सत्यमेव जयते

CMLRE's Compilation of Recent First Reports and New Species













CCTATATCTAGTATTTGGTGCCTCCTATATCTAGTATTTGGTGCCTG

CCTATATCTAGTATTTGGTGCCTCCTATATCTAGTATTTGGTGCCTG

Centre for Marine Living Resources & Ecology (CMLRE)
Ministry of Earth Sciences, Government of India
Atal Bhavan, L.N.G. Road, Puthuvype,
Kochi, Kerala 682508
www.cmlre.gov.in

सत्यमेव जयते
डॉ. एम. राजीवन
DR. M. RAJEEVAN

सचिव
भारत सरकार
पृथ्वी विज्ञान मंत्रालय
पृथ्वी भवन, लोदी रोड, नई दिल्ली-110 003
SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
PRITHVI BHAVAN, LODHI ROAD, NEW DELHI-110003

FOREWORD

I am very pleased to learn that our young team of researchers at CMLRE have contributed substantively towards inventorization of marine organisms from our Exclusive Economic Zone (EEZ). Marine taxonomic studies are the fundamental requirements for describing the biodiversity extant in our oceans. In the last 8-9 years from their very meticulous, time taking and diligent analyses of a variety of biological samples collected from various depth zones within India's EEZ, these researchers have published excellent set of taxonomy papers in peer reviewed journals. These quality publications reflect the authenticity of the fundamental taxonomy work and, its global acceptance.

I understand that innumerable samples of biological specimens were collected during 2010-2016 from deep sea surveys onboard FORV *Sagar Sampada*. Our scientists at CMLRE have carried out both ecological and biodiversity related analyses on many of these samples. From their efforts, many new species of marine animals have been identified and assigned new names. Further, the authentic identification and conformation of many groups of marine animals by CMLRE researchers have helped, for the first time, to recognize the occurrences of some so far unreported species of two sea spiders, one crab, and many echinoderms and over 36 fishes from our EEZ. Apart from reporting relevant details of these new species and new records in specialised journals, the general details presented in this booklet, "*CMLRE's Compilation of Recent First Reports and New Species*" is for familiarising the importance of biodiversity studies among the youngsters, students and general public.

I am also glad to learn that there are numerous taxonomic works being carried out at CMLRE and other institutes. Those efforts are certain to add many more new species/new records from India's EEZ. These efforts would add information the biogeography of these new records of animals. More pertinently would be providing data and, information-base for biodiversity conservation, sustainable harnessing and intellectual property sharing.

The Fisheries Research Vessel Sagar Sampada is a matter great pride for us. This Danish built vessel commissioned back in 1984 completed 35 year this November. I am very pleased that a detailed write up on the fisheries and marine ecology research facilities onboard is presented in this compilation. I am sure this will be very informative and useful to many researchers looking up for exploring the seas and for opting ocean sciences as a career.

(M. Rajeevan)

Tel. : +91-11-24629771, 24629772 ❑ Fax : +91-11-24629777 ❑ E-mail : secretary@moes.gov.in

CMLRE's Compilation of Recent First Reports and New Species

Preface

The Centre for Marine Living Resources and Ecology (CMLRE) has a vison and mandate to provide better insights on the extant diverse marine life forms in and around the Indian EEZ. During the last two decades, the Centre has begun adding information on many new marine species. Marine biology, ecology, biological oceanographic and biogeochemistry researches undertaken by the Centre have an inherent purpose as to understand the ecological role of each cluster of flora and fauna in ecosystem functioning and biogeochemistry of the Northern Indian Ocean. The two recent flagship programs of CMLRE are: Resource Exploration and Inventorization System (REIS) and Marine Ecosystem Dynamics of the eastern Arabian Sea (MEDAS). They have made significant strides in close-grid sampling within the EEZ of the mainland as well as Island systems.

Careful analyses of samples collected from deep sea surveys of FORV *Sagar Sampada* during 2010-2016 yielded many new species of marine animals (nematodes, polychaetes, crustaceans, chaetognath, echinoderm and over a dozen fishes). These have been identified and assigned new names. The CMLRE scientists' trailblazing efforts of authentic identification and conformation have helped, for the first time, to recognize the occurrences of hitherto unreported species of sea spiders, a crab, echinoderms and fishes in our EEZ. These new records by CMLRE scientists have extended the biogeography of these animals. These observations are published already in many peer reviewed journals. Nonetheless, this compilation is to highlight and popularise the importance of marine biodiversity assessment going on at CMLRE. Currently, numerous taxonomic works are being carried out at CMLRE and other institutes. All these efforts are certain to add many more new species/new records from India's EEZ.

Following is an overview of the information in the articles put together in this booklet.

At the very base of consumer-dominant marine food chain are the autotrophic, photosynthetic aquatic phytoplankton. Being the primary source of energy, phytoplankton are the pivotal carbon sinking entities in the marine realm. These vegetative, microscopic life forms through their biomass production, control climate, aid carbon cycling, alter biogeochemistry and, are themselves the basis of marine bioorganic energy. Their biomass upon consumption is moved up into the food-web in the ocean, part of which is exploited by mankind mainly through fishing. Naseera Kottangodan has provided basic account on phytoplankton types, their functional roles and the recent research carried out under the MEDAS program of CMLRE. some common genera of phytoplankton she recorded are *Coscinodiscus, Asterionellopsis* (diatoms); *Protoperidinium, Tripos* (dinoflagellates); *Dictyocha* (silicoflagellate) and *Trichodesmium (*cyanobacteria).

Zooplankton serve many important ecological roles. They are the intermediary link between the primary producers and higher trophic levels. Kusum Komal Karati has developed a comprehensive report on different groups of marine zooplankton and their ecological functions. Researches supported earlier -and being currently carried out at CMLRE- on diversity, distribution, and ecology are highlighted by him. By supporting the researches under the MRLR programme, the taxonomic studies have added from the Indian Ocean many new species such as *Pseuderythrops abrahami*, *Krohnitta balagopali* and *Sagitta meenakshiae* to the existing records of this important plankton group.

In his extensive and quite fascinating descriptions on deep-water crustaceans, Vinay Padate has documented CMLRE's efforts of conducting dedicated surveys of the deep waters within the EEZ of India onboard FORV *Sagar Sampada*. Padate has affirmed that these surveys have yielded large collections of deep-sea crustaceans including several new species, which are in the process of being described. It is apparent from his lucid descriptions and illustrating photographs as many as 11 new records of crustaceans in the waters below 1000 m water column are noted from the efforts so far. With a careful scrutiny he is at ascertaining correct identification and inventorization of many new species and new records from Indian waters.

Sudhanshu Dixit has carried out systematic collection of marine flatworms, the polyclads. These are a group of small-sized (a few centi-meters) colourful animals yet to receive greater attention. With their distinct and captivatingly colourful pattern, polyclads can be distinguished from other flatworms. As he points out, their role in ecosystem functioning, distribution patterns, food and feeding habits are yet to receive greater attention. Their commercial significance both in terms of ecotourism via diving and aquarium industry are of interest. His collections by diving in the Lakshadweep waters have enabled him to describe seven new species so far.

Two new species of segmented worms, the polychaetes (Annelida; Greek: poly=many, chaeta=bristles) are reported by Aiswarya Gopal from her recent studies at CMLRE. These are *Pettibonella shompens* Gopal *et al.,* 2014 (named after Andaman shompen tribe) and *Armandia sampadae* Gopal *et al*., 2016 (after FORV *Sagar Sampada*). While some polychaete species are pelagic, most are benthic dwelling in or on the seabed usually in the top layers of sediments or on hard substrates like corals, coral rubbles, rocks. The CMLRE studies on marine benthos have been focusing on the community structure of polychaetes in the insular slope of Andaman Nicobar margin and in the intertidal regions of Lakshadweep Islands has been conducted as a part the project Resource Exploration and Inventorization System (REIS). Also, the abundance and biomass of macrobenthos along Indian EEZ with the reported number of polychaete species is presented in her article.

Excepting the holothurian sea-cucumbers, most other classes of echinoderms bearing radial symmetry are readily recognised. They have another notable feature, the 'water vascular system', which is a hydraulic system of canals and tubes. Found at all depths from the coasts to deep-ocean trenches, over 7200 species of echinoderms are presently known. An article in this compilation written by Usha Parameswaran provides an account of CMLRE's studies on distribution of echinoderms in the EEZ of India. She has presented adequate details on different Classes in Echinodermata and, aptly, has highlighted the threats this group is vulnerable to. Her studies published variously have noted10 new records of this group apart from her group identifying, so far, one new species of deep-sea echinoderm, *Asteroschema sampadae*, from samples collected off cape Comerin at a depth of 450 m.

From extensive earlier publications on new species and new records of anglerfishes (Order Lophiiformes), Rajeesh Kumar et al have presented a comprehensive report on their taxonomy, diversity and distribution within Indian EEZ. Their extensive trawling surveys carried out during 2013 to 2018 have enabled new researches at CMLRE on deep sea fishes. From the detailed analyses, as many as 36 species of deep-sea angler fishes are documented by Rajeesh Kumar and colleagues. Of these, eight species (*Halieutaea* sp. A; *Chaunax* sp. A; *Oneirodes* sp. A; *Chaunax multilepis; Halieutopsis* sp. B; *Malthopsis* sp. A; *Himantolophus* sp. A and *Oneirodes* sp.) are new to science. Further, seven new records extending the biogeography of these Lophiiformes to different regions of the Northern Indian Ocean. They have also included an updated check list of Indian Lophiiformes from Indian EEZ in this article.

Aneesh et al present additional sets two new species of anglerfishes namely *Chaunax multilepis* and *Oneirodes sanjeevani*, the latter being latest addition to the family Oneirodidae which now has 37 valid species. These authors also reported new species of deep-sea eel, *Ophichthus mccoskeri* from Andaman waters. Deep-sea white spotted moray eel, *Gymnothorax smithi* is another new species they have reported. Also, new distributional records of four deep-sea anglerfishes from Indian EEZ is included in this article. Further, they mention that CMLRE has recently identified a unique deep-sea habitat, the Terrace of Trivandrum in South-eastern Arabian Sea (SEAS). This region, authors state: "is exceptionally fascinating with very high mega-faunal diversity" with ca.148 species being highly endemic. It is also stated that detailed analyses have add around 10 new records to the biodiversity of SEAS.

Marine biodiversity assessment, taxonomic authentication, cataloguing and documentation are significant science feats in the last 2-3 decades. Since it allows to identify all stages of life cycle and quantify considerable intra-specific variations rather reliably swiftly and, is cost-effective the DNA barcoding has been an effective tool for species identification and marine biodiversity assessment. Vishnu et al have combined the use of DNA barcode along with morphological characters and have presented taxonomic descriptions of deep-sea fishes (eels and angler fishes). In their first-time study on barcoding of deep-sea eels the COI barcode sequences for 11 deep-sea eels belonging to 11 genera and 5 families have been obtained.

The exclusively marine, sac-like, soft bodied, bottom living Ascidians (Ascidiacea) found from the intertidal region to greater depths of the ocean are, as Jhimli Mondal terms them, are treasure troves of a variety of bioactive molecules. These animals are of great importance in ecology, developmental biology, evolution and pharmacology. In view of the sparser information on ascidians from Indian seas, besides providing a list of some, known moieties of pharmaceutical importance identified from them, Mondal has provided an account on the ascidian research interest recently initiated at CMLRE.

The Arctic and Antarctic regions influence the Earth's climate due to their faster warming up. Partnering with the sister laboratory, the NCPOR, researchers from CMLRE do carry out sampling for biota and record basic data on the flora and fauna from the polar seas. For this compilation, Shahin Badesab and Ashadevi have provided a succinct gist on their 3-year study on zooplankton community from the Arctic waters. They find ciliates, among microzooplankton, to be predominant with the greatest spatial (inner and outer fjords) variability of *Parafavella*, the most dominant genus. Among meso-zooplankton, Copepoda is the dominant community with individuals of Calanoida followed by Cyclopoida being most abundant.

FORV *Sagar Sampada* is nation's floating laboratory. Subramanian and Shivaji have provided a very detailed account on Fisheries Oceanographic Research Vessel (FORV) *Sagar Sampada*. On November 6, 2019 she completed 35 years of service to the nation. From their detailed description, one gets to know the humongous service she has provided to the nation in the arena of fisheries and allied marine research. Built in Denmark and commissioned back in 1984, she is India's national facility open to all sea-related research and training of Indian marine researchers. She also was deployed for a couple of expeditions to the Antarctic waters. She is a dedicated ship for researches on marine ecology, biology, biogeochemistry and deep-sea ecosystems.

Owned and operated by the Ministry of Earth Sciences, she is our nation's pride. There are seven laboratories (Hydrographic, Oceanographic, ^{14}C isotope, Met-lab, Hydro-acoustic, Microbiology and Wet fish lab) onboard. Also, adequate space provided for fishing gear and other scientific stores. Equipped with contemporary sampling gadgets and instruments, she facilitates onboard analyses of water and sediment samples. In addition to laboratory space she has accommodation for 22 scientists and 37 crew members.

As detailed by Subramanian and Shivaji, this research vessel has been an important MoES platform cementing many collaborative research programs at regional, national and international levels. She has offered innumerable opportunities for collection of scientific data. The research outcomes and information generated from the sampling has been instrumental in collecting, analysing and creating pertinent data sets for establishing our national programme on marine living resources. Recent sampling efforts onboard this vessel are focussed on addressing issues pertaining to ocean living resources, ocean health, marine biogeochemistry and climate change. Every new biogeographic record of marine fauna and all the new species being reported in this compilation are from the sampling onboard *Sagar Sampada*.

We desired this compilation to be informative to any aspiring youngster, high school student and, public in general. Therefore, we sought from these enthusiastic authors to glean from their previously published researches with the purpose of providing glimpses of the new additions they have made to marine ecology and/or biodiversity. We hope that their articles will be found very informative and variously useful.

We gratefully thank Dr M Rajeevan, Secretary, MoES and all authors for their contributions in developing this compilation.

December 12, 2019
Kochi, India.

M. Sudhakar and N. Ramaiah

Profiles of Contributing Authors of CMLRE

Dr. Sudhakar M.

Director, CMLRE with over 37 years of research experience; Admistering and steering several National and International R&D Programs

Mr. Saravanane N.

Scientist E, Marine Biologist with over 25 years of expertise in marine biodiversity assessment and open ocean bioresources

Dr. Shivaji A.

Scientist E, specialised in managing research vessel at CMLRE.

Dr. Sherine Sonia Cubelio

Scientist D, Marine biologist with more than 20 years or research expertise in marine ecology and with molecular taxonomy of marine biota.

Mrs. Asha Devi C. R.

Scientist D, Marine Biologist with 18 years of research experience in microzooplankton,

Profiles of CMLRE's Contributing First Authors

Dr. Aiswarya Gopal

Marine biologist with expertise in polychaete taxonomy and benthic ecology, with an emphasis on coral reef ecosystems.

Dr. Aneesh Kumar K. V.

Research interest: Systematics, ecology and ecomorphology of deep-sea fish assemblages, otolith studies.

Dr. Jhimli Mondal

Specialization in Ascidian Taxonomy, Reef Ecology, Microzooplankton ecology. Was previously at ZSI, ANRC.

Dr. Kusum Komal Karati

Marine biologist working on zooplankton ecology of marine & estuarine ecosystems. Before joining CMLRE, he was with CSIR-NIO.

Ms. Naseera Kottangodan

Marine biologist with interest in Biotechnology, Biochemistry Microalgae and Phytoplankton taxonomy.

Dr. Rajeesh Kumar M.P.

Area of Interest: Systematics, Taxonomy and Distribution of Deep-Sea Fishes resources. Specialized in the taxonomy of Deep-sea Anglerfishes.

Ms. Shahin K. Badesab

Marine Biologist interested the role of zooplankton in arctic food webs and impact of changing climate on their ecology with emphasis on copepods.

Mr. Subramanian M.

Specialised in handling research vessel at CMLRE.

Dr. Sudhanshu Dixit

Marine biologist & avid diver with > 550 dives to his credit. His interests are taxonomy of Polyclads and Heterobranchs.

Dr. Usha V. Parameswaran

Marine biologist with a keen interest in benthic biodiversity and ecology. Specialised in the Taxonomy of Echinoderms.

Dr. Vinay P. Padate

Marine biologist with experience in biodiversity studies, specialised in taxonomy and biogeography of crustaceans.

Dr. Vishnu K. V.

Area of Interest: DNA barcoding, Metagenomics, Use of Molecular techniques for Biodiversity Studies, Clinical and Lipid Biochemistry, Marine Bioactive Compounds.

CMLRE's Compilation of Recent First Reports and New Species

Contents

Phytoplankton: The Autotrophs at the Base of Marine Food Web

Naseera K.
Centre for Marine Living Resources and Ecology, Kochi
Email: nasioceanographer@gmail.com

The autotrophic, self-propagating and photosynthetic aquatic phytoplankton are at the very base of consumer-dominant food chain. They are pivotal in the marine ecosystem as important source of energy and are the major carbon sink in the marine realm. It's important to study the phytoplankton to understand their role, activities and ecological functions. Phytoplankton control the climate, carbon cycling, biogeochemistry and vegetative biomass production, the bioorganic energy of which upon consumption is moving up into the food-web in the ocean, part of which is exploited by mankind mainly through fishing.

1. Introduction

Phytoplankton (*Greek: phytos* = plant, *plankton* = wanderer or drifter) are mostly microscopic and unicellular life-forms in marine and freshwater environments. They are the primary producers that support the aquatic food-web. These chlorophyll-bearing autotrophic life-forms use photosynthetic mechanism under sunlight to propagate by taking up and transforming CO_2 into their biomass and, as a result, give out oxygen.

Through photosynthesis, phytoplankton uptake and fix the carbon dioxide on a scale equivalent to forests and other land plants. Some of this carbon sinks to the deeper layers through exudation, senility and death of phytoplankton. As such most biomass of phytoplankton is are eaten up by primary consumers (most zooplankton, herbivorous fishes and some marine birds).

2. Classification

Phytoplankton can be classified based on size and using the pigment with in it and the storage material they produce. A taxonomic list of major phytoplankton types is given in Table 1.

Table 1. List of major types of phytoplankton (Tomaselli 2004, Reynolds 2006, Lalli and Parsons 2006, Al-Kandari 2009)

	Class	Common name	Pigment	Storage material	Area of predominance
Prokaryotes	Cyanophyta	Blue-green algae	Chl a, Phycocyanin & phycoerythrin	Glycogen and cyanophycin	Cosmopolitan
	Prochlorophyta	-	Chl a & b	Starch-like polysaccharide	-
	Anoxyphotobacteria	-	Bacteriochlorophyll a, b or c	-	-
Eukaryotes	Rhodophyta	Red algae	Chl a & d, phycoerythrin & phycocyanin	Floridean starch	Cold temperate
	Chlorophyta	Green algae	Chl a & b, carotenoids	Starch	Coastal
	Dinophyta	Dinoflagellates	Chl a & c2, carotenoids	Starch	All waters, esp. warm
	Chrysophyta	Golden-brown algae	Chl a, c1, c2, fucoxanthin and b-carotene	Chrysolaminarin	Coastal Cold waters
	Prymnesiophyta	Coccolithophorids Prymnesiomonads	Chl a, c1 & c2, fucoxanthin	Chrysolaminarin	Oceanic Coastal
	Bacillariophyta	Diatoms	Chl a, c1 & c2, fucoxanthin & b-carotene	Chrysolaminarin	All waters, esp. coastal
	Xanthophyta	Yellow-green algae	Chl a and carotenoids	Chrysolaminarin	Very rare
	Eustigmatophyta	-	Chl a, violaxanthin	Probably lipid	Estuarine, Very rare
	Rhaphidophyta	Chloromonads	Chl a, c1 & c2, some carotenoids, often fucoxanthin	Lipid	Brackish
	Phaeophyta	Brown algae	Chl a, c1 & c2, Fucoxanthin	Laminarin	-
	Cryptophyta	Cryptomonads	Chl a & c2	Starch	Coastal
	Euglenophyta	Euglenoids	Chl a & b.	Paramylon, oil	Coastal
	Prasinophyta	Prasinomonads	Chl a & b	Mannitol, starch	Cosmopolitan

An early approach to partitioning of this autotrophic pool of phytoplankton was that based on cell size (Sieburth et al., 1978). Picophytoplankton (0.2–2 µm); nanophytoplankton (2–20 µm), and microphytoplankton (<20 µm). The influence of size on the physiology of the phytoplankton is well-established (Chisholm, 1992; Platt and Jassby, 1976; Raven, 1998). Picophytoplankton, due to their high surface-area-to-volume ratio, can absorb nutrients with high efficiency under nutrient-limited conditions, and therefore dominate plant-nutrient impoverished oligotrophic waters. They sink more slowly than larger cells. Microphytoplankton, represented chiefly by diatoms and dinoflagellates, dominate nutrient-rich waters and are the principal agents of the export of carbon to deeper waters. The links between size, weight, abundance, growth and metabolic rate, long recognised as the basis for the size spectra of pelagic organisms (Platt and Denman, 1977, 1978), are now known as the metabolic theory of ecology.

Approximately, 5000 species of marine phytoplankton have been described world vide (Simon et al. 2009), and new species are continually being added to this total. The two most prominent groups of phytoplankton, in the marine ecosystem, are diatoms (Bacillariophyceae) and dinoflagellates (Dinophyceae). In addition to this there are other numerous and diverse collection of phytoplankton classes which are termed microflagellates (naked flagellates), silicoflagellates and cyanophytes (blue-green algae) (described below).

2.1 Diatoms

Diatoms are unicellular or colonial coccoid algae belonging to Bacillariophyceae, widespread in both marine and freshwater habitats. Even though most species of diatoms bear photosynthetic pigments, a few species can live heterotrophically in the dark if supplied with a suitable source of organic carbon (Hoek, 1995). Their chloroplasts are usually golden-brown, because the chlorophyll is masked by the accessory pigment fucoxanthin. Their size ranges from about 2 µm to over 1000 µm, and some species form larger chains or other forms of aggregates in which individual cells are held together by mucilaginous threads or spines. Diatom cells are encased in a siliceous external skeleton (cell wall, or frustule), which is composed of two halves forming a 'box' with an overlapping lid. The frustule is usually sculptured into patterns of spines, pores, channels, and/or ribs which are distinctive to individual species (See Fig 1 for some of these features).

Diatoms form an important part of the planktonic algal community and are often the dominant phytoplankton in temperate and high latitudes. In the marine habitat, diatoms live floating freely in the water, on the mud and sand of the shallow seabed within the euphotic zone, and on the surface of rocks and seaweeds. Diatoms have been abundant in the seas since the Cretaceous (about 100 million years ago) and, over geological time, sedimented frustules have formed seafloor deposits called diatomaceous ooze.

The diatom contains two major groups, the centric diatom and the pennate diatom, which are recognized by two orders Centrales and Pennales. These are distinguished from each other based differences in the cell wall stricture (Sykes, 1981; Hoek, 1995). Pennate diatoms have elongate-shapes and usually bilaterally symmetrical (valve view), with a lanceolate and elliptical outline and are mostly benthic with few planktonic genera. Centric diatoms have valves that are arranged radially (radially symmetrical) or concentrically around a point, the frustules often resembling a Petri dish. Most of the centric diatoms are planktonic, with somewhat over 1000 species. Both in pennate and centric diatoms, the valves are beautifully ornamented with species specific patterns and structures.

Asexual division of diatoms can lead to very rapid population growth under optimal conditions. However, with repeated divisions, there may be a decrease in size of some of the progeny. When a diatom reaches a certain critical minimal size, it undergoes sexual reproduction by forming a cell that lacks a siliceous skeleton and contains only half of the genetic material. Such cells fuse to form a zygote, and this swells to produce an auxospore, referred as “resting spores”. These can survive under unfavourable conditions, such as winter or while nutrients are depleted and germinate when the conditions are favourable.

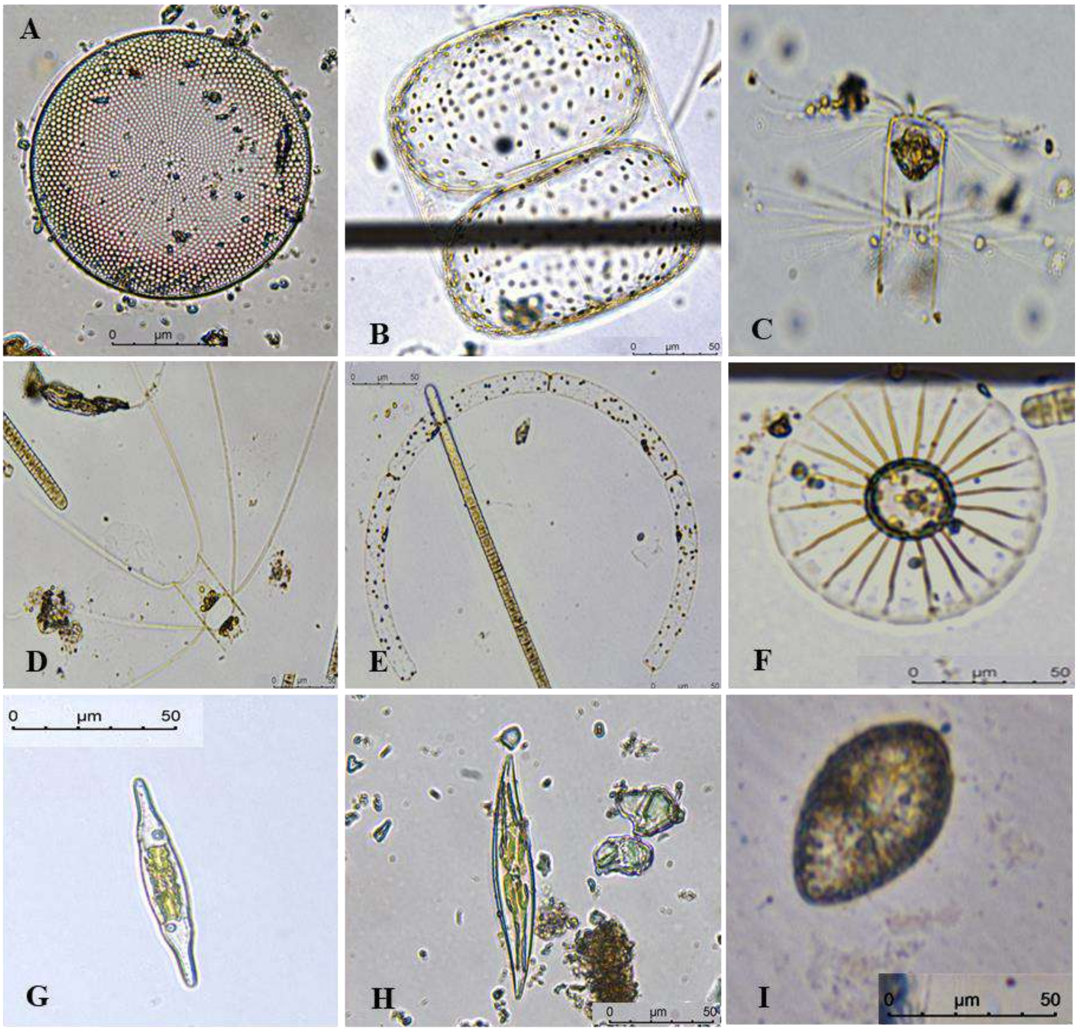


Fig 1. Common diatom species in the water samples collected and identified under the CMLRE MEDAS program: (**A-F Centrales, G-I Pennales**) **A**. *Coscinodiscus* sp.; **B**. *Coscinodiscus* granii; **C**. *Bacteriastrum hyalinum*; **D**. *Chaetoceros lorenzianus* **E**. *Guinardia striata* and *Trichodesmium* sp. **F**. *Planktoniella sol*; **G**. *Mastogloia rostrata*; **H**. *Pleurosigma* sp. **I**. *Surirella* sp.

2.2 Dinoflagellates

Dinoflagellates belong to the class Pyrrophyceae, possess two dissimilar flagella (transverse and longitudinal), or whip-like structure, and are motile. Transverse flagella is ribbon shaped and encircles the cell in a semi-helical fashion and, the longitudinal flagellum is whip-like and trails behind the cell. Based on the presence of thecal plates (thick cellulose cell wall) dinoflagellates can be divided into armoured and unarmoured (naked). These thecal plates are species specific with beautiful ornamentation.

The dinoflagellate can be taxonaomically divided in to two groups. Desmophyceae is a small group in which the species is characterised by having both the flagella arising from the anterior end of the cell (Eg. *Prorocentrum*). Dinophyceae having the thecae belongs to dinoflagellate, which includes genera *Ceratium*, *Protoperidinium*, *Gonyaulax* and *Dinophysis* etc. Unlike diatoms the armour of the two different groups differs both in structure and chemical composition. Some of the dianoflagellates observed in the Arabian Sea during 2018 is shown in Figure 2.

Fig. 2. Common dinoflagellates in the water samples collected and, identified under the CMLRE MEDAS program: (**A & B** Naked, **C-F** Armoured) **A**. *Prorocentrum* sp. **B**. *Noctiluca* sp.; **C**. *Dinophysis miles*; **D**. *Protoperidinium* sp.; **E**. *Ceratium breve*; **F**. *Tripos furca*.

Energy source of the dinoflagellate changes with species, some are strictly autotrophic, obtaining their energy from photosynthesis and some are heterotrophic, obtaining their energy by feeding on phytoplankton and small zooplankton. Some are mixotrophic, capable of both autotrophic and mixotrophic production and some other species are parasitic or symbiotic. Approximately 1500 to 1800 species of free-living dinoflagellates are identified so far.

Dinoflagellates reproduce asexually by dividing to form two cells of equal size. The theca may divide, with each new cell forming a new half, or the theca may be lost before division, in which case each new cell forms an entirely new cell wall. Sexual reproduction occurs in some species of dinoflagellates by forming a thick-walled, dormant cysts that settle on the seafloor, which is capable of surviving for years. Under favourable environmental conditions these cysts germinate to produce swimming cells.

2.3 Coccolithophorids

Coccolithophorids come under the class Prymnesiophyceae, with ~500 living species in 50 genera which form a major part of tropical-marine nanoplankton, with most of the species being smaller than 20µ. A microscopic exoskeleton made up of limestone (calcite), known as coccoliths is the major characteristics of this diverse group. They are spherical or oval, and like dinoflagellates possess two flagella. Because of their abundance, with large seasonal blooms, and the preservation of coccoliths in sediments, coccolithophorids are playing major role in the global carbon cycle.

They range in age from the Upper Triassic to Holocene, although dubious examples have been described from the Upper Precambrian and Palaeozoic. The coccolith accumulate on the bottom of the ocean as the organism die, and there contribute to the formation ocean sediments, carbonate ooze, and rocks such as the Mesozoic limestone and chalks.

2.4 Silicoflagellates

These are planktonic marine chromists that are both photosynthetic and heterotrophic, with two flagella and thin pseudopodia, but based on their pigmentation, mitochondria, chloroplasts and siliceous skeleton, silicoflagellates are considered golden algae or Chrysophytes. The cell size ranges from 20 to 80 µm. Some of these resembles to the radiolarians since their internal silica skeletons are composed of a network of bars (Fig. 3).

Silicoflagellate skeletons usually comprise 1-2% of the siliceous component of marine sediments. Although they are thus much less abundant than diatoms, they are widely distributed throughout the world ocean. The spines on the skeleton may function in retarding sinking, which is of obvious importance to a photosynthetic organism.

2.5 Cyanobacteria

Cyanobacteria, also known as blue-green algae (due to the presence of bluish pigment phycocyanin), belongs to the group Cyanophyceae, are some of the oldest living (occurring as long ago as 3500 million years; Schopf, 1993) photosynthetic bacteria on earth (Fig. 3). They include 2000 species in 150 genera with a wide range of size and shapes. The cell wall is made up of peptidoglycan with an external polysaccharide layer, and it may also have mucilaginous layer.

Cyanobacteria contain chlorophyll a, and pigments which belongs to phycobiliproteins, which they use to capture light for photosynthesis. Some filamentous cyanobacteria possess specialized nitrogen-fixing cells, named heterocysts, and have the ability to fix nitrogen under nitrogen deficient conditions.

A B

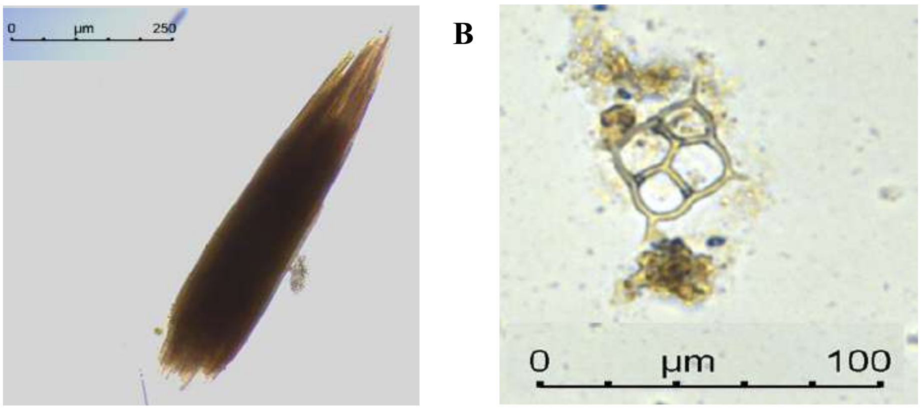


Fig 3. Common cyanobacteria and silicoflagellate in the water samples collected and, identified under the CMLRE MEDAS program: **A**. *Trichodesmium erythraeum*; **B**. *Dictyocha* sp.

Based on their distinct biogeochemical roles, phytoplankton functionally vital in the marine environment. They can be grouped as nitrogen-fixers, calcifiers, silicifiers and DMS producers (Nair et al. 2008).

3. Functional Groups of Phytoplankton

3.1 Nitrogen-fixers (Diazotrophs)

Trichodesmium is the dominant nitrogen-fixing cyanobacterium in oligotrophic oceans. The ability of this diazotroph to utilize atmospheric nitrogen as a raw material for growth has a direct impact on the nitrogen cycle and on other factors that influence climate change. Nitrogen fixing phytoplankton other than *Trichodesmium* have also been identified. The symbiont of the diatom *Hemiaulus* sp which contributes about 15% of the total nitrogen fixed in the Pacific Ocean (Fuhrman and Capone, 2001; Scharek et al., 1999).

3.2 Silicifiers

Silicification by marine phytoplankton has both contributed to and been influenced by the marked changes in the biogeochemistry of Si in the surface ocean. Phytoplanktonic silicifiers comes mainly under four taxonomic groups-Chrysophyta, Prymnesiophyta, Xanthophyta and Bacillariophyta (Brownlee and Taylor, 2002). Among this, diatoms (Bacillariophyta) represent the dominant silicifying phytoplankton in oceans and contribute about 40% of the total marine primary production (Sarthou et al., 2005).

Expansion of diatoms in the world oceans resulted in the extensive depletion of silicate from the surface ocean, leading to the decline of heavily silicified sponges and decreased silicification in radiolarians (Lazarus et a. 2009, Maldonado et al. 1999). Si has therefore become a limiting nutrient for silicifying phytoplankton and even if other nutrients such as nitrate or phosphate are still available, then Si limitation can contribute to seasonal succession, where an initial diatom spring bloom is followed by subsequent blooms of non-siliceous phytoplankton.

3.3 Calcifiers

Coccolithophorids are the major calcifying phytoplankton in the ocean and comprise 30% to 90% of carbonate in the sediments (Broecker and Clark, 2009). Through calcification, coccolithophores take up bicarbonate (HCO_3^-) and calcium ions for the formation of external plate coccoliths ($CaCO_3$) and releases carbon dioxide (CO_2). This lowers the surface ocean carbonate concentration, which in turn reduces sea water alkalinity. Coccolithophores can therefore influence both the biological carbon pump and the alkalinity pump.

Release of CO_2 during calcification causes an increase in the partial pressure of CO_2 in surface waters and therefore serves as a source of carbon dioxide to the atmosphere (Robertson et al., 1994; Rost and Riebesell, 2004). The increasing concentration of atmospheric carbon dioxide in turn lowers the carbonate concentration of the surface ocean and affects calcification (Nair et al. 2008). Hence, the process of calcification in coccolithophores has received increased research attention regarding anthropogenic ocean acidification and the associated elevated energy demand to build their $CaCO_3$ structures (Hofmann et al., 2010).

