R, Barnes RD. 2004. Invertebrate Zoology: a Functional Evolutionary Approach. 7th Edition: 1008 pages.

Sabu P, Revichandran C. 2011. Mixed layer processes of the Arabian Sea Warm Pool during spring inter monsoon: - A study based on observational and satellite data. International Journal of Remote Sensing 32(19): 5425-544.

Sajan S, Joydas TV, Damodaran R. 2010a. Meiofauna of the western continental shelf of India, Arabian Sea. Estuarine, Coastal and Shelf Science 86: 665–674.

Sajan S, Joydas TV, Damodaran R. 2010b. Depth-related patterns of meiofauna on the Indian continental shelf are conserved at reduced taxonomic resolution. Hydrobiologia 652(1): 39–47.

Sameoto JA, Ross T, Metaxas A. 2010. The effect of flow on larval vertical distribution of the sea urchin, *Strongylocentrotus droebachiensis*. Journal of Experimental Marine Biology and Ecology 383(2): 156–163.

Sanders HL. 1958. Benthic Studies in Buzzards Bay I. Animal-Sediment Relationships. Limnology and Oceanography 3(3): 245-258.

Sanders HL. 1968. Marine benthic diversity: A comparative study. The American Naturalist 102: 243-282.

Sane SR, Chapghar BF. 1962. Intertidal Echinodermata of Bombay. Journal of the Bombay Natural History Society 4(2): 89-100.

Sanjeevan VN, Jasmine P, Smitha BR, Ganesh T, Sabu P, Shanmugaraj T. 2009. Eastern Arabian Sea Marine Ecosystems. In: MECOS '09 – International symposium on Marine Ecosystems Challenges and Opportunities, Book of Abstracts (Ed. Vivekanandan E et al.). Kochi: ESO-01.

Sanjeevan VN, Achuthankutty CT, Cubelio SS. 2014. Report of the Expert Group on Marine Biodiversity. National Report (India) for the workshop under the auspices of United Nations in support of the Regular process for Global Reporting and assessment of the state of the Marine Environment, including socio-economic aspects. Chennai, India: 18-23.

Sardá R., Pinedo S, Gremare A, Taboada S. 2000. Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea. ICES Journal of Marine Science. Journal du Conseil 57(5): 1446-1453.

Sarladevi K, Jayalakshmy KV, Venugopal P. 1991. Communities and coexistence of benthos in northern limb of Cochin backwaters. Indian Journal of Marine Sciences 20: 249-254.

Sarladevi K, Sheeba P, Balasubramanian T, Venugopal P, Sankaranarayanan VN. 1996. Benthic fauna of southwest and south east coast of India. The fourth Indian Fisheries Forum Proceedings: 9-12.

Sastry DRK. 1977a. Some new records of Ecinoidea (Echinodermata) from Andaman & Nicobar Islands. Newsletter of the Zoological Survey of India 3(3): 117-118.

Sastry DRK. 1977b. On some crustacean associates of sea urchins of the Andaman & Nicobar Islands. Newsletter of the Zoological Survey of India 3(3): 119-120.

Sastry DRK. 1981a. On some crustacean associates of Echinodermata from the Bay of Bengal. Records of the Zoological Survey of India 79: 19-30.

Sastry DRK. 1981b. Emendation of the name *Peronella rullandi* (Koehler) (Echinodermata: Echinoidea). Bulletin of the Zoological Survey of India 4(2): 239 pages.

Sastry DRK. 1981c. On the occurrence of the brittle star *Ophiophryxus confinus* Koehler (Echinodermata: Ophiuroidea) in the Indian Ocean. Current Science 50: 554-555.

Sastry DRK. 1987. A note on the brittle star *Ophiomusium simplex* Lyman (Echinodermata: Ophiuroidea) new to Bay of Bengal. Bulletin of the Zoological Survey of India 8: 217-220.

Sastry DRK. 1991a. Echinodermata. Animal Resources of India. Zoological Survey of India, Calcutta: 559-569.

