DEEP-SEA ANGLERFISHES (PISCES-LOPHIIFORMES) OF THE INDIAN EEZ: SYSTEMATICS, DISTRIBUTION AND BIOLOGY

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Deep-sea Anglerfishes (Pisces- Lophiiformes) of the Indian EEZ: Systematics, Distribution and Biology

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Ph. D. Thesis in Marine Biology

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Front cover

New species of *Himantolophus* (Ceratioidei: Himantolophidae) collected onboard FORV *Sagar Sampada* from Andaman Sea. Cover Design- Shebin Jawahar

Certificate

This is to certify that the thesis entitled "**Deep-sea Anglerfishes (Pisces- Lophiiformes) of the Indian E.EZ: Systematics, Distribution and Biology**" is an authentic record of the research work carried out by Mr. Rajeesh Kumar M. P. (Reg. No.: 4323), under my scientific supervision and guidance at the Centre for Marine Living Resources & Ecology (CMLRE), Kochi, in partial fulfilment of the requirements for award of the degree of Doctor of Philosophy of the Cochin University of Science & Technology and that no part thereof has been presented before for the award of any other degree, diploma or associateship in any University. Further certified that all relevant corrections and modifications suggested during the pre-synopsis seminar and recommended by the Doctoral Committee have been incorporated in the thesis.

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Declaration

I hereby declare that the thesis entitled "**Deep-sea Anglerfishes (Pisces- Lophiiformes) of the Indian EEZ: Systematics, Distribution and Biology**" is an authentic record of research work conducted by me under the supervision of Dr. V. N. Sanjeevan, Former Director, Centre for Marine Living Resources & Ecology (CMLRE), Kochi and no part of it has been presented for any other degree or diploma in any University.

Kochi-16 **Rajeesh Kumar M. P.**
June, 2018

Dedicated to my family

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Rajeesh Kumar M. P.

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List of Abbreviations

AMS	Australian Museum, Sydney, Australia.
AN	Andaman Sea
ANOVA	Analysis of Variance
AS	Arabian Sea
ASIZP	Academia Sinica, Biodiversity Research Center, Taiwan
BMNH	British Museum (Natural History), London
BoB	Bay of Bengal
CMLRE	Centre for Marine Living Resources & Ecology
DNA	Deoxyribo Nucleic Acid
EEZ	Exclusive Economic Zone
FORV	Fishery Oceanographic Research Vessel
HOT	High Opening Trawl
HSDTCV	High Speed Demersal Trawl Crustacean Version
LACM	Natural History Museum of Los Angeles County, U.S.A.
LDA	Linear Discriminant Analysis
MANOVA	Multivariate Analysis of Variance
MNHN	National Museum of Natural History, France
PCA	Principal Component Analysis
PCR	Polymerase Chain Reaction
PRIMER	Plymouth Routines in Multivariate Ecological Research
RIMS	Royal Indian Marine Survey
USNM	National Museum of Natural History Washington D.C.
WoRMS	World Register of Marine Species
ZIN	Zoological Institute, Russian Academy of Sciences, St. Petersburg
ZMA	Zoological Museum Amsterdam, Netherlands
ZSI	Zoological Survey of India, Kolkata, India.
mtDNA	Mitochondrial Deoxyribo Nucleic Acid
DNA	Deoxyribo Nucleic Acid

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Chapter 1

GENERAL INTRODUCTION

Contents

1.1 Introduction

THE OCEANS cover 70.8% or 361 million square kilometers (139 million square miles) of earth surface and form the most conspicuous feature of Planet Earth. Oceans are a major reservoir of global biodiversity. The Indian Ocean -the third largest Ocean after the Pacific and Atlantic, cover about 14% of the Earth's surface and has an area of 73. 44 million km^2 (21% area of world oceans).

Based on depth the Ocean is divided into the Epipelagic zone (surface to 200 m), the Mesopelagic zone (between 200 to 1000 m), the Bathypelagic zone (between 1000 to 2000 m), the Abyssal pelagic zone (between 2000 to 6000 m) and the Hadal pelagic zone (greater than 6000 m). The Challenger expedition (1872-1876) revealed the existence of life on Ocean floor. It is believed that life may have originated in the deep-sea some 3.5 to 4 billion years ago (Kato and Horikoshi 2004).