3.4 DMS producers

Half of the biogenic sulfur flux to the Earth's atmosphere arises from the oceans. Dimethyl sulfide (DMS) is a semi-volatile organosulfur compound, produced by marine organisms, particularly phytoplankton, which constitutes about 90% of this marine sulfur flux. DMS is produced by the enzymatic cleavage of the marine biogenic product dimethyl sulfoniopropionate (DMSP), a low molecular-mass sulphur compound found in phytoplankton (Andreae 1990; Kiene et al. 2000).

DMS influences the Earth's climate through the formation of sulphate aerosols which maintain the global radiation balance by serving as crucial precursor of cloud condensation nuclei that can back-scatter the radiation from the sun and help in cooling the earth. In the ocean, DMS is produced by phytoplankton belonging to the classes dinophyceae, haptophyceae, chrysophyceae, pelagophyceae and prasinophyceae. The intracellular concentration of DMSP is highest in dinoflagellates and haptophytes (Sunda et al., 2002). Haptophytes such as *Emiliania huxleyi* and *Phaeocystis* sp. are known to form extensive blooms in several coastal and oceanic waters (Tyrell and Merico, 2004). Since *E. huxleyi* is a coccolithophore as well, it is both a calcifier and a DMS producer.

4. Phytoplankton blooms

A major outcome of eutrophication may be the proliferation of phytoplankton beyond their normal community structure. These proliferations or significant population increase are known as algal blooms (Smayda, 1997a, 1997b). Eutrophication, with its increase in nutrients overall and also commonly a shift from the normal nutrient ratios, therefore, affects both the scale and type of phytoplankton biomass. Since blooms composed of mostly single species, during bloom events, only the species/animals feed on the bloom species have plenty of food, while other species/animals feed on other species may not have and eventually decline in number. This shift in phytoplankton community in the food web can affect the zooplankton, fish and other animals in the food web. Low dissolved oxygen levels are one of the remarkable characteristics of bloom events. After the bloom event, the organism dies and undergo decomposition, uses dissolved oxygen by decomposing bacteria also removes oxygen from the water columns. Depletion of oxygen due to decomposition is a direct cause of fish kill.

Algal blooms may be detrimental to the functioning of the ecosystem by causing oxygen and consequent death of fish and aquatic animals. The physical presence of such densities of phytoplankton cause damage to other organisms. A few species of phytoplankton produce powerful biotoxins, which is most damaging to the ecosystem and can also cause severe health impacts in human and animal who eats contaminated food. Both toxic and other nuisance blooms are collectively called harmful algal blooms or HAB. Toxin-producing microalgae are found in a diversity of algal classes: the Dinophyceae (dinoflagellates), Bacillariophyceae (diatoms), Raphidophyceae (raphidophytes), Prymesiophyceae (prymnesiophytes) and cyanobacteria (blue-green algae) (Daranas et al., 2001).

A total of 86 bloom events were observed along the Indian EEZ during our studies in the Indian Ocean (Fig. 4). Among this, 45 phytoplankton blooms formed were found to be toxic.

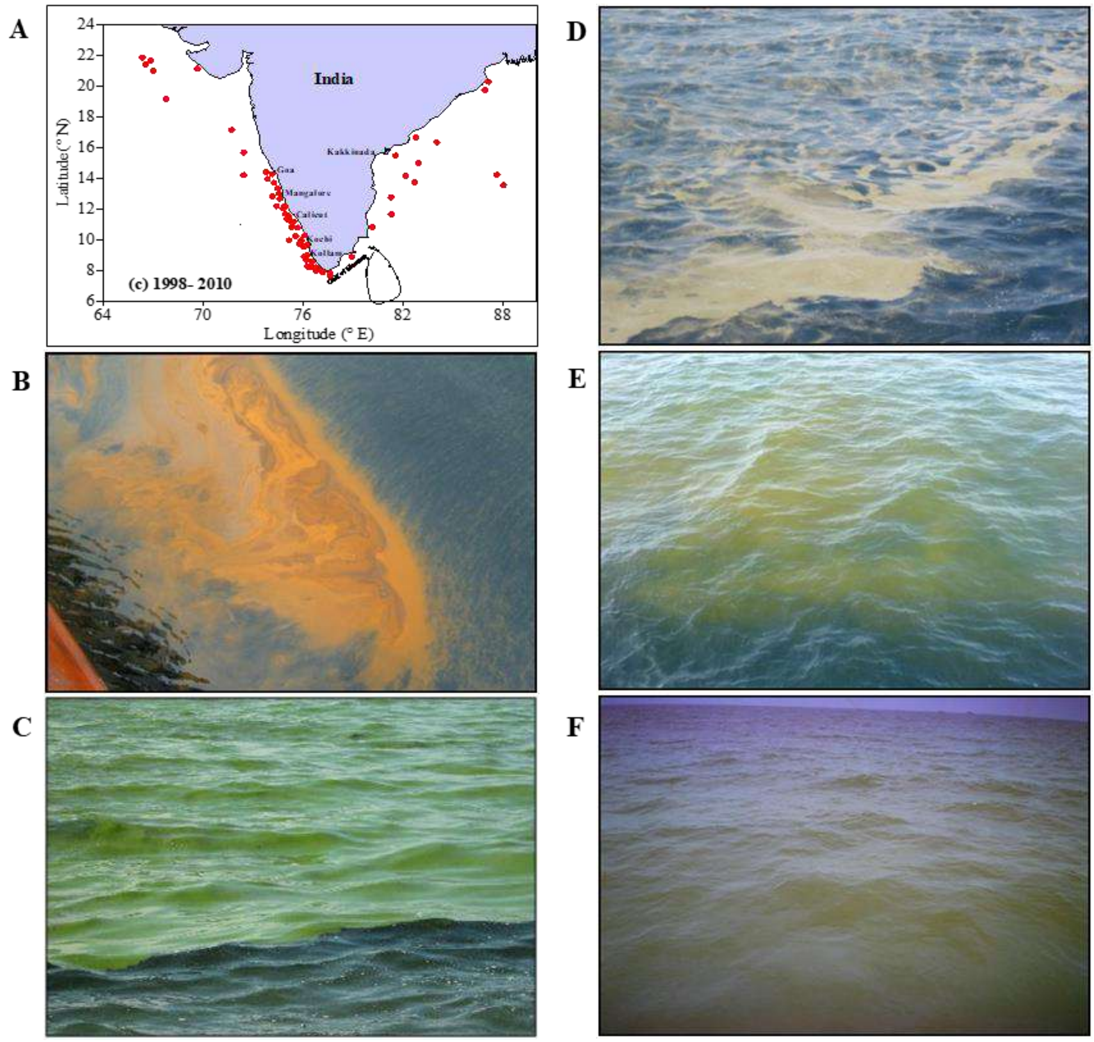


Fig. 4. A. Location map of Algal blooms reported along the Indian EEZ; **B.** Red *Noctiluca* bloom along SEAS (Aug 2008); **C.** Green *Noctiluca* bloom at Gulf of Mannar (Oct 2008); **D.** *T. erthraeum* bloom at Off Manglore (March 2010); **E.** *Gonyaulax* sp. bloom at Off Mangalore (Oct 2008); **F.** *Coscinodiscus* sp. bloom at Off Calicut (Aug 2006)

4.1 Arabian Sea OMZ and its expansion is associated with the phytoplankton bloom

Oxygen Minimum Zones (OMZ) are the places in the world ocean where oxygen saturation in the water column is at its lowest which typically occurs at depths of about 200 to 1,500 meters in the world ocean. It is supposed to believe that OMZ in the Arabian Sea is expanding due to phytoplankton bloom. This expansion is having a greater impact on the entire Arabian Sea ecosystem, its biogeochemistry and even on the global climate. OMZ water is exposed to the rain of sinking organic matter. Bacteria and Archea feed on this organic matter and oxygen is used for decomposition. In most of the OMZ regions oxygen concentration reaches zero, which enable substantial nitrogen loss because in the absence of oxygen, nitrate represents the 'next best' electron acceptor available for respiration (Fussel et al. 2012).

5. Phytoplankton studies carried out by CMLRE

To understand spatio-temporal and compositional variability phytoplankton and their impact around the biogeochemistry, fisheries resources and climatic change around the Indian water, the CMLRE studies the phytoplankton including the classical taxonomy to HPLC pigment analyses to ocean colour. Innumerable samples collected under the MEDAS program, are analysed to delineate biogeography, seasonal differences and diversity indices of phytoplankton in the Arabian Sea. In the overall, some common genera of phytoplankton recorded under the MEDAS program are *Coscinodiscus*, *Asterionellopsis* (diatoms); *Protoperidinium, Tripos* (dinoflagellates); *Dictyocha* (silicoflagellate) and *Trichodesmium (*cyanobacteria). The satellite imageries are also made use of for mapping the spatio-temporal variability of the photosynthetic pigments.

References

Al-Kandari, M., Al-Yamani, F. Y., Al-Rifaie, K. Marine Phytoplankton Atlas of Kuwait's Waters. Kuwait Institute for Scientific Research, Kuwait (2009).

Andreae, M.O. Ocean-atmosphere interactions in the global biogeochemical sulfur cycle. Marine Chemistry 30(1–3):1-29 (1990).

Brownlee, C., Taylor, A.R. Algal calcification and silification. In: Encyclopedia of life sciences. Macmillan Publishers Ltd, Nature Publishing Group. 1-6, (2002).

Chisholm, S. W. Phytoplankton size. In Falkowski P. G., Woodhead A. D. (Eds.), Primary productivity and biogeochemical cycles in the sea. Plenum press, New York (1992).

Daranas, A.H., Norte, M., Ferna´ndez, J.J. Toxic marine microalgae. Toxicon, 39, 1101–102 (2001).

Fuhrman, J. A., Capone, D. G. Nifty nanoplankton. Nature, 412, 593−594 (2001).

Füssel, J., Lam, P., Lavik, G., Jensen, M. M., Holtappels, M., Günter M., Kuypers, M.M.M. Nitrite oxidation in the Namibian oxygen minimum zone. ISME J 6, 1200–1209 (2012). doi:10.1038/ismej.2011.178.

Hoek, C. V. D. Algae: An introductory to phycology. Cambridge University Press: Cambridge, UK (1995).

Hofmann, G. E., Barry, J. P., Edmunds, P. J., Gates, R. D., Hutchins, D. A., Klinger, T., Sewell, M. A. The effect of ocean acidification on calcifying organisms in marine ecosystems: an organism to-ecosystem perspective. Annu. Rev. Ecol. Evol. Syst. 41, 127–147 (2010). doi: 10.1146/annurev.ecolsys.110308.120227

Lalli, C. M., Parsons, T.R.: Biological Oceanography an introduction. 2nd edn. Elsevier Butterworth-Heinemann, London (2006).

Lazarus, D. B., Kotrc, B., Wulf, G., Schmidt, D. N. Radiolarians decreased silicification as an evolutionary response to reduced Cenozoic ocean silica availability. Proceedings of the National Academy of Sciences USA, 106, 9333–9338 (2009).

Kiene, R.P., Linn, L.J., Bruton, J.A. New and important roles for DMSP in marine microbial communities. Journal of Sea Research, 43(3–4):209-224 (2000).

Maldonado, M., Carmona, M. G., Uriz, M. J. & Cruzado, A. Decline in Mesozoic reef-building sponges explained by silicon limitation. Nature 401, 785–788 (1999).

Nair, A., Sathyendranath, S., Platt, T., Morales, J., Stuart V., Forget, M. H., Devred, E., Bouman, H. Remote sensing of phytoplankton functional types. Remote Sensing of Environment, 112, 3366-3375 (2008).

Platt, T., Denman, K. L. Organisation in the pelagic ecosystem. HelgolaÉnder Wissenschaftliche Meeresuntersuchungen, 30, 575−581 (1977).

Platt, T., Denman, K. L. The structure of pelagic marine ecosystems. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer (pp. 60–65) (1978).

Platt, T., Jassby, A. D. The relationship between photosynthesis and light for natural assemblages of coastal marine phytoplankton. Journal of Phycology, 12(4), 421−430 (1976).

Raven, J. A. Small is beautiful: The picophytoplankton. Functional Ecology, 12, 503−513 (1998).

Reynolds, C. S.: The ecology of phytoplankton. Cambridge University Press, UK (2006).

Robertson, J. E., Robinson, C., Turner, D. R., Holligan, P., Watson, A. J., Boyd, P., Fernandez, E. Finch, M. (1994). The impact of a coccolithophore bloom on oceanic carbon uptake in the Northeast Atlantic during the summer 1991. Deep-Sea Research I, 41, 297-314.

Rost, B., Riebesell, U. Coccolithophores and the biological pump: Responses to environmental changes. In H. R. Thierstein & J. R. Young (Eds.), Coccolithophores, from molecular processes to global impact. Springer, (2004).

Sarthou, G., Timmermans, K. R., Blain, S., Tréguer, P. Growth physiology and fate of diatoms in the ocean: A review. Journal of Sea Research, 53, 25−42 (2005).

Scharek, R., Tupas, L. M., Karl, D. M. Diatom fluxes to the deep sea in oligotrophic North Pacific gyre at Station ALOHA. Marine Ecology. Progress Series, 182, 55−67 (1999).

Schoemann, V., Becquevort, S., Stefels, J., Rousseau, V., Lancelot, C. Phaeocystis blooms in the global ocean and their controlling mechanisms: A review. Journal of Sea Research, 53, 43-66 (2005).

Schopf, J.W. Microfossils of the Early Archean Apex chert: new evidence of the antiquity of life. Science, 260: 640–646 (1993).

Sieburth, J. McN., Smetacek, V., Lenz, J. Pelagic ecosystem structure: heterotrophic compartments of the plankton and their relationship to plankton size fractions. Limnology and Oceanography 23, 1256–63(1978).

Simon, N., Cras, A. L., Foulon, E., Lemée, R. Diversity and evolution of marine phytoplankton. C. R. Biologies 332: 159-170 (2009).

Smayda, T.J. Harmful algal blooms: Their ecophysiology and general relevance to phytoplankton blooms in the sea. Limnology and Oceanography, 42, 1137–53 (1997a).

Smayda, T.J. What is a bloom? A commentary. . Limnology and Oceanography, 42, 1132–36 (1997b).

Sunda,W., Kleber, D. J., Klene, R. P., Huntsman, S. An antioxidant function for DMSP and DMS in marine algae. Nature, 418, 317−320 (2002).

Sykes, J. B. An illustrated guide to the diatoms of British coastal plankton. Field Studies 5: 425-468 (1981).

Tomaselli, L.: The Microalgal Cell. In: Richmond, A., Hu, Q. (Eds.), Handbook of microalgal culture: biotechnology and applied phycology. Blackbell publishing, UK (2004).

Tyrell, T., Merico, A. *Emiliania huxleyi*: Bloom observations and the conditions that induce them. In Theirstein, H. R., Young, J. R. (Eds.), Coccolithophores, from molecular processes to global impact (2004).

Ecological Roles of Diverse Zooplankton Community

Kusum Komal Karati
Centre for Marine Living Resources, Kochi
Email: kusum111@gmail.com

Zooplankton, as an intermediary link between the primary producers and higher trophic levels, have a pivotal role in the pelagic trophodynamics. Comprehensive researches have been conducted on the diversity, distribution, and ecology of the Indian Ocean zooplankton since the 1960s. The Centre for Marine Living Resources and Ecology (CMLRE) with a mandate to provide a better insight on the diverse marine life forms in and around the Indian EEZ, have added information on many new zooplankton species and also on the ecological role of the zooplankton community. Presently, under the project, Marine Ecosystem Dynamics of the eastern Arabian Sea (MEDAS), CMLRE is giving prime focus on the zooplankton community of the Arabian Sea and the estuaries along the west coast of India to understand in detail their influence on the ecosystem functioning and biogeochemistry of the Northern Indian Ocean.

1. Introduction

Zooplankton are small heterotrophic organisms found ubiquitously from marine to freshwater ecosystems. The term 'Zooplankton' takes its origin from Greek words, "Zoo" meaning animals and "Planktos" meaning "wanderer". Having feeble locomotive power, they have limited ability to counteract waters currents and are found to be drifting in the water bodies with winds and currents. Zooplankton community includes a diverse array of organisms from microscopic protozoans to large metazoans. Based on the size, they are broadly categorized as ***Microzooplankton*** (20-200µm), ***Mesozooplankton*** (0.2-20mm), ***Macroplankton*** (2-20cm) and ***Megaplankton*** (>20cm) (Seiburth et al., 1978). They are also classified according to their life history strategies as ***holoplankton,*** organisms spending their entire life cycle as plankton and ***meroplankton***, those spending only part of their life as plankton before transforming into nektonic or benthic adults.

Zooplankton are crucial components of all aquatic ecosystems from oceans to freshwater bodies. They act as efficient intermediary conduits in both the classical and microbial food webs by channelling the carbon produced by the primary producers to higher trophic levels. Thus their standing stock, community structure, and distribution are taken as efficient tools for predicting the secondary productivity and fishery potential of aquatic ecosystems. Furthermore, the zooplankton community through the incorporation and modification of dissolved and particulate organic matter through their feeding, defecation, and decomposition upon death plays a significant role in nutrient regeneration and biogeochemical cycling in the aquatic ecosystems. They also contribute immensely to the biological carbon pump/carbon sequestration of the marine ecosystem through their active feeding at the surface at night and subsequent release of carbon through respiration, moulting, and defecation at depths, a phenomenon known as diel vertical migration. Their cosmopolitan distribution, shorter life span, comparatively less commercial exploitation than fin and shellfishes, and extreme sensitivity of their physiological process to subtle variations in their habitat makes them ideal indicators for predicting the ecosystem health in conjunction with both the climatic variability and anthropogenic interferences (Richardson, 2008).

2.1. Microzooplankton community

Heterotrophic plankton having size between 20-200μm constitute the microzooplankton community (Table 1). They form important constituents of the 'microbial food web' where the unutilised dissolved organic carbon produced in aquatic environments through the cell lysis, exudation and excretion are channelled to higher trophic levels via the bacterial biomass.

Table 1: Marine ecological roles of microzooplankton

<table>
<tr><th>Major Communities</th><th>Dominant group</th><th>Ecological role</th></tr>
<tr><td>Heterotrophic dinoflagellates</td><td>Protoperidinium sp.
Phalocroma sp.
Ornithocercus sp.</td><td rowspan="4">Important component of pelagic food web of warm, oligotrophic stratified waters.
Vital constituent of the microbial food web
Important grazers of the pico and nano phytoplankton community
Form major prey item for many vertebrate and invertebrates
Significant role in nutrient regeneration and biogeochemical cycling in marine ecosystems
Loricate ciliates are taken as good indicators of eutrophication.</td></tr>
<tr><td>Ciliates</td><td>Loricates
Aloricates</td></tr>
<tr><td>Sarcodines</td><td>Radiolarians
Acantharians</td></tr>
<tr><td>Crustacean larvae</td><td>Nauplii</td></tr>
</table>

2.2. Mesozooplankton community

Mesozooplankton (Groups named in Table 2) comprises of organisms having a size span between 200 μm to 2 cm. They include representatives from every animal phyla ranging from Porifera to Chordata and are categorised either as the holoplankton or the meroplankton groups.

Table 2: Marine ecological roles of major mesozooplankton communities

Major Communities	**Dominant group**	**Ecological role**
	Holoplankton	
Crustacean plankton		
Copepoda "Insects of the sea"	Calanoida Cyclopoida Poecilostomatoida	Copepods are the predominant and diverse mesozooplankton taxa contributing ~90% of biomass of the total zooplankton community. They form the major primary consumers in the pelagic food web transferring carbon from the primary producers to higher trophic levels. They have crucial role in the biological carbon pump, nutrient regeneration and biogeochemical cycling of the aquatic ecosystem.
Euphausiacea "Krill"		Often rank second to copepod in abundance and hence contribute significantly to the secondary productivity of marine ecosystems. Abundantly found in the Antarctic Ocean and thus have a vital role in the Antarctic food chain.
Cladocera "Water Fleas"	*Evadne* sp. *Penilia* sp.	Dominant zooplankton component of neritic and freshwater ecosystems. Forms dense swarms through parthenogenesis upon favourable conditions.
Ostracoda "Seed Shrimps"	Cyprinidae Halocyprinidae	Detritivorous zooplankton.
Amphipoda	Hyperiidea Gammaridea	Hyperiid amphipods are mostly parasitic on salps and pyrosomes.
Mysidacea "Opposum Shrimps"		Omnivorous zooplankton Mostly inhabits estuarine and coastal ecosystems.
Gelatinous plankton		
Hydrozoa	Siphonophora	Exclusively marine and carnivorous. Often form large colonies.
Scyphozoa "True jelly fishes"		Carnivorous zooplankton taxa considered as negative indicator of fishery as they exert high predatory impact on the fish eggs and larvae and on copepods.
Ctenophora "Comb jellies"	Tentaculata Nuda	Voracious carnivores.
Chaetognatha "Arrow worms"	*Sagitta*	Ambush predators preying on copepods and other zooplankton taxa.
Planktonic tunicates		
Larvacea	Appendicularia	Filter feeders living in the epipelagic photic waters. Discarded larvacean test or house contribute greatly to the marine snow and in the biological carbon sequestration of the marine ecosystem.
Thaliacea	Doliolida Salpa Pyrosoma	Colonial filter feeders. The sinking of their dense faecal pellets have crucial role in the oceanic biologic carbon pump.
Planktonic molluscans		

Pteropods	Thecosomes - “Sea Butterflies” Gymnosomes- “Sea Angels”	Thecosomes have calcareous skeleton which contribute greatly to the global calcium carbonate flux. Greatly affected by ocean acidification. Gymnosomes are carnivores preying mostly upon thecosomes.
Heteropods	Pterotraceoida - “Sea elephants”	Active predators feeding on other zooplankton taxa
Meroplankton		
Crusatacean Larvae	Zoea, Mysis and Megalopa stages of decapods, Alima larvae of Stomatopoda, Furcilia of Euphausiids, Cypris stage of barnacles, Phyllosoma of lobsters	Contribute to the standing stock and diversity of the nektic and benthic community
Molluscan larvae	Trochophore, Veliger and juveniles of gastropods, bivalves and cephalopods	
Ichtyoplankton	Fish eggs and larvae	

2.3. Zooplankton studies in the Northern Indian Ocean

Compared to the Atlantic and the Pacific Ocean, the zooplankton community of the Indian Ocean has received less research attention in the earlier days. Zooplankton studies in the Northern Indian Ocean gained impetus after the International Indian Ocean Expedition (1960-65). The expedition widely explored the basin-scale information regarding the physical, chemical and biological attributes of the Indian Ocean and succeeded in paving way for elaborative investigations on the diverse zooplankton community of the lesser-studied Indian Ocean. Later major scientific programs like Indian Joint Global Ocean Flux Study (1994 - 2000), Bay of Bengal Process Studies (2000-2006), Marine Research on Living Resources study (Phase I & II, 1998-2007) and other scientific explorations in and around the Indian EEZ helped in the better elucidation of the taxonomy, ecology and spatiotemporal distribution of the diverse mesozooplankton community of the Northern Indian Ocean.

Studies on the influence of oxygen minimum zones, upwelling, cyclones, river plume fronts, mesoscale process like eddies, gyres, and regional-scale process like Lakshadweep Low on the zooplankton community and secondary productivity pattern helped greatly in unravelling the plankton ecology of the Northern Indian Ocean (Madhupratap et al 1990, 1996; Padmavati et al 1998; Smith and Madhupratap 2005; Muraleedharan et al 2007; Fernandes 2008; Karati et al., 2018, 2019).

2.4. Climate change impacts on the zooplankton community

Zooplankton are threatened by a multitude of factors leading to a conspicuous change in their abundance, community structure, and distribution. The rising temperature associated with global warming evokes potential impacts on the zooplankton community. Being poikilothermic organisms whose physiological attributes, growth and reproduction rely on external temperatures, the zooplankton community is heavily influenced by the changes in the temperature patterns ranging from shorter to longer periods. Variability in the phenology or the timing of repeated seasonal events like migration and reproduction are the most conspicuous impacts of global warming on the zooplankton community.

Ocean acidification, the "evil twin of global warming" also has substantial effect on the zooplankton community. Rising atmospheric CO_2 levels and the uptake of CO_2 by the world's oceans leads to a subsequent drop in the seawater pH. This, in turn, affects the zooplankton community especially the calcified forms like Pteropoda and Foraminifera by altering their calcifying rates, physiology, growth, and larval recruitment thus leading to an impending change in the population dynamics of these ecologically significant organisms (Fabry et al 2008).

Expansion and shoaling of hypoxic zones in the marine ecosystem in association with global warming and increasing eutrophication is another major threat to the zooplankton community. The decline in oxygen levels below a threshold limit affects the abundance, distribution, vertical migration and the community structure of the zooplankton community.

3. Contribution of CMLRE to the zooplankton research of the northern Indian Ocean

CMLRE, by implementing several extensive oceanographic research programmes added momentum to the zooplankton research in the northern Indian Ocean. Under the MRLR programme of CMLRE, elaborative works have been carried out on the ecology and taxonomy of several zooplankton taxa of the northern Indian Ocean. The detailed taxonomic studies on the Mysidacea of the Indian EEZ by Biju and Pannapunayil (2011) added a new species *Pseuderythrops abrahami* to the Indian Ocean mysid population. Likewise, comprehensive researches on the chaetognath community by Nair et al. (2008) added two new chaetogantha species, *Krohnitta balagopali* and *Sagitta meenakshiae* to the existing records of this important plankton group from the Indian Ocean. Examples of different groups of zooplankton (and some of their developmental stages, photographs taken at CMLRE) are shown in Figure 1.

Recently, under the CMLRE project Marine Ecosystem Dynamics of the eastern Arabian Sea (MEDAS) extensive zooplankton sampling is being carried out in the Arabian Sea and along estuaries connected to it with an aim to understand the influence of the zooplankton community on the biogeochemistry and trophic dynamics.

4. Conclusion

Till date, several studies carried out on the zooplankton community of the Northern Indian Ocean have helped in providing baseline information regarding their taxonomy, ecology, and distribution. However, the impacts of climate variability such as rising sea surface temperature, ocean acidification and the expansion of OMZ on the phenology and the secondary productivity and their ultimate impacts on the biological pump and fishery potential of the Northern Indian Ocean are least explored in comparison to other world oceans and hence requires extensive research attentions. CMLRE has always been one of the leading institutes dealing with zooplankton research in the Indian Ocean and with the ongoing research programmes focusing on their role in biogeochemistry and trophic dynamics will further augment knowledge regarding this important pelagic component.

Acknowledgments: I thank the Director, Centre for Marine Living Recourses and Ecology, Kochi for providing facilities for the study. I am also thankful to Dr. Vineetha G, CMFRI, Kochi, for her help during the drafting of the manuscript.

References

Biju, A., Panampunnayil, S.U. Mysids (Crustacea) from the Exclusive Economic Zone of India with description of a new species. Marine Biology Research 7(4), 332-364 (2011).

Fabry, V.J., Seibel, B.A., Feely, R.A., Orr, J.C. Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Sciences 65, 414–432 (2008).

Fernandes, V. The effect of semi-permanent eddies on the distribution of mesozooplankton in the central Bay of Bengal. Journal of Marine Research 66, 465-488 (2008).

Karati, K.K., Vineetha, G., Raveendran, T.V., Dineshkumar, P.K., Muraleedharan, K.R., Joseph, T., Jayalakshmi, K.V. Implications of a regional-scale process (the Lakshadweep low) on the mesozooplankton community structure of the Arabian Sea. Marine and Freshwater Research https://doi.org/10.1071/MF17238 (2019).

Karati, K.K., Vineetha, G., Raveendran, T.V., Muraleedharan, K.R., Habeebrehman, H., Philson, K.P., Achuthankutty, C.T. River plume fronts and their implications for the biological production of the Bay of Bengal, Indian Ocean. Marine Ecology Progress Series 597, 79-98 (2018).

Madhupratap, M., Nair, S.S., Haridas, P., Padmavati, G.. Response of zooplankton to physical changes in the environment: coastal upwelling along the central west coast of India. Journal of Coastal Research 6, 413-426 (1990).

Madhupratap, M., Kumar, S.P., Bhattathiri, P.M.A., Kumar, M.D., Raghukumar, S., Nair, K.K.C., Ramaiah, N. Mechanism of the biological response to winter cooling in the northeastern Arabian Sea. Nature 384(6609), 549 (1996).

Muraleedharan, K.R., Jasmine, P., Achuthankutty, C.T., Revichandran, C., Kumar, P.D., Anand, P., Rejomon, G. Influence of basin-scale and mesoscale physical processes on biological productivity in the Bay of Bengal during the summer monsoon. Progress in Oceanography 72, 364-383 (2007).

Nair, V.R., Panampunnayil, S.U., Pillai, H.U. Gireesh, R. Two new species of chaetognatha from the Andaman Sea, Indian Ocean. Marine Biology Research 4(3), 208-214 (2008).

Padmavati, G., Haridas, P., Nair, K.K.C., Gopalakrishnan, T.C., Shiney, P., Madhupratap, M. Vertical distribution of mesozooplankton in the central and eastern Arabian Sea during the winter monsoon. Journal of Plankton Research 20, 343-354 (1998).

Richardson, A.J. In hot water: zooplankton and climate change. ICES Journal of Marine Science 65, 279-295 (2008).

Sieburth, J.M., Smetacek, V., Lenz, J. Pelagic ecosystem structure: Heterotrophic compartments of the plankton and their relationship to plankton size fractions. Limnology and Oceanography, 23, 1256-1263 (1978).

Smith, S.L., Madhupratap, M. Mesozooplankton of the Arabian Sea: patterns influenced by seasons, upwelling, and oxygen concentrations. Progress in Oceanography 65, 214-239 (2005).

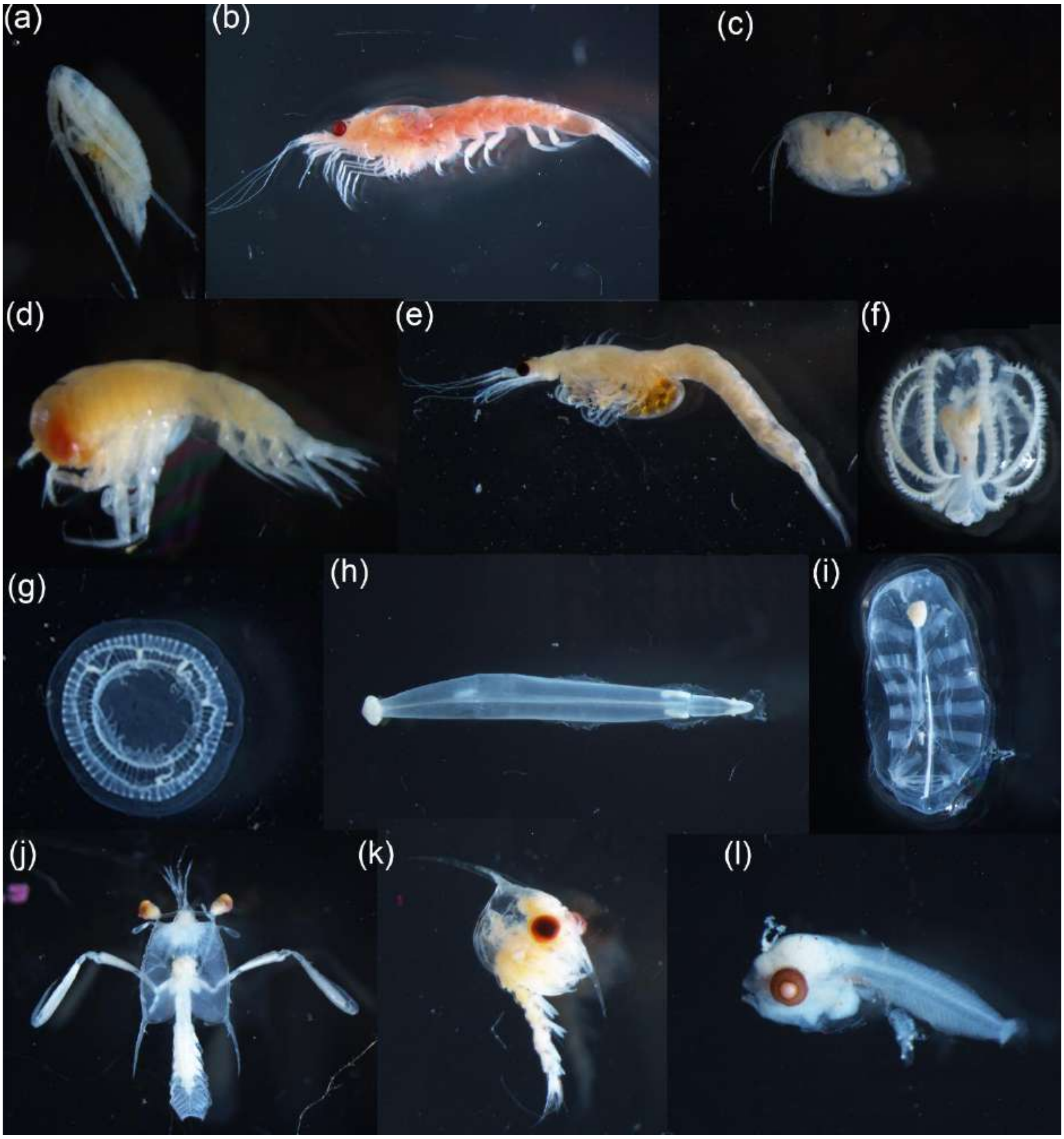


Figure 1: Major zooplankton taxa (a) Copepoda, (b) Euphausiid, (c) Ostracoda, (d) Amphipoda, (e) Mysid, (f) Ctenophora, (g) Hydrozoa, (h) Chaetognatha, (i) Salp, (j) Alima larva, (k) Zoea, (l) Fish larva.

CMLRE's Collection and Inventorization of Deep-water Crustaceans

Vinay P. Padate
Centre for Marine Living Resources and Ecology, Kochi
Email: vinaypadate@gmail.com

This article is to introduce the strange world of deep-water crustaceans collected by the CMLRE in recent years. Crustaceans are a large and diverse group of external shell-bearing invertebrate animals inhabiting a variety of environments ranging from high mountain lakes to deep ocean trenches. The most familiar members of this group are prawns, crabs and lobsters, known for their delicious taste and rich sources of protein and omega-3 fatty acids.

A catch of deep-sea shrimps

Crustaceans display myriad adaptations in response to the ambient environmental conditions, among which the deep-sea realms are the harshest, and have resulted in fascinating adaptations with regard to their peculiar shapes, sizes, colors and habits.

Deep-sea crustaceans include diverse animals such as barnacles, amphipods, isopods, krill, mantis shrimps, shrimps and shrimp-like forms, lobsters, hermit crabs, king crabs, squat lobsters and true crabs. They attain sizes ranging from a few millimeters (shrimp-like amphipods), to a humungous 4 meters by the Japanese Spider crab. Some crabs have extremely long legs (*Platymaia alcocki*), probably useful in travelling long distance in search of food or a potential mate.

Platymaia alcocki

Acanthephyra fimbriata

Total darkness in depths beyond 1000 meters has resulted in body colouration in the range from orange to deep pink and dark red (*Acanthephyra fimbriata*). The orange and red components of the visible spectrum with their relatively longer wavelengths and lesser energy do not penetrate beyond a depth of 50 meters, resulting in absorption of all wavelengths including orange and red, thus making the animal appear black in the deep sea.