Sastry DRK. 1991b. Echinodermata: Asteroidea, Ophiuroidea, Echinoidea. State fauna Series 2: Fauna of Lakshadweep. Zoological Survey of India, Calcutta: 363-397.

Sastry DRK. 1995. Asteroidea, Ophiuroidea, Echinoidea (Echinodermata). Estuarine Ecosystem Series 2: Hugli Matla Estuary. Zoological Survey of India, Calcutta: 327-338.

Sastry DRK. 1996. Some echinoderms new to Mahatma Gandhi Marine National Park with two new records for India. National Symposium on Island Ecosystem and Sustainable Development, Abstract. Andaman Science Association, Port Blair 54: 40 pages.

Sastry DRK. 1997. New records of Echinodermata from Andaman & Nicobar Islands. Journal of Andaman Scientific Association 13(1-2): 48-55.

Sastry DRK. 1998a. Some echinoderms new to Mahatma Gandhi National Park with two new records for India. Symposium Proceedings on Island Ecosystem and Sustainable Development. Andaman Science Association, Port Blair: 133-138.

Sastry DRK. 1998b. Echinodermata. State fauna Series 3: Fauna of West Bengal, Part 10. Zoological Survey of India, Calcutta: 463-489.

Sastry DRK. 1999a. Echinodermata of Great Nicobar Island, Bay of Bengal. Journal of Andaman Scientific Association 15(1): 91-93.

Sastry DRK. 1999b. New records of Echinodermata from Andaman Islands. Andaman Scientific Association 15(2): 17-20.

Sastry DRK. 2001a. Echinodermata. Estuarine Ecosystem Series 4: Fauna of Godavary Estuary. Zoological Survey of India, Calcutta: 83-84.

Sastry DRK. 2001b. Echinodermata (other than Holothuroidea) from the Ritchie's Archipelago, Andaman Islands. Records of the Zoological Survey of India 99: 157-170.

Sastry DRK. 2002. Echinodermata associated with coral reefs of Andaman & Nicobar Islands. Records of the Zoological Survey of India 100(3-4): 21-69.

Sastry DRK. 2004. Echinodermata. State fauna Series 8: Fauna of Gujarat, 2. Zoological Survey of India, Calcutta: 59-66.

Sastry DRK. 2005. A checklist of Echinodermata of the Andaman & Nicobar Islands, Records of the Zoological Survey of India, Occasional Paper No. 233: 207 pages.

Sastry DRK. 2007. Annotated Checklist of Echinoderms from Indian Records of Zoological Survey, India, Occ. Paper No. 271: 387 pages.

Satyamurti ST. 1976. The Echinodermata in the collection of the Madras Government Museum. Bulletin of the Madras Government Museum (Natural History) 7(3): 1-279.

Sellner KG. 1997. Physiology, ecology, and toxic properties of marine cyanobacteria blooms. Limnology and Oceanography 42(5): 1089-1104.

Seshappa G. 1953. Observations on the physical and biological features of the inshore sea bottom along the Malabar Coast. Proceedings National Institute of Sciences, India 19: 257-279.

Shankar D, Vinayachandran PN, Unnikrishnan AS. 2002. The monsoon currents in the north Indian Ocean. Progress in Oceanography 52: 63–120.

Sharma GS. 1966. Thermocline as an indicator of upwelling. Journal of Marine Biological Association of India 8(1): 8-19.

Shenoi SSC, Shankar D, Shetye SR. 2004 Remote forcing annihilates barrier layer in southeastern Arabian Sea. Geophysical Research Letters31: 4 pages.

Shenoi SSC, Shankar D, Gopalakrishna VV, Durand F. 2005. Role of ocean in the genesis and annihilation of the core of the warm pool in the southeastern Arabian Sea. Mausam 56(1): 147-160.

Shepard FP. 1954. Nomenclature based on sand-silt-clay ratios: Journal of Sedimentary Petrology 24: 151-158.

Shephard S, Brophy D, Reid DG. 2010. Can bottom trawling indirectly diminish carrying capacity in a marine ecosystem?. Marine Biology 157(11): 2375-2381.