Oceans primary production is largely restricted to the euphotic zone where light is adequate enough to support photosynthesis. Organisms in the zones below depend on the food that sink down from above, ranging from tiny clumps of bacteria and dead algae to occasionally dead and decaying fishes or whales. About 20% of the surface primary production is transferred to the mesopelagic zone and only about 5% of the primary production from the surface makes it to the bathypelagic zone. On the basis of depths they occupy the deep-sea fishes are classified into mesopelagic, bathypelagic and benthopelagic groups.

The deep-sea is defined here as the water column and the seafloor deeper than 200 m, which comprise ~ 95 % of the volume of the ocean. In addition to broad-scale deep-sea habitats which are less productive, there are many smaller habitats that add to the heterogeneity and diversity of the deep-sea; such as the seamounts, canyons and channels, fjords, hydrothermal vents, and methane seeps (Ramirez-Llodra *et al.* 2010). The sea mounts provide varied substrata and often harbor numerous fragile, vulnerable and long-lived epi-fauna that support high biodiversity and rich fishing grounds (Clark *et al.* 2008, 2010; Norse *et al.* 2012; Chivers *et al.* 2013). One of the most notable ecosystem services from the deep sea are the fish stocks, which are increasingly finding their way into human diets. Overexploitation of shallow water and shelf fish stocks have prompted the harvesting of deep-sea fish stocks over the past 40 years. Mean depth of fishing is increasing at a rate of 62.5 m per decade (Morato *et al.* 2006, 2013; Watson and Morato 2013).

Deep-sea fishes are adapted to live in the harsh environment of the deep-sea where temperature is near freezing, solar radiation is absent, pressure is inconceivable, food is scares and sex ratios are unbalanced. In the perpetual darkness of the abyss, many species depend on photophores and sound production for intra-species recognition and successful communication. These extreme conditions of the deep-sea are reflected in their feeding and reproductive strategies. However, fishes are there in surprising profusion having adapted to these extreme limitations in a host of bizarre and unpredictable ways. Among the few groups of deep-sea fishes, the teleost Order Lophiiformes performs quite impressive mode of life.

1.2 Order LOPHIIFORMES

Kingdom— *Animalia* Linnaeus, 1758
Phylum —*Chordata* Bateson, 1885
Subphylum —*Vertebrata* Cuvier, 1812
Superclass — *Gnathostomata* Zittel, 1879
Class— *Actinopterygii* Woodward, 1891
Subclass— *Neopterygii* Regan, 1923
Infraclass—*Teleostei* Müller, 1845
Order —*Lophiiformes* Rafinesque, 1810
Classification based on Nelson (2006)

The Order Lophiiformes contains highly diverse groups of marine fish that primarily inhabit both shallow and deep-water environments. Commonly referred to as anglerfishes, the group is strikingly characterized by the structure of the first dorsal-fin spine (known as illicium), 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 and 18 families (Fig. 1.1). These 18 families are distributed among five suborders (Pietsch and Grobecker 1987; Pietsch and Orr 2007): namely the Lophioidei, containing a single family, four genera, and 28 valid species of relatively shallow-water dorso-ventrally flattened forms, commonly referred to as the goosefishes or monkfishes (Caruso and Bullis 1976; Caruso 1981, 1983, 1985; Ho *et al.* 2016b); the Antennarioidei, with four families, 20 genera, and about 65 species (Pietsch *et al.* 2009b; Arnold 2010, 2012, 2013) that are nearly laterally compressed, shallow- to moderately deep-water and benthic forms, with a host of common names such as frogfishes, sea-mice, sea-toads, warty anglerfishes and handfishes (Pietsch 1981, 1984a, 1984b; Last *et al.* 1983) the Chaunacoidei or coffinfishes, represented by one family and two genera and 25 nominal species (Caruso 1989a, 1989b, Ho *et al.* 2013, 2015, 2016; Ho and Ma 2016) of more or less globose, deep-water benthic forms; the Ogcocephaloidei or batfishes comprising of a single family and ten genera and some 70 species of dorsoventrally flattened, deep-water benthic forms (Bradbury 1967, 1980, 1988, 1999; Ho *et al.* 2008, 2009, 2013; Ho and Shao 2008, 2010a, 2010b) and the Ceratioidei, the deep-sea anglerfishes, containing 11 families, 35 genera and 166 species (Bertelsen 1951, 1984; Pietsch 1972, 1979, 1984a, 1986, 1999; Pietsch and Orr 2007; Pietsch 2009, Prokofiev 2014; Ho *et al.* 2016a; Rajeeshkumar *et al.* 2017). Family antennariidae spent most of their lives squatting on the bottom, maintaining immobile or inert appearance. Well known for its amazing luring behavior (Pietsch and Grobecker 1978) and aggressive mimicry in the animal kingdom (Luria *et al.* 1981). Antennariids prefer shallow depth, mostly abundant in sandy, eel-grass or rocky and coral reef habitats of all tropical oceans (Pietsch 1984a; Randall 2005). Present study is restricted to depths beyond 200 m and therefore antennariids are not included in this study.