Oplophorus gracilirostris

In addition, darkness has also resulted in the development of "bioluminescence" (emission of light by the organisms). Two types of bioluminescence, namely the presence of "photophores" (light-bearing organs) and "spew" (forceful discharge of glowing vomit), are known in the deep-water shrimp *Oplophorus gracilirostris*. These are useful to attract a mate as well as for defence against predators. In addition, "benthic" (bottom-dwelling) crabs employ two types of light-sensitive pigments to assist in vision. However, the sense of vision is extremely variable among the deep-sea crustaceans. The benthic giant isopod *Bathynomus* possesses small compound eyes with densely packed light-receiving cells called "ommatidia" to sense even the slightest movement of prey on the seafloor. On the other hand, some mesopelagic crustaceans (living in the twilight zone of the water column between 200 and 1000 m depths) have proportionally larger, compound eyes with lesser number of ommatidia to detect moving shadows and flashes of light. In complete contrast to these is the absence of eyes in the blind lobsters of the dark "bathyal" zone at 1000–4000 m depths.


Giant isopod *Bathynomus keablei*


Blind lobster, *Stereomastis*

Hydrostatic (water mass) pressure in the deepest part of the ocean is approximately 1000 times that at the sea level. Most crustaceans have good amounts of calcium carbonate exoskeletons which react with carbon dioxide in the sea water at such high pressures leaving their bodies vulnerable to the extreme cold environment. To counter this effect, amphipods extract aluminium from the bottom sediment and produce a protective gel-like coating with the help of digestive enzymes. At the cellular level, the body fluids of crustaceans contain high concentration of the "osmolyte" Trimethylamine N-oxide, which maintains their protein structure even at very high pressures.

Free-floating shrimp, *Sergia*

The interplay between low water temperature and low dissolved oxygen concentration on one hand, and the physical activities of the deep-sea crustaceans on the other, regulates the rates of "metabolism" (the sum total of all the processes needed to maintain life). For example, the free-floating shrimps (*Sergia*) undertaking extensive vertical migration spanning hundreds of metres have higher metabolic rates as compared to the sluggish benthic shrimps and other crustaceans. Few deep-sea crabs and shrimps have adapted to low oxygen conditions by having thin, long legs, which require less oxygen, and hence consume less energy.

Scarcity of food compels the animals to either depend on "marine snow", (sinking of "detritus", or dead particulate organic material) and nutrients from the upper layers of the water column or consume whatever is available. This has resulted in the evolution of diverse feeding habits, for example, "nektonic" (actively swimming) "sergestid" shrimp undertake vertical migration at night, coinciding with large aggregations of prey in shallower waters; the yeti crabs of hydrothermal vents feed on chemosynthetic bacteria; the squat lobster *Munidopsis andamanica* feeds on sunken wood; deep-water shrimps are generally carnivores and even omnivores; lobsters and crabs exhibit carnivory as well as scavenging.

Dairoides seafdeci *Psalidopus huxleyi* *Glyphocrangon*

The relatively less complex deep-sea environment offers less protection to its inhabitants as compared to the shallow water coral reefs and mangrove forests, which has resulted in the development of external body armour with varied sculpturing (*Dairoides seafdeci*) and accessory structures such as spines (scissor-foot shrimp *Psalidopus huxleyi*) and tubercles (*Glyphocrangon*).

Extreme environment in the deep-sea also influences reproduction (the process of generating offspring) in deep-sea crustaceans. Eggs of deep-sea squat lobsters and king crabs are larger than their shallow water counterparts with higher yolk content, which allows their "larvae", or immature life stages, to survive for longer periods without any alternate food source in the water column.

The “planktonic” (free-floating) monster shrimp *Cerataspis monstrosa* with an armoured body, previously considered to be an adult shrimp, is now known to be a larval form of the common deep-water shrimp *Plesiopenaeus armatus*.Scarcity of food and shelter in the deep-water realm has resulted in the evolution of peculiar symbiotic relationships (interactions between two or more organisms in close contact). Some typical examples include the hydrothermal vent shrimp *Rimicaris exoculata*, which cultivates symbiotic bacteria in its “branchial” (respiratory) chambers to receive direct nutrition; the parasitic copepods and isopods feeding on the blood and flesh of deep-sea fishes; the transparent amphipod *Phronima* is a “parasitoid” that attacks a “salp” (a transparent jelly-like barrel-shaped free-floating animal), consumes the host tissue, and uses the barrel as a mobile home and nursery for its offspring!!!

Nephropsis stewarti

Besides the well-known symbiotic relationships based on nutritional requirements, there are other interactions such as the bioluminescent bacteria in several deep-sea shrimps, the barnacles hitchhiking onto squat lobsters and so on. The deep-water crustaceans of the Indian seas are extremely diverse (almost 400 species known to date !!!) and include some of the most bizarre creatures depicted in this article. Studies on the documentation of these creatures began in the year 1871 during the British colonial period with the discovery of the deep-sea lobster *Nephropsis stewarti* off the Ross Island in the Andaman Sea. However, these studies developed further only after the commissioning of the Royal Indian Marine Survey Ship *Investigator* in 1881. From 1884 to 1912, the R. I. M. S. *Investigator* conducted exploratory surveys at 177 locations in the Indian seas, which resulted in documenting 309 species of deep-sea crustaceans, out of which 207 species were newly discovered!!! These discoveries appeared in several research articles in scientific journals and monographs published by the Indian Museum, Kolkata (now Zoological Survey of India) and Taylor and Francis, London. After Indian independence, very few deep-water surveys were done jointly with Norwegian government.

Recently, with the improvement in fishing technology, the expansion of marine fishing to the deeper waters and the appearance of rare crustaceans in the trawl catch landed at our fish landing centres, there has been a renewed interest in scientifically documenting these animals. Several marine biology-related research and academic institutes are actively pursuing this subject. In this regard, the Centre for Marine Living Resources and Ecology, Kochi has been conducting dedicated surveys of the deepwaters of the Indian Exclusive Economic Zone with its Fishery Oceanographic Research Vessel *Sagar Sampada*. These surveys have yielded large collections of deep-sea crustaceans including several new species, which are in the process of being described.

Kasagia sudhakari, a new crab

References

Alcock A. (1902) *A Naturalist in Indian Seas, or, four years with the Royal Indian Marine Survey Ship "Investigator"*. London: John Murray, 328 pp.

Baba K., Fujita Y., Wehrtmann I.S. and Scholtz G. (2011) Chapter 4. Developmental biology of squat lobsters. In: G.C.B. Poore, S.T. Ahyong, J. Taylor (Editors), *The Biology of Squat Lobsters* 20. Melbourne: CSIRO Publishing, pp. 105–148.

Boxshall G.A. (1998) Host specificity in copepod parasites of deepsea fishes. *Journal of Marine Systems* **15**: 215–223.

Bracken-Grissom H.D., Felder D.L., Vollmer N. L., Martin J.W. and Crandall K.A. (2012) Phylogenetics links monster larva to deep-sea shrimp. *Ecology and Evolution* **2**: 2367–2373.

Chamberlain S.C., Meyer-Rochow V.B. and Dossert W.P. (1986) Morphology of the compound eye of the giant deep-sea isopod *Bathynomus giganteus*. *Journal of Morphology* **189** (2): 145–156.

Donaldson H.A. (1975) Vertical distribution and feeding of sergestid shrimps (Decapoda: Natantia) collected near Bermuda. *Marine Biology* **31** (1): 37–50.

Frank T.M. and Case J.F. (1988) Visual spectral sensitivities of bioluminescent deep-sea crustaceans. *The Biological Bulletin* **175** (2): 261–273.

Frank T.M., Johnsen S. and Cronin T.W. (2012) Light and vision in the deep-sea benthos: II. Vision in deep-sea crustaceans. *The Journal of Experimental Biology* **215**: 3344–3353.

Hoyoux C., Zbinden M., Samadi S., Gaill F. and Compère P. (2009) Wood-based diet and gut microflora of a galatheid crab associated with Pacific deep-sea wood falls. *Marine Biology* **156** (12), 2421–2439.

Kobayashi H., Shimoshige H., Nakajima Y., Arai W. and Takami H. (2019) An aluminum shield enables the amphipod Hirondellea gigas to inhabit deep-sea environments. *PloS One* **14** (4): e0206710.

Madin L.P. and Harbison G.R. (1977) The associations of Amphipoda Hyperiidea with gelatinous zooplankton—I. associations with Salpidae. *Deep Sea Research* **24**: 449–463.

Marshall, N. B. 1979. *Deep-sea biology: Developments and perspectives*. New York: Garland STPM Press.

Meyers-Rochow V.B. and Walsh S. (1978) The eye of mesopelagic crustaceans. III. *Thysanopoda tricuspidata* (Euphausiacea). *Cell and Tissue Research* **195**: 59–79.

Padate V.P., Manjebrayakath H. and Ng P.K.L. (2019) *Kasagia sudhakari*, a new species of deep-sea spider crab (Crustacea: Brachyura: Majidae) from the southeastern Arabian Sea. *Marine Biology Research* **15** (3): 290–296.

Silver M. (2015) Marine snow: a brief historical sketch. *Limnology and Oceanography Bulletin* 24(1): 5–10.

Stevens B.G. (2019) *Adaptations of Crabs to Life in the Deep Sea*. Available at: https://oceanexplorer.noaa.gov/explorations/02alaska/background/crabs/crabs.html oaa.gov/explorations/02alaska/background/crabs/crabs.html (accessed 16 October 2019)

Yancey P.H., Blake W.R. and Conley J. (2002) Unusual organic osmolytes in deep-sea animals: adaptations to hydrostatic pressure and other perturbants. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* **133** (3): 667–676.

Zbinden M., Le Bris N., Gaill F. and Compère P. (2004) Distribution of bacteria and associated minerals in the gill chamber of the vent shrimp *Rimicaris exoculata* and related biogeochemical processes. *Marine Ecology Progress Series* **284**:237–251.

New Records of Polyclads from Lakshadweep Islands

Sudhanshu Dixit
Centre for Marine Living Resources and Ecology, Kochi
Email: sid2130@gmail.com

Polyclads are a group of colourful marine flatworms yet to receive greater attention to unravel their biology, role in ecosystem functioning, distribution pattern and, among others, the commercial significance both in terms of ecotourism via diving and aquarium industry. When we think of flatworms, a picture of small, slimy, weird and waggling parasites may come to our mind. With their distinct and captivatingly colourful pattern, polyclads truly stand out from crowd of other flatworms. In this article collection of polyclads from Lakshadweep Islands and their identification are described. As many as nine new species are reported

1. Introduction

Polyclads (Order Polycladida; Phylum Platyhelminthes) are among the oldest living primitive creatures which are free living, unsegmented, stunning and intriguingly coloured. The average size range of these bilaterally symmetrical primitive life-forms is usually from 10mm to 15mm. Despite being tiny, they are "ace predators" with very complex body systems. These soft bodied dorso-ventrally flattened possess simple yet effective body plan. Unlike their sparsely granule ventral surface, the dorsal surface is covered with pigment granules imparting attractive colour and patterns. They possess both male and female reproductive systems (complex, hermaphroditic) with well-developed nervous system. These worms can be found crawling or hiding under stones from intertidal to sub tidal region, sometimes swimming over coral reefs and sandy slopes. Most species of polyclads are active under darker/nocturnal conditions.

2. Distribution and Ecology

Polyclads are found throughout the world but the tropical species are most colourful Similar to many other aspects of their biology, habitat preference of polyclads is not yet well known. Though their species are reported to be found from intertidal to greater depths of ocean with species inhabiting reef areas tend to be more colourful and staggering than those found in intertidal area under stones and darker crevices. This can be a protective measure or an act of mimicry by displaying brighter colours to show unpalatability. Polyclads are often confused with nudibranchs (molluscs) due to bright colours and patterns

Polyclads are known to feed upon sponges, ascidians, small anemones and many polyclads strictly feed upon bivalve molluscs thus creating complications in shellfish industry. On some occasions polyclads are also seen preying upon crabs, molluscs and other flatworms too. Although potential predators are not well known due to lack of studies, some reports suggest puffer fishes eating these flatworms. Reproductive behaviour of polyclads is quite bizzare and was studied quite late and published in *Nature* in 1998. They are credited to engage in a ritual called, "penis-fencing". For this, two sexually aroused worms try to stab each other with their erected penis on any part of the body and inoculate sperms which can be visible as white spots. Once fertilised, eggs are laid on a hard substratum in clusters. Mostly eggs hatch into a young worm while some hatch into Muller's or Gotte's larvae which feed on plankton and eventually metamorphose into young adults.

Polyclads are one of the lesser known marine faunal groups from Indian waters. Spotting one in wild and then its collection is the tricky part. Even if a polyclad is collected, the battle is still half won until it is fixed and preserved properly for further taxonomic studies. Many species are often cryptically camouflaged and difficult to spot even in day light. The above-mentioned reasons are good enough to pull off many young researchers who try to study them.

3. Polyclads' long history and inadequate scientific attention

The first monograph published on these worms came in the year 1884 by Arnold Lang from Bay of Naples in which he illustrated drawings of living worms which are followed till date and are considered as masterpieces in polyclad world. Polyclad research from India came into existence when first report on polyclads was published by Laidlaw in the year 1902, in which he described 7 new species of polyclads from Laccadives (Lakshadweep). Then after a gap of hundred years, polyclads started appearing in scientific reports as new records and new descriptions. Around 1010 species are reported from world oceans out of which 57 species are reported from Indian waters. Till date 17 species are described from India waters as new species to science out of which 10 species are described recently in the years 2017, 2018 and 2019 (Table 1).

Table 1. List of polyclads species described from India (2017 onwards)

Sl. No	Species	Major Trait	Reference
1	*Pseudoceros galatheesnis*	Blue background colour with orange median stripe	Dixit et al. 2017 a
2	*Pseudoceros nigropunctatus*	Background body colour mix of light brown and orange shades, numerous black coloured spots of variable sizes	Dixit et al. 2017 a
3	*Pseudoceros auranticrinis*	Cream background colour, orange pseudotentacles	Dixit et al. 2017 b
4	*Pseudoceros vishnui*	Purple to violet spots on dorsum with margin made up of blue spots	Dixit et al. 2017 b
5	*Prosthaceraeus fuscolineatus*	Brown longitudinal lines on dorsum and black erected tentacles	Dixit et al. 2017 b
6	*Pseudceros meenae*	Cream background colour, three marginal bands (inner black followed by orange and white)	Dixit et al. 2018
7	*Acanthozoon fucobulbosum*	Brown and bulbous papillae of variable sizes on dorsum	Dixit et al. 2018
8	*Pseudoceros stellans*	Brown background colour with a black marginal band, lighter microdots and a unique pattern of white dorsal blotches on dorsum	Dixit et al. 2019
9	*Pseudoceros agattiensis*	brown to black background colour, three longitudinal white bands on dorsum	Dixit et al. 2019
10	*Stylostomum mixtomaculatum*	Creamish-buff dorsal surface with black minute spots arranged in a circular manner	Pitale & Apte 2019

4. Collection, Preservation and Identification

Polyclads indeed are very attractive but have always been notoriously difficult to preserve for taxonomic study. Therefore, many biologists rather ignored to investigate on this group. Being touch or abrasion sensitive, they can shrink or disintegrate even on a slight disturbance. Thus, fixing/preserving them in formalin will not serve the purpose of taxonomic studies.

To find and collect these animals pose a daunting challenge. Due to their small size, cryptic nature and ability to fit in small spaces, it is always strenuous and hard to spot a flatworm. It is even quite tricky underwater to scoop them into a container since they are too fragile to be picked up by hands. After collection, flatworms must be kept in separate containers as they secrete mucous when touched or stressed which can be toxic for other flatworms. The process of being autolysis under stress conditions is another major challenge that biologists must tackle between the time of collection and preservation.

5. Polyclad studies at CMLRE

As a part of the CMLRE's continuing efforts on biodiversity studies of coral reef and associated organisms, many visits to Lakshadweep Islands and underwater diving were conducted. Coral reefs, the "rainforests" in the seas, are quite colourful themselves and, many animal-groups such as sea anemones, feather stars, nudibranchs and marine flatworms inhabiting within reefs are also colourful. Polyclads are an integral part of coral reef ecosystem as they prey on variety of sessile and mobile animals.

During the diving many of the spotted specimens were collected. Identification of Polyclads is based on external as well as internal characters. External characters like shape and size of pharynx, number and position of eyes, number of gonopores, presence or absence of sucker and most importantly colour patterns are studied for identification. For generic and species level identification and especially for similarly coloured species, histological studies of male and female reproductive structures and molecular studies have to be carried out to confirm the identity.

6. Conclusion

Limited number of specimens also adds to the difficulty in studying them thus information regarding their ecology, food and feeding habits, prey predator relations and reproductive behaviour is also meagre. With advances in preservation techniques and fast developing underwater photography, polyclads can be a good subject to study, to describe and to find missing links in the evolutionary history. Economically and scientifically, flatworms are best known for their role in regeneration studies, bioactive compounds from their skin and mucous, bio mimicry and most significantly for evolutionary studies. Also, studies on their toxins can be vital in development of various important drugs used for benefit to mankind.

Pseudoceros paralaticlavus on its ascidian prey (Agatti Island by Dr. Sudhanshu Dixit).

Pseudobiceros hymanae on sandy substrate at 20 meters depth (Agatti Island by Dr. Sudhanshu Dixit)

An undescribed polyclad from Agatti Island (Agatti Island by Dr. Sudhanshu Dixit)

Pseudoceros galatheensis crawling over rock in intertidal area (Agatti Island by Dr. Sudhanshu Dixit)

References:

Dixit, S., Raghunathan, C., Chandra, K.: Two new marine flatworms (Polycladida: Pseudocerotidae) from Andaman & Nicobar Islands, India. Zootaxa, 4221 (1), 111–122 (2017a).

Dixit, S., Raghunathan, C., Chandra, K.: Two new *Pseudoceros* (Polycladida: Pseudocerotidae) and a *Prostheceraeus* (Polycladida: Euryleptidae) from Andaman and Nicobar Islands, India. Zootaxa, 4269 (4), 495–512 (2017b).

Dixit, S., Sivaperuman, C., Raghunathan, C.: Description of two new pseudocerotids (Rahabditophora: Rhabditophora; Polycladida) from Andaman & Nicobar Islands, India. Zootaxa, 4403 (2), 365–377 (2018).

Dixit, S., Bayyana, S., Manjebrayakat, H., Saravanane, N., Sudhakar, M.: Polyclad fauna of Agatti Island, Lakshadweep, India: new records and description of two new species. Zootaxa 4657 (2): 246–260 (2019)

Laidlaw, F.F.: The marine Turbellaria with an account of the anatomy of some species. In: Gardiner, J.S. (Ed.), The Fauna and Geography of the Maldive and Laccadive Archipelagoes: Being the Account of the Work carried on and of the Collections made by an Expedition during the years 1899 and 1900. Vol. 1. The University Press, Cambridge, pp. 282– 312 (1902).

Lang, A.: Die Polycladen des Golfes von Neapel und der angrenzenden Meeresabschnitte. Eine Monographie. Fauna Flora des Golfes v. Neapel, Leipzig, 11, 1–688 (1884).

Pitale, R., Apte, D.: Intertidal Euryleptid polyclads and description of a new Stylostomum Lang, 1884 from Maharashtra, India. Zootaxa 4652 (2): 317–339 (2019)

Polychaetes: The Ocean Floor Cleansers

Aiswarya Gopal
Centre for Marine Living Resources, Kochi
Email: gopalaiswarya@gmail.com

The segmented worms, the Polychaetes (poly=many, chaeta=bristles) under Phylum Annelida in (Kingdom Animalia) are mainly marine forms (11,881 species, WoRMS, 2019) distributed all over the ocean at all depths from poles to tropics, coast to deep sea with only a few species (168 species) being reported from freshwater. While some species are pelagic, the majority are benthic dwelling in or on the seabed substratum, they usually live in the top layers of sediments or on hard substrates like corals, coral rubbles, rocks etc.

1. Introduction

Polychaetes are the most abundant and diverse group in all marine sediments. The community structure of polychaetes and their distribution on a global scale are mainly affected by the dispersal of larvae and their settlement, sediment stability, sediment grain size and texture, recirculating currents, hydrographic parameters like temperature, salinity, oxygen etc. and food availability (in the form of organic matter and interstitial organisms). Most marine benthic invertebrates have planktonic larvae which have great dispersal abilities and the suitability of habitats can vary with space and time, greatly affecting the dispersal, settlement and survival of larvae (Carson & Hentschel, 2006). Studies conducted along the eastern Arabian Sea margin revealed the fact that the main breeding phase of polychaetes coincides the monsoon season (Abdul Jaleel *et al*., 2015).

2.1 Description of Taxa

Polychaetes are mainly classified based on their body structure into subclasses Errantia and Sedentaria. The Errantians are chiefly crawlers or swimmers, with well-developed parapodia (foot with chaetae or bristles) and are principally scavengers or predators with strong jaws. Sedentarians are tube dwelling or burrowing forms, with reduced parapodia (uncini), mainly feeding on deposited organic matter on the sediment or suspended particles in the water column (Fauchald and Jumars, 1979). Among polychaetes, some species build their tubes using chaetal fibres produced by spinning glands or by using mucus for entrapping sediment particles to construct tubes. Some species dig galleries in live coral (Fig.1. Christmas tree worm) or dead coral skeletons, using their well-developed jaws or live attached to the interstices of coral, sponges, or coarse sediment.

Sediment texture and grain size which form the substratum play a vital role in their colonization (Gray & Elliott, 2009). The organic matter (OM) in marine sediments which forms food of deposit and suspension feeding polychaetes originates directly or indirectly from primary production in the water column and also from terrestrial materials brought to oceans through rivers etc. The quantity and preservation of organic matter reaching the bottom is strongly influenced by the supply of OM from the overlying water column, settling flux and sedimentation rate, decomposition rate of the organic matter, availability of dissolved oxygen, sediment grain size etc. Polychaetes plays a key role in benthic-pelagic coupling in the marine realm. They are major contributors of secondary production, as they obtain energy by feeding on other organisms or detritus falling on the sediments.

2.2 Distribution and Ecological Roles

Polychaetes are known to occur also in extreme conditions through their physiological and morphological adaptations. In the oxygen minimum zones (oxygen level ≤2ml/l, ~100-1200m depth), certain polychaetes like *Prionospio pinnata, Levinsenia gracilis* can thrive in hypoxic conditions (oxygen level ≤2ml/l) due to smaller size with high surface area volume ratio and well-developed extended branchiae which enhances their capacity for oxygen uptake from oxygen minimum waters (Levin, 2003). Besides these, the biochemical adaptations of OMZ tolerant polychaete species is due to the presence of pyruvate oxidoreductase enzymes that are involved in their anaerobic metabolism, enabling them to survive in such hypoxic conditions (Gonzalez & Quinones, 2000). These adaptations have enabled polychaetes to thrive in low oxic and hyperthermal zones in the oceans. Due to the sedentary nature and their ability to respond environmental to stress in several ways, polychaetes can be used as indicators of environmental quality, organic enrichment, organic contaminants, heavy metals etc. They also play a key role in chemical transformation of pollutants settling on the seafloor, which may accumulate in their tissues, and are subsequently conveyed through the food chain.

“Pomepii worms” are the most heat tolerant polychaetes (45 to 60 °C and even upto 105°C), and were found in hydrothermal vents in the Pacific Ocean with two known species *Alvinella pompejana* and *Alvinella caudata.* They possess symbiotic relationship with chemolithotrophic bacteria on their body, making them thrive at high temperatures. *Riftia* spp., *Lamellibranchia* spp., are some examples of other polychaete species occurring in the hydrothermal vents, cold seeps etc. “Bone eating worms" or "zombie worms” under the genus *Osedax* with 26 known species are polychaetes lacking mouths and guts which feeds on whale carcasses on the deep-sea floor. These worms possess root like structures which secrete acid to dissolve the bone and to release protein and lipids. The roots houses symbiotic bacteria playing a major role in digesting the lipids and protein and releasing nutrients playing a vital role in nutrition of the worms (Vrijenhoek *et al*., 2009).

Polychaetes are a key link in the energy transfer between primary producers and tertiary consumers especially by forming food of demersal fishes and shellfishes (Parulekar *et al*., 1980). Information on their abundance, biomass and community composition is useful for estimating the availability of potential food for demersal fishes. Organic matter falling on the sediment is ingested by polychaetes and egested as faecal pellets. These pellets, degraded by microorganisms, release nutrients back to water column, thereby playing a major role in cleaning the ocean floor. The movement, burrowing, tube-building, and feeding activities of polychaetes cause the reworking of sediment particles, thereby enhancing pore ventilation, and mixing of OM to deeper layers of sediments, which makes the OM available for microbial remineralization – a process termed as ‘bioturbation’ (Hutchings, 1998).

2.3 Collection and Analyses

The polychaetes which reside in the sediment layers are collected using a sediment grab (Eleftheriou 2013; Fig.2). A portion of sediment from grab is transferred to sieve using 300μm or 500μm mesh gently under running seawater. The residual sediment left on the sieve with organisms is usually narcotised with magnesium chloride solution and preserved in 5% buffered formalin solution. These samples are stained overnight using Rose Bengal solution which stains only tissues giving them a pink colour. The stained polychaete specimens are sorted out and identified up to species level under stereo-zoom and compound microscope using standard taxonomic keys (Fauchald, 1997) and revisions of polychaetes.

2.4 Economic Benefits

Polychaetes, being nutritionally wholesome, are used as feed for crustaceans and fish in aquaculture industry. The brood stock are fed with polychaetes to boost the supply of essential fatty acids known to stimulate gonadal development. They are also used as fresh bait in sport and commercial fishing. Chemists have isolated and characterised more than 121 compounds from polychaetes (Coutinho *et al*., 2018). Nereistoxin extracted from *Lumbriconereis heteropoda* is used to produce pesticides such as Padan and Cartap. These pesticides are widely used in agriculture due to their low toxicity and high insecticidal activity, but safe to humans and domestic animals because it can be decomposed and excreted. Some polychaetes are fouling organisms especially Sabellidae and Serpulidae which are tubiculous that damage to ships hulls, water pipes etc. submerged in seawater, causing increased maintenance costs.

3 Research on Benthos at CMLRE

The Marine Living Resources Programme on Marine Benthos is a part of major research effort of the CMLRE. The Fishery Oceanographic and Research Vessel *Sagar Sampada*, is the major platform used for carrying out the benthic studies of Indian EEZ. The Marine benthos programme began during the IX plan (1997-2002) as a multi-institutional project aimed at gaining a comprehensive picture of benthic productivity of the continental shelf regions of the EEZ. Studies on marine benthos continued in the Xth, XIth, XIIth plans concentrating on the benthic communities of continental slope of Indian EEZ, effect of trawl ban on benthos, island ecosystem studies etc.

The abundance and biomass of macrobenthos along Indian EEZ with number of polychaete species is presented in Table 1. In the running 14th Finance Commission Scheme (2017-20), studies on marine benthos have been focusing on the community structure of polychaetes in the insular slope of Andaman Nicobar margin and in the intertidal regions of Lakshadweep Islands has been conducted as a part the project Resource Exploration and Inventorization System (REIS). Two new species of polychaetes *Pettibonella shompens* Gopal *et al.*, 2014 (Fig. 3), *Armandia sampadae* Gopal *et al*., 2016 (Fig. 4) have been described from CMLRE collected in the surveys along the insular margin of Andaman and Nicobar Islands. *Pettibonella shompens* has been collected at a depth of 50m in coralline sandy sediments off Car Nicobar Island and species name “shompens” refers to the tribe inhabiting in the islands. *Armandia sampadae* has been collected from at a depth of 50m in coralline sandy sediments off Rutland Island, Andaman Islands with species name “sampadae” in the honour of FORV *Sagar Sampada*, which is the backbone of the marine biological studies of Indian Ocean.

Table 1. Standing stock of benthos and number of polychaete species recoded by CMLRE efforts from samples collected along Indian EEZ

Location	Depth (m)	Abundance of macrobenthos (no.m^{-2})	Biomass of macrobenthos (g.m^{-2})	No. of species of polychaetes	Reference
North Eastern Arabian Sea (NEAS)	30-200 200-1000	1340 156	5.7 1.8	165 121	Joydas and Damodaran, 2009; Damodaran, 2010; Anilkumar, 2017
South Eastern Arabian Sea (SEAS)	30-200 200-1000	1743 584	7.78 6.03	 194	Damodaran, 2010 Abdul Jaleel, 2012
North Western Bay of Bengal (NWBoB)	30-200 200-1000	812 1266	4.12 4.46	60 58	Ganesh & Raman, 2007; Rao *et al*., 2009; Damodaran, 2010; Raman *et al*., 2012
South Western Bay of Bengal (SWBoB)	30-200	776	6.83	113	Khan & Lyla, 2012; Manokaran *et al*., 2013
Andaman and Nicobar Islands	50-200	1166	4.99	606	Aiswarya Gopal, 2017

4 Conclusion

Polychaetes are the dominant fauna in the benthic ecosystem and plays a major role in ecosystem functioning. The abundance and biomass of polychaetes is a major dataset used in the prediction of demersal fishery resources in the area, as they are major feed of demersal fishes and shell fishes. Polychaetes plays an important role in the degradation of organic matter back to nutrients via bioturbation and ingesting the organic matter in the sediments thereby, cleaning the ocean floor and forming a connecting link between pelagic and benthic realm. They are used to assess the environmental health as they are indicators of pollution, natural disasters (e.g. tsunami).

References

Abdul Jaleel, K.U.: Macrobenthos of continental margin (200-1000m) of south eastern Arabian Sea with special reference to polychaetes. Ph.D. Thesis. Cochin University of Science and Technology, Kochi. 238pp (2012).

Aiswarya Gopal: Benthic macrofauna of Andaman and Nicobar insular margin with emphasis on polychaetes. Ph.D. Thesis. Cochin University of Science and Technology, 284pp (2017).

Anilkumar, P.R..: Macrobenthos of the north western continental margin (200-1000m) of India with special reference to polychaetes. Ph.D. Thesis. Cochin University of Science and Technology. 229pp (2017)

Coutinho, M.C.L., Teixeira, V.L., Santos, C.S.G.: A review of "polychaeta" chemicals and their possible ecological role. *Journal of chemical ecology 44*(1), 72-94 (2018).

Damodaran, R.: Marine manpower development programme, MLR related research onboard FORV *Sagar Sampada*, benthic productivity. Final Report. Department of Marine Biology, Microbiology and Biochemistry, CUSAT, Kochi, 214pp (2010).

Eleftheriou, A.: Methods for the study of marine benthos. 4th edn. John Wiley & Sons, UK (2013).

Fauchald, K.: The Polychaete Worms: Definitions and Key to the Orders, Families and Genera. *Natural History Museum of Los Angeles County, Science Series* (1977).

Fauchald, K., Jumars P.A.: The diet of worms: a study of polychaete feeding guilds. *Aberdeen University Press* 17 (1979).

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

González. R.R., Quiñones, R. A.: Pyruvate oxidoreductases involved in glycolytic anaerobic metabolism of polychaetes from the continental shelf off central-south Chile. *Estuarine, Coastal and Shelf Science* 51(4), 507-519 (2000).

Gopal, A., Abdul Jaleel, K.U., Saramma, A.V., Sanjeevan V.N.: A new species of polychaete, *Pettibonella shompens* sp. nov. (Orbiniidae), from the Nicobar Islands, North Indian Ocean. *Marine Biology Research* 10(10), 1033-1037 (2014).

Gopal, A., Abdul Jaleel, K.U., Usha, V.P., Anil Kumar, V.: *Armandia sampadae,* a new species of polychaete (Opheliidae) from Andaman Sea, Northern Indian Ocean. *Journal of the Marine Biological Association of the United Kingdom* 96(8), 1625-1632 (2016).

Gray, J.S., Elliott, M.: Ecology of marine sediments: from science to management. 2nd edn. *Oxford University Press on Demand.* (2009).

Hutchings, P.: Biodiversity and functioning of polychaetes in benthic sediments. *Biodiversity and conservation* 7(9), 1133-1145 (1998).

Joydas, T. V., Damodaran, R.: Infaunal macrobenthos along the shelf waters of the west coast of India, Arabian Sea. *Indian Journal of Marine Sciences* 38(2), 191-204 (2009).

Khan, S.A., Lyla, P.S.: Final Report of Research Project Marine Benthos of Indian EEZ (Southeast coast of India). CAS, Annamalai University, Tamilnadu. 311pp (2012).

Levin: Oxygen minimum zone benthos: Adaptation and community response to hypoxia. In: *Oxygen minimum zone benthos: adaptation and community response to hypoxia* (Eds. Gibson RN & Atkinson RJA, 2003) *Oceanography and Marine Biology: An Annual Review* 41, 1-45 (2003).

Manokaran, S., Khan, S. A., Lyla, P. S.: Macrobenthic composition of the southeast continental shelf of India. *Marine Ecology,* 36(1), 1-15 (2015).

Rao, Y.K.V. Macrobenthos off North East Coast of India, Bay of Bengal: A case for Inshore, Shelf and Upper Slope Areas. Ph.D. Thesis, Andhra University, Vizag. 199pp (2009).

Vrijenhoek, R.C., Johnson, S.B., Rouse, G.W.: A remarkable diversity of bone-eating worms (Osedax; Siboglinidae; Annelida). *BMC biology 7*(1), 74 (2009).

Fig.1. *Spirobranchus giganteus*, a Christmas tree polychaete on the corals of Lakshadweep waters (Photo courtesy: CMLRE)

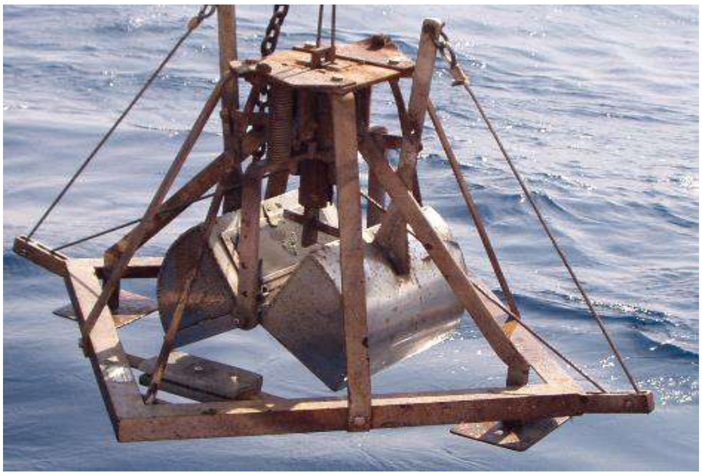


Fig.2. Smith-McIntyre grab, useful for collection of sediment samples for benthos (Photo courtesy: CMLRE)

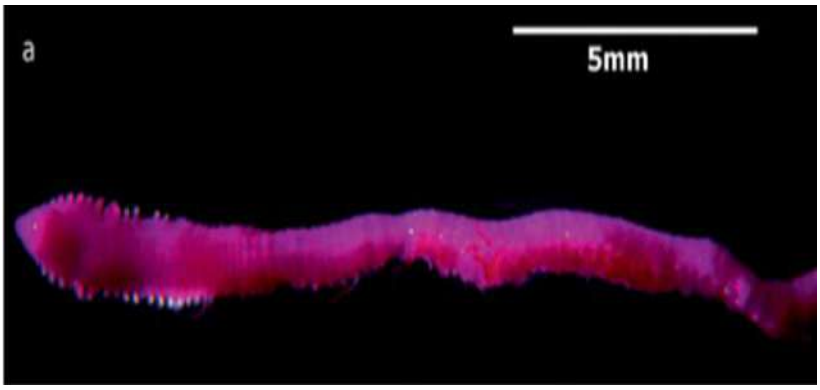


Fig.3. *Pettibonella shompens*, a polychaete named after the tribe inhabiting in the Nicobar Islands

Fig.4. *Armandia sampadae*, a polychaete named after the research vessel FORV *Sagar Sampada*, which is the backbone of the ocean studies in India

Several new Records of Echinoderms from India's EEZ

Usha V. Parameswaran
Centre for Marine Living Resources and Ecology, Kochi
Email: usha.param@cmlre.gov.in

Excepting the holothurian sea-cucumbers, most other classes of echinoderms bearing radial symmetry are readily recognised. They have another notable feature, the 'water vascular system', which is a hydraulic system of canals and tubes. This network is used for locomotion, food and waste transportation, respiration and excretion, and is not found in any other group of the animal kingdom. This article provides an account of CMLRE's studies on distribution of echinoderms in the EEZ of India as well as noting of 10 new record and identification of one new species so far.