Shepherd SA. 1968. The shallow water Echinoderm fauna of South Australia. Part 1: The Asteroids. Records of the South Australian Museum 15(4): 729-756.

Shetye SR, Shenoi SSC. 1988. The seasonal cycle of surface circulation in the coastal North Indian Ocean. Proceedings of the Indian Academy of Science (Earth & Planetary Science) 97: 53–62.

Sibuet M. 1977. Distribution and diversity of deep-sea echinoderms (Holothuroidea and Asteroidea) in Bay of Biscay. Deep-Sea Research 24(6): 549-563.

Silas EG. 1977. Indian fisheries 1947 - 1977. Technical Report. CMFRI, Kochi: 81 pages.

Simpson GG. 1961. Principles of animal taxonomy. No: 20. Columbia University Press: 248 pages.

Sivadas SK, Nagesh R, Gupta GVM, Gaonkar U, Mukherjee I, Ramteke D, Ingole BS. 2016. Testing the efficiency of temperate benthic biotic indices in assessing the ecological status of a tropical ecosystem. Marine pollution bulletin 106(1): 62-76.

Sladen WP. 1889. Report on the Asteroidea collected by HMS Challenger during the years 1873-1876. Report on the Scientific Results of the Voyage of HMS Challenger during the years 1873. 76(30): 893 pages.

Sluiter CP. 1901. Die holothurien der Siboga-expedition. EJ Brill. 2(7): 1 page.

Smirnov AV. 1998. On the classification of the apodid holothurians. In: Echinoderms:n San Francisco (Ed. Mooi R & Telford M). Balkema, Rotterdam: 517–522.

Smith AB. 1988a. Fossil evidence for the relationships of extant echinoderm classes and their times of divergence. In: Echinoderm phylogeny and evolutionary biology (Eds. Paul CRC, Smith AB). Clarendon Press, Oxford: 85–97.

Smith AB. 1988b. Phylogenetic relationship, divergence times, and rates of molecular evolution for camarodont sea urchins. Molecular Biology and Evolution 5(4): 345–365.

Smith AB, Lafay B, Christen R. 1992. Comparative variation of morphological and molecular evolution through geologic time: 28s ribosomal RNA versus morphology in echinoids. Philosophical Transactions of the Royal Society of London. Series B. Biological Sciences 338: 365–382.

Smith AB, Paterson GLJ, Lafay B. 1995. Ophiuroid phylogeny and higher taxonomy: morphological, molecular and palaeontological perspectives. Zoological Journal of the Linnean Society 114: 213–243.

Smith AB. 1997. Echinoderm larvae and phylogeny. Annual review of ecology and systematics: 219-241.

Smith AB, Pisani D, Mackenzie-Dodds JA, Stockley B, Webster BL, Littlewood TJ. 2006. Testing the molecular clock: molecular and paleontological estimates of divergence times in the Echinoidea (Echinodermata). Molecular Biology and Evolution 23(10): 1832–1851.

Smith AB. 2007. Intrinsic versus extrinsic biases in the fossil record: Contrasting the fossil record of echinoids in the Triassic and early Jurassic using sampling data, phylogenetic analysis and molecular clocks. Paleobiology 33: 310-323.

Smith CJ, Papadopoulou KN, Diliberto S. 2000. Impact of otter trawling on an eastern Mediterranean commercial trawl fishing ground. ICES Journal of Marine Science. Journal du Conseil 57(5): 1340-1351.

Smith CL, Tyler JC. 1969. Observations on the commensal relationship of the western Atlantic pearlfish, *Carapus bermudensis*, and holothurians. Copeia 1969(1): 206-208.

Smith W, McIntyre AD. 1954. A spring-loaded bottom sampler. Journal of Marine Biological Association UK 33: 261 pages.

Smitha BR, Sanjeevan VN, Vimalkumar KG, Revichandran C. 2008. On the upwelling off the southern tip and along the west coast of India. Journal of Coastal Research 24(4C): 95-102.