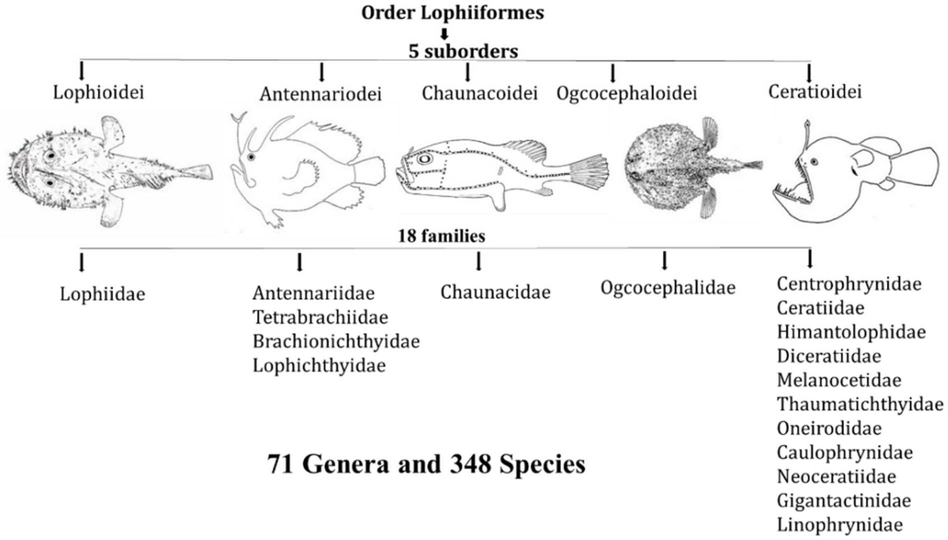

Figure 1.1. General classification of Order Lophiiformes.

1.2.1 General Characteristics

Anglerfishes show amazing morphological disparity in their body shapes, from globose to almost spherical, elongate, laterally compressed or extremely dorso-ventrally depressed. The head and mouth are typically large and the premaxillae is protractile. Teeth in the jaws are numerous, small, villiform and arranged in several rows or very few in number and developed to form large fangs (as in most Ceratioidei). Vomerine teeth are usually present (absent in some Ceratioidei); palatine teeth may be present or absent. Eyes are typically large except in most adult female

Ceratioidei. Anterior-most dorsal spine or illicium is nearly always present (absent in male Ceratioidei and in both sexes of the ceratioid family Neoceratiidae), usually bearing a terminal bait or esca (absent in some Antennariidae, male Ceratioidei, and in both sexes of the ceratioid family Neoceratiidae). Esca is simple to highly complex and bioluminescent in nearly all female Ceratioidei. The bony support for the illicium (illicial pterygiophore), which lies within a shallow trough on the anterodorsal surface of the cranium, is highly protrusible in some taxa. Pectoral fins are highly modified and leg-like (except in Ceratioidei). The pelvic fins when present, are jugular in position and consist of 1 spine and 4 or 5 rays (pelvics are absent in Ceratioidei, except for larval Caulophrynidae). The gill openings are restricted to a small, elongate, tube-like opening situated immediately dorsal to, posterior to, or ventral to (rarely partly anterior to) the base of the pectoral fin. A pseudobranch is present or absent. Swim-bladder is usually absent (present and physoclistous in some Antennariidae). The eggs are spawned in a double, scroll-shaped mucous sheath. The soft dorsal fin consists of 3-22 rays, the anal fin 3-19 rays, the pectoral fin 4-30 rays, and the caudal fin 8-10 rays (Pietsch 2009).