1. Introduction

The starfishes (also known as sea stars), along with related organisms, represent a distinctive group of animals and are collectively classified under the Phylum 'Echinodermata'. This name was coined by the German Scientist Jacob Klein in 1734, from the ancient Greek words '*echinos*', meaning 'spiny' and '*derma*', meaning 'skin'. The term refers to the hard shell and spiny structures commonly found in the members of this group. The hard shell is composed of calcite, which is a form of calcium carbonate which is invested with magnesium. The shell or 'endoskeleton' is composed of interlocking plates of calcite, which may be rigid or loose and flexible, and protects their soft tissues from damage. The echinoderms are exclusively marine and, cannot be found on land or in freshwater ecosystems (Hyman, 1955; Pawson, 2007).

All echinoderms are readily recognised by their radial (i.e. five-pointed) symmetry, with a central mouth located on their ventral side, and radiating arms. Another notable feature is the presence 'water vascular system', which is a hydraulic system of canals and tubes. This network is used for locomotion, food and waste transportation, respiration and excretion, and is not found in any other group of the animal kingdom (Hyman, 1955).

2. Diversity and classification

Over 7200 species of echinoderms are presently known from the world's oceans, and they can be found at all ocean depths, from the coasts to deep-ocean trenches. These species are classified into five distinct 'classes', namely the Asteroidea (sea stars), Ophiuroidea (brittle stars and basket stars), Crinoidea (feather stars and sea lilies), Echinoidea (sea urchins and sand dollars) and Holothuroidea (sea cucumbers).

The class Asteroidea comprises the sea stars, which have a star-shaped or pentagonal body. They are the most easily recognised group among echinoderms which are commonly used as universally recognisable symbols in marine realm. The arms of asteroids each possess a ventral groove called the 'ambulacrum', which lead to the mouth. Parts of the water-vascular system, known as ‘tube feet’, project from this groove, and are used extensively for locomotion, burrowing, feeding 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. There are around 1900 species of sea stars, out of which nearly 160 species are reported from Indian waters (WoRMS Editorial Board, 2019; Sastry, 2007).

The class Ophiuroidea is composed of the brittle stars and basket stars. Their body consists of a central disc, with five (sometimes 6 or 7) radiating arms. The dorsal and ventral surfaces of the disc are covered by skin, usually embedded with thick calcite plates. Basket-stars are distinguished in having characteristic branching arms, while brittle stars have simple arms. Ophiuroids are diverse in their feeding modes – from active predation and scavenging, to detritivory and suspension feeding. Over 2100 species of ophiuroids are reported from the oxeans and about 180 of them are reported from Indian seas (WoRMS Editorial Board, 2019; Sastry, 2007).

The class Crinoidea comprises the un-stalked ‘feather stars’ and stalked ‘sea-lilies’. Their 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. While the feather stars are capable of active swimming, they are usually found attached to the seabed by means of cirri. In contrast, the sea lilies are predominantly sessile. The crinoids use their arms and pinnules to filter suspended organic matter from the near-bottom water, which are carried to the mouth. There are approximately 670 species of crinoids known from the oceans, and about 65 species are reported from Indian waters (WoRMS Editorial Board, 2019; Sastry, 2007).

Class Echinoidea includes the sea urchins and sand dollars. The common feature within this class is the occurrence of a thick test, comprising interlocking plates, which bears numerous spines of varying size and shape. In the sea urchins or ‘regular urchins’, the test is spherical or nearly so, and the spines are usually long and stout. The sand dollars which have flattened tests are collectively called the ‘irregular urchins’. The mouth is ventral in all echinoids, and in regular urchins, it 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. Echinoids may be active predators, algal grazers or detritivores. Around 800 species of echinoids are known from around the world, out of which about 120 species are recorded from the Indian seas (WoRMS Editorial Board, 2019; Sastry, 2007).

The Holothuroidea or sea cucumbers are the only class to have outgrown the radial symmetry which is characteristic of echinoderms, and have developed bilateral (i.e. two-sided) symmetry. The calcareous skeleton of sea cucumbers 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. Holothurians are chiefly detritivorous, either ingesting and digesting organic matter directly from sediments, or suspension feeders, making use of their tentacles. Over 1700 species of sea cucumbers are known around the world, out of which about 150 species have been reported from Indian waters (WoRMS Editorial Board, 2019; Sastry, 2007). 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 about 66 species are economically exploited across the world. Overfishing and unmanaged harvesting are reported from several regions, leading to decline in population of several sea cucumber species (Purcell et al., 2012). For this reason, 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.

3. Ecological role and importance

Except for a few species of swimming deep-sea cucumbers, all adult echinoderms are benthic organisms, i.e. they live in or on the seafloor. 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.

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. By this process, they incorporate organic matter and oxygen into deeper layers of sediments and thereby enhance remineralization processes which occur there (Uthicke, 1999). Many forms, particularly sea urchins and sea stars are apex predators and occupy keystone position in some ecosystems. Owing to their relatively large size among the sea-floor fauna and their diverse feeding habits, echinoderms are important members of marine food webs. Many species also interact with other organisms such as sponges, gorgonids and also other echinoderms to form various obligatory and facultative associations. Brittle stars, in particularly, are known to be epiboints on sea fans, sea sponges and sea urchins (Parameswaran et al., 2013).

Other organisms, like polychaete worms are known commensals in the ambulacral grooves of starfishes, while polychaetes, crustaceans, fishes etc. are known to be commensals or parasites in the cloaca of sea cucumbers. Sexes are separate in all echinoderms, but conspicuous external sexual dimorphism is very rare (Parameswaran et al., 2013). Fertilization occurs externally after broadcast spawning, and the resulting larvae undergo a planktonic phase (i.e. floating in the water column) before settling and transforming into the adult forms. However, some echinoderms are known to brood juveniles within their bodies.

Owing to their calcareous skeleton, echinoderms are commonly found as well-preserved fossils throughout their evolutionary history, starting from the Cambrian Period (540-485 million years ago). Nearly 13,000 species of fossil echinoderms have been discovered around the world. This exceptional fossil record of echinoderms has enabled scientists to understand their evolution in relation to the evolution of the world's oceans. Thus, it can be summarised that echinoderms are an important group both from an ecological and evolutionary perspective.

4. Threats to echinoderm diversity

Echinoderms are highly vulnerable to natural as well as anthropogenic disturbances such as ocean warming, acidification, oxygen depletion, climate variability, bottom trawling and other exploitative activities. Over 60 species of holothurians are exploited across the world, and 172 species are under the threat of extinction (IUCN Red List), as a result of extensive harvesting

(Purcell et al. 2012). 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. Many countries have adopted conservation measures for protection of echinoderms including ban on the trade of holothurian meat.

Echinoderms, along with other invertebrates (corals, sponges etc.) also form major by-catch in bottom trawls. Since the endoskeletons of echinoderms are composed of calcium carbonate (calcite), the increasing acidification of the oceans poses a serious threat to them. Scientists have provided proof that the formation of skeleton or 'calcification' in larval and juvenile echinoderms are strongly impacted under acidified conditions (Dupont et al., 2010). Climate variability and the increasing spread of oxygen deficiency in near bottom waters also poses serious threats to echinoderms, as they are known to be highly susceptible to such oxygen depleted conditions.

A study carried out at CMLRE, Kochi based on extensive field sampling on-board FORV Sagar Sampada has revealed that within the southeastern Arabian Sea, the distribution of echinoderms is governed by the availability of suitable seafloor habitats as well as oxygen availability (Parameswaran et al., 2018). In this region, the echinoderms were found to be very poorly represented in areas which experience seasonal oxygen depletion, while they thrived in high diversity and abundance in well oxygenated areas.

5. CMLRE Research on Echinoderms

While around 700 species of echinoderms have been recorded from Indian waters (Sastry, 2007; Parameswaran, 2018; Samuel, 2018), most of the studies are restricted to the shallow waters, close to the shore (up to about 200m depth). Very little is known about this group from the deep-sea areas around India, and next to nothing is known about their distribution beyond 1000m depths.

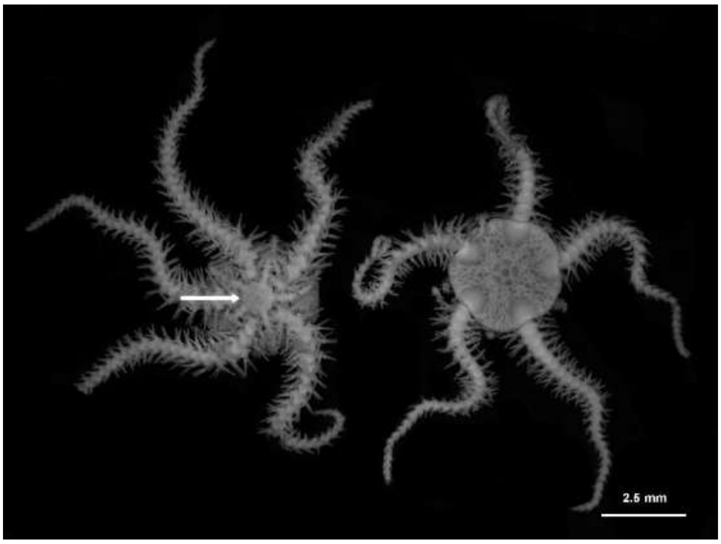
To explore offshore regions, dedicated efforts are ongoing at CMLRE to understand the diversity of flora and fauna, including echinoderms in the deep-sea regions of the northern Indian Ocean. In 2012, a new species of deep-sea brittle star was discovered through CMLRE's efforts and it was named as *Asteroschema sampadae*, the species name being selected in honour of the FORV Sagar Sampada on which it was collected (Parameswaran & Abdul Jaleel, 2012).

Table 1 shows the new species and new records of echinoderms recorded from Indian waters through efforts of CMLRE. Research is also being conducted on the ecological importance in coral reef ecosystems around the Lakshadweep Islands.

Table 1. Echinoderm species recorded from Indian waters through CMLRE's efforts

No.	Species name	Type	Locality	Reference
1.	*Asteroschema sampadae* Parameswaran & Abdul Jaleel, 2012	New species	Off Cape Comerin, 450m	Parameswaran & Abdul Jaleel (2012)
2.	*Ophiodaphne scripta* (Koehler, 1904)	New record	Off Trivandrum, 50-100m	Parameswaran et al. (2013)
3.	*Ophiomyces delata* Koehler, 1904	New record	Andaman Islands, 55m	Parameswaran et al. (2015)
4.	*Saracrinus angulatus* (Carpenter, 1884)	New record	Andaman Sea, 650m	Khader et al. (2018)
5.	*Amphiura (Amphiura) constricta* Lyman, 1879	New record	Off Trivandrum, 100m	Parameswaran et al. (2018)
6.	*Amphiura (Fellaria) heptacantha* (Mortensen, 1940)	New record	Off Cape Comerin, 30m	Parameswaran et al. (2018)
7.	*Ophiosphaera insignis* Brock, 1888	New record	Off Cape Comerin, 50m	Parameswaran et al. (2018)
8.	*Ophiacantha dallasii* Duncan, 1879	New record	Off Cape Comerin & Nicobar Islands, 50m	Parameswaran et al. (2018)
9.	*Ophioconis cupida* Koehler, 1905	New record	Off Cape Comerin, 50m	Parameswaran et al. (2018)
10.	*Petasometra helianthoides* A. H. Clark, 1912	New record	Off Cape Comerin, 50m	Parameswaran et al. (2018)

Sea star, *Asteropsis carinifera*, from Agatti Island, Lakshadweeep

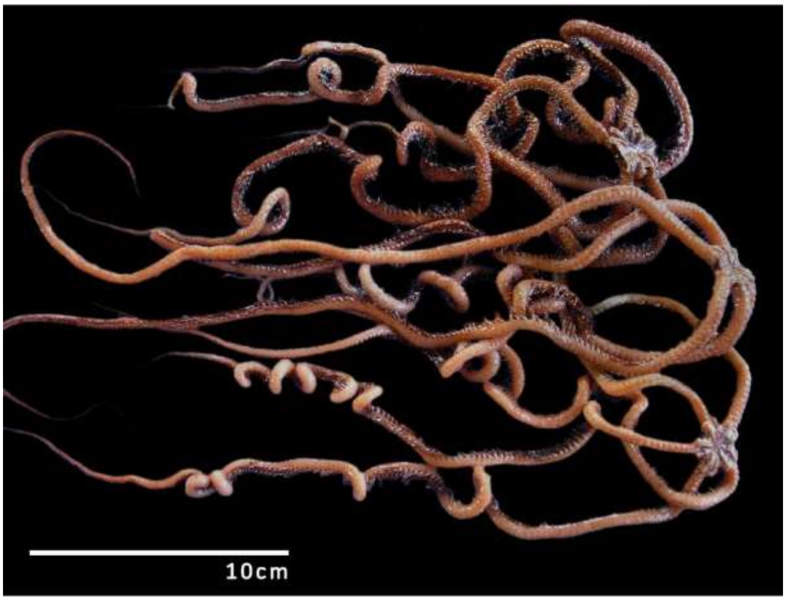


Brittle star, *Ophiodaphne scripta*, from off Trivandrum, Kerala

Feather star*,* *Himerometra robustipinna*, from Agatti Island, Lakshadweep

Sea urchin, *Tripneustes gratilla*, from Agatti Island, Lakhsadweep

Sea cucumber, *Stichopus chloronotus*, from Agatti Island, Lakshadweep



Asteroschema sampadae, a deep-sea echinoderm discovered and described though efforts of CMLRE, and named in honour of FORV *Sagar Sampada*

References

Chippy K., Saravanane N., Kumar B.K., Sanjeevan V.N. (2018). New record of the stalked crinoid *Saracrinus angulatus* (Echinodermata: Crinoidea: Isocrinida) from Andaman Sea, Northern Indian Ocean. Marine Biodiversity, 48(3), 1429-1437.

Dupont S., Ortega-Martinez O., Thorndyke M. (2010). Impact of near-future ocean acidification on echinoderms. Ecotoxicology, 19(3):449-462.

Hyman L.H. (1955). Echinodermata. McGraw-Hill.

Parameswaran U.V., Abdul Jaleel K.U., Sanjeevan V.N., Gopal A., Anil Kumar V., Gupta G.V.M., Sudhakar M. (2018) Diversity and distribution of echinoderms in the south eastern Arabian Sea shelf under the influence of seasonal hypoxia. Progress in Oceanography, 165:189-204.

Parameswaran U.V., Sanjeevan V.N., Abdul Jaleel K.U., Jacob V., Gopal A., Vijayan A.K., Sudhakar M. (2018). An updated checklist of echinoderms of the southeastern Arabian Sea. Marine Biodiversity, 48(4):2057-2079.

Parameswaran U.V., 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. Zootaxa, 3269(1), 47-56.

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.

Parameswaran U.V., Abdul Jaleel K.U., Gopal A., Sanjeevan V.N., Vijayan A.K. (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, 46(1), 151-156.

Pawson D.L. (2007). Phylum Echinodermata. Zootaxa, 1668(1), 749-764.

Purcell S.W., Samyn Y., Conand, C. (2012). Commercially important sea cucumbers of the world. FAO, Rome.

Samuel V.K.D., Pandian K., Sreeraj C. R., Chamundeeswari K., Parthiban C., Sekar V., Patro S., Saravanan R., Abhilash K.R., Ramachandran P., Ramesh, R. (2017) An updated checklist of Echinoderms from Indian waters. Zootaxa 4354, no. 1: 1-68.

Sastry D.R.K. (2007). Echinodermata of India: An annotated list. Zoological Survey of India. 271pp.

Uthicke S. (1999). Sediment bioturbation and impact of feeding activity of *Holothuria (Halodeima) atra* and *Stichopus chloronotus*, two sediment feeding holothurians, at Lizard Island, Great Barrier Reef. Bulletin of Marine Science, 64(1):129-141.

Waggoner, B (1995). Echinodermata: Fossil Record. Introduction to the Echinodermata. Museum of Paleontology: University of California at Berkeley.

WoRMS Editorial Board (2019). World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2019-11-28. doi:10.14284/170.

Diversity and Distribution of Anglerfishes (Lophiiformes) in Indian EEZ

Rajeeshkumar MP*, Saravanane N, Sudhakar M.
Centre for Marine Living Resources and Ecology, Kochi
Email: rajeeshmeleppura@gmail.com

A comprehensive report on the taxonomy, diversity and distribution of Order Lophiiformes (anglerfishes) from Indian waters is presented in this article. Extensive trawling surveys were carried out on board Fishery Oceanographic Research Vessel *Sagar Sampada* during the years 2013 to 2018. Trawl samples from the Indian EEZ in Arabian Sea, Bay of Bengal and the Andaman Sea regions during 19 cruises and coverage of 78 stations in the depth range 200 - 1337 m yielded several specimen samples of these fishes. From the analyses, 36 species of deep-sea angler fishes were documented in this study. Of these 8 species are new to science and 7 new records. In this article an updated check list of Indian Lophiiformes from Indian EEZ is included.

Introduction

Deep-sea exploratory surveys in India were carried out by the Royal Indian Marine Steamer *R.I.M.S. Investigator* during 1884 - 1914. Lt. Col. A. W. Alcock, through his publications―A Descriptive Catalogue of the Indian deep-sea fishes in the Indian museum" (1889, 1898 and 1899) described many new deep-sea fishes. This catalogue is the first detailed report of Indian Deep-sea fishes. Only limited studies were carried out later, and no greater attention being laid on Lophiiformes in our seas on their systematics or distribution.

The Order Lophiiformes contains highly diverse groups of fish that primarily inhabit both shallow and deep-water environments. Commonly referred to as anglerfishes, the group is characterized by the structure of the striking first dorsal-fin spine (known as illicium) which is typically placed out on the tip of the snout and modified to serve as a luring apparatus. The Order contains approximately 348 living species, under 71 genera, 18 families and 5 suborders (Pietsch 2009). Previously Indian Lophiiformes were known from 7 families, 13 genera and 21 species. From the recent efforts at CMLRE, the list is updated to 8 families, 17 genera and 36 species.

Bottom trawl operations were conducted on onboard FORV- SS in the continental slope areas of Indian EEZ (12 cruises and 33 stations in the Arabian Sea; 2 cruises and 13 stations in the Bay of Bengal; 5 cruises and 32 stations in the Andaman Sea; Figure 1). Before conducting the trawling, suitable grounds were identified through acoustic scanning using the multi-frequency echo sounder SIMRAD EK 60 (frequency 38, 120 and 200 kHz) according to bottom depths. Trawling time (net dragging time) varied depending upon the nature of the bottom or water currents. Three types of bottom trawl nets, namely High-Speed Demersal Trawl- Crustacean

Version (HSDT II CV), EXPO-Model trawl and High Opening Trawl (HOT-I) were employed. Taxonomic identifications are based on morphometric and meristic counts followed by appropriate taxonomic keys or other illustrations.

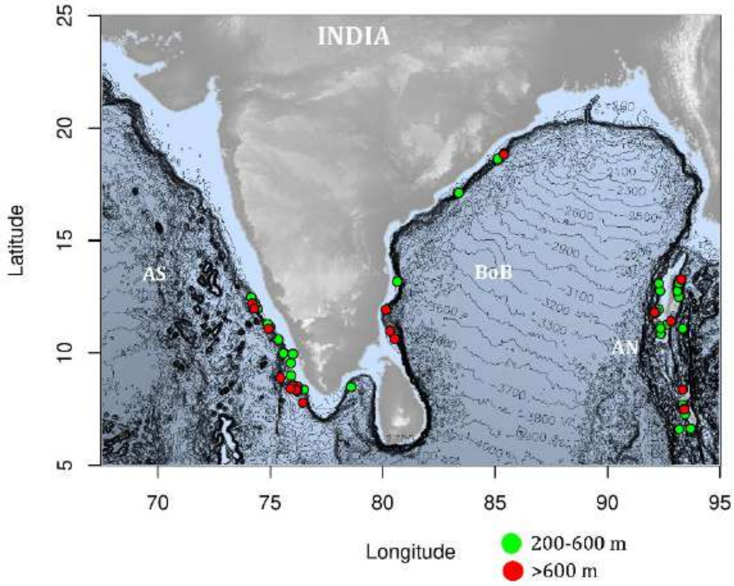


Fig.1. Explains sampling locations; green dots represent station depth between 200-600m; red dots represents >600 m up to 1337 m; AS- Arabian Sea; BoB- Bay of Bengal and AN- Andaman Sea.

Salient Findings

A total of 36 species were recorded and documented in the course of the present study period (Table 1-4; Figures 2-30, new species and records). Among the 21 species previously known, as many as 7 species were not found in any of the 78 hauls. The following species were not encountered in the present study; *Halieutopsis nudiventer* (Lloyd, 1909); *Malthopsis mitrigera* Gilbert and Cramer, 1897; *Dibranchus nasutus* (Alcock, 1891); *Lohodolos indicus* Lloyd, 1909; *Halieutaea nigra* Alcock, 1891; *Halieutea fumosa* Alcock, 1894 and *Diceratias bispinosus* (Günther, 1887). The status of *Halieutopsis nudiventer* is still uncertain, because the holotype of the species, ZSI 1127/1 is lost. The status of *Dibranchus nasutus* (Holotype- ZSI F13028, poor condition) recorded from 11°31'40" N, 92°46'40" E, Andaman Sea, Investigator station 115, depth 343-402 m is uncertain, as it resembles *Halieutopsis nasuta* (Alcock, 1891). Lloyd, 1909 described *Malthopsis triangularis* from Andaman Sea (Syntypes- ZSI F1121/1 (1), F1125/1 (1)10°21' N, 92°46' E, Investigator station 332, depth 510 m.), which later studies of Bradbury 1967 synonymized as *Malthopsis mitrigera* Gilbert and Cramer, 1897. Further, the taxonomic status of *Halieutaea nigra* and *Halieutea fumosa* from Indian water remains uncertain. This can be clarified only on obtaining additional specimens. *Diceratias bispinosus* (Holotype- BMNH 1887.12.7.14), Challenger station 194A, Off Banda Island, 659 m and *Lohodolos indicus* (Holotype-ZSI 1024/1, Investigator station 307, off Trivandrum, depth 1624 m) are still valid species.

Table 1. Members of Lophiiformes recorded from the Arabian Sea during 2013-2018

No	Species	Remarks	Depth Range	Further Reading
1	*Lophiodes lugubris* (Alcock, 1894)		300-1000	RajeeshKumar 2019
2	*Lophiodes mutilus* (Alcock, 1893)		330	RajeeshKumar 2019
3	*Lophiodes triradiatus* (Lloyd,1909)		243–1043	RajeeshKumar 2019
4	*Lophiodes gracilimanus* (Alcock,1899)		124-270	RajeeshKumar 2019
5	*Lophiomus setigerus* (Vahl, 1797)		180-200	RajeeshKumar 2019
6	*Chaunax multilepis* Ho HC, Meleppura RK & Bineesh, 2016	NS	295-350	Ho et.al. 2016
7	*Chaunax* sp. A	NS	1050-1100	RajeeshKumar 2019
8	*Chaunax apus* Lloyd, 1909 (NR)	NR	200-245	RajeeshKumar 2019
9	*Coelophrys micropa* (Alcock,1891)		1300-1350	RajeeshKumar 2019
10	*Halicmetus ruber* Alcock, 1891		950-100	RajeeshKumar 2019
11	*Halieutopsis stellifera* (Smith & Radcliffe, in Radcliffe, 1912)	NR	1337	Rajeeshkumar et al. 2013
12	*Halieutaea* sp. A	NS	150-200	RajeeshKumar 2019
13	*Halieutaea stellata* (Vahl, 1797)		200	RajeeshKumar 2019
14	*Halieutaea coccinea* Alcock, 1889		200-1075	RajeeshKumar 2019
15	*Halieutaea indica* Annandale and Jenkins, 1910	RD	200	RajeeshKumar 2019
16	*Halieutaea nigra* Alcock, 1891		200-400	RajeeshKumar 2019
17	*Halieutea fumosa* Alcock, 1894		200-400	RajeeshKumar 2019
18	*Halieutopsis* sp. A	NS	934	RajeeshKumar 2019
19	*Malthopsis lutea* Alcock, 1891	NR	200-400	RajeeshKumar 2019
20	*Dibranchus nasutus* Alcock, 1891		300-1200	RajeeshKumar 2019
21	*Ceratias uranoscopus* Murray, 1877		300-900	Rajeeshkumar et.al. 2016
22	*Cryptopsaras couesi* Gill, 1883	NR	900-923	RajeeshKumar 2019
23	*Diceratias trilobus* Balushkin and Fedorov, 1986	NR	1300–1350	Rajeeshkumar et.al. 2016
24	*Bufoceratias shaoi* Pietsch, Ho and Chen, 2004	NR	1300–1350	Rajeeshkumar et.al. 2016
25	*Bufoceratias thele* (Uwate, 1979)	NR	1000	RajeeshKumar 2019
26	*Lohodolos indicus* Lloyd, 1909		400-900	RajeeshKumar 2019
27	*Oneirodes* sp. A	NS	1000	RajeeshKumar 2019
28	*Melanocetus johnsonii* Günther, 1864		1000	RajeeshKumar 2019

NR-New Record; RD-Rediscovery from this study; NS- New Species described from the CMLRE collections

Table 2. Members of Lophiiformes recorded from the Bay of Bengal during 2013-2018

No	Species	Remarks	Depth Range	Further Reading
1	*Lophiodes lugubris* (Alcock, 1894)	NR	648-700	RajeeshKumar 2019
2	*Lophiodes mutilus* (Alcock, 1893)		650	RajeeshKumar 2019
3	*Lophiomus setigerus* (Vahl, 1797)		100-200	RajeeshKumar 2019
4	*Chaunax multilepis* Ho HC, Meleppura RK & Bineesh, 2016	NS	645	Ho et.al. 2016
5	*Chaunax apus* Lloyd, 1909		620	RajeeshKumar 2019
6	*Coelophrys micropa* (Alcock, 1891)		650	RajeeshKumar 2019
7	*Halicmetus ruber* Alcock, 1891 (NR)		307	RajeeshKumar 2019
8	*Halieutaea stellata* (Vahl, 1797)		200-300	RajeeshKumar 2019
9	*Halieutaea coccinea* Alcock, 1889	NR	500	RajeeshKumar 2019
10	*Halieutaea indica* Annandale and Jenkins, 1910	RD	200-300	RajeeshKumar 2019
11	*Halieutea fumosa* Alcock, 1894		200-350	RajeeshKumar 2019
12	*Halieutopsis nudiventer* (Lloyd, 1909)		900-1200	RajeeshKumar 2019
13	*Diceratias bispinosus* (Günther, 1887)		600-700	RajeeshKumar 2019

NR-New Record; RD-Rediscovery from this study; NS- New Species described from the CMLRE collections

Table 3. Members of Lophiiformes recorded from the Andaman Sea during 2013-2018

No	Species	Remarks	Depth Range	Further Reading
1	*Lophiodes lugubris* (Alcock, 1894)	NR	300-550	RajeeshKumar 2019
2	*Lophiodes mutilus* (Alcock, 1893)	NR	290-635	RajeeshKumar 2019
3	*Lophiodes triradiatus* (Lloyd, 1909)	NR	290-646	RajeeshKumar 2019
4	*Lophiodes gracilimanus* (Alcock, 1899)	NR	270-650	RajeeshKumar 2019
5	*Lophiomus setigerus* (Vahl, 1797)		100-200	RajeeshKumar 2019
6	*Chaunax multilepis* Ho HC, Meleppura RK & Bineesh, 2016	NS	295-350	Ho et al. 2016
7	*Chaunax apus* Lloyd, 1909	NR	337-650	RajeeshKumar 2019
8	*Chaunax penicillatus* McCulloch, 1915	NR	321-337	RajeeshKumar et.al 2019
9	*Halieutopsis stellifera* (Smith & Radcliffe, in Radcliffe, 1912)	NR	480-1337	RajeeshKumar 2019
10	*Coelophrys micropa* (Alcock, 1891)		500-600	RajeeshKumar 2019
11	*Halicmetus ruber* Alcock, 1891		400-500	RajeeshKumar 2019
12	*Halieutaea stellata* (Vahl, 1797)	NR	332-576	RajeeshKumar 2019
13	*Halieutaea coccinea* Alcock, 1889		338-576	RajeeshKumar 2019
14	*Halieutaea nigra* Alcock, 1891		300-400	RajeeshKumar 2019
15	*Halieutopsis* sp. B	NS	635-646	RajeeshKumar 2019

16	*Malthopsis lutea* Alcock, 1891		300-650	RajeeshKumar 2019
17	*Malthopsis mitrigera* Gilbert & Cramer, 1897		300-400	RajeeshKumar 2019
18	*Malthopsis gigas* Ho and Shao, 2010	NR	300-308	RajeeshKumar 2019
19	*Malthopsis* sp. A	NS	398	RajeeshKumar 2019
20	*Dibranchus nasutus* Alcock, 1891		400-600	RajeeshKumar 2019
21	*Ceratias uranoscopus* Murray, 1877	NR	850-900	RajeeshKumar 2019
22	*Cryptopsaras couesi* Gill, 1883		600-850	RajeeshKumar 2019
23	*Himantolophus* sp. A	NS	635	RajeeshKumar 2019

NR-New Record from this study; NS- New Species described from the CMLRE collections

Table 4. Status of Lophiiformes based on present study

Family	**Species**		**Remarks**
	Previous	**Present**	
Lophiidae	5	5	
Chaunacidae	1	4	2 new sp.; 1 new rec.
Ogcocephalidae	11	17	4 new sp.; 2 new rec.
Oneirodidae	1	2	1 new sp.
Melanocetidae	1	1	
Ceratiidae	1	2	1 new rec.
Diceartiidae	1	4	3 new rec.
Himantolophidae	-	1	1 new sp.
Total	**21**	**36**	

From the extensive collection and systematic analyses, as many as 7 new records of lophiiforms within the Indian EEZ were documented and 8 new species could be identified. Thus, the updated list of lophiiforms in the Indian waters is 36 species under 17 genera and 8 families. The number of new species region wise are 4 from Arabian Sea and 3 from Andaman Sea. New records include 8 from Arabian Sea; 3 from Bay of Bengal and 10 from Andaman Sea). Among the new records 3 rare, diceratiid anglerfishes were observed. Diceratiids are rare, the present specimen of *B. shaoi* represents the fifth known in the world. Similarly, *Ceratias uranoscopus* is the second known record from the Indian Ocean. Other new records are *Bufoceratias thele* and *Diceratias trilobus* collected from Arabian Sea. *Halieutaea indica* represents the rediscovery of the species from Indian waters after 108 years of its original description by Annandale and Jenkins in 1910. Similarly, *Lophiodes gracilimanus* represents the rediscovery after 35 years from Indian waters (Andaman Sea).

Arabian Sea contributed 28 species; Bay of Bengal 13 species and Andaman Sea 22 species (including previously known). Among these only 9 species are common to the Arabian Sea, Bay of Bengal and Andaman Sea. Previously only 3 species were represented from the suborder Ceratioidei (most species rich suborder, 166 species worldwide, Pietsch 2009; Prokofiev 2014; Ho *et al.* 2016) from Indian waters. The present study updated the ceratioid species to 9 with 2 new species and 4 new records. During the course of study, a new species of deep-sea ceratioid species, *Oneirodes sanjeevani* Rajeeshkumar, 2017 is described from the Western Indian Ocean at depths ranging from 380-600 m (Rajeeshkumar 2017)

Suborder—LOPHIOIDEI

Family—LOPHIIDAE Rafinesque, 1810**.**

The monkfishes or goose fishes

The family, Lophiidae contains four genera (*Sladenia* Regan, 1908; *Lophiodes* Regan, 1908; *Lophiomus* Gill, 1883 and *Lophius* Linnaeus, 1758) and 28 valid species worldwide. Two genera and five species are represented in the Indian EEZ of which 4 species are new records from the study area (Fig. 2-6)

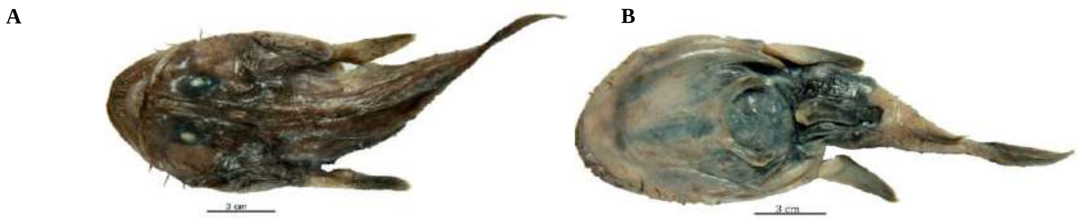


Fig. 2 *Lophiodes lugubris,* A—dorsal view B—ventral view New record from Andaman Sea, 332 m depth

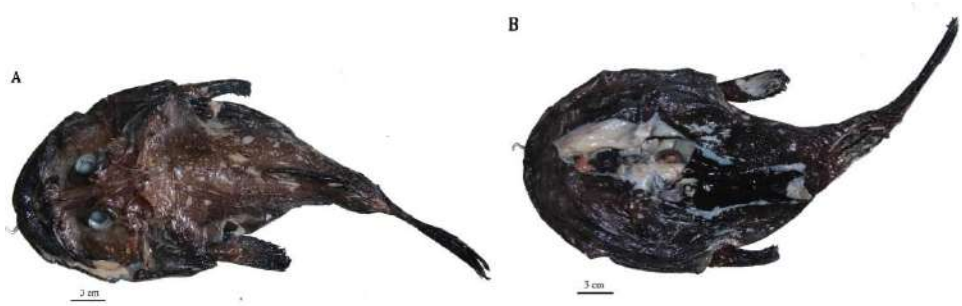


Fig. 3 *Lophiodes triaradiatus* (36715), A—dorsal view, B—ventral view
New record from Andaman Sea, 646 m depth

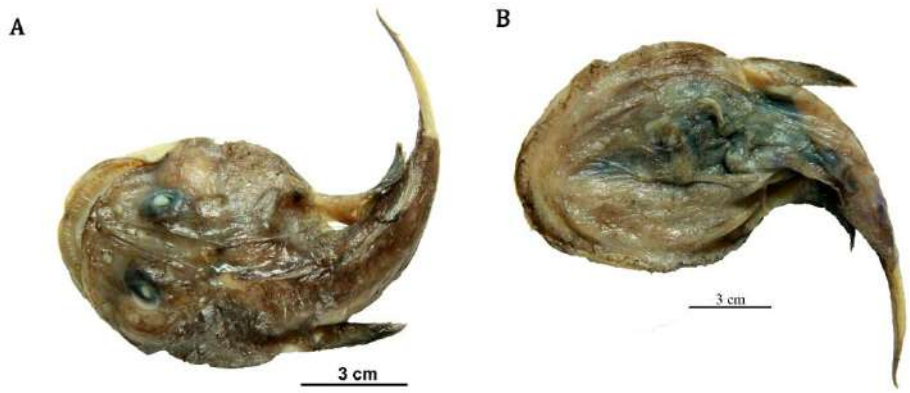


Fig. 4 *Lophiodes mutilus* (34503), A—dorsal view, B—ventral view
New record from Arabian Sea, 330 m depth

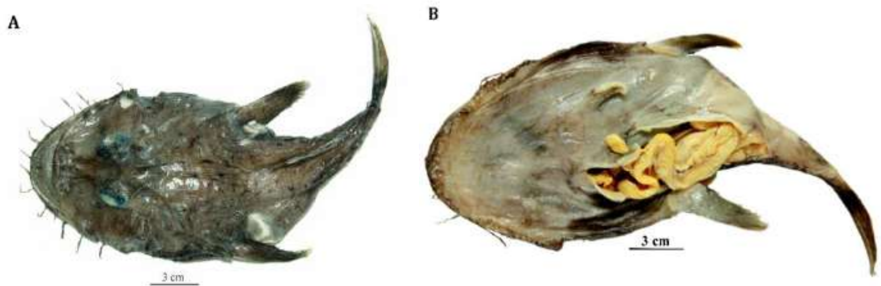


Fig. 5 *Lophiodes gracilimanus* (349 02A) A—dorsal view, B—ventral view Rediscovery of species after 35 years from Indian waters; collection location— Andaman Sea, 650 m depth

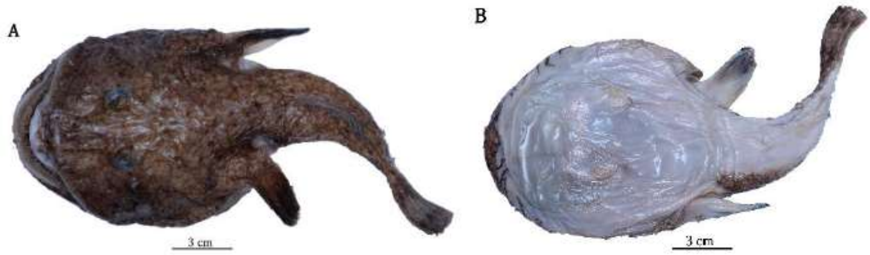


Fig. 6 *Lophiomus setigerus* (27807), A—dorsal view, B—ventral view

i. Suborder—CHAUNACOIDEI

Family—CHAUNACIDAE Gill, 1863

Sea toads or coffinfishes

At present the family comprise two genera (*Chaunacops* Garman, 1899 and *Chaunax* Lowe, 1846) and 29 species (4 *Chaunacops* and 25 *Chaunax* species respectively) Ho and Mc Grouther (2015); Ho and Ma (2016). From Indian waters only 4 species of *Chaunax* are reported that include two new species and one new record from the present study (Fig. 7-10).