Smitha CK. 2011. Marine benthos of south west and south east coast of India. Ph. D Thesis. Cochin University of Science and Technology. 321 pages.

Snelgrove PVR. 1998. The biodiversity of macrofaunal organisms in marine sediments. Biodiversity and Conservation 7: 1123–1132.

Solovjev AN, Markov AV. 2004. The early evolution of irregular echinoids. In: Echinoderms: München (Ed. Heinzeller T & Nebelsick JH). Taylor & Francis, London: 551–556.

Soota TD, Sastry DRK. 1979. Notes on two species of *Echinaster* Mueller & Troschel (Echinodermata: Asteroidea) from Indian Ocean. Records of the Zoological Survey of India 75: 343-352.

Soota TD, Mukhopadhyay SK, Samanta TK. 1983. On some holothurians from the Andaman & Nicobar Islands. Records of the Zoological Survey of India 80: 507-524.

Sponer R, Roy MS. 2002. Phylogeographic analysis of the brooding brittle star *Amphipholis squamata* (Echinodermata) along the coast of New Zealand reveals high cryptic genetic variation and cryptic dispersal potential. Evolution 56(10): 1954-1967.

Stara P, Sanciu L. 2014. Analysis of some astriclypeids echinoids (Echinoidea Clypeasteroidea). – In: Studies on some astriclypeids (Echinoidea Clypeasteroida) (Ed. Stara P). Biodiversity Journal 5(2): 291-358.

Stockley B, Smith AB, Littlewood T, Lessios HA, Mackenzie-Dodds JA. 2005. Phylogenetic relationships of spatangoid sea urchins (Echinoidea): taxon sampling density and congruence between morphological and molecular estimates. Zoological Scripta 34(5): 447–468.

Stöhr S. 2001. *Ampnipnolis linopneusti* n. sp., a sexually dimorphic ampmurid brittle star (Echinodermata: Ophiuroidea), epizoic on a spatangoid sea urchin.

In Echinoderms 2000: Proceedings of the 10th International Conference, Dunedin 178(18): 317 pages.

Stöhr S, O'Hara TD, Thuy B. 2012. Global diversity of brittle stars (Echinodermata: Ophiuroidea). PloS one 7(3): e31940.

Stöhr S, Sautya S, Ingole B. 2012. Brittle stars (Echinodermata: Ophiuroidea) from seamounts in the Andaman Sea (Indian Ocean): first account, with descriptions of new species. Journal of the Marine Biological Association of the United Kingdom 92(5): 1195-1208.

Stöhr S, O'Hara T, Thuy B. (Eds) 2016. World Ophiuroidea database. Accessed through: World Register of Marine Species at http://www.marinespecies. org/aphia.php?p=taxdetails&id=123084 on 2016-09-20

Stramma L, Schmidtko S, Levin LA, Johnson GC. 2010. Ocean oxygen minima expansions and their biological impacts. Deep Sea Research I. Oceanographic Research Papers 57(4): 587-595.

Strickland JDH, Parsons R. 1972. A manual of seawater analysis. Bulletin of the Fishery Research Board of Canada 125: 61–69.

Telford MJ, Lowe CJ, Cameron CB, Ortega-Martinez O, Aronowicz, J, Oliveri P, Copley RR. 2014. Phylogenomic analysis of echinoderm class relationships supports Asterozoa. Proceedings of the Royal Society of London B: Biological Sciences: 281(1786): 20140479.

Thandar AS. 1990. The phyllophorid holothurians of southern Africa with the erection of a new genus. South African Journal od Zoology 25(4): 207-223.

Thayer CW. 1975. Morphologic adaptations of benthic invertebrates to soft substrata. Journal of Marine Research 33(2): 177-189.

Théel H. 1882. Report on the Holothuroidea dredged by H.M.S. 'Challenger' during the years 1873-76. Part i. Challenger Reports, Zoology 4: 176 pages.

Thomas JV, Sreedevi C, Kurup BM. 2006. Variations in the infaunal polychaetes due to bottom trawling along the inshore waters of Kerala (Southwest coast of India). Indian Journal of Marine Sciences 35(3): 249–256.