The coloration of anglerfishes ranges from uniform grey, brown to black, without markings of any kind (e.g. some Lophioidei and Ceratioidei), to multicolored and complexly patterned in Antennariidae, Chunacidae and in some Ogcocephalidae (Pietsch 2009). Typically small fishes, the largest known individuals of most families attain standard lengths of approximately 100-250 mm, but some (e.g. Lophiidae, some Antennariidae, Himantolophidae, Thaumatichthyidae, Ceratiidae, and Gigantactinidae) become much larger. Some lophiids exceed a meter in length and weigh approximately 27 kg. Ceratioids display extreme sexual dimorphism in which males are dwarfed, the largest known free-living individuals of most families measuring 10-30 mm SL (standard length), but reaching 40 mm SL in Himantolophidae; parasitically attached individuals usually range from about 7-30 mm SL, but reach nearly 120 mm SL in Ceratiidae.

1.2.2 Phylogenetic Relationships

Regan (1912) believed that the Order Batrachoidiformes and Lohiiformes are two closely related groups and allied these two groups as a suborder of Order Pediculati (based on osteological evidence). Later, Regan (1926) separated the Lophiiformes from Batrachoidiformes based on differences in other characters that are sufficient to separate Lophiiformes from Batrachoidiformes. Regan (1912) conceptualized three major Lophiiform taxa together with currently recognized families (families of the suborder Ceratioidei not included, Bertelsen 1951 and Pietsch 1972) as follows;

- Suborder Lophioidei
  - Family Lophiidae
- Suborder Antennarioidei
  - Family Antennariidae
  - Family Tetrabrachiidae
  - Family Lophichthyidae
  - Family Brachionichthyidae
  - Family Chaunacidae
  - Family Ogcocephalidae
- Suborder Ceratioidei

Using cladistic analysis, Pietsch (1981) attempted to validate Regan's (1912) concept of three major lophiiform taxa wherein serious difficulties were encountered to establish monophyly for the six families of Regan's (1912) Antennarioidei. Later, Pietsch and Grobecker (1987) proposed a revised cladogram different from the cladogram of Pietsch (1981) which helped in resolving these difficulties. In this, the suborder Antennarioidei is restricted to just four families: in this clad the Antennariodei is sister group of the Tetrabrachiidae, these two families together forming sister group of the Lophichthyidae, and previous three families forming sister groups of the Brachionichthyidae (Fig. 1.2)

At least six unique morphological synapomorphic characters (1 to 6 in the cladogram; modification of Pietsch 1981, 1984a) are shared by all taxa included under Lophiiformes.

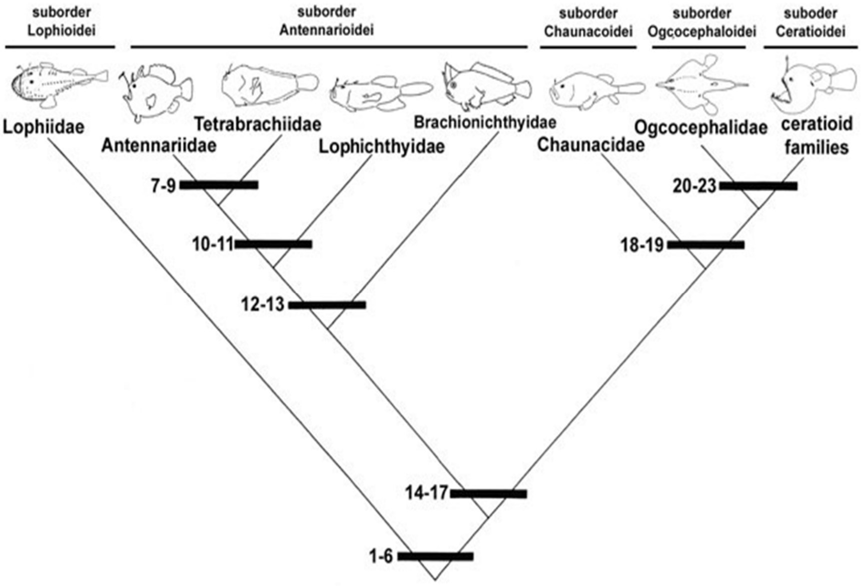

Figure 1.2. The relationships of the Lophiiformes as presented by Pietsch and Grobecker 1987.