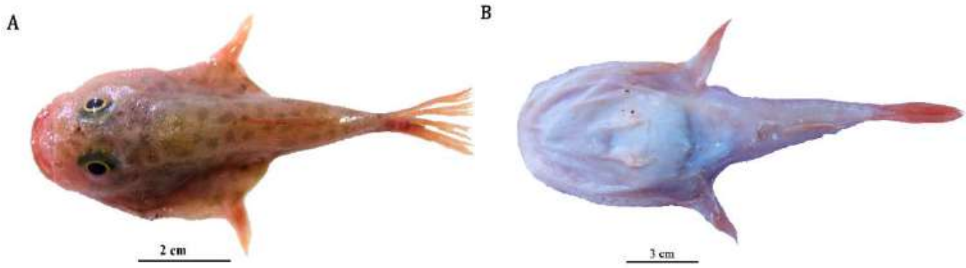


Fig. 7 *Chaunax multilepis*, A—dorsal view, B—ventral view
New species described, Holotype—CMLRE 2923417A, 130 mm SL, 13.26° N, 93.17° E; off North Andaman, 295−323 m, also present in Arabian Sea and Bay of Bengal

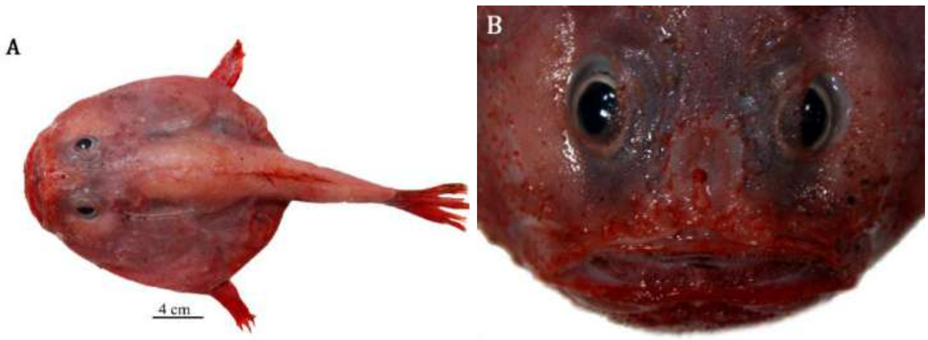


Fig. 8 *Chaunax* sp. A, A—dorsal view, B—enlarged view of head showing illicium
New species, Material—CMLRE 30501, 196 mm SL, 8.28° N, 76.20° E; 1050-1100 m, Arabian Sea

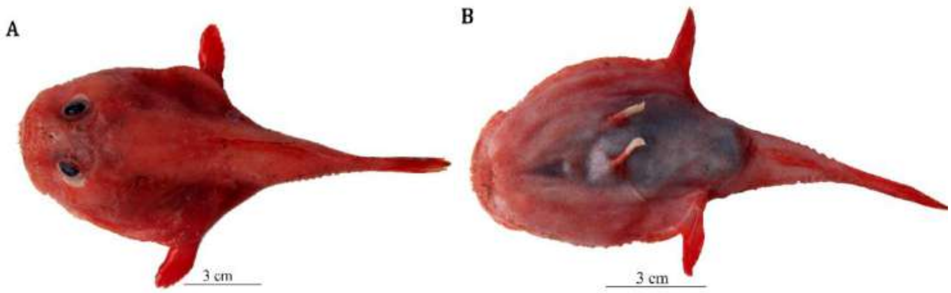


Fig. 9 *Chaunax apus* (34902A) A—dorsal view, B—ventral view
New record from Arabian Sea and Andaman Sea, 650 m depth. This is one of the oldest nominal species of *Chaunax*

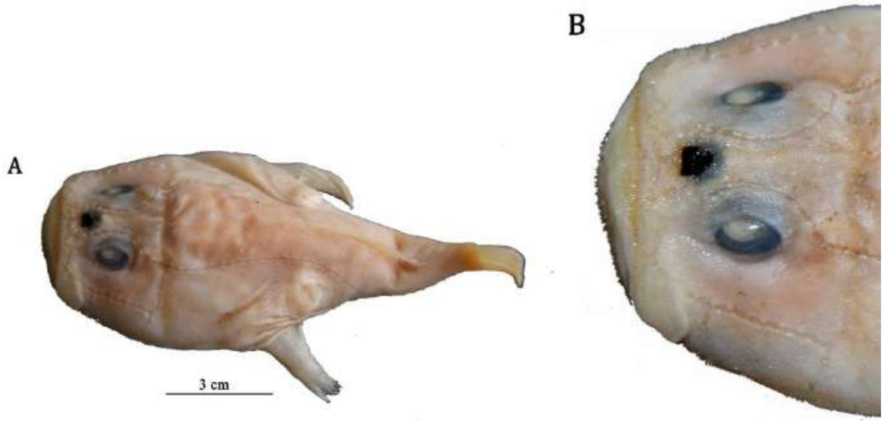


Fig. 10 *Chaunax penicillatus* (2803730). A—dorsal view, B—enlarged view of head showing illicium.
New record from Andaman Sea, 321 m depth, only member in the *Chaunax pictus* group that occurs outside the Atlantic Ocean

ii. Suborder—OGCOCEPHALOIDEI

Family—OGCOCEPHALIDAE Gill, 1893

Bat fishes

The family comprises 10 genera and some 70 species. A total of 5 genus and 11 species are represented from India, among them 3 new species and 6 new records are reports from the present study (Fig. 11-22)

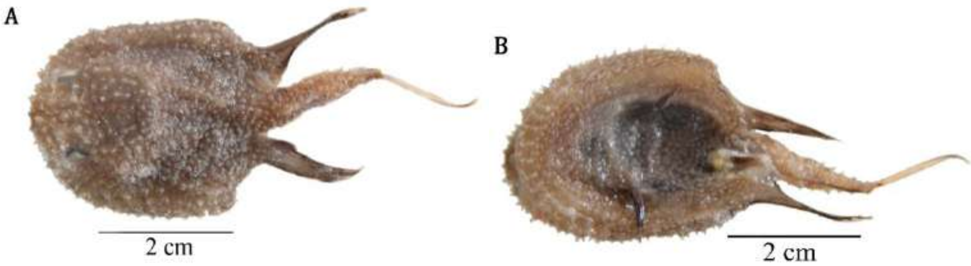


Fig. 11 *Halieutopsis stellifera* (2928922 A), A—dorsal view, B—ventral view
New record from Andaman Sea, 580 m depth

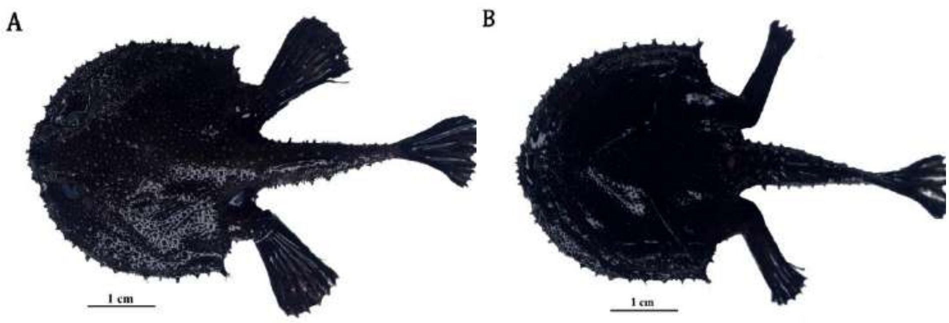


Fig. 12 *Halieutopsis* sp. A, A—dorsal view, B—ventral view
New species, common name—Indian black batfish, Material—CMLRE 36603, 125 mm SL, 8.36° N, 76.24° E, Arabian Sea, 934 m.

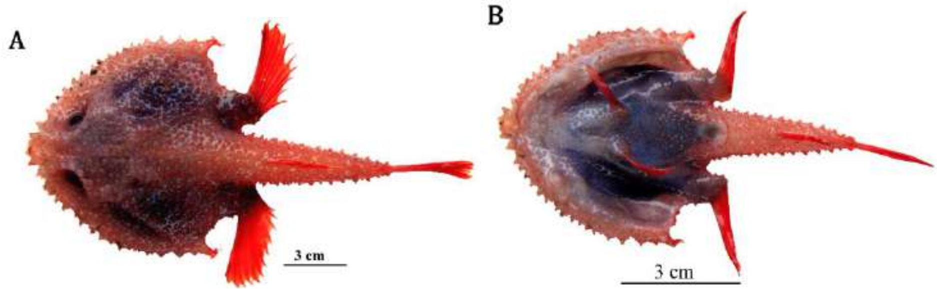


Fig. 13 *Halieutopsis* sp B, A—dorsal view, B—ventral view
New species, common name— Indian red bat fish, Material—36715A, 90 mm SL; 11.8° N, 92.1° E, Andaman Sea, 646 m.

Fig. 14 *Halieutaea* sp. A, Dorsal view New species, common name— Indian spiny batfish Material—2881736, 118 mm SL, 9.99° N, 75.60° E, Arabian Sea, 150-200 m

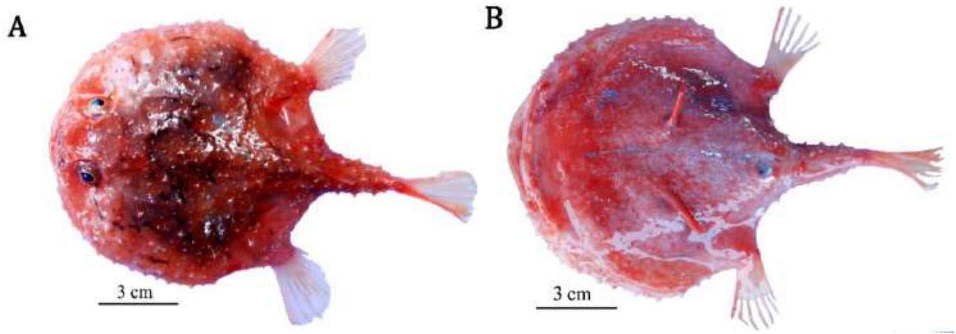


Fig. 15 *Halieutaea stellate* (34910), A—dorsal view, B—ventral view
New record from Andaman Sea, 520 m depth

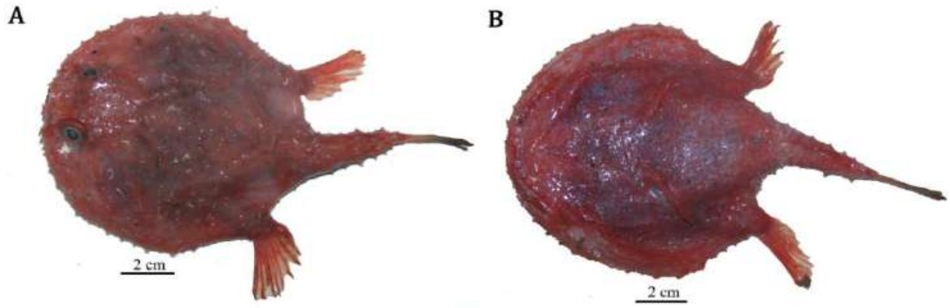


Fig. 16 *Halieutaea coccinea* (29106), A—dorsal view, B—ventral view
New record from Bay of Bengal; specimen

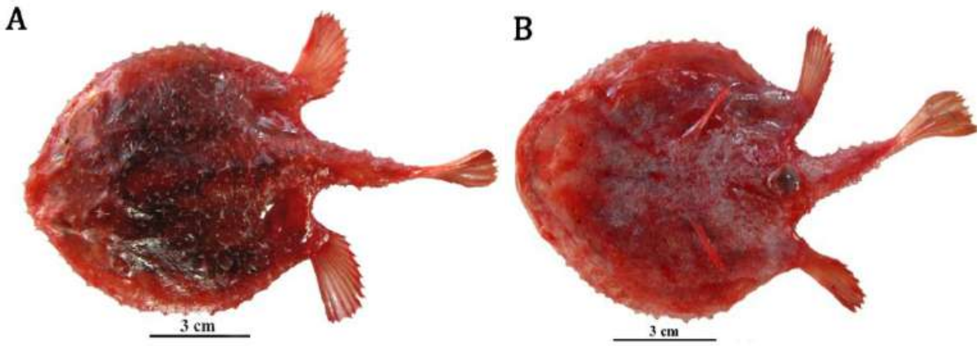


Fig. 17 *Halieutaea indica* A—dorsal view, B—ventral view
Material—288 09, 74 mm SL, Arabian Sea, 11.99° N, 74.42° E, 200 m. The species represents rediscovery from Indian waters after 108 years of its original description by Annandale and Jenkins in 1910

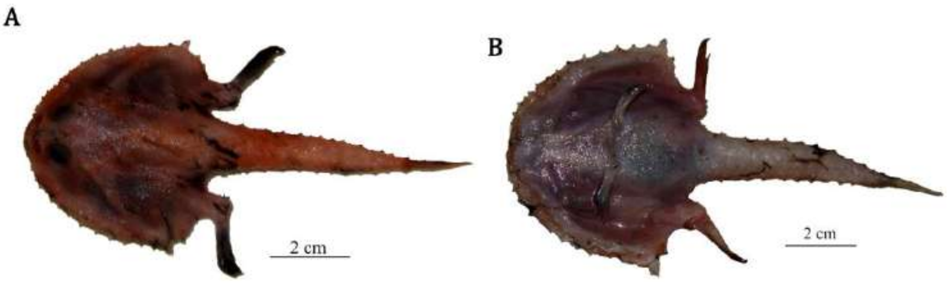


Fig. 18 *Halicmetus ruber* (27911A) A—dorsal view, B—ventral view
New record from Bay of Bengal, 307 m depth

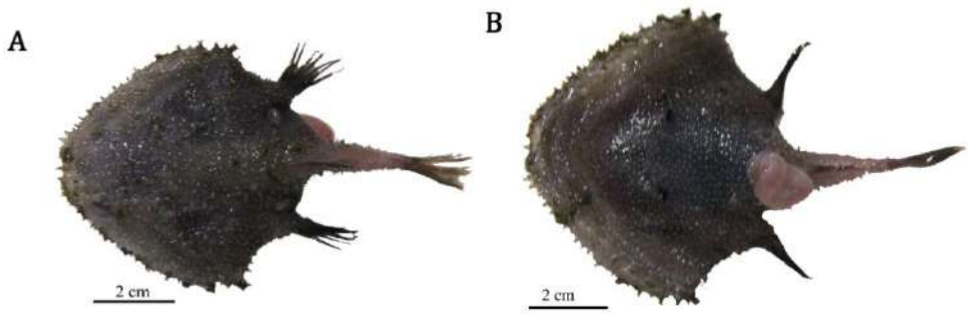


Fig. 19 *Coelophrys micropa* (31601) A—dorsal view, B—ventral view

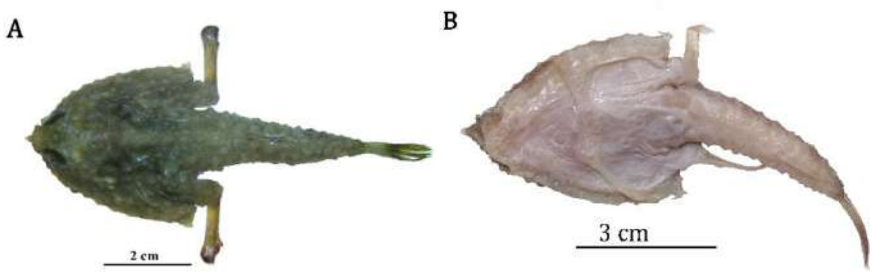


Fig. 20 *Malthopsis lutea* (30505) A—dorsal view, B—ventral view
New record from Arabian Sea, 400 m depth

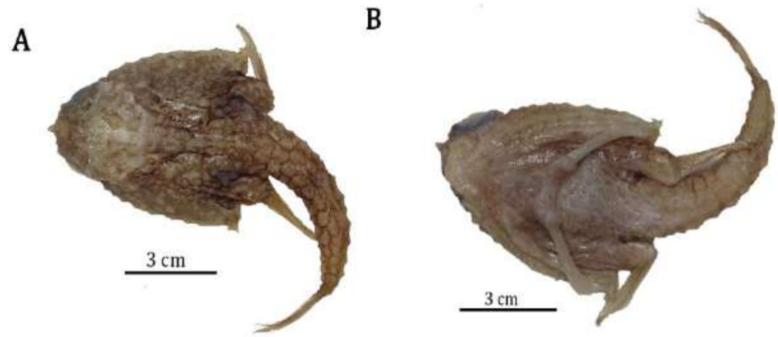


Fig. 21 *Malthopsis gigas* (29234) A—dorsal view, B—ventral view New record from Andaman Sea, 300 m depth

Fig. 22 *Malthopsis* sp. A, dorsal view.
New species, common name—Andaman triangular batfish, Material—33416, 55 mm SL, 13.3° N, 93.1° E, Andaman Sea, 398 m

iii. Suborder—CERATIOIDEI

Family—CERATIIDAE Gill, 1861

The Family Ceratiidae contains two genus and four species. *Ceratias* includes *C. tentaculatus* (Norman, 1930), *C. holboelli* Kröyer, 1845, and *C. uranoscopus* Murray, 1877. The genus *Cryptopsaras* contains only *C. cousi* Gill, 1883. (Figs. 23-27)

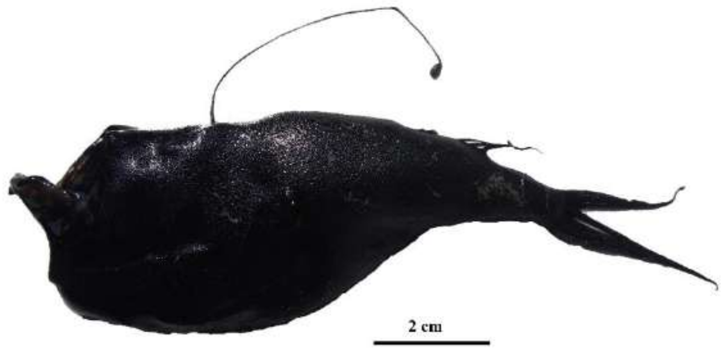


Fig. 23 *Ceratias uranoscopus* (3341210); New record from Andaman Sea, 850–900 m depth

Fig. 24 *Cryptopsaras couesi* (30506)
New record from Arabian Sea, 923 m depth

Suborder—CERATIOIDEI

Family—DICERATIIDAE Regan and Trewavas, 1932

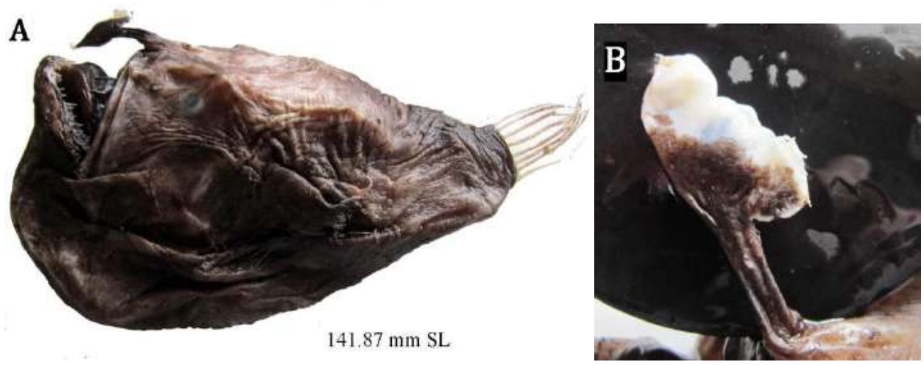


Fig. 25 *Diceratias trilobus* (3160107), A—lateral view, B—illicial apparatus
New record from Arabian Sea, 1350 m depth

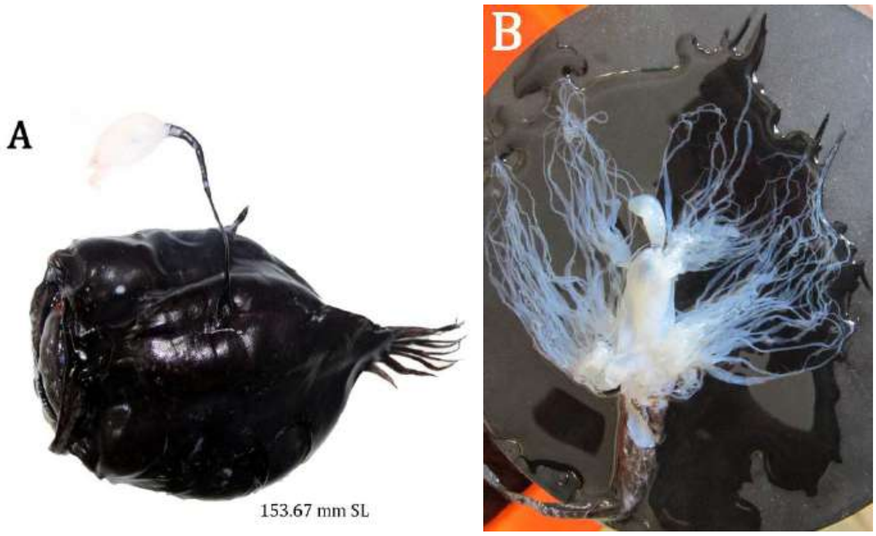


Fig. 26 *Bufoceratias shaoi* (3160210), A—lateral view, B—illicial apparatus
New record from Arabian Sea**,** 1350 m depth, presented specimen represents fifth known specimen in the world

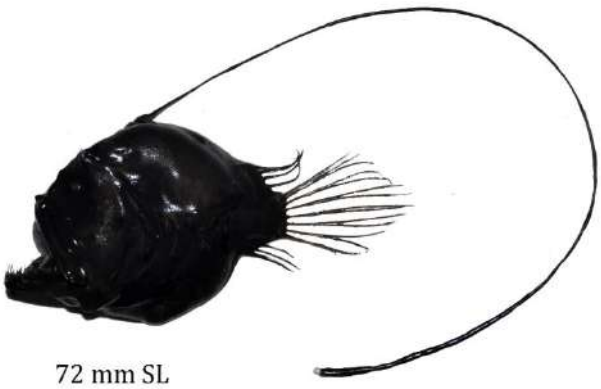


Fig. 27 *Bufoceratias thele* (32202). New record from Arabian Sea, 1000 m depth

Suborder**—**CERATIOIDEI

Family—HIMANTOLOPHIDAE Gill, 1861

Family comprising a single genus (*Himantolphus*) and 19 species (Bertelsen and Krefft, 1988; Pietsch and Kenaley, 2011). Bertelsen and Krefft (1988) divided *Himantolohus* females into five species groups: *H. albinares* group; *H. appelii* group; *H. cornifer* group; *H. groenlandicus* group and the *H. nigricornis* group (Figs. 28-30)

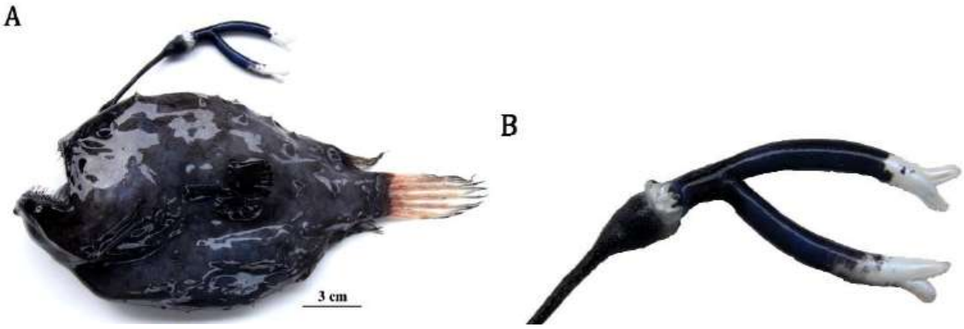


Fig. 28 *Himantolophus* sp A., A—lateral view, B—illicial apparatus
New species, common name— Indian football fish**,** Material—36708, ♀, 150 mm SL, Andaman Sea, 635 m depth

Suborder**—**CERATIOIDEI
Family—ONEIRODIDAE Gill, 1878

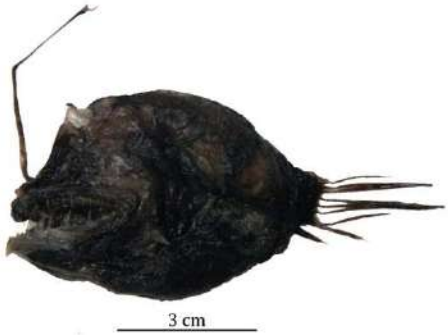


Fig. 29 *Oneirodes* sp. A, lateral view
New species, common name—Indian dreamer, Material—32202, 65 mm SL, ♀, Arabian Sea, 1000 m depth

Fig. 30 *Oneirodes* sp.
Material—30506, 160 mm SL, Arabian Sea, 923 m, totally damaged

References

Alcock, AW.: Natural history notes from H.M. Indian marine survey steamer `Investigator,' Commander Alfred Carpenter, R. N., D. S. O., commanding.-No. 13. On the bathybial fishes of the Bay of Bengal and neighbouring waters, obtained during the seasons 1885-1889. *Annals and Magazine of Natural History*, (Ser. 6) 4 (24): pp. 450-461 (1889)

Alcock, AW.: Illustrations of the zoology of the Royal Indian marine surveying steamer Investigator, Fishes. Calcutta. *Illustrations of the zoology of the Royal Indian marine surveying steamer Investigator, Fishes*. Part 5: 249p. Pls: 18-24 (1898)

Alcock, AW.: A descriptive catalogue of the Indian deep-sea fishes in the Indian Museum. Being a revised account of the deep sea fishes collected by the Royal Indian marine survey ship Investigator. Calcutta. *A descriptive catalogue of the Indian deep sea fishes in the Indian Museum*, i-iii + 1-211 + i-viii (1899)

Annandale, N., Jenkins, JT.: Report on the fishes taken by the Bengal Fisheries Steamer ―Golden Crown.‖ Part III. Plectognathi and Pediculati. *Memoirs of the Indian Museum*. 3(1) pp. 7-21 (1910)

Bradbury, MG.: The genera of batfishes (family Ogcocephalidae). *Copeia*, pp. 399–422 (1967)

HC, Ho., Kawai, T., Kunio, A.: Records of deep-sea anglerfishes (Lophiiformes: Ceratioidei) from Indonesia, with descriptions of three new species. *Zootaxa*, 4121 (3) pp. 267–294 (2016)

Ho, HC., Meleppura, RK., Bineesh, KK. *Chaunax multilepis* sp. nov., a new species of *Chaunax* (Lophiiformes: Chaunacidae) from the northern Indian Ocean. Zootaxa, 4103(2), pp. 130-136 (2016)

Lloyd, RE.: A description of the deep-sea fish caught by the R. I. M. S. ship `Investigator' since the year 1900, with supposed evidence of mutation in *Malthopsis*. *Memoirs of the Indian Museum*, Vol. 2 (1909).

Prokofiev, AM.: New species and new records of deep-sea anglerfish of the family Oneirodidae. *Journal of Ichthyology*, 54 (8), pp. 602–607 (2014)

Pietsch, TW.: Oceanic Anglerfishes: Extraordinary Diversity in the Deep-sea, University of California Press (2009)

Rajeeshkumar, MP., Vinu, J., Sonia, CS., Jayalakshmi, KJ., Sanjeevan ,VN.: First record of the batfish, *Halieutopsis stellifera* (Lophiiformes: Ogcocephalidae) from the eastern Indian Ocean. *Marine Biodiversity Records*, 6, e84 (2013)

Rajeeshkumar, MP., Jacob ,V., Sumod, KS., Sanjeevan, VN., Hashim, M., Sudhakar, M.: Three new records of rare deep-sea Anglerfishes (Lophiiformes: Ceratioidei) from the Northern Indian Ocean. *Marine Biodiversity*, 46(4), pp. 923-928 (2016)

Rajeeshkumar, MP., Meera, KM., Hashim, M.: A New Species of the Deep-Sea Ceratioid Anglerfish Genus Oneirodes (Lophiiformes: Oneirodidae) from the Western Indian Ocean. *Copeia*, 105(1), pp. 82-84 (2017)

Rajeeshkumar, MP.: Deep-sea Anglerfishes (Pisces-Lophiiformes) of the Indian EEZ: Systematics, Distribution and Biology. PhD Thesis, Cochin University of Science and Technology, Kerala, India (2019)

Rajeeshkumar, MP., Bineesh, KK., Hashim, M. Sherine, CS., Sudhakar, M.: New Geographical Record of *Chaunax penicillatus* McCulloch, 1915 (Chaunacoidei: Chaunacidae) from the Eastern Indian Ocean. *Thalassas: An International Journal of Marine Science* https://doi.org/10.1007/s41208-019-00183-x (2019)

CMLRE Studies on Deep-Sea Fishes from Indian Waters

Aneesh Kumar KV, Saravanane N, Sudhakar M

Centre for Marine Living Resources and Ecology, Kochi

Email: aneeshmenan12@gmail.com

Deep-sea is the layer below 200 m from the surface where sunlight starts to fade rather rapidly. It is estimated that 60% of our planet is underneath 1600m deep waters and, nearly half of the world's marine waters are over 3000m deep. Encompassing ~75% of biosphere, the deep oceans (>1000m) are permanently no light regions. Such regions are further exceptional with very low temperature, no primary production, low oxygen and enormous pressure, all these features making deep-sea a hostile environment for life to live or thrive. Thus, the life-forms which live in these ecosystems mostly rely for subsistence on the marine snow (falling organic matter) produced in the surface, photic zone. In this article, apart from listing the new species and new records of deep-sea fishes, brief historical accounts of earlier expeditions that led to expansion of fish taxonomy are presented.

1. Introduction

Scientists once believed that deep-sea below 600 m is barren and, lifeless (azoic). However, our understanding about the deep-sea ecosystems completely changed after various dedicated surveys and expeditions to the deep-sea viz., Challenger Expedition (1872-1876), RIMS "Investigator" (1884-1914) and Valdivia Expedition (1898-1899) which documented enormous life in the deep-sea floor. Recent studies estimated that deep seabed habitats of world oceans harbor around 5,00,000 to 10 million species, most of them remaining unreported or undescribed. We may have explored a mere 1% of the seafloor and, our understanding about these habitats is scanty and much less than that of distant moon's surface because of inaccessibility and due mainly to the lack of will to support the deep ocean explorations.

Fish species constitute more than half of all living vertebrates so far identified globally (Nelson, 2006). The number of valid fish species is nearly 31,000. Interestingly, mainly due to expanded deep sea surveys, around 500 new species are being added in every year. Recent dedicated surveys/expeditions carried out in the hitherto unexplored areas and depths not accessible earlier have added to the growing list of new additions.

India is bestowed with 2.02 million square kilometers of Exclusive Economic Zone which can enjoy the exclusive legal rights to utilize all living and non-living resources. The pelagic and demersal fishery resources and their status are better known compared to deep-sea fishes. As such, deep-sea exploratory surveys in our waters are mostly in the west coast leaving the Bay of Bengal and Andaman and Nicobar waters almost unexplored. Efforts to explore these least studied areas to enhance our knowledge on the deep-sea fishery resources and to understand their status are essential for their sustainable management and responsible utilization.

2. Surveys for Deep-sea Fishery Resources in the Seas Around India

Indian waters are well known for rich deep-sea biodiversity. Modern approaches to taxonomy and cataloguing of the resources through globally networked agencies viz; OBIS, CoML have motivated and promoted the discovery of new species from Indian waters (Eschmeyer *et al.,* 2010). Exploratory surveys for deep-sea and demersal fishery resources in India were initiated and carried out by Fishery Survey of India (FSI), Integrated Fisheries Project (IFP) and Central Institute of Fisheries Nautical and Engineering Training (CIFNET) on the continental shelf and slope of Indian EEZ. India's deep-sea surveys reached another dimension after the procurement of FORV *Sagar Sampada* by the erstwhile Department of Ocean Development (presently The Ministry of Earth Sciences). The Centre for Marine Living Resources and Ecology (CMLRE) with the Ministry of Earth Sciences) has built adequate capacity to explore the fishery resources up to 1100m using deep-sea trawl. FORV *Sagar Sampada* is the only vessel in the country which can perform deep-sea trawling operations and collecting associated oceanographic parameters. Under CMLRE, the exploratory studies conducted onboard FORV *Sagar Sampada* from 1986 onwards brought to light many deep-sea fishes from the Indian EEZ and most of them are new to science or new records throwing new light on range extensions.

Experimental trawling operations using FORV *Sagar Sampada* also help to identify new trawlable grounds for deep-sea as well as coastal fishery resources for commercial exploitation. These surveys also benefit to identify potential alternative fishery resources which are quite essential when the coastal fishery resources of the country are either depleted or no scope for the further expansion. Recent estimates indicate that India possesses a potential of additional 1.7 million tonnes of unexploited or underexploited deep-sea finfishes and shellfish resources.

3. Records of Deep-sea fishes from Indian waters:

Deep-sea fishes, in their relatively homogenous environment, are highly diverse morphology and, possess special adaptations necessary to live in deep-sea environment. There is in general higher diversity in the depth range of 200 -400 m, low species richness and lower endemicity than shelves. Previous exploratory surveys have documented around 139 species from Arabian Sea followed by Andaman waters and Bay of Bengal (68 and 53, respectively). All together 188 different deep-sea fish species were recorded from Indian EEZ.

Past exploratory deep-sea fishery operations have identified potential alternative fishery resources from Indian waters viz., Green eyes (*Chlorophthalmus corniger. C. agasizzi),* Opal fish (*Bembrops caudimacula),* Indian ruff (*Psenopsis cyanea*), snake mackerel (*Neoepinnula orientalis*) and many species of bullseye (*Priacanthus* spp). All these species are estimated to contribute substantially in the 200-400 depth range. Among these, *Priacanthus* spp already entered the market and well accepted by the fish-consuming population of the country. Most of the fishes listed above are also caught as bycatch during the trawling operations targeting deep-sea shrimps in significant quantity.

Species composition greatly changes beyond 400-500 m depth with much more morphological diversities and specialized adaptations to live in extreme environmental conditions. Anglerfishes, rat tails and cusk-eels predominate. However, these fishes fail to meet the aesthetic expectations as food fishes which makes them unpopular in the market. Most of these caught by bottom trawlers targeting deep-sea shrimps are either discarded in the sea itself or some portion will be transported to feed mills.

The enormous quantity of bycatch generated during trawling for deep-sea shrimps pose serious threat to the deep-sea marine biodiversity which may hinder our steps for the conservation of marine fishery resources of the country. However, recent researches on the development of bycatch reduction devices for trawling gives promising results.

4. CMLRE’s contributions to deep-sea fish discoveries

Every year there is a huge revision is happening in the taxonomy which leads to increase in the number of species. During the past 5-8 years, CMLRE has made immense contributions to the marine biodiversity assessment. As the premier institute in the country, CMLRE is involved in research on deep-sea biodiversity and ecology of various group of organisms. It is worthy to note that the institute has discovered 4 deep-sea fish species new to science and around 14 new records adding to the deep-sea fish diversity. Among these organisms, *Bufoceratias shaoi* is a rediscovery after 100 years.