Thomas LC, Padmakumar KB, Smitha BR, Asha Devi CR, Bijoy Nandan S, Sanjeevan VN. 2013. Spatio-temporal variation of microphytoplankton in the upwelling system of South Eastern Arabian Sea during the summer monsoon 2009. Oceanologia 55(1): 185-204.

Thorson G. 1950. Reproductive and larval ecology of marine bottom invertebrates. Biological reviews 25(1): 1-45.

Thrush SF. 1999. Complex role of predators in structuring soft-sediment macrobenthic communities: Implications of changes in spatial scale for experimental studies. Australian Journal of Ecology 24(4): 344-354.

Thurston E. 1895a. Rameswaram Island. Madras Government Museum Bulletin 3(1): 79-101.

Thurston E. 1895b. Littoral fauna of the Gulf of Mannar. Madras Government Museum Bulletin 3(2): 102-138.

Thuy B, Meyer C. 2013. The pitfalls of extrapolating modern depth ranges to fossil assemblages: new insights from Middle Jurassic brittle stars (Echinodermata: Ophiuroidea) from Switzerland. Swiss Journal of Palaeontology 132(1): 5–21.

Thuy B, Stöhr S. 2011. Lateral arm plate morphology in brittle stars (Echinodermata: Ophiuroidea): new perspectives for ophiuroid micropalaeontology and classification. Zootaxa 47: 1–47.

Tillin HM, Hiddink JG, Jennings S, Kaiser MJ. 2006. Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale. Marine Ecology Progress Series 318: 31–45.

Turner SJ, Thrush SF, Pridmore RD, Hewitt JE, Cummings VJ, Maskery M. 1995. Are soft-sediment communities stable? An example from a windy harbour. Marine ecology progress series. Oldendorf 120(1): 219-230.

Tyler PA, Banner FT. 1977. The effect of coastal hydrodynamics on the echinoderm distribution in the sublittoral of Oxwich Bay, Bristol Channel. Estuarine and Coastal Marine Science 5(3): 293-308.

Underwood AJ. 1997. Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge University Press: 524 pages.

Underwood AJ. 2000. Importance of experimental design in detecting and measuring stresses in marine populations. Journal of Aquatic Ecosystem Stress and Recovery 7(1): 3-24.

Van Hoey G, Degraer S, Vincx M. 2004. Macrobenthic community structure of soft-bottom sediments at the Belgian Continental Shelf. Estuarine, Coastal and Shelf Science 59(4): 599-613.

Van Soest, Rob WM, Nicole Boury-Esnault, Jean Vacelet, Martin Dohrmann, Dirk Erpenbeck, Nicole J De Voogd, Nadiezhda Santodomingo, Bart Vanhoorne, Michelle Kelly, John NA Hooper. 2012. Global diversity of sponges (Porifera). PLoS one 7(4): e35105.

Vázquez-Bader A, Laguarda-Figueras A, Gracia A, Solis-Marin F, Celaya-Hernández E, Durán-González A. 2008. Seasonal changes in the density and species composition of the epifaunal echinoderms recorded from the southwestern Gulf of Mexico. Revista de biologia tropical 56(3): 297–310.

Venkataraman K, Raghunathan C, Tamal Mondal, Raghuraman R. 2015. Lesser known marine animals of India. Published by the Director. Zoological Survey of India, Kolkata: 550 pages.

Venkatraman C, Venkataraman K, Rajan Rajkumar, Shrinivaasu S, Padmanaban P, Paramasivam K, Sivaperuman C. 2013. Diversity and Distribution of Echinoderms in Palk Bay and Gulf of Mannar Biosphere Reserve, Southern India. In: Ecology and Conservation of Tropical Marine Faunal Communities (Eds. Venkataraman K, Sivaperuman C, Raghunathan C). Springer-Verlag, Berlin Heidelberg: 197–212.

Verrill AE. 1885. Results of the explorations made by the steamer Albatross off the northern coast of the United States in 1883. Govt. print. 503-699.