Synapomorphic characters shared by all the tax of Lophiiformes;

1) Dorsal fin spines primitively six in number, the anterior-most three being cephalic position with the first modified as a luring apparatus (involving numerous associated specializations, e.g. a medial depression of the anterior portion of the cranium, loss of the nasal bones and supraoccipital lateral-line commissure, and complex modifications of associated musculature and innervation).
2) Epiotics and parietals separated and joining on the midline, posterior to the supraoccipital.
3) Gill opening small, elongate, tube-like and located immediately dorsal to, posterior to, or ventral to the pectoral-fin base.
4) Hypural plate emerging from a single complex half-centrum.
5) Ventral most pectoral radial considerably expanded distally (Pietsch 1981).
6) Eggs spawned in a double, scroll-shaped mucous sheath (Rasquin 1958; Pietsch and Grobecker 1987).

1.2.3 Food and Feeding

All lophiiform fishes studied to date are primarily piscivorous (Bertelsen 1951; Randall 1967; Pietsch and Grobecker 1987) and utilize their lure to attract prey. Available records on the feeding habits of lophiids reveals that major part of their diet is contributed by small fishes and then crustaceans; occasionally cephalopods have also been reported from the stomach (Preciado *et al.* 2006; Valentim *et al.* 2007; Espinoza and Wehrtmann 2008). Tendency for greater consumption of fish in their diets are reported by many authors (Soares *et al.* 1993; Crozier 1985; Armstrong *et al.* 1996; Muto *et al.* 2005). The family is often known as opportunistic feeders or sit-and-wait type feeders. Similarly benthic associated small fishes, crustaceans and gastropods have been reported from ogcocephalids (Nagareda and Shenker 2008). 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 epipelgic zones and mainly feed on copepods and chaetognaths (Pietsch 2009).

1.2.4 Reproduction and Early life history

Present knowledge on reproduction and early life history of lophiiiform fishes are limited. Courtship and spawning behavior of few antennariids have been reported. Within the antennariidae, scattered information on early life-history stages is available only for four out of the 42 recognized species. Pietsch and Grobecker (1980) have reported egg attachment of tetrabrachiidae and brachionichthyidae on dorsal fin-rays 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 (Pietsch 1984a). Details regarding the larvae are available for most of the ceratiids, but nothing is known on their eggs (Pietsch 1984a; Pietsch and Grobecker 1980).

1.2.5 Sexual Dimorphism

Sexual dimorphism is common in the suborder Ceratioidei, -the most phylogenetically diversified and species-rich vertebrate taxon-occupying the bathypelagic zone (Pietsch 1984a; Pietsch and Grobecker 1987). Exhibiting a unique mode of reproduction in which the males are dwarfed, eg. in some members of linophrynids (family Linophrynidae) adults attain only 6–10 mm SL and attach to relatively gigantic female either temporarily or permanently (Pietsch 2005; Kottelat *et al.* 2006). Most extreme dimorphism is seen in *Ceratias holboelli,* the Northern giant sea devil, in which females are 60 times larger than male (Bertelsen 1951; Pietsch 1976, 2005). Males are without luring apparatus (modified first dorsal fin spine, absent in both sexes of family Neoceratiidae) and possess well developed eyes and nostrils (Munk 1964, 1966; Marshall 1967a). The main function of nostril is homing in on a female-emitted, species-specific pheromone for successful communication (Bertelsen 1951; Pietsch 1976, 2005; Munk 1992). Family Lophiidae and Chaunacidae also show strong sexual dimorphism. Olfactory organs present at the base of the eyes are highly developed in males (Caruso 1975).

1.2.6 Sexual Parasitism

Male sexual parasitism is unique in the suborder Ceratioidei. Reproductive strategies in lophiiform fishes exist in four states: (1) males never attach themselves to females; (2) males attach temporarily to females but never become parasitic; (3) parasitism is facultative in some taxa; and (4) parasitism is obligate in other taxa (Pietsch 1976, 2005).