Recently, CMLRE has identified a unique deep-sea habitat called as Terrace of Trivandrum in southeastern Arabian Sea (SEAS). This region is exceptionally fascinating with very high megafauanal diversity represented by nearly 148 species with much endemicity. This was the first attempt to document the deep-sea biodiversity in India after RIMS *Investigator* conducted over 100 years ago. Detailed analyses of the collections from these surveys could add around 10 new records to the biodiversity of SEAS apart from rerecording a century later *Corphaenoides hextii* which was recorded earlier by Alcock. Two new species each of anglerfishes viz., *Chaunax multilepis and Oneirodes sanjeevani* (Ho et al., 2016; Rajeeshkumar et al., 2017) and deep-sea eels (*Ophichthus mccoskeri* and *Gymnothorax smithi* (Sumod et al., 2019a, b) are described by CMLRE. A separate chapter is included in this edition exclusively on the discovery of deep-sea anglerfishes, and hence a detailed information is not included in this paper.

4.1 New Species

Chaunax multilepis and *Oneirodes sanjeevani* were the two strange deep-sea anglerfishes discovered by CMLRE (Fig 2). *C. multilepis* is the seventh species in the family Chaunacidae from the Indian Ocean. This species is named as *multilepis* since it possesses a greater number of scales compared to their congeners. *Oneirodes sanjeevani* is the latest addition to the family Oneirodidae which contains 37 valid species. This species is named in honor of Dr. V. N. Sanjeevan, former Director of CMLRE, in recognition of his remarkable contributions to the field of Marine Living Resources.

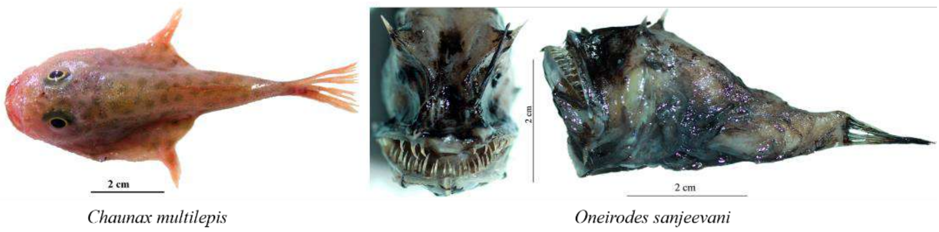


Fig 2. *Chaunax multilepis* and *Oneirodes sanjeevani*, two new species of deep-sea anglerfishes discovered by CMLRE from Indian waters (collected from Northern and western Indian Ocean, respectively)

Ophichthus mccoskeri is a new deep-sea eel discovered from Andaman waters during September 2010 (Fig 3). This species is named in honor of the well-known snake eel expert John E. McCosker for his immense contributions to ophichthid eel systematics and phylogeny.

This species is known only from the continental slopes off Andaman waters. *Gymnothorax smithi* is a new species of deep-sea white spotted moray eel described from southeastern Arabian Sea during August 2011. Species is named in honor of well-known eel expert David G Smith, United States National Museum who has contributed significantly to the Anguilliform fishes of the world.

Fig 3. *Ophichthus mccoskeri* and *Gymnothorax smithi*, two new species of deep-sea eels discovered by CMLRE from Indian waters (collected from Andaman Sea and Arabian Sea, respectively)

4.2 New Records

A compilation of taxonomic discoveries by CMLRE (Sudhakar et al., 2019) from northern Indian Ocean is made. Also, distributional records of four new deep-sea anglerfishes from Indian EEZ (Fig 4) is reported. *Halieutopsis stellifera* a new report from eastern India Ocean previously reported from northern Celebes to the Philippine archipelago and Okinawa Trough (Rajeeshkumar et al., 2013). It is a dorso-ventrally flattened fish with a sit and weight mode of feeding. *Bufoceratias shaoi* represents the fifth known specimens in the world and *Ceratias uranoscopus* is the second known record from the Indian Ocean. *B. shaoi* is previously reported from Taiwan waters and Mossambique channel and our record indicates its distribution towards northern Indian Ocean (Rajeeshkumar et al., 2016).. The distribution *Diceratias trilobus* was previously restricted to Pacific Ocean.

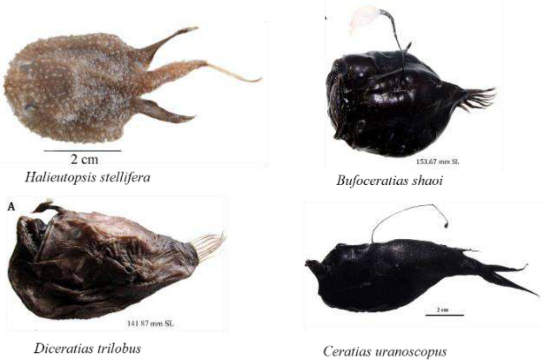


Fig 4. New records of four deep-sea anglerfishes from Indian waters (collected from Andaman Sea, Arabian Sea, Arabian Sea and Andaman Sea, respectively)

Armored sea robins or armored gurnards belong to Family Peristediidae. These strange deep-sea fishes with barbels are encased in heavy scales with sharp and prominent spines. These species are named due to the presence of armor plates throughout the body. A total of seven species were reported from Indian waters (Fig 5).

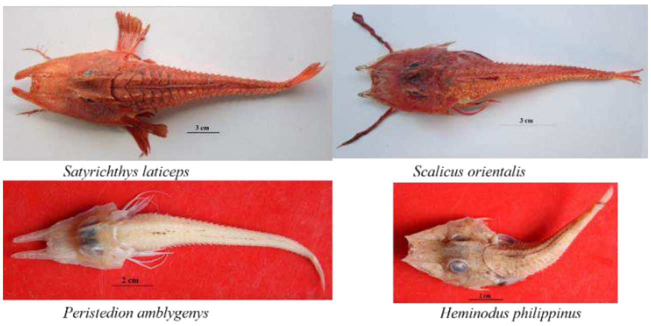


Fig 5. New records of four deep-sea armored searobins from Indian waters (collected from Bay of Bengal, Andaman Sea, Andaman Sea and Andaman Sea respectively.)

Aphanopus microphthalmus is a rare benthopelagic deep-sea species popularly known as small-eye scabbardfish (Fig 6). This species belongs to the group of ribbonfishes of Family Trichiuridae which are commercially very important. Occurrence of this species from the world oceans is found to be scanty. Previously this genus has not been reported from Indian waters. *Neobythites multistriatus,* popularly known as cusk-eels, is also a new report to Andaman waters. This species belongs to Ophidiidae (Order, Ophidiiformes) is one of the most dominant members of the deep-sea fishes from the continental slopes of Indian EEZ along with the rattails (Order Gadiiformes). *Nettastoma solitarium* is a deep-sea eel recently reported from Andaman waters which was previously reported from western Pacific and western Indian Ocean.

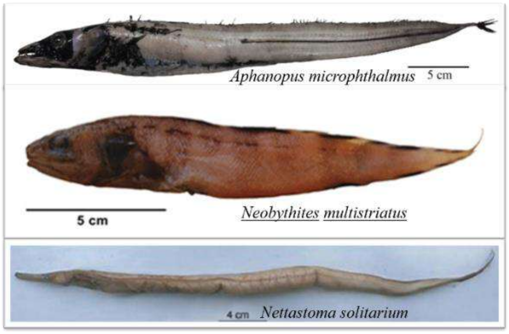


Fig 6. New records of *Aphanopus microphthalmos*, *Neobythites multistriatus* and *Nettastoma solitarium* by from Indian waters (Collected from south eastern Arabian Sea, Andaman Sea, and eastern Arabian Sea, respectively)

Lepidion inosimae is a rare gigantic deep-sea cod reported for the first time from north-western Indian Ocean (Fig 7). Presence of this species from the south-west coast of India indicate a marked extension in the range of distribution from the western Pacific to western Indian Ocean. The presence of the deep-water flathead, *Bembradium magnoculum* from the north-eastern Indian Ocean is a recent addition to the ichthyofaunal diversity of deep-sea waters of India (Kumar et al., 2019). This species was previously known from a single specimen collected off Phuket, Thailand, eastern Andaman Sea.

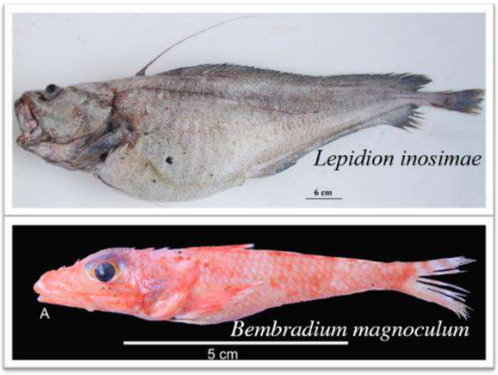


Fig 7. New record of *Lepidion inosimae* and *Bembradium magnoculum* from Indian waters (collected from northwestern Indian Ocean and Andaman Sea, respectively)

It is observed that more and more new species and new records are reported from Indian waters every year indicating the higher diversity of the region and need for more dedicated surveys. Andaman and Nicobar waters are very well known for their high species diversity and most of the recent discoveries are from this region which deserves more devoted surveys. CMLRE has already selected Andaman and Nicobar waters as a “biodiversity hotspot” and extensive surveys will be carried out in the coming years.

5. Future Research

From the published papers and reports available on the deep-sea fishes of Indian waters, it is evident that most of these studies are restricted to taxonomy, distribution, and basic biological characteristics such as food and feeding and length-weight relationships (Hashim, 2012). No effort has been made to understand their stock structure and various population characteristics which are very essential for the stock assessment and management of resources.

CMLRE has laid emphasis on the research on deep-sea fishes from taxonomy to ecology, ecomorphology and otolith studies. Recently, CMLRE used otolith morphology and morphometry to differentiate the species and population of deep-sea fishes from Indian EEZ. These analyses have confirmed that shape of otoliths can be used as an effective, fast and inexpensive approach to discriminate the fish stocks compared to time-consuming and expensive molecular analysis. We successfully differentiated the population of a deep-sea fish known as *Bembrops caudimacula* (Opal fish) which is a very common species seen in both Arabian Sea and Bay of Bengal (200-400m) using otolith morphometric analysis (Deepa et al., 2019). Models developed at CMLRE using various otolith morphometric parameters are found to be very useful for estimating the type and size of prey species for food and feeding and paleontological studies. Recently, scientists of CMLRE studied depth related changes in the sound reception capacities in fishes using otoliths. Study indicated that there is an increase in the sound reception capacities in fishes with depths up to 900 m and declines thereafter.

CMLRE has done considerable progress in understanding the ecological interactions among deep-sea fishes such as predation, niche overlap and diet partitioning using an ecomorphological approach under theoretical ecology (Kumar et al., 2017). It is very much necessary to understand the resource partitioning among deep-sea fishes, to describe the functioning of resource poor deep-sea marine ecosystem. Functional morphology is an effective approach to understand and compare taxonomic units with different phenotypic characteristics related to swimming and foraging. This is relatively a new area of research in our country and institute has made significant strides on that in the form of publications in peer-reviewed journals. CMLRE has already initiated the setting up of India’s first otolith museum of deep-sea fishes with digital library for the benefits of future taxonomy, studies on food and feeding habits, population dynamics, for ecological as well as paleontological studies.

References

Deepa. K. P., Kumar, K.V.A., Oxona, K., Nikki, R., Bineesh, K.K., Hashim., M, Saravanane, N. and Sudhakar, M. (2019). Population variations of Opal fish, *Bembrops caudmacula* Steindachner, 1876 from Arabian Sea and Andaman Sea: Evidence from otolith morphometry. Regional Studies in Marine Sciences 25 https://doi.org/10.1016/j.rsma.2018.100466.

Hashim, M. (2012). Distribution, diversity and biology of deep-sea fishes in the Indian EEZ (Ph.D. thesis). Cochin University of Science and Technology, Kerala, India.

Ho, H. C., Meleppura, R. K. and Bineesh, K. K. (2016). *Chaunax multilepis* sp. nov., a new species of *Chaunax* (Lophiiformes: Chaunacidae) from the northern Indian Ocean. Zootaxa, 4103(2): 130-136.

Kumar, K.V.A, Sileesh, M., Rajeesh Kumar, M. P., Bineesh, K. K., Hashim, M., Saravanane, N. and Sudhakar. M. (2019). New record of *Bembradium magnoculum* (Scorpaeniformes: Plectrogenidae) from north-eastern Indian Ocean. Acta Icthyologica et Piscatoria 49(3): 269-274.

Kumar, K. V. A, V. M. Tuset, Hashim M., Sumod, K. S., Sudhakar, M., Otero-Ferrer, J. L. and Lombarte, A. (2017). Functional approach reveals low niche overlap among common deep-sea fishes from the south-eastern Arabian Sea. Deep-sea Research 1, 119: 16-23.

Rajeeshkumar, M. P., Meera, K. M., and Hashim, M. (2017). A New Species of the Deep-Sea Ceratioid Anglerfish Genus Oneirodes (Lophiiformes: Oneirodidae) from the Western Indian Ocean. Copeia, 105(1): 82-84.

Rajeeshkumar, M. P., Jacob, V., Sumod, K. S., Sanjeevan, V. N. and Hashim, M. (2016). Three new records of rare deep-sea Anglerfishes (Lophiiformes: Ceratioidei) from the northern Indian Ocean. Marine Biodiversity 46(4): 923- 928.

Rajeeshkumar, M. P., Jacob, V., Cubelio, S. S., Jayalakshmi, K. J. and Sanjeevan, V. N. (2013). First record of the batfish, *Halieutopsis stellifera* (Lophiiformes: Ogcocephalidae) from the eastern Indian Ocean. Marine Biodiversity Records, 6; e84; doi:10.1017 /S1755267213000626

Sudhakar, M., Parameswaran UV, Kumar KVA, Hashim M, Saravanane N (2019). Taxonomic discoveries from northern Indian Ocean. Centre for Marine Living Resource and Ecology, India, p 111.

Sumod, K. S., Hibino, Y., Manjabrayakath, H., and Sanjeevan, V. N. (2019a). Description of a new species of deep-water snake eel, *Ophichthus mccoskeri* (Ophichthidae: Ophichthinae) from Andaman Sea, India. Zootaxa, 4686(1): 112-118.

Sumod, K. S., Mohapatra, A., Sanjeevan, V. N., Kishor, T. G., and Bineesh, K. K. (2019b). A new species of white-spotted moray eel, *Gymnothorax smithi* (Muraenidae: Muraeninae) from deep waters of Arabian Sea, India. Zootaxa, 4652(2): 359-366.

Deep sea Biodiversity Assessment by DNA Barcoding

K.V. Vishnu, K.S. Sumod, M.P. Rajeesh Kumar, S.C. Sherine, N. Saravanane, M. Sudhakar.

Centre for Marine Living Resources and Ecology, Kochi

Email: vishnukalladath@gmail.com

Marine biodiversity assessment, taxonomic authentication, cataloging and documentation are significant science feats in the last 2-3 decades. In this regard, the DNA barcoding has been an effective tool for species identification and marine biodiversity assessment since it allows to identify all stages of life cycle and quantify considerable intra-specific variations rather reliably swiftly and, is cost-effective. Combined use of DNA barcode along with morphological characters has received wide acceptance in taxonomic studies. Together with newer and faster high-throughput sequencing technique, DNA barcoding can serve as an effective modern tool in marine biodiversity assessment and conservation. This article presents taxonomic descriptions of deep-sea fishes (eels and lophiiformes) identified based on the use of DNA sequencing and barcoding. In a first-time study on barcoding of deep-sea eels the COI barcode sequences for 11 deep-sea eels belonging to 11 genera and 5 families were obtained.

1. Introduction

Fish species is traditionally identified based on morphological, meristic and sometimes anatomical characters. But in many cases especially in deep-sea fishes, because of their overlapping meristic traits, high phenotypic plasticity and diverse developmental stages, morphological characters alone are not sufficient to identify the species. This drawback can be overcome by using DNA barcoding. It is a powerful taxonomic tool allowing to identify all stages of the life cycle and helps in quantifying intra-specific variations. Global initiatives, like Barcode of Life Database (www.barcodinglife.org) and the Fish Barcode of Life (www.fishbol.org) are exclusively DNA based identification systems, in which more than 5000 species have already been DNA barcoded, with an average of five specimens per species.

Biodiversity assessment of deepsea fishes in Indian seas by the application of DNA barcoding technique along with morphometric/merestic analyses is quite rare. In this article, baseline information on molecular taxonomy and phylogenetic relationships among the specimens of Anguilliformes (eels) and Lophiiformes recovered from various trawling operations by FORV *Sagar Sampada* is documented. The DNA samples extracted by following standard methods of fish sample collection and ethanol fixation were used.

2. CO1 sequence of deep-Sea Anguilliformes from Indian EEZ

Deep-sea eel specimens were collected onboard FORV Sagar Sampada from various regions of Indian EEZ. The samples were thoroughly washed and a portion of muscle was dissected from each species and preserved in 70% ethanol in sterile vials and stored at $^{-}20^{o}$ C for further molecular analysis.

A total of 11 different CO1 sequences data from 11 genera in 5 families of Anguilliformes were obtained for final analyses. All sequences were compared with NCBI GenBank and BOLD (www.barcodinglife.org, see Ratnasingham and Hebert 2007) for confirmation of the species. Partial but non-chimeric sequences of mitochondrial-DNA generated in this study were deposited in the GenBank. All amplified sequences were >655 bp with no insertions, deletions, stop codons and NUMTs. The shortest sequence observed was 551bp in *Sauromuraenesox vorax* and the longest was 715 bp in *Nemichthys scolopaceus*. Sequences were aligned and multiple alignments resulted in consensus length of 655bp per taxon was used for analysis. Out of the total 655 sites obtained 178 were constant, 102 variable, 7 singleton and 95 parsimony informative sites. A total of 26 haplotypes were observed across the taxa.

Table 1. Details of deep-sea eel species included for the molecular identification.

Family	**Genus**	**Species**	**Reference**
Congridae	*Xenomystax*	*trucidans*	Froese R *et al.*, 2019
	Bathymyrus	*echinorynchus*	Sumod K S (2019) PhD Thesis CUSAT (Deep-Sea Eels (Teleostei:Anguilliformes) of the Indian EEZ:systematics, Distribution and Biology)
	Japonoconger	*Sp. unidentified*	
	Bathyuroconger	*vicinus*	
	Gavialiceps	*Sp. unidentified*	
Muraenesocidae	*Sauromuraenesox*	*vorax*	
Ophichthidae	*Ophichthus*	*Sp. unidentified*	

	Neenchelys	*Sp. unidentified*	
Synaphobranchidae	*Dysomma*	*muciparus*	
	Synaphobranchus	*Sp. unidentified*	
Nemichthyidae	*Nemichthys*	*scolopaceus*	

The Neighbour joining phylogenetic tree (Figure1) is developed with COI sequences of 11 taxa of deep-sea eels from CMLRE collection (indicated with green dots) and the others represents COI sequences adopted from NCBI. The NJ phylogenetic tree infers that most of the species were clustered into different clades with respective to their families. However, the species in families, Ophichthidae and Muraenesocidae formed a single clade implying that at least some members of both these are phylogenetically closer. The first clade (family Congridae) was formed with 10 species. Among them the placement of genus *Gavialiceps* was questionable for long time and the issue was solved only recently. Smith (2002) first placed the genus *Gavialiceps* in the family Congridae. Smith (2017) again commented that *Gavialiceps* should be removed from Muraenesocidae due to their resemblance of genus *Xenomystax* of the family Congridae. Our phylogenetic tree shows close relationship of *Gavialiceps* genera to the *Xenomystax* genera of Congridae family as commented by Smith (2017) and agrees well with the recent placement of genus *Gavialiceps* into the family Congridae. Another genus, *Japonoconger* sp. A, shows genetic relationship with *Ariosoma prorigerum* which is a senior synonym of *Japonoconger proriger*.

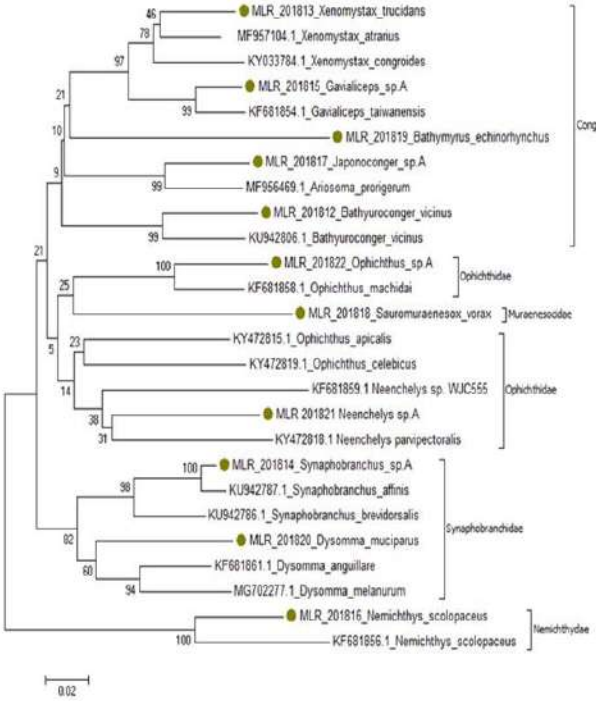


Figure 1. Neighbour Joining (NJ) phylogenetic tree of deep-sea Anguilliformes based on mitochondrial COI sequences.

These results from our molecular analyses conform the previously established morphological identification. In addition, our study also revealed the presence of two cryptic species (*Bathyuroconger vicinus* and *Nemichthys scolopaceus*) belonging to the families Congridae and Nemichthyidae. These two species bear high intraspecific distances of 8.2% from *Bathyuroconger vicinus* and 10.3% from *Nemichthys scolopaceus*. Though these two species are reported to be morphologically same, there are clear genetic variations among these two species as noted in our data. These data also conform Smith et al. (2018) in the case of *B. vicinus* and Gaither et al. (2016) in the case of *N. scolopaceus*. Both the authors have pointed about the presence of likely species complex in these two circumglobal species. An exceptional example is bonefish *Albulla vulpes* which was previously considered as circumglobal species differentiated into 12 or more lineages (Rocha et al. 2008; Hidaka et al. 2008). All the sequences of deep-sea eels developed will be useful for the ongoing global phylogenetic classification studies.

2.1 Deep sea eels from Indian EEZ

Bathymyrusechinorhynchus

Xe nomystaxtrucidens

Sauromuraenesoxvorax

Dysommamuciparus

Bathyurocongervicinus

Fig. 2 Deep sea eels (Sumod et al., 2019 PhD Thesis (CUSAT)

2.1 Characteristics and Reproduction

The mucus that makes eels so slimy allows the live out of water longer than other fish. The major interesting feature is some eel species can survive droughts. Some eel species can hibernate in the clay during winter season. They can eat small fish, crustaceans and planktons. They can move 10 miles per hour. After eel's spawn, they die. Eel eggs hatch into larvae at a depth about 1,000 feet in February and March. Like other fish the larvae look nothing like adults and scientist for a long time thought eel larvae and eels were separate species. Most of the larvae are consumed by predators

3. Molecular Identification of Lophiiformes

Besides being the least studied groups, the taxonomic ambiguities are aplenty among the deep-sea fishes in most of their families. This study represents the first molecular survey using COI gene data of deep-sea fish diversity, some members of the Order Lophiiformes trawled from Arabian Sea, Bay of Bengal and Andaman waters of Indian EEZ. COI barcodes for 13 species were generated and through detailed analysis, a confirmation of four species based on morphology and molecular data was made. Sequences of many species showed high genetic divergence with available sequence in the GenBank and BOLD databases (Fig.3). This may indicate the presence of cryptic species in the genus *Halieutopsis*. Recently, cryptic species were also observed in the family Myctophidae by Zahuranec et al. (2012). Two species, *Halieutopsis* sp. A and *Halieutopsis* sp. B are confirmed as new species based on the morphological analysis. However, more and fresh samples are required to describe the species.

3.1 Food and Reproduction

All lophiiform fishes studied to date are primarily piscivorous (Bertelsen 1951) and utilize their lure to attract prey. Present studies on the feeding habits of lophiids reveals that major portion of their diet is contributed by small fishes and then crustaceans; occasionally cephalopods have also been reported from the stomach. Tendency for greater consumption of fish in their diets are reported by many authors (Soares *et al*. 1993). The family is often known as opportunistic feeders or sit-and-wait type feeders. Ceratioids are predominantly piscivorous and their stomach contents include different kinds of meso and bathypelagic fishes. Traces of crustaceans, cephalopods, holothurians have also been reported; larval forms and early stages of life occupy epipelagic zones and mainly feed on copepods and chaetognaths (Pietsch 2009).

Reproduction and early life history of lophiiiform fishes are limited. Courtship and spawning behaviour of few antennariids have been reported. Many researchers have reported egg attachment of tetrabrachiidae and brachionichthyidae on dorsal finrays and substrate respectively. Recent studies of Arnold (2010) provide additional information regarding the egg and early life history of few more antennariids. Brief descriptions of ovaries are available for chaunacids and ogcocephalids. Details regarding the larvae are available for most of the ceratiids, but nothing is known on their eggs.

Table. 2 Details of lophiiformes studied for molecular identification

Family	Genus	Species	Reference
Lophiidae	*Lophiodes*	*lugubris*	**Rajeeshkumar MP** *et al.*, 2019 (PhD Thesis CUSAT)- Titlrd Deep – Sea Anglerfishes (Pisces: Lophiiformes) of the Indian EEZ :Systematics, Distribution and Biology
	Lophiodes	*mutilus*	
	Lophiodes	*triradiatus*	
	Lophiomus	*setigerus*	
Chaunacidae	*Chaunax*	*apus*	
	Chaunax	*multilepis*	
Ogcocephalidae	*Halieutaea*	*coccinea*	
	Coelophrys	*micropa*	
	Halieutopsis	sp.	
	Halieutopsis	sp.	
	Malthopsis	*lutea*	
	Malthopsis	sp.	
Diceratiidae	*Bufoceratias*	*Bufoceratias thele*	

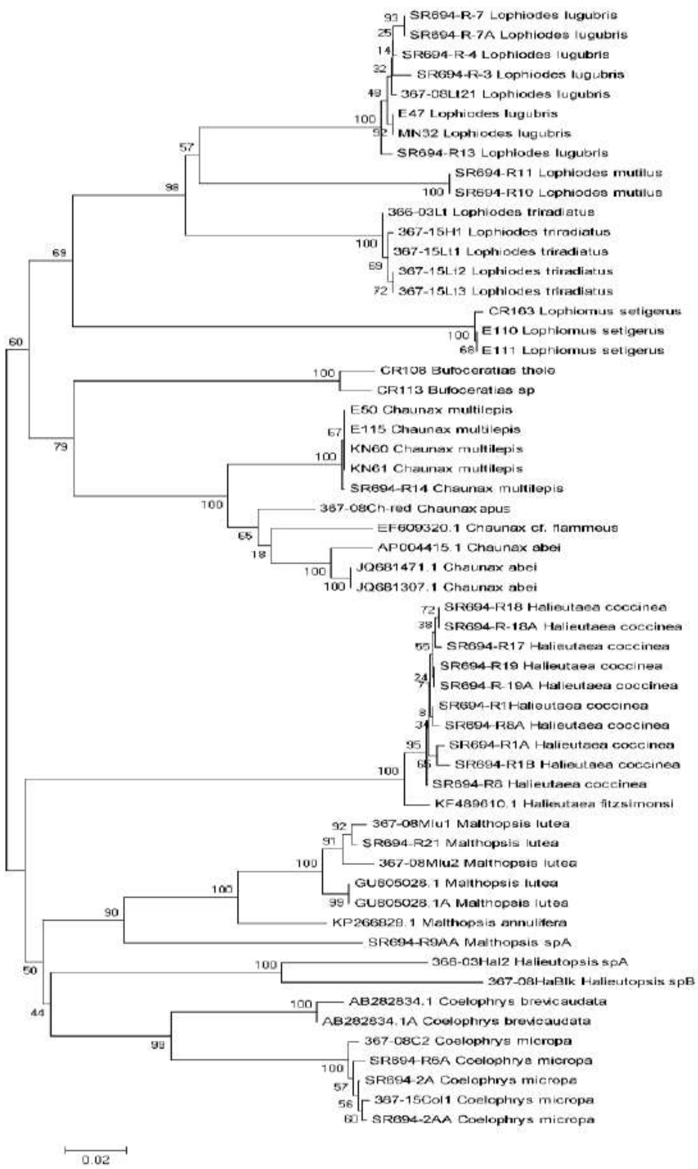


Figure 3. Neighbour joining (NJ) phylogenetic tree of fishes belonging to Order Lophiiformes inferred from mitochondrial COI sequence analysis.

4. Conclusion

DNA-based identification techniques have proven to be rapid, accurate and cost-effective in resolving taxonomic ambiguity at species level facilitating biodiversity studies and elucidating evolutionary relationships. The DNA barcoding efforts on fish biodiversity assessment on going at the CMLRE clearly point to the importance combining the morphological taxonomy along with COI data to identify the cryptic species and to authentically describe the new species or genera.

References

Gaither, M. R., Bowen, B. W., Rocha, L. A., & Briggs, J. C. (2016). Fishes that rule the world: circumtropical distributions revisited. Fish and Fisheries, 17(3), 664-679.

Gomon MF, Ward RD, Chapple S, Hale JM. 2014. The use of DNA barcode evidence for inferring species of *Chlorophthalmus*(Aulopiformes, Chlorophthalmidae) in the Indo- West Pacific. *Marine and Freshwater Research*, 65(11), 1027-1034.

Hebert PDN, Cywinska A, Ball SL. 2003a. Biological identifications through DNA barcodes. *Proceedings of the Royal Society of London B:Biological Sciences*, 270(1512), 313-321.

Hidaka, K., Iwatsuki, Y., & Randall, J. E. (2008). A review of the Indo-Pacific bonefishes of the Albulaargentea complex, with a description of a new species. Ichthyological Research, 55(1), 53-64.

Ilves KL, Taylor EB. 2009. Molecular resolution of the systematics of a problematic group of fishes (Teleostei: Osmeridae) and evidence for morphological homoplasy. *Molecular phylogenetics and evolution*, 50(1), 163-178.

Ratnasingham, S., & Hebert, P. D. (2007). BOLD: The Barcode of Life Data System (http://www. barcodinglife. org). Molecular ecology notes, 7(3), 355-364.

Rocha, L. A., & Bowen, B. W. (2008). Speciation in coral-reef fishes. Journal of Fish Biology, 72(5), 1101-1121.

Smith, D. G. (2002). Larvae of the garden eel genus Gorgasia (Congridae, Heterocongrinae) from the western Caribbean Sea. Bulletin of marine science, 70(3), 831-836.

Smith, D. G., Ho, H. C., Huang, J. F., & Chang, Y. H. (2018). The congrid eel genus Ariosoma in Taiwan (Anguilliformes: Congridae), with description of a new species. Zootaxa, 4454(1), 84-106.

Smith, D. G., Jawad, L., & Al-Kharusi, L. H. (2017). New records and new information on four eel species from Oman (Teleostei: Anguilliformes: Congridae, Muraenesocidae). Journal of the Ocean Science Foundation, 28, 34-46.

Zahuranec B, Karuppasamy PK, Valinassab T, Kidwai S, Bernardi J, Bernardi G. 2012. Cryptic speciation in the mesopelagic environment: molecular phylogenetics of the lanternfish genus *Benthosema*. *Marine genomics*, 7, 7-10.

Ward RD, Zemlak TS, Innes BH, Last PR, Hebert PD. 2005. DNA barcoding Australia's fish species. *Philosophical Transactions of the Royal SocietyB: Biological Sciences*, 360(1462), 1847-1857.

Froese, R. and D. Pauly. Editors. (2019). FishBase. Xenomystax trucidans Alcock, 1894. Accessed through: World Register of Marine Species at: http://www.marinespecies.org/aphia.php?p=taxdetails&id=283192 on 2019-11-17

Bertelsen E. 1951.The ceratioid fishes.Ontogeny, taxonomy, distribution and biology. Dana Report, 39, 276 pp.

Soares LSH, Gasalla MA, Rios MAT, Arrasa MV, Rossi-Wongtschowski CLDB. 1993. Grupos tróficos de onze espécies dominantes de peixes demersais da plataforma continental interna de Ubatuba, Brasil, Publicação Especial do Instituto Oceanográfico de São Paulo, 10:189- 198.

Pietsch TW, Orr JW. 2009. Phylogenetic relationships of deep-sea anglerfishes of the suborder Ceratioidei (teleostei: Lophiiformes) based on morphology. Copeia 1:1–34.

Arnold RJ. 2010. Evolutionary History of the Teleost Family Antennariidae Order Lophiiformes): Evidence from DNA, Reproduction, and Geographic Distribution, with Notes on Conservation Implications. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science University of Washington.

Ascidians: Treasure Troves of Bioactive Molecules

Jhimli Mondal
Centre for Marine Living Resources and Ecology, Kochi, Kerala
Email: jmjhimli@gmail.com; jhimli@cmlre.gov.in

Ascidians are sac-like exclusively marine animals under the class Ascidiacea. Ascidians are found from the intertidal region to greater depths of the ocean. As they live on the ocean floor, ascidians are commonly grouped as benthos. These animals are with great importance in ecology, developmental biology, evolution and pharmacology. As per the research status in Indian subcontinent ascidians are considered as lesser known faunal group.

1. Introduction

Ascidians have a tough covering made of *tunicin* a kind of cellulose which protects their delicate body from the surrounding environment as well as it also provides refuge to the animals from its predator. Hence, the group is also known as tunicates (subphylum: Tunicata). These are the only chordates which can produce cellulose, the peculiar cellulosic covering protects them along with their photosymbionts from the UV radiation. Commonly known as sea-squirts, as they spray waters when disturbed, ascidians display *retrogressive metamorphosis* (free swimming larval stages metamorphose during their development into sessile adults by attaching to suitable substratum with the help of sensory organs).These peculiar animals were recognized as a distinct group from Aristotle's time (Shenkar and Swalla, 2011). First clear description of ascidians published during 18th century (1756). In 1824, Blainville coined the term 'Ascidiacea' not as a class but as one of the families under Mollusca. Through the decades of research on their biology, the group is now considered as distant ancestor of chordates and placed in the hinge of the invertebrate to vertebrate evolution. They serve as ideal model animals in developmental biology and evolutionary studies.

2. Very Diverse Group

About 3000 species of ascidians have been reported till date world-wide with about 450 ascidian species have been reported from the Indian subcontinent. In India the study of ascidians was started during 20th century (1915) by Japanese scientist Oka, when he studied the ascidians collected during the *R.I.M.S. Investigator* voyage. While the studies are mostly focused around Gulf of Mannar region, very few studies have been undertaken from Andaman and Nicobar Islands. Ascidians from other reef ecosystems like Gujarat and Lakshadweep Islands remain untouched even after more than hundred years of pioneering ascidians study. As both morphology and anatomy are playing an essential role in authentic taxonomy, correct identification of ascidian is crucial. Many ascidians are identified to genus level among the 450 reported species from India with only 263 species described up to species level (Meenakshi and Gomathy, 2018).

1. Ecological Role

Ascidians play an important role in the coral reef ecosystem where they provide shelter to other smaller invertebrates as well as cyanobacteria and other micro-organisms. The tunic (outer covering) provides the space for the settlement of other invertebrates along with other ascidians and several symbiotic and parasitic animals take shelter in branchial sac and in gut loop of the animal. Ascidians have an important role in ecology as they act as macrobiofoulers and can grow by attaching to any hard substrates like jetties, buoys, ship hulls, floating pontoons etc. They also cause a great economic loss every year by fouling on bivalve shells of mussel culture and ship hulls. However, due to their spectacular appearance in live conditions these animals attract aquarists. Ascidians are very reliable bio-indicators of heavy metal pollution as they can accumulate various heavy metals such as iron, copper, lead etc. in their tissue cells and act as cleaner and purifier of metal polluted water. Concentrations of vanadium (transition metal) found in ascidian blood cells is 100 million times more than in seawater as they store vanadium in their tissues and cells known as vanadocytes.