Vickery M. McClintock JB. 2000. Comparative morphology of tube feet among the Asteroidea: phylogenetic implications. American Zoologist 40: 355–364.

Vijay JG. 2005. Nutrient Dynamics in the EEZ of the West Coast of India with Special Reference to the Oxygen Minimum Zone and Denitrification. Ph.D. Thesis. Cochin University of Science And Technology: 100 pages.

Vivekanandan E, Najmudeen TM, Jayasankar J, Narayanakumar R, Ramachandran C. 2010. Seasonal Fishing Ban. CMFRI, Special Publication 103: 44 pages.

Wafer M, Venkataraman K, Ingole B, Ajmal Khan S, Loka Bharathi P. 2011. State of knowledge of coastal and Marine biodiversity of Indian Ocean countries. PLoS one 6(1): e14613.

Walsh JHT. 1891. List of deep-sea holothurians collected during seasons 1887 to 1891, with description of new species. Natural History Notes from HM. Indian Survey Steamer INVESTIGATOR, Commander RF. Hoskyn, RN. Commanding. No. 24. Journal Asiatic Society, Bengal 60: 197-204.

Warner M. 1982. Food and feeding mechanisms: Ophiuroidea. In: Echinoderm nutrition (Eds. Jangoux M, Lawrence JM). CRC Press: 161-184.

Warner GF, Woodley JD. 1975. Suspension-feeding in the brittle-star *Ophiothrix fragilis*. Journal of the Marine Biological Association of the United Kingdom 55(1): 199-210.

Warner GF. 1979. Aggregation in echinoderms. In: Biology and systematics of colonial organisms (Eds. Larwood G, Rosen BR). Academic Press, London: 375-396.

Whitlatch RB. 1981. Animal-sediment relationships in intertidal marine benthic habitats: some determinants of deposit-feeding species diversity. Journal of Experimental Marine Biology and Ecology 53(1): 31-45.

Williams A, Althaus F, Dunstan PK, Poore GC, Bax NJ, Kloser RJ, McEnnulty FR. 2010. Scales of habitat heterogeneity and megabenthos biodiversity on an extensive Australian continental margin (100–1100 m depths). Marine Ecology 31(1): 222-236.

Williams GC. 2011. The global diversity of sea pens (Cnidaria: Octocorallia: Pennatulacea). PLoS one 6(7): e22747.

Wood-Mason J, Alcock A. 1891. Natural history notes from H.M. Indian marine survey steamer 'Investigator', Commander RF Hoskyn, R.N., commanding. Series II, No. 1. On the results of deep-sea dredging during the season 1890-1891 Annals of the Magazine of Natural History VIII, Sixth series (XLVIII): 427-452. Pl: 17.

WoRMS Editorial Board 2016. World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2016-08-01.

Yokota Y, Matranga V, Smolenicka Z. 2002. The sea urchin: from basic biology to aquaculture. Balkema, Rotterdam: 293 pages.

APPENDICES

Publications

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1. Parameswaran, U. V. and Abdul Jaleel K. U. (2012) *Asteroschema sampadae* (Ophiuroidea: Asteroschematinae), A new deep-sea brittle star from the continental slope off the southern tip of India, 2012, Zootaxa 3269: 47–56.
2. Parameswaran, U. V., Abdul Jaleel, K. U. & Sanjeevan, V. N. (2013) *Ophiodaphne scripta* (Ophiuroidea: Amphiuridae), a brittle star exhibiting sexual dimorphism and epibiosis: first record from India, with notes on adaptations, systematics and distribution. Marine Biodiversity, 43(4):333-339. DOI: 10.1007/s12526-013-0160-9.u.
3. Parameswaran, Usha V., Abdul Jaleel, K. U., Gopal, A., Sanjeevan, V. N. & Anil Kumar, V. (2016) On an unusual shallow occurrence of the deep-sea brittle star *Ophiomyces delata* in the Duncan Passage, Andaman Islands (Northern Indian Ocean). Marine Biodiversity, 36(1):151-156. DOI 10.1007/s12526-015-0344-6.