2. Ascidians as delicacy

Being easy to digest, ascidians have a good food value being rich in proteins, minerals, iodine and vitamins. Ascidians are cultivated for consumption in Japan and Korea however, in Australia ascidians are used as fishing bait (Watters, 2018). In India, scientists are making pickles of *Herdmania pallida* as it has high protein content (Tamilselvi *et al*., 2010).

3. Pharmaceutical Moieties Identified from Ascidians

Interest in the chemistry of ascidians was ignited during 1847 when a German physiologist revealed the presence of vanadium and sulphuric acid along with a nitrogenous metabolite in blood cellsof ascidians (Menna *et al*., 2011). A wide variety of secondary metabolites (various aromatic alkaloids, cyclic peptides and depsipeptides) are produced by ascidians and their endosymbiotic micro-organisms to ensure protection from predation (Watters, 2018). Members of Didemnidae, Polyclinidae and Polycitoridae are reported to produce great numbers of bio-active compounds with a diversified potentiality to develop the therapeutic drugs for a large number of diseases (Watters, 2018).

Some of these metabolites are cytotoxic, antimicrobial, anti-inflammatory, antibacterial, diuretic, anti-fungal, anti-oxidant, anti-diabetic, anti-proliferative, anti-malarial, inhibitors of cholinergic neurotransmission, pesticidal, anti-leukemic, anti-tumourous (apoptosis, anti-angiogenesis, microtubules, anti-proliferative), anti-cancerous or chemo-protective (Dharan, 2018; Watters, 2018). Additionally, members of Perophoridae and Ascidiidae families are also a great source of secondary metabolites. More than 580 compounds are isolated from ascidians and their structure deduced and, biological activity evaluated. Several secondary metabolites necessary for the defence mechanisms of ascidians are synthesized by their symbiotic bacteria (Watters, 2018). Till date about 80 secondary metabolites have been extracted as bio-active molecules form symbiotic bacteria and most of these are essential for the host-symbiont interaction (Watters, 2018).

In India, research on bio-active molecules are mostly conducted on the *Phallusia nigra* (non-indigenous species), *Polyclinum indicum*, *Polyclinum madrasensis*, (native species), *Aplidium multiplicatum*, *Ecteinascidia venui*. Among the natural products from ascidians Ecteinascidin 743 (ET-743, trabectedin) from *Ecteinascidia turbinata* is FDA approved and marketed under the trade name Yondelis (Watters, 2018). Aplidin (dehyrodidemnin B, plitidepsin)—first isolated from *Aplidium albicans*—has attained orphan drug status (Watters, 2018). Cyclic depsipeptides 'Dehydrodidemnin B' and 'Didemnin B' from *Trididemnum solidum*, cyclic peptide 'Vitilevuamide' from *Didemnum cuculiferum* and 'Diazonamide' from *Diazona angulata* and several others tunicate compounds are in anticancer preclinical or clinical trials (Bragadeeswaran *et al*., 2010, Palaniswamy *et al*., 2015).

4. Research Outlook at CMLRE

CMLRE has recently started the study of ascidians. As a part of benthos study under MEDAS project they have been collected along the Gujarat coast and detailed taxonomic analysis is in progress. Exploration of ascidians will give an insight to the diversity of the Gujarat coast for the first time.

5. Overview

The study of ascidians in Indian subcontinent has received less attention. As per the above noted pharmacological potential of the ascidians, a greater attention to discover the wide variety of drugs/novel moleculesfrom ascidians is essential. For successful pharmacology, species identification should be proper as these secondary metabolites are often species-specific due to their unique endosymbiosis irrespective of the geographic distribution. As the taxonomic identification is always tricky in terms of ascidians, India needs to encourage the taxonomic study to explore their “yet unknown” diversity as well as to initiate the cultivation of economically and pharmacologically significant ascidians. The work started by CMLRE will further help to understand and estimate the availability of the pharmacologically potential native and non-native ascidians.

References:

Bragadeeswaran, S., Ganesan, K., Prabhu, K., Balasubramanian, T., Venkateswarlu, Y., Meenakshi, V.K.: Pharmacological properties of biofouling ascidian, P*olycinum madrasensis* Sebastian, 1952 from Tuticorin Coast of India. Advances in Environmental Biology 4(2), 138-146 (2010).

Dharan, D.T.: FTIR and GCMS studies on the ethanol extract of *Aplidium multiplicatum* from Vizhinjam, Kerala. International Journal of Zoological Studies 3(3), 15-19 (2018).

Meenakshi, V.K., Gomathy, S.: Indian ascidians over the hundred years - a checklist. Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemical Sciences 4(6), 134-170 (2018).

Menna, M., Fattorusso, E., Imperatore, C.: Alkaloids from Marine Ascidians. Molecules 16, 8694-8732 (2011).

Palaniswamy, S.K., Giacobbe, S., Sundaresan, U.: Marine ascidians potential source for new class of anti-cancer drugs. World Journal of Pharmaceutical Sciences 4(8), 474-485 (2015).

Shenkar, N., Swalla, B.J.: Global Diversity of Ascidiacea. Plos one 6(6), 1-12 (2011).

Tamilselvi, M., Sivakumar, V., Jaffar Ali, H.A., Thilaga, R.D.: Preparation of Pickle from *Herdmania pallida*, Simple ascidian. World Journal of Dairy and Food Sciences 5(1), 88-92 (2010).

Watters, D.J.: Ascidians Toxins with Potential for Drug Development. Marine drugs 16(5), 162 (2018).

Clavelina moluccensis Sluiter, 1904 *Clavelina robusta* Kott, 1990

Didemnum molle Herdman, 1886 *Diplosoma simile* Sluiter, 1909

Eusynstyela misakiensis Watanabe & Tokioka, 1972 *Rhopalaea macrothorax* Tokioka, 1953

Photo courtesy:

Didemnum molle: Dr. Sudhanshu Dixit, CMLRE
Rhopalaea macrothorax: ZSI, ANRC
Eusynstyela misakiensis: ZSI, ANRC
Clavelina moluccensis: ZSI, ANRC
Diplosoma simile: ZSI, ANRC
Clavelina robusta: ZSI, ANRC

CMLRE in India's Arctic Research Program

Shahin K. Badesab and Asha Devi C.R.
Centre for Marine Living Resources and Ecology, Kochi
Email: marine.06shahin@gmail.com

The coldest Polar regions, Arctic and Antarctic influence the Earth's climate. Surprisingly, the warming up is quicker at the poles, especially, at the North Pole (http://www.educapoles.org/multimedia/video_detail/what_is_the_point_of_studying_the_poles). Arctic, a polar region in the northernmost part of the Earth consists of the Arctic Ocean, adjacent seas and parts of Alaska, Finland, Greenland, Iceland, Northern Canada, Norway, Russia and Sweden (https://en.wikipedia.org/wiki/Arctic).

1. Introduction

The Arctic land encompasses seasonally varying snow and ice cover with permafrost containing tundra dominance. Mean temperature during winter is -14ºC and during summer is +5 ºC (http://www.ncaor.gov.in/app/webroot/pages/view/339-ny%C3%85lesund). Artic region is unique with the cultures indigenous peoples having adapted to cold and extreme conditions. Arctic life includes those living in and under the sea ice (such as microbes, single celled algae) and others planktonic forms such as phytoplankton, zooplankton, fishes and marine mammals, birds. The terrestrial forms include land animals, plants and human settlements (Krembs & Jody, 2006). Arctic region is known for its extremely lower temperatures, lower precipitation, limited growing season of 50 to 90 days and prolonged darker winters. The Arctic provides important natural resources to the world (for ex. oil, gas, and fish) which will be affected by climate change (Hassol, 2004).


Flora


Polar Bear


Fox


Reindeer

For understanding the Arctic ecology, study of both terrestrial and oceanic aspects of the region is needed. Arctic ecosystem is unique in its complex food web that is shaped by its distinct planktonic and other animal species, and the environmental features. The autotrophic phytoplankton and algae use the CO_2 from sea water and transforms it into organic carbon, which later flows through the different trophic levels by being eaten up and upon digestion and excretion, it sinks as faecal pellets. During all the subsequent heterotrophic processes, CO_2 is given out through respiration processes (http://polardiscovery.whoi.edu/arctic/ecosystem.html). Sea ice that moves with the ocean currents forms an important habitat and a resting place for organisms especially during winter. While permafrost is a ground consisting of rock or soil, with temperatures remaining below freezing point of water for 2 or more years (https://en.wikipedia.org/wiki/Arctic_ecology).

2. Need for Arctic Research in Climate Change Studies

Arctic research forms an important component in the climate change studies as the effect of global climate change with increasing temperature trend would be first evident in the Arctic (Hassol, 2004). The increasing temperatures lead to melting of glaciers, short spans of sea ice, rise in sea level, permafrost thawing and the changing patterns of weather. These in turn can have a substantial impact on the polar marine ecosystem (Wassmann et al., 2011) affecting the ecology by modifying the trophic interactions. This may further bring regime shift as well. Polar bears living on sea ice depend on the surrounding waters for food will have to search for food or else, will have no sea ice to live on if melting continues. Melting of permafrost due to increasing temperatures could lead to release of large amounts of carbon locked inside them, thus contributing to increased level of global CO_2 in the atmosphere (https://en.wikipedia.org/wiki/Arctic_ecology).

The marine environment of Arctic has been undergoing major changes in temperature and ice cover over the decades and warming is expected to continue (IPCC, 2014). The warm Atlantic Water (AW) intrusion is the largest oceanic heat transport to the Arctic basin (Beszczynska-Möller et al., 2011) and over the years it has become the main indicator of climate change in the Arctic marine environment (Onarheim et al., 2014). The knowledge on the Arctic marine ecosystem has been reviewed by Hop et al. (2002). The Arctic dominance in winter to Atlantic dominance in summer is the resultant of advection of Atlantic water along the shelf (Svendsen et al., 2002) which shows interannual variations.

It is understood that the Arctic also ~~has~~ experiences cold and warm years similar to some tropical regions due to temperature variations in the Western Spitsbergen Current (WSC). Along with the heat, the AW current brings in the phytoplankton (Metfies et al., 2016) and zooplankton from Atlantic (Gluchowska et al., 2017). This inflow of zooplankton in the Arctic through Atlantic-Arctic passage is much greater than through the shallow Pacific-Arctic passage because of the differences in the advected water volume (Wassmann et al., 2015). A synthesis on the occurrence of Atlantic Copepod species in the Arctic is available in Hop et al., 2017. However, presently, the studies on the transport of AW zooplankton into Arctic waters are not adequately available to understand the changing Arctic zooplankton communities thus making it difficult for future projections (Basedow et al., 2018).

2.1 India in the Arctic

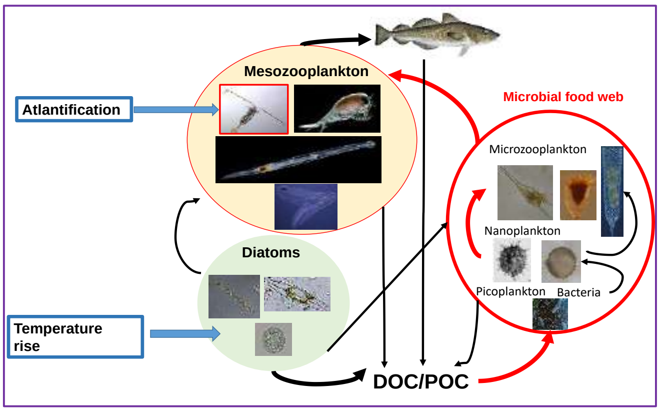
India, being a member of various international forums such as The Scientific Committee on Antarctic *Research (*SCAR) and The International *Arctic* Science Committee (IASC) plays a pivotal role through its national polar research programs in addressing the significant research problems and challenges globally (https://www.downtoearth.org.in/news/climate-change/here-is-why-researchers-working-in-polar-regions-are-coming-together-61009). To yield a better understanding on the dynamics and functioning of the fjords in Arctic from regional and global point of view, comprehensive research plan is designed by identifying the long-term and short-term objectives (http://www.ncaor.gov.in/arctics/display/397-long-term-monitoring-)

National Centre for Polar and Ocean Research (NCPOR) is the nodal agency for the Indian Arctic programme. India has stepped into Arctic research since the year 2008. 'Himadri' as its first research station established in 2008 located at International Arctic Research base, Ny-Ålesund, Svalbard archipelago focusses on atmospheric sciences, marine ecosystems and pollution. Presently, 11 institutions from 10 different countries have permanent research stations in Ny-Ålesund (https://kingsbay.no/research/research_stations/). The fjords in the Arctic are the focal points for measuring the causes and impacts of climate change. Numerous studies have been initiated to study the Arctic marine environment in the last several decades, Understanding the impact of climate change with respect to dynamics and functioning of Arctic fjords will continue to be the focus of all participating nations in the Arctic research. In this context, India's research has ~~been~~ designed and initiated to establish a long term and comprehensive study programme in atmospheric sciences, marine ecosystems and pollution. The focus is to understand the climate

induced variability in food web structure, carbon dynamics, transport and fate of pollutants, physical oceanography, fjord-atmospheric interactions, phytoplankton productivity, bio-optical oceanography and biogeochemistry, paleo-environment, carbon sequestration, sea-ice microbial communities, glacier monitoring and others (http://www.ncaor.gov.in/arctics/display/397-long-term-monitoring-)

3. Role and Researches by CMLRE in India's Arctic Research Program

Centre for Marine Living Resources and ecology (CMLRE) has been a part of India's Arctic Research program since the year 2015. Since then, CMLRE researchers have participated in six Indian Arctic Expeditions. Research team of CMLRE jointly with NCPOR finds its interest in studying the food web ecology and plankton dynamics of Kongsfjorden, a glacial fjord with a length of 40 km and width of 5-10km is located on the west coast of Svalbard. It is significantly influenced by the glacial melt freshwater at the inner fjord and by the intrusions of warm Atlantic water from the west Spitsbergen current. The interaction between the warm AW and turbid glacial melt water over a period is expected to affect the pelagic ecosystem in the fjord. The zooplankton along with phytoplankton, microplankton (bacteria, archaea, microbial eukaryotes) form the base of the Arctic marine food web, and provide food for the large sized other zooplankton, fishes, sea birds and marine mammals in the region. With anticipated increase in stratification resulting from increased inflow of Atlantic water into the Arctic fjord small phytoplankters may increase implying the significance of microbial grazers. However, any changes in these group of organisms can have severe negative impact in the ecosystem and may also lead to shifts in the ecosystem (Secretariat, A. C. (2017).

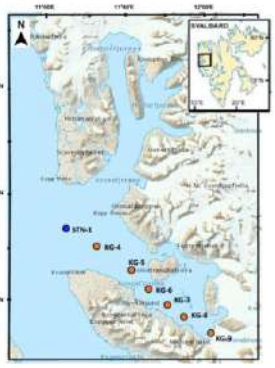


A Schematics of Arctic Food web

*Organisms' images courtesy: Google

From the CMLRE perspective, understanding the influence of changing climate and warm Atlantic water intrusion on the Arctic zooplankton community structure is the focus. Zooplankton community can considerably impact the higher trophic levels in the food chain (Falk-Petersen et al., 2014). Most zooplankton studies in the Arctic and sub-arctic region have focussed on dominant calanoid copepods (Søreide et al. 2010). But there is a need to have a wider perception, for which quantification of plankton community as a whole is needed for understanding the long-term changes occurring at different trophic levels in relation to changing environment (Hays et al. 2005). The CMLRE research program will aid in identifying the functional species of zooplankton and elucidate their role in the planktonic food web. Further, it will unveil the variability in zooplankton community structure in response to changing global climate. Regular and continuous long-term monitoring studies are therefore essential to understand these changes in the present warming trend observed in the Arctic.

In this regard, field campaigns over four years during summer (August 2015, June 2016, August 2018 and August 2019) for collection of zooplankton samples have been carried out in the Kongsfjorden covering locations from inner fjord having glacial input to the outer fjord with AW influence.



Study Area

Sampling

Our preliminary results show that there is inter-annual variability in the micro- and meso-zooplankton community between the three summer campaigns (August 2015, June 2016 and August 2018) in the Kongsfjorden. The ciliates were predominant microzooplankton community and the largest variability in the ciliate species being observed between the inner and the outer fjords with *Parafavella* as the dominant species. Copepoda dominated the zooplankton community during all three years with Calanoida being most abundant and followed by Cyclopoida. In the middle fjord region, differences in the dominance of non-copepod groups was evidenced over the three years. Among non-copepoda, Chaetognatha dominated the zooplankton community in 2015, while Amphipoda and Bivalvia veligers dominated during 2016 and 2018 respectively. Ctenophora was abundant in the middle fjord in 2015, while Pteropoda was abundant in 2016 and 2018. Variability in mesozooplankton biomass upto subsurface chlorophyll maxima (SCM) between the years is shown in table 1. This variability observed could be due to the fluctuating patterns that are linked to the ocean dynamics. Further, long term monitoring will help us in unveiling the changes occurring in zooplankton communities with the global climate change.





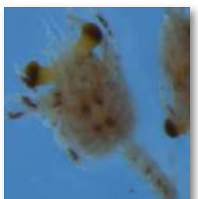


Table 1 showing variations in biomass over three years during summer

St. no.	Mesozooplankton Biomass (ml m^{-3})		
	August 2015	**June 2016**	**August2018**
KG 1	NS	0.0084	0.20
KG 2	NS	0.062	NS
KG 3	1. 77	NS	NS
KG 3.1	3.30	0.039	
KG 3.2	NS	NS	NS
KG 4	NS	NS	0.05
KG 4.1	7.08	0.061	NS
KG 5	2.36	0.042	0.026
KG 6	NS	0.048	0.052
KG 7	1. 77	0.024	0.39
KG 8	NS	0.15	0.13
KG 9	3.10	0.06	0.32
KG 10	NS	0.10	NS

NS-No sample

References

Basedow, S. L., Sundfjord, A., von Appen, W. J., Halvorsen, E., Kwasniewski, S., Reigstad, M.: Seasonal Variation in transport of zooplankton Into the Arctic Basin through the Atlantic gateway, Fram Strait. Frontiers in Marine Science 5, 194 (2018).

Beszczynska-Möller, A., Woodgate, R. A., Lee, C., Melling, H., Karcher, M.: A synthesis of exchanges through the main oceanic gateways to the Arctic Ocean. Oceanography 24, 82–99 (2011). doi: 10.5670/oceanog.2011.59

Krembs, C., Deming, J.: Organisms that thrive in Arctic sea ice in National Oceanic and Atmospheric Administration (2006).

Falk-Petersen, S., Pavlov, V., Berge, J., Cottier, F., Kovacs, K. M., Lydersen, C.: At the rainbow's end: high productivity fueled by winter upwelling along an Arctic shelf. Polar Biology, 38, 5–11 (2014). doi: 10.1007/s00300-014-1482-1

Gluchowska, M., Trudnowska, E., Goszczko, I., Kubiszyn, A. M., Blachowiak-Samolyk, K., Walczowski, W., Kwasniewski, S.: Variations in the structural and functional diversity of zooplankton over vertical and horizontal environmental gradients en route to the Arctic Ocean through the Fram Strait. PLoS ONE 12:e0171715 (2017). doi: 10.1371/journal.pone.0171715

Hassol, S.: Impacts of a warming Arctic-Arctic climate impact assessment. Cambridge University Press (2004).

Hays, G. C., Richardson, A. J., Robinson, C.: Climate change and marine plankton. Trends in ecology & evolution, 20(6), 337-344 (2005).

Hop, H., Pearson, T., Hegseth, E.N., Kovacs, K.M., Wiencke, C., Kwasniewski, S., Eiane K, Mehlum F, Gulliksen B, Wlodarska-Kowalczuk M, Lydersen C, Weslawski, J.M., Cochrane, S., Gabrielsen, G.W., Leakey, R.J.G., Lønne, O.J., Zajaczkowski, M., Falk-Petersen, S., Kendall, M., Wa¨ngberg, S-A°., Bischof, K., Voronkov, A.Y., Kovaltchuk, N.A., Wiktor, J., Poltermann, M., di Prisco, G., Papucci, C., Gerland, S. : The marine ecosystem of Kongsfjorden, Svalbard. Polar Research, 21, 167–208 (2002).

Hop, H., Wold, A., Vihtakari, M., Daase, M., Kwasniewski, S., Gluchowska, M., Lischka, S., Buchholz, F., Falk-Petersen, S. (this volume-b) Chapter 7: Zooplankton in Kongsfjorden (1996–2016) in relation to climate change. In: Hop H, Wiencke C (eds). The ecosystem of Kongsfjorden, Svalbard, Advances in polar ecology 2. Springer, Cham.

IPCC Climate Change 2014: Synthesis Report. Contribution of Working Groups, I., II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp 151 (2014).

Onarheim, I. H., Smedsrud, L. H., Ingvaldsen, R. B., Nilsen, F.. Loss of sea ice during winter north of Svalbard. Tellus A 66:23933 (2014) doi: 10.3402/tellusa.v66.23933

Secretariat, A. C.: State of the Arctic Marine Biodiversity summary report; Key findings and advice on monitoring: 2017 (2017).

Wassmann, P.: Arctic marine ecosystems in an era of rapid climate change. Progress in Oceanography, 90(1-4), 1-17 (2011).

Wassmann, P., Kosobokova, K. N., Slagstad, D., Drinkwater, K. F., Hopcroft, R. R., Moore, S.E., Ellingsen, I., Nelson, R.J., Carmack, E., Popova, E., Berge, J.: The contiguous domains of Arctic Ocean advection: trails of life and death. Progress in Oceanography, 139, 42-65 (2015).

Metfies, K., von Appen, W.-J., Kilias, E., Nicolaus, A., Nöthig, E.M.: Biogeography and photosynthetic biomass of Arctic marine pico-eukaryotes during summer of the record sea ice minimum 2012. PLoS ONE 11:e0148512 (2016). doi: 10.1371/journal.pone.0148512

Søreide, J. E., Leu, E., Berge, J., Graeve, M., Falk-Petersen, S. Timing of blooms, algal food quality and Calanus glacialis reproduction and growth in a changing Arctic. Global Change Biology. 16, 3154–3163 (2010). doi: 10.1111/j.1365-2486.2010.02175.x

Svendsen, H., Beszczynska-Möller, A., Hagen, J.O., Lefauconnier, B., Tverberg, V., Gerland, S., Ørbæk, J.B., Bischof, K., Papucci, C., Zajaczkowski, M., Azzolini, R., Bruland, O., Wiencke, C., Winther, J-G., Dallmann, W.: The physical environment of Kongsfjorden-Krossfjorden, an Arctic fjord system in Svalbard. Polar Research, 21:133–166 (2002).

http://www.educapoles.org/multimedia/video_detail/what_is_the_point_of_studying_the_poles

https://www.downtoearth.org.in/news/climate-change/here-is-why-researchers-working-in-polar-regions-are-coming-together-61009

https://en.wikipedia.org/wiki/Arctic

http://www.ncaor.gov.in/app/webroot/pages/view/339-ny%C3%85lesund

http://www.ncaor.gov.in/arctics/display/397-long-term-monitoring-

https://en.wikipedia.org/wiki/Arctic_ecology

http://polardiscovery.whoi.edu/arctic/ecosystem.html).

Role of FORV *Sagar Sampada* in India's Marine Fisheries and Allied Research

M Subramanian and A Shivaji
Centre for Marine Living Resources and Ecology, Kochi 682037
Email: subramanian@cmlre.gov.in

The Fisheries Oceanographic Research Vessel (FORV) *Sagar Sampada* owned and operated by the Ministry of Earth Sciences is a one-of-a-kind research vessel in India. This vessel, built in Denmark and commissioned back in 1984, is India's national facility open to all sea-related research and training of Indian marine researchers. *Sagar Sampada* has been deployed mainly in the Arabian Sea and Bay of Bengal apart from a couple of expeditions to the Antarctic waters. It is a dedicated ship for researches on marine ecology, biology, biogeochemistry and deep-sea ecosystems. The research vessel has been offering a wide range of opportunities for collection of scientific data. The research outcomes and information generated from the sampling has been instrumental in establishing the marine living resources programme of the Ministry of Earth Sciences, Govt. of India.

1. Introduction

The Fisheries Oceanographic Research Vessel (FORV) *Sagar Sampada* is owned by the Ministry of Earth Sciences (MoES) and managed by its Centre for Marine Living Resources and Ecology (CMLRE), Kochi, a constituent laboratory of MoES. This 71.5m long multipurpose fishery oceanographic research vessel was built at the Dennebrog Shipyard Ltd, Denmark, under the Danish Assistance programme to India. The vessel was commissioned on November 6, 1984. The Danish International Development agency (DANIDA) provided for some scientific equipment when she was being built. Many of those have been replaced using the grants from MoES during these ensued 35 years.

Specifically designed to operate all forms of fishing gear, the vessel can deploy and retrieve other research equipment. This is due to installed winch capacity to take very large load. With the maximum speed of 13 knots and an operational speed of 10 knots, she can operate in all sea conditions experienced off the Indian coastline. The vessel has a, accommodation for up to 35 crew and 22 scientists.

Through the declaration of the Exclusive Economic Zone (EEZ), the extension of national maritime jurisdiction limit to 200 nautical miles was implemented by the UN in 1976. This was to explore, manage and conserve the living and non-living resources by all maritime nations. This opened a new chapter in the maritime activities of our country and provided a great opportunity as well as some challenges for the purposeful and beneficial use of the resources contained in this regime. In this regard, a need of FORV was thought of and, *Sagar Sampada* acquired.

Figure 1: Fisheries Oceanographic Research Vessel *Sagar Sampada*,

2. Technical Data

Table 1: Major technical details of the vessel FORV *Sagar Sampada*

Technical Data	**Units**
Length overall	71.5 m
Length between perpendiculars	63 m
Breadth	16.4 m
Draught	5.6 m
Displacement	3145 MT
GRT	2661 MT
NRT	798 MT
DWT	1140.1MT
Power	B & W – ALPHA, DIESEL 2284BHP / 1680 KW
Max,Speed in open water	13 knots
Classification	IRS / IR NO.05464
SPEED FOR CRUISE PLANNING	
Cruising speed in open water	08 knots
PERSONEL	
crew	37
Scientific participants	22

3. Research Objectives

FORV *Sagar Sampada* was designed for fisheries and oceanographic research in the Exclusive Economic Zone of India and the contiguous high seas. The Vessel is ice-strengthened to give support to India's Antarctic Scientific programmes for working as far south as 60˚ S Latitude. It is equipped for geoscientific, meteorological, physical, biological and chemical oceanographic work, by fulfilling the needs of on-board research on marine living organisms and their environment.

Marine Fisheries Resources Research is the principal function of the vessel. It is well equipped for locating fish resources, assessing their extent of distribution and quantifying the fish stocks in the column waters and on sea bottom through effective use of a multiplicity of fishing gear such as bottom trawl, pelagic and midwater trawls and long-line, and aided by modern underwater acoustics and electronic data processing systems.

The vessel was deployed to acquire data through these integrated methods for a high degree of reliability in estimating the commercial fish stocks and to recognise those stocks which are over/under-exploited, non-conventional and new to the fishery. The vessel would also carry out directed research on spawning populations/grounds and young fish, information on which is essential for fishery predictions, conservation and management of resources.

Oceanographic Research which forms an integral part of marine fisheries research is the second plank of operation of the vessel. The physical chemical and biological factors which influence and control the quality and levels of primary secondary and tertiary production, life-history of fishes and special features such as upwelling, convergence, deep-scattering layers and marine pollution are to be investigated. Such wide-ranging studies facilitated through automated data acquisition, water sampling and analysis of different parameters through sophisticated instruments and temperature-controlled aquarium facility conveniently spread out in the specific laboratories.

4. Major and Envisaged Investigation Programmes

- Physical, chemical and biological oceanography
- Acoustic Surveys
- Met-Ocean data collection
- Marine benthos and bio regionalisation
- Monitoring of algal blooms
- Demersal fishery resources in the outer continental shelf
- Bathypelagic resources in the EEZ and oceanic regions of EEZ
- Crustacean resources in the continental shelf and oceanic regions of EEZ
- Molluscan resources (mainly oceanic squids), in outer continental shelf, oceanic regions of EEZ
- Southern Ocean MLR
- Marine reptiles, birds and mammals
- Marine invertebrates of economic use and potential
- Krill resources in Antarctic waters
- Marine biotechnology and microbiology
- Physiology and behaviour of marine organisms
- Meteorology and marine environment
- Ecology of deep-sea grounds
- Fishing gear research and harvesting technology
- Post-harvest technology
- Instrumentation development
- Collaboration with remote sensing programme

5. Research Facilities

FORV *Sagar Sampada* serves as a multi-disciplinary facility. This vessel has installations of different types of winches and cables, cranes (Annexures I and II), laboratories and a live-fish hold. The vessel is essentially a stern trawler. Bottom trawling upto and at a depth of 1000 m is a special feature. It is also suited for midwater and pelagic trawling. There are two main split trawl winches, each to take 4000m length of 22mm φ wire with a pulling capacity of 35t. The fishing gear on board includes bottom trawls, cosmos trawl, High Speed Demersal Trawl (HSDT) - fish and crustacean version, High opening mid water trawls (RMT, Tucker Trawl etc) and Krill trawl. Additional facilities for benthic sampling with 10t A-Frame, grab, dredge and sieve, plankton sampling with Bongo Net, Multiple plankton Net with various mesh size are provided on the fishing deck.

Laboratories onboard include Hydrographic lab, Oceanographic lab, Chemistry lab, Isotope lab, Meteorology lab, Acoustic lab, Microbiology lab, Wet Fish lab, Tunnel Freezer & Fish Hold and Conference hall cum library. The vessel has outstanding facilities with an Aquarium and recirculating facility for investigation on the physiology, reproductive and nutritional aspects on live fish. This system is also being useful in studying planktonic eggs and larvae.

The acoustics lab performs one of the principal functions of the research vessel forming the main centre of operations for research relating location and estimation of fish biomass. The instrumentation comprises of two scientific echosounders, one of frequency 12 khz with booster and transceiver, and one of 38/120/200 khz comprising the EK-60 echosounder system. Data analysis, TS analysis and biomass estimation are computerized, and printouts of basic data are obtained. The lab is also provided with an Integrated Fish Finding System. An ADCP (75 kHz-RD instrument) is also provided in the lab for in-situ measurement of water currents.

The meteorological data coming from sensors located in different parts of the ship are stored in the computer in the Met Office. The data logged are wind direction and velocity, air and water temperatures, barometric pressure, sunshine intensity and radiation, and atmospheric humidity. Data on rainfall, clouds and sea state are collected. Weather chart by a facsimile recorder is obtained through satellite communication and radio transmission. The Met data can be read off on the display screen and evaluated simultaneously. The data is linked to the Integrated Data Acquisition System.

The 2018 installation of CUFES is helping in the collection of vital data on fish eggs and larvae for more accurate assessment of fish larval recruitment and hence an important step in the stock-estimates of many commercial fish species. The Big Eye will provide greater opportunities for sighting the mega-fauna of different species of whales, dolphins, dugon, turtles etc essential for promulgating and implementing suitable conservation measures.

Table 2: Facilities for scientific work onboard *Sagar Sampada*

Laboratories and accessories	**Area (Sq M)**
Hydrographic Oceanographic lab	55
Chemistry lab	42
Isotope lab,	17
Meteorology lab	12
Acoustic lab	25
Microbiology lab	29
Wet Fish lab	76
Conference hall cum library	34
Tunnel Freezer; Fish Hold	**1ton; 15ton**
Winch and Cables	**Length (m)**
Hydrographic winch (mm)	6900
Plankton winch (mm)	5000
2 X split trawl winch and trawling cable for fisheries (mm)	4000

5.1 Major Sampling and Analytical Facilities

1. Conductivity-Temperature-Depth (CTD) Profiler of make Sea Bird SBE 911 plus
2. Acoustic Doppler Current Profiler (ADCP) –VM Broad band- RDI OS II 75KHz for vertical current profiler
3. Auto Analyzer, Autosal, Spectrophotometer, pH meter for Chemical Oceanography
4. MPN, Bongo & VEL Net for sampling for Secondary Productivity
5. Grab, Dredge and Corer for Benthic studies
6. Fishery gears- Expo Model Trawl (Fish), HSDT (CV)
7. Multi frequency Echo Sounder- EK – 60 (38KHz, 120KHz, 200KHz) and SONAR (Side scan)- SX 90 Split Beam
8. Integrated Trawl Instrumentation system
9. PP mooring system
10. Milli Q system
11. Integrated fish finding system (IFFS)

6. Utilisation of *Sagar Sampada*

The extension of the national maritime jurisdiction limit to 200 nautical miles in 1976 to explore, manage and conserve the living and non-living resources of our seas by the declaration of the Exclusive Economic Zone opened a new chapter in the maritime activities of our country. This has provided a great opportunity and a challenge for the purposeful and beneficial use of the resources contained in this regime.

One of the important constraints in the investigation of maritime resources of our seas, which are of multi- and inter-disciplinary nature, has been the lack of an ocean-going vessel adequately equipped for the purpose. Realising this, the Govt of India took action to procure two ocean-going research vessels. ORV SAGAR KANYA launched in 1983 for investigations on the non-living resources and is now managed by National Centre for Polar and Ocean Research (NCPOR) located at Goa. FORV *SAGAR SAMPADA* launched in 1984 is for researches on living resources of our seas.

Marine fisheries resources research is the principal function of the vessel. It is very well and adequately equipped for locating fish resources, assessing their extent of distribution and quantifying the fish stocks in the column waters and on sea bottom through effective use of a multiplicity of fishing gear such as bottom trawl, pelagic and midwater trawls and long-line, and aided by modern underwater acoustics and electronic data processing systems

The Vessel is mainly deployed for scientific cruises across Arabian Sea and Bay of Bengal. The Vessel has as of November 2019 undertaken 392 scientific cruises including the Southern Ocean expedition conducted during 1995 – 1996. She has covered more than 1, 00,000 nautical miles. During 2014-2018, the operating days at sea have averaged 220 days per year (Fig 1). Notably, after a major fire accident on February 16, 2019 while at sea, the repair work was swiftly completed and, within 85 days of this accident, the vessel was back at sea for CMLRE's research program of REIS.

This report is a documentation of some of the important research outcomes from the cruses onboard this vessel including the cruise to the Southern Ocean (First Indian Krill Expedition) in 1995, Central Indian Ocean and Oman Coast for myctophid surveys in 2014 and 2015. This vessel is a critical platform for ocean observations and has served the ocean sciences community extremely well over the past 35 years.

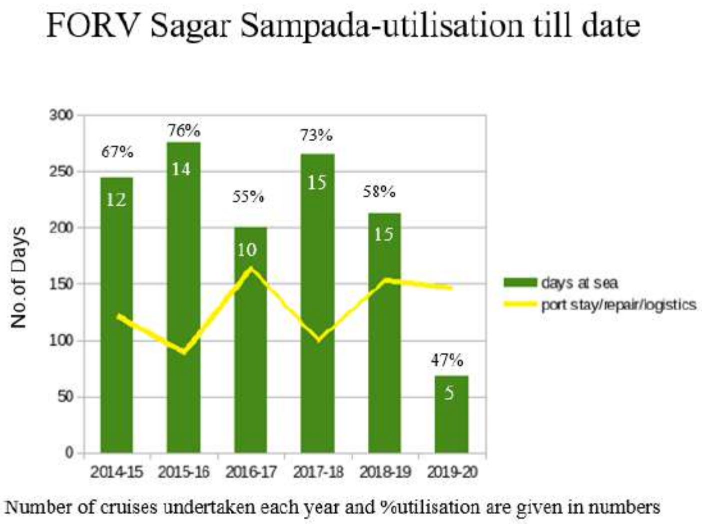


Figure 1: FORV *Sagar Sampada*-utilisation during 1986-July 2019

7. Area of Operation and Cruises Completed

The main operation area of FORV *Sagar Sampada* is the Arabian Sea, Bay of Bengal and Andaman Waters as shown in Fig 2.

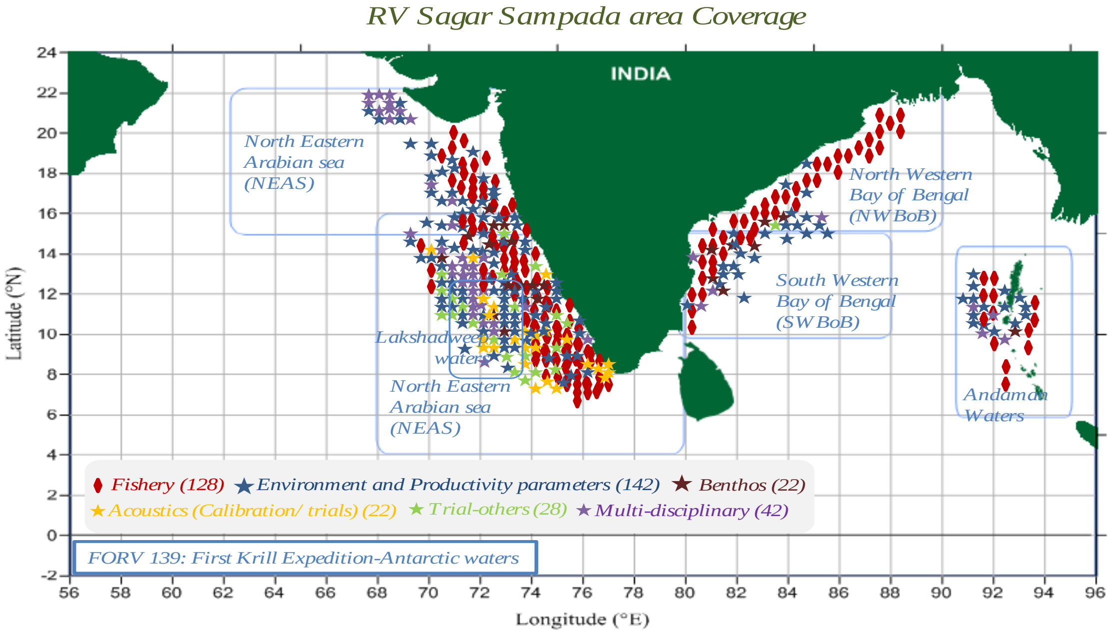


Figure 2: Cruise survey-span of FORV *Sagar Sampada* in the northern Indian Ocean for fisheries-resource assessment, ecology, biogeochemistry and productivity studies

8. Major Participating Institutions

As many as 64 national and seven international institutions have been facilitated the use of FORV *Sagar Sampada* (See Annexure III). The international institutional participation is a recent effort. This cooperation has led to the installation and operation of CUFES gear and Big Eye binocular. Installation of CUFES is helping in the collection of vital data on fish eggs and larvae for more accurate assessment of fish larval recruitment and hence an important step in the stock-estimates of many commercial fish species. The Big Eye will provide greater opportunities for sighting the mega-fauna of different species of whales, dolphins, dugon, turtles etc essential for promulgating and implementing suitable conservation measures.

Being a national facility, the user organizations comprise of all the National Institutes engaged in the R&D programmes in marine fisheries research and education, Universities and other organizations concerned with research and promotion of marine sciences, particularly on living resources. Following is the list of institutions facilitated with cruise opportunities on board FORV *Sagar Sampada*.

FORV *Sager Sampada* has been the platform on which the young scientists learned ship-board methods for sampling and analysing waters ranging from the shelf and deep waters of the Arabian Sea, Bay of Bengal, Andaman & Lakshadweep waters. Numerous junior scientists, research students, postgraduate students and academic students have been trained on many facets of biological, physical oceanography and biogeochemistry

Outcomes from this training platform have variously helped enhancing capabilities of our marine researchers for undertaking studies leading to enhanced understanding of the ecology and living resources of the northern Indian Ocean.

9. FORV *Sagar Sampada* Data Centre

Since 1992, planning, scheduling, and operation of the vessel are done by CMLRE. This Centre has supported all the major efforts of ocean science research during the past three decades. A Joint Scientific and Technical Advisory Committees (JSTAC) constituted by the MoES offers advisories and guidance to the vessel managers on a wide range of issues, including vessel scheduling, technical support on vessels, marine operations and, vessel improvement including dry docking for maintenance and repairs.

FORV *Sagar Sampada* Data Centre was established at CMLRE in 2000 for archiving of all Oceanographic and Meteorological data gathered through the research surveys of the vessel. The Centre archives and distributes physical (atmospheric and oceanic), chemical (dissolved oxygen and nutrients), biological (primary and secondary) and fishery (deep-sea Demersal) data collected under the Marine Living Resources programme (MLRP) since February 1998 till date Data and information at the center includes CTD profiles, weather data from IDAS/AWS, vertical current profiles from ADCP, hydro-acoustics Nutrients and Dissolved Oxygen, Primary productivity, Zooplankton (Meso & Micro), benthic and fishery data.

10. Major Accomplishments

The first workshop on scientific results of FORV *Sagar Sampada* was held at Cochin June 5-7, 1989. This workshop was sponsored by the Ministry of Earth Sciences (former Department of Ocean Development) and was jointly organized by the CMFRI and CIFT, Cochin. Proceedings of the Second workshop on scientific results of FORV *Sagar Sampada* were held at Cochin during February 15-17, 1994. During the Workshop about 60 scientific papers as the outcomes of data collected using *Sagar Sampada* were presented on physical oceanography, microbiology, hydrology, productivity, plankton distribution and fishery resources, trawling methods, gear technology, resources processing and utility, pollution monitoring. Achievements of FORV *Sagar Sampada* were highlighted in the Indian Ocean Marine Living Resources third symposium held at Cochin during December 2-3, 2010.

Marine Living Research Programme (MLRP) activities have been undertaken through the effective utilization of the Fishery Oceanographic Research Vessel (FORV) *Sagar Sampada* in the disciplines of Monitoring and Modelling of Marine Ecosystem, Marine Fishery Resources, Integrated Taxonomic Information System, Southern Ocean Marine Living Resources, Marine Living Resources Technology Development are given in detail. The effective utilization of the vessel by the various fisheries and oceanographic research organizations since 1985 is conversed.

11. Major Research Outcomes

The research cruises during the past 35 years have significantly facilitated the sampling of biological samples for a detailed analysis of biotic composition. The vessel enabled completing large coverage of Indian EEZ from depths beyond 30m. Seasonal distribution and average catch per unit effort of the deep-sea shrimps, lobsters and finfishes in the 200 to 1000m meters depth zones of Indian EEZ have been carried out. This is achieved using Expo Model Trawl and High-speed Demersal Trawl based on as many as 35 dedicated cruises for this purpose. These survey results are the first and perhaps the only available information on the deep-sea fishery resources of Indian EEZ.

Studies on Environment and Productivity, Monitoring and Surveillance of Harmful Algal Blooms, Delineation of Grounds for Bottom Trawling along the Continental Shelf and Slope areas, Marine Mammals Sightings from onboard, Description of benthos biodiversity in the Indian Continental Shelf and Slope and listing of many New Records of Species are also made possible by deploying the vessel. Major details mentioned below.

During the 9th & 10th plan periods, the focus of Marine Living Resources Programme (MLRP) was on establishing baseline information on the distribution and abundance of marine benthos, harmful algae, zooplankton, marine mammals, deep-scattering organisms and deep-sea demersal fishes within the Indian EEZ. Corresponding environmental data from surface to 1000m depths were also collected along pre-decided tracts and stations all along the Indian EEZ covering all the seasons. While the collection of data from these stations was continued during the 11th plan period also, integrating the data and information generated specific data products have been developed viz. (i) Climatological atlas of the Indian EEZ, which describes the environmental features on a seasonal basis together with information on the primary and secondary productivity, distribution of fish eggs and larvae, etc., (ii) CD-ROM on

Marine Mammals which document their distribution and migratory routes in the Indian EEZ, (iii) CD-ROM on zooplankton of Andamans, and (iv) Monograph of Bothid (flat fish) eggs and larvae of Indian Ocean. Data and information gathered through FORV cruises are archived at the CMLRE Data Centre. With the initiation of Indian Ocean Biogeographic Information System (IndOBIS) in 2009, CMLRE has been recognized by the Intergovernmental Oceanographic Commission (IOC) as the regional node for the Indian Ocean.

From the analyses of samples collected from deep sea surveys of FORV *Sagar Sampada* during 2010-2016 many new species of marine animals (ex: three nematodes, two polychaetes, one echinoderm, over 15 fishes) and new records (sea spiders, crab, echinoderms, 11 fishes) have been reported by CMLRE scientists. A partial list of new species and records is included in Annexure IV. Apart from these, there are numerous taxonomic works currently being carried out by CMLRE and other institutes, whose efforts are certain to add more new species/records from India's EEZ.

12. Conclusion

FORV '*Sagar Sampada*' has been a vital component of national marine living resources programme. The Indian Ocean science of marine living resources and non-living resources have benefited by extensive access to its state-of-the-art facilities. Timely implementation of cruise requirements submitted by the various stake holders, institutes, universities and academic institutions and facilitations following critical scrutiny by the JSTAC have helped the collection of a variety of data. Also, largely efficient management of the vessel ensured that the oceanographic scientific community to achieve their scientific objectives. In the next 3-5 years, this vessel will reach its end-of-life. Hence, plans for replacing her with a modern, well equipped fisheries research vessel is mandatory. With timely replacement, the MoES will be in a position of great strength to provide timely data and information on environmental impacts, biogeochemistry, fishery resources and other biological aspects in the Indian EEZ. Such a replacement would result in expanding the scope of our researches on ecology of marine living resource surveys and assessments as well as biogeochemistry. This will certainly continue to bring in numerous benefits to the Nation.

Acknowledgments

We thank Dr M. Sudhakar, Director for guidance and support extended, all the past Directors Prof. V. Ravindranathan, Dr V. N. Sanjeevan, Dr P. Madeswaran and Former Technical Officer Shri. M. K. Somasekaran, and all present Scientists and project staff of CMLRE and advisory committees for their significant directives in the operation and upkeep of FORV *Sagar Sampada*. We also thank Dr Ramaiah Nagappa, Former Chief Scientist, CSIR- NIO, Goa for guidance and support extended.

References (not cited in text, but used variously for developing this article)

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung.(2017).*Research Vessel HEINCKE Operated by the Alfred-Wegener-Institute*. Journal of large-scale research facilities, 3, A120.http://dx.doi.org/10.17815/jlsrf-3-164

C. Saito, H. Momma, S. Tashiro, K SHIBATA *Five-year operation of the oceanographic research vessel MIRAI* October 2003 DOI 10.1109/OCEANS2003.178310 JEEE Xplore OCEANS 2003 Proceedings Vol.5

B H Ketchum *Facilities for Biological Study on Oceanographic Research Vessel* March 1960 Science 131(3398):400-1 DOI.10.1126/science.131.3398.400 Source Pub Med

J.M. Ringelberg, G.W. Beers T.B. Powell *US oceanographic research vessels and the International Safety Management Code (ISM)* February 1999 DOI 10.1109/OCEANS.1999.799796 Source IEEE Xplore Conference: OCEANS '99 MTS/IEEE. Riding the Crest into the 21st Century Volume: 1

Masaro Saiki, Toshihiko Yano *Oceanographic Research Vessel Keifn Marn* September 2001Marine Technology Society Journal 35(3):59-63 DOI 10.4031/002533201788057846

Larry Atkinson, Mark Brzezinski, David Hebert, Chris Measures, Bill Smethie, Tom Weingartner, Joseph Coburn *Academic research fleet faces ship shortage* January 2000 Eos Transactions American Geophysical Union 81(30):334-334

Larry Atkinson, David Hebert, Chris Measures, Niall Slowey, Terry E. Whitledge, Clare Reimers, Ronald Benner, Joe Coburn *First-year performance assessment of SWATH Research Ship* July 2003 Eos Transactions American Geophysical Union 84(27) DOI 10.1029/2003EO270004

Jonathan M. Berkson, George W. DuPree *United States Arctic Research Vessels September 2001* Marine Technology Society Journal 35(3):31-37 DOI 10.4031/002533201788057882

A. DeSilva, M. Prince *Oceanographic research vessel science mission requirements* June 2003 Sea Technology 44(6):35-40

Jonathan M. Prince *The University-National Oceanographic Laboratory System (UNOLS)—The Academic Research Fleet and Oceanographic Facilities* September 2001 Marine Technology Society Journal 35(3):18-22 DOI10.4031/002533201788057919

Tim Cowles, Mike Prince *Renewal of the Academic Research Fleet* June 2004 Marine Technology Society Journal 38(2):55-62 DOI10.4031/002533204787522794

Seung-Hoon Yoo, Suk-Jae Kwon *Non-market Benefits of Building the Large Oceanographic Research Ship* June 2012 Ocean and Polar Research 34(2):175-183 DOI 10.4217/OPR.2012.34.2.175

Georg Wüst *The major deep-sea expeditions and research vessels 1873 1960 A contribution to the history of oceanography December 1964 Progress* In Oceanography 2:1 DOI 10.1016/0079-6611(64)90002-3

Adler A[1] *The ship as laboratory: making space for field science at sea*. Journal of History of Biology 2014 Fall;47(3):333-62. DOI: 10.1007/s10739-013-9367-7.

Joaquin del Rio, Enric Trullols Farreny, J. Sorribas, José Alberto Serrano, O. Garcia, Joan Olivé, Dulce Afonso, Eduardo Arilla, Alberto Hernández, Juan Luis Ruiz, Xoan Romero, Antonio Sandoval *Data Acquisition in Oceanographic Research Vessels* July 2010 DOI 10.1109/MESH.2010.25 Conference International Conference on Advances in Mesh Networks Projects UTM DATA

Oceanographic Research Ships History and Future needs by Richard F.Pittenger, The Journal of Ocean Technology. Vol.8, No.2, 2013

L.P. Atkinson, "*Future research vessels", MAR TECH SJ*, 35(3), 2001, pp. 43-45

ANNEXURE I

List of Scientific Equipment Onboard FORV *Sagar Sampada*

Name of Equipment	Purpose/Use/Application
Echosounder 50 Khz	Determines the depth of water by transmitting sound pulses into water.
Echosounder 49Khz	-do-
Doppler Speed Log 270 KHz	Measures ship's speed by using Doppler Effect, which is observed as a frequency shift resulting from relative motion between a transmitter and receiver.
Cableless Trawl sonde with a. Depth/ Temperature combi sensor b. Height sensor c. Trawl Eye sensor d. Catch sensor e. Spread /remote sensor	ITI is a special acoustic instrument to monitors the operation of trawl net with the help of ITI sensors fixed in the head rope and otter board of the trawl net.
Integrated Fish Finding System	Used for bottom/ sea floor mapping. It is interfaced with DGPS, Echosounder, Gyro etc.
Sonar SX90	Used for tacking and behavioural studies of fish. Sonar transducer is retractable and can be tilted and trained in 90deg and 360 respectively.
Aspiration Psychrometer	The aspiration psychomotor serves for measuring the air temperature and the humidity.
Aneroid Barometer	Aneroid barometer is a device for measuring atmospheric pressure.
Marine Barograph	As atmospheric pressure responds in a predictable manner and recorded charts during cruises.
Marine Mercury Barometer	A barometer is a scientific instrument used in meteorology to measure atmospheric pressure.
Automatic Weather Station	Real time Weather data can be collected and recorded (Lat, Long, Wind Speed, Wind direction, etc) data automatically recorded as per user defined interval.
HP Server E5504	Used as server.
HP Desktop 3000 Pro 3090MT, 18.5" LED Monitor	Used as PC, Printer & scanner.
LAN System complete with 12 Port LAN Hub, inter-connections in all laboratories, LAN cabling and standard accessories	Network system used to interconnect with all computers.
Echosounder 38/120/200 Khz unit	For fish finding and biomass estimation. Three different frequency transducers are transmitted simultaneously for comparative echo studies.
Acoustic Doppler Current	For monitoring underwater current in magnitude and direction at pre-determined depth layers.
EA-600 Echosounder	Used for detection at any ocean depths.
Depth display unit	To display depths in meters.
Differential Global Positioning System (DGPS)	Tells a subject's location on Earth; displays speed of movement.
Portable Echosounder EY-60	It is a portable Echosounder used for biomass estimation and fish finding.
Isotope Fume Cupboard	To avoid chemical fumes and vapors directed through exhaust.
Refrigerator	To store samples at lower temperature
pH meter	To analyse the sea water sample is acidic or Alkaline.

Titrator	For titrating the sea water sample for measuring the oxygen content.
Salinometer	Salinometer is used to measure the salinity of sea water sample.
CTD/Rosette Sampler with a) Underwater unit with sensors b) Niskin Bottles c) Deck unit and related equipments d) Triggering unit	A CTD measures Conductivity, Temperature, and Depth. Also used to measure parameters (such as dissolved oxygen, salinity, temperature, PAR irradiance, turbidity, fluorometer, altimeter, etc.) and a water sampler to collect water samples for later analysis in the lab.
Fume Cupboard	To avoid chemical fumes and vapours which can directly enter our bloodstream, so that it is directed to exhaust.
Refrigerator	Used to store samples at low temperature
Expendable Bathy Thermograph unit with	The unit is composed of a probe; a wire link; and a shipboard canister. The probe falls freely at 20 feet per second and that determines its depth and provides a temperature-depth trace on the recorder.
HP Deskjet 3000 Series PC	Normal PC and scanner.
System Digital Clock	Marine precision clock
Underwater Camera	Used for monitoring underwater activities.
Dual Beam Spectrophotometer	A spectrophotometer is an instrument that measures the numbers of photons (the intensity of light) absorbed after it passes through sample solution. With the spectrophotometer, the amount of a known chemical substance (concentrations) can also be determined by measuring the intensity of light detected. % transmittance and Absorbance of the same is identified.
Water purifying plant with Prefiltration unit	Used for producing Milli-Q water using ion exchange & carbonex cartridges. The purity of the water is monitored by measuring the conductivity. The higher resistance, the fewer ions in the water. A value greater than 18.2 MΩ cm-1 (@ 25 Â°C) is desirable. As a final step, the water is normally dispensed through a 0.22 µm membrane filter.
Insulated water samplers	For collecting water samples from various depths.
Deep Sea Pressure protected reversing thermometer	Reversing thermometer is able to record a given temperature to be viewed at a later time. If the thermometer is flipped upside down, the recorded temperature will be shown until it is turned upright again. Protected thermometer is able to withstand higher pressure.
Deep Sea Pressure unprotected reversing thermometer	For deep water operation, it Can withstand high pressure operations.
Incubator	To grow and maintain microbiological cultures or cell cultures
Muffle Furnace	Furnace with upper temperature limit of 480°C
Fume cupboard	A ventilated enclosure in a chemistry laboratory, in which harmful volatile chemicals can be used or kept.
Multiple Plankton Net Spare nets and buckets	For collecting plankton samples from required depths in a vertical profile.
Bongo net	For collecting plankton samples from surface layer hauled horizontally.
Fume cupboard	A ventilated enclosure in a chemistry laboratory, in which harmful volatile chemicals can be used or kept.
Incubator	A device used to grow and maintain microbiological cultures or cell cultures
Refrigerator 190 lit.	Used for keeping samples
Electronic Marine Balance	Used to find accurate measurements of weight
Electronic Marine Balance	used to find accurate measurements of weight
Electronic Marine Balance	used to find accurate measurements of weight
Binocular Microscope	A binocular microscope refers to any microscope with two eyepieces. Compound or high-power microscopes typically have two eyepieces which view images through a single high-power objective lens. The image presented to each eye is a flat, 2-dimentional 'mono' image.
Stereoscopic Microscope	Stereo microscopes always have two eyepieces, since stereoscopic vision requires two distinct images, one presented to the left eye, and one to the right. The result is a 3-dimentional 'stereo' image.

Stereoscopic Microscope	Stereo microscopes always have two eyepieces, since stereoscopic vision requires two distinct images, one presented to the left eye, and one to the right. The result is a 3-dimentional 'stereo' image.
Binocular Microscope	A binocular microscope refers to any microscope with two eyepieces. Compound or high-power microscopes typically have two eyepieces which view images through a single high-power objective lens. The image presented to each eye is a flat, 2-dimentional 'mono' image.
Fluorescent Trinocular Microscope with Digital Camera	Microscope with three optical paths, two for eye piece and one for a digital camera. Digital camera is connected to a PC and data can be stored.
Vacuum Pump	A pump used for creating a vacuum.
Hot Air Oven	Hot air ovens are electrical devices which use dry heat to sterilize. Generally, they can be operated from 50 to 300 °C, using a thermostat to control the temperature
BOD Incubator	Refrigerated Incubators, often called B.O.D Incubators or Low Temperature Incubators, are commonly used for applications such as B.O.D. Determinations, Fermentation Studies, and Bacterial Culturing among many others.
Laminar Flow	Used to keep samples under a steady laminar flow of air.
Vertical Deep Freezer	To keep samples up to -80°C.
Colony Counter	Biological procedures often rely on an accurate count of bacterial colonies and cells. Colony counters are used to estimate a liquid culture's density of microorganisms by counting individual colonies on an agar plate, slide, mini gel, or Petri dish.
Laboratory Autoclave with Foot Lifting Arrangement	An autoclave is a piece of equipment that is used to sterilize instruments. It uses steam under high pressure to remove any contaminants or bacteria.
Fume cupboard	Fume cupboard is a type of local ventilation device that is designed to limit exposure to hazardous or toxic fumes, vapors or dusts.
Electronic Marine Balance	*Weighing scales* are used to measuring fish samples.
Electronic Marine Balance	Measuring weights
Electronic Marine Balance	Measuring weights
Ice Machine	This instrument is used for making ice flakes instantly
Mincing Machine	Used to mince fish samples
Peeling Machine	To remove the outer covering or skin of prawns
Oscilloscope	Oscilloscopes are used to observe the change of an electrical signal over time.
Power Supply unit	A power supply unit converts mains AC to low voltage regulated DC power
Power Supply unit	Same as above
Megger	The device enables us to measure electrical leakage in wire. It is basically used for verifying the electrical insulation level of any device such as CTD cable, motor, cable, generator winding, etc.
Digital Flow Meter	A flow meter is a device used to measure the flow rate or quantity of water moving through bongo net.
Current Meter	Measure water current velocities over a depth
Smith Mc-Intyre Grab	Instrument used to sample sediment in water environments. Usually it is a clamshell bucket made out of stainless steel.
Dredge	Used for collecting samples from sea floor. Dredge is normally dragged through the bottom for nearly half an hour for collecting samples.
Box Corer	The Box corer is a marine geological sampling tool for collecting undisturbed sediments from ocean. It can be deployed for collecting samples from any depth.
HP Deskjet 3000 Series	Normal PC and scanner
Oscilloscope Infinium	Oscilloscopes are used to observe the change of an electrical signal over time.

Saw Microtome	A microtome is a tool used to cut samples to extremely thin slices of material, known as sections. Microtomes uses diamond blades for slicing specimens.
Fluorescent Trinocular Microscope with digital camera.	A fluorescence microscope, on the other hand, uses a much higher intensity light source which excites a fluorescent species in a sample of interest. This fluorescent species in turn emits a lower energy light of a longer wavelength that produces the magnified image instead of the original light source.
Stereo Microscope with high resolution camera Canon Power shot S50	The stereo Microscope is an optical microscope variant designed for low magnification observation of a sample, typically using light reflected from the surface of an object rather than transmitted through it.
Portable ADCP	An acoustic Doppler current profiler (ADCP) is used to measure underwater current in magnitude and direction from predetermined depth layers.
Fluorometer	Fluorometer is a device used to measure parameters of fluorescence, its intensity and wavelength distribution of emission spectrum after excitation by a certain spectrum of light. These parameters are used to identify the presence of specific molecules in a medium.
Quartz Distillation Plant	Used for collecting distilled water for laboratory purpose.
Thermosalinograph	Thermosalinograph used to collect sea surface (2 to 3 meters from surface) Temperature and Salinity data underway.
CUFES	Continues Underway Fish Egg Sampler – Used to collect Fish egg samples underway, by filtering 500 Litres Seawater per minute with 500 microns net.
Big Eye	Long range Binocular for Marine Mammal watch / identification.
High speed demersal trawl - Fish version (HSDT – FV)	Bottom trawling
High speed demersal trawl - crustacean version (HSDT – CV)	Bottom trawling
Isaacs-Kidd midwater trawl (IKMT)	Mid water & pelagic trawling
EXPO Model Trawl	Bottom Trawling

ANNEXURE II

Major Facilities Available Onboard

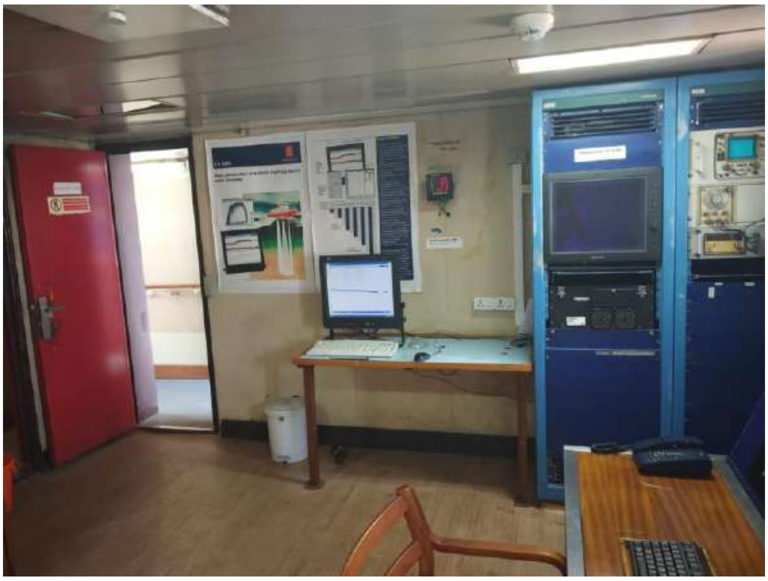
Oceanography lab. – CTD & MPN operation desk

CTD Rosette with Niskin Water Samplers

Smith Mc-Intyre Grab. – for Seabed sediment sampling.

Van Veen Grab - for Seabed sediment sampling.

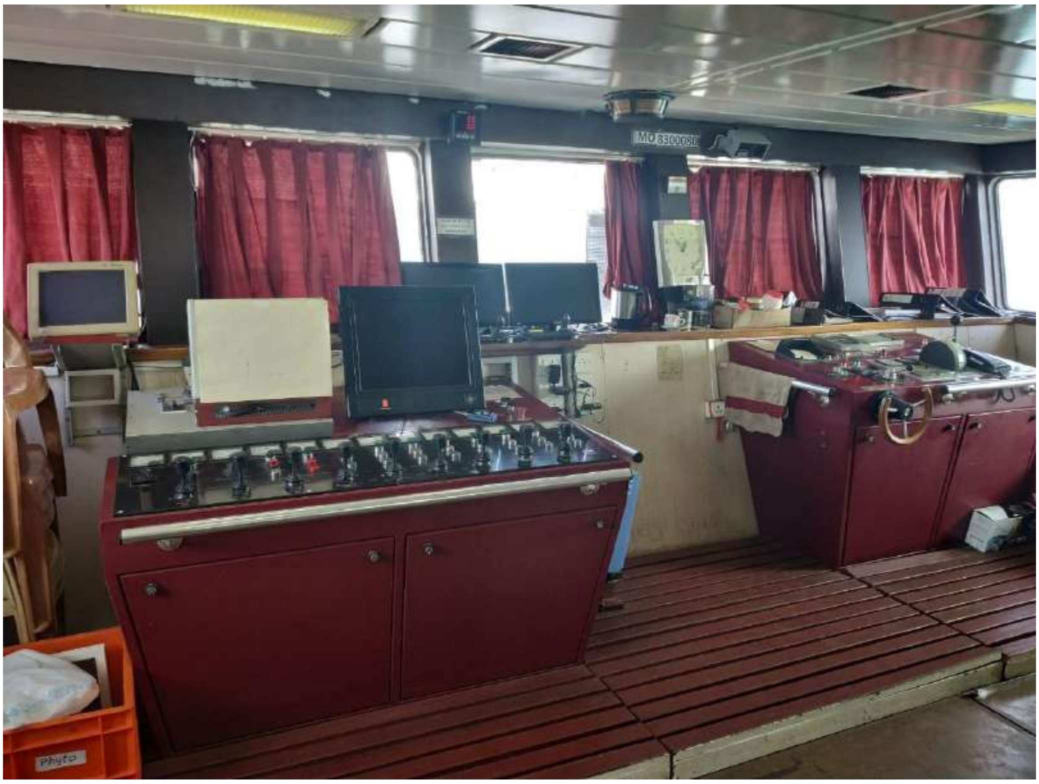
Acoustic Lab. – equipped with CM-60 Fish finding / chart mapping,



ADCP, Scientific echo- sounder EK-60 and Deepsea Echo sounder EA-600.

Wheelhouse **-** equipped with all Navigational equipment, Sonar, Integrated Trawl Instrument etc.

Sonar, Navigational echo-sounder and Speed log. – Bridge FWD – for Navigation



Bridge AFT - for Fishing operation

Integrated Trawl Instrument (ITI).

CUFES (Wet Lab)	
Concentrator and sample collector	Submersible pump base unit
	

Microbiology lab

Water purification plant (Wet lab)

Wet fish lab – equipped with – Mincing machine, peeling machine, weighting machine, Ice machine etc.

Chemistry Lab equipped with Autosal, Dosimat, pH meter etc.

Meteorology Lab

Conference room / Library

Sweep Trawl winch – for Dredge operation.

CTD winch – for CTD / MPN operation.

Split trawl winches – for Fishing operation.

Plankton winch – for Bongo and Grab operations.

ANNEXURE III

Participation of National and International Institutions on FORV Sagar Sampada Cruises

Sl.No.	Name of the Institutions Utilized	Number of Researchers participated
National		
1	Centre for Marine Living Resources & Ecology (CMLRE), Kochi, Kerala	1039
2	Central Marine Fisheries Research Institute (CMFRI), Kochi	1332
3	Central Institute of Fisheries Technology (CIFT), Kochi, India	609
4	Central Institute of Fisheries Education and Nautical Engineering (CIFNET), Kochi	06
5	Fisher survey of India (FSI), Kochi	137
6	Integrated Fisheries Project (IFP), Kochi	07
7	National Institute of Oceanography (NIO), Goa & Kochi	672
8	National Institute of Ocean Technology (NIOT), Chennai,	23
9	National Centre for Coastal Research Centre, Chennai	
11	National Centre for Polar Ocean Research, Goa	01
12	Central institute of Fisheries Education (CIFE), Mumbai, India	25
13	Cochin University of Science & Technology (CUSAT), Kochi, India	273
14	Kerala University, Kerala, India	22
15	Kerala University of Fisheries and Ocean Studies, Panangad, Kerala	18
16	IOM, Anna University, Chennai, India	
17	Madurai Kamaraj University, Madurai, Tamil Nadu, India	05
18	Manonmaniam Sundaranar University, Tirunelveli, Tamil Nadu, India	03
19	CAS in MB, Annamalai University, Tamil Nadu	77

20	Andhra University, Vishakapatnam , India	89
21	Mangalore Fisheries University, Mangalore	03
22	Pondicherry University, Port Blair, Andaman, India	09
23	Madras University, Tamil Nadu	34
24	Tamil Nadu Agricultural University	02
25	Kerala Agriculture University	02
26	Goa University, Goa	16
27	Jadavpur University	03
28	Junagadh Agricultural University	
29	Berhampur University, Orissa	09
30	Calcutta University, Kolkata	
31	Karn University	04
32	Marath wada University	02
33	Baroda University	02
34	Gauhti.University	03
35	University of Kalyani	02
36	Nagarjuna University	03
37	Vikram University , M P	04
38	Pune Uniersity, Pune	03
39	Fisheries College.Tuticorin	02
40	Fisheries College, Ratnagiri	02
41	IIT, Madras	01
42	IIT, Mumbai	01
43	National Institute of Engineering Technology, Alwar, Rajasthan	11
44	Bose Institute, Kolkatta	01
45	Indian Institute of Chemical Technology, Hyderabad	02
46	Space Application Centre, Ahamedabad	29
47	Physical Research Laboratory, Ahamedabad	59
48	Regional Research Laboratory, Thiruvananthapuram	01
49	Zoological Survey of India, Port Blair & Kolkatta	15
50	National Bureau of Fish Genetic Resources, Kochi	01
51	Naval Physical and Oceanographic Laboratory, Kochi	22
52	Central Agricultural Research Institute (***CARI***), Port Blair	09
53	National Remote Sensing Agency (**NRSA**), Hyderabad	01
54	Centre for Earth Science Studies (***CESS***), Thiruvananthapuram	02
55	Indian Navy	02
56	Vikram Sarabhai Space Centre (**VSSC**),Thiruvananthapuram	01
57	Department of Ocean Development, Kochi	661
58	India Meteorological Department (IMD)	02
59	**INCOIS**, Hyderabad	19
60	Tamil Nadu Agricultural University	02
61	Norinco Private Ltd, AMC, Kochi	849
62	Wild-Life Institute of India	01
63	Konkan Cetacean Team	01
64	National Centre for Biological Sciences (NCBS), Bangalore	01
6,159 Marine Researchers have benefited scientifically		
International		
1	WOPRDSWORTH CENTRE, USA	01
2	IAEA, MORACCA	01
3	Biglow Lab, USA	02
4	Bowdoin College, USA	03

5	Colombia University, USA	02
6	University of Texas`	02
7	University of Wahington	01
8	National Oceanic and Atmospheric Administration **(**NOAA), USA	03

ANNEXURE IV

Partial New Records and New Species

A total of eight new species (three nematodes, two polychaetes, one echinoderm, fishes) and 23 new records (sea spiders, crab, echinoderms, 11 fishes) have been reported by CMLRE scientists, through surveys of FORV Sagar Sampada (see Table below).

Groups	Species Name	Sampled Area	Sampling Depth
Nematodes	*Paramicrolaimus damodarani*	South eastern Arabian Sea	95-207m
	Scaptrella filicaudata	South eastern Arabian Sea	1100m
	Psammonema kuriani	North eastern Arabian Sea	214m
Polychaetes	*Pettibonella shompens*	Nicobar Islands	49-50m
	Armandia sampadae	Andaman Islands	52-57m
Sea spiders	*Ascorhynchus levissimus*	Nicobar Islands	601-560m
	Colossendeis colossea	South eastern Arabian Sea	1241-1262m
Crabs	*Lyphira perplexa*	South eastern Arabian Sea	85m
Echinoderms	*Asteroschema sampadae*	South eastern Arabian Sea	450m
	Ophiodaphne scripta	South eastern Arabian Sea	38-111m
	Ophiomyces delata	Andaman Islands	56m
	Amphiura (Amphiura) constricta	South eastern Arabian Sea	52-106m
	Amphiura (Fellaria) heptacantha	South eastern Arabian Sea	31m
	Ophiosphaera insignis	South eastern Arabian Sea	49m
	Ophiacantha dallasii	South eastern Arabian Sea	49m
	Ophioconis cupida	South eastern Arabian Sea	49m
	Petasometra helianthoides	South eastern Arabian Sea	49m
	Saracrinus angulatus	Nicobar Islands	601-643m
Fishes	*Chaunax multilepis*	Andaman Islands	295-323m
	Oneirodes sanjeevani	Western Indian Ocean	380-600m
	Aphanopus microphthalmus	South eastern Arabian Sea	1000m
	Halieutopsis stellifera	Andaman Islands	480-580m
	Satyrichthys laticeps	Western Bay of Bengal	200m
	Scalicus orientalis	Nicobar Islands	388-402m
	Peristedion amblygenys	Andaman Islands	312-441m
	Heminodus philippinus	Nicobar Islands	300-325m
	Bufoceratias shaoi	South eastern Arabian Sea	1300-1350m
	Diceratias trilobus	South eastern Arabian Sea	1300-1350m

	Ceratias uranoscopus	Andaman Islands	850-900m
	Neobythites multistriatus	Andaman Islands	320-410m
	Nettastoma solitarium	Andaman Islands	400-441m