Male's attach to the female by fusion of epidermal and dermal tissues and gradually establishes a connection of the circulatory systems so that the male becomes ultimately dependent on the female for nutrients, while the host female becomes a kind of self-fertilizing hermaphrodite (Regan 1926; Parr 1930; Regan and Trewavas 1932; Bertelsen 1951; Pietsch 1975, 1976 and Munk 2000). Permanent attachment is usually accomplished by means of separate outgrowths from the snout and tip of the lower jaw of the male, both of which eventually fuse with the skin of the female. In some cases the heads of males become fused to the skin of the female, while in others, the male is carried at the tip of an elongate, cylindrical stalk of female tissue (Pietsch 2009).

1.2.7 Bioluminescence

Ceratioid anglerfishes differ from its shallow water relatives in having a bacterial mediated bioluminescent bait or lure (esca at the tip of illicium) except in the family Neoceratiidae. The external morphology of escae (structure, size and shape of esca, number of escal appendages and filaments) plays an important role in the identification of ceratioids (Pietsch 1974a, b; Bertelsen 1982; Bertelsen and Krefft 1988). Internal structure of esca is quite complex. It contains bacteria-filled vesicles, light-absorbing pigment layers, reflecting tissues, tubular light guiding structures, nerves, blood vessels, and smooth muscle fibers (Munk and Bertelsen 1980; Munk *et al.* 1998; Munk 1999). It is believed that ceratioid escae contain pheromone-producing glands that secretes pheromone to attract a conspecific male (Munk 1992), but the true nature and adaptive significance of these structures and most of the other internal structures are still unknown (Pietsch 2007). Unlike other ceratioids, genus *linophryne* bear a bioluminescent hyoid barbell, in which light production is not at all mediated by bacteria, but is intracellular. Paracrystalline photogenic granules, which are mesodermal in origin act as the source of light, whereas bacteria-filled esca is derived from ectoderm (Hansen and Herring 1977). Their unique mode of reproduction has significant biomedical implications to the fields of endocrinology and immunology. Though some work has been carried out earlier, no satisfactory hypothesis of relationships exists for the suborder (Pietsch 2007).

1.2.8 Economic Importance

Some lophiids fishes are used for human consumption, in fresh or frozen state eg. *Lophius americanus* from northwest Atlantic Ocean. In the United States, its popularity has grown considerably. This species contributes a significant portion of the commercial landings in recent years (Armstrong *et al.* 1996; ICES 2004; Preciado *et al.* 2006). Similarly *Lophius gastrophysus* and *Lophiodes beroe* are the target fishery in the deep-sea operations off the southern and southeastern regions of Brazil. Their distribution extends from North Carolina (USA) to Argentina (Valentim *et al.* 2007, 2008; Rotundo and Jùnior 2009). Several species of *Lophius (L. vomerinus, L. vaillanti*, *L. budegassa, L. litulon, L. piscatorius)* have recently gained much economic importance in fishery industry and are exploited worldwide especially northwestern Atlantic (Colmenero *et al.* 2013). The landings of *L. piscatorius* and *L. budegassa* contributed over 6000 metric tons during the past 10 years from northwestern Mediterranean Sea (Afonso-Dias and Hislop 1996).

Chaunacids also serves as valuable food fish in some Asian Countries (personal communication with Ho. HC). Antennariids and to a lesser extent ogcocephalids also are used for aquarium trade.

1.2.9 Geographic Distribution

Lophiiformes are marine fishes distributed widely throughout all oceans and major seas of the world except a single species of Antennariidae (*Antennarius biocellatus*) occasionally taken in brackish water (Pietsch and Grobecker 1987). It is observed that some members of lophiidae are present in the Mediterranean (Pietsch 2009). Most of the members are benthic as adults and occupy depths ranging from 200 m to 2000 m. However, some species extend their habitat towards deeper waters, 2500 m or more. All the members of ceratioidei are meso and bathypelagic, mostly preferring depths between 800 and 2500 m (Pietsch 2009).

1.2.10 Fossil Lophiiformes

Fossils offer unique information on evolution, providing the only evidence for the past existence of organisms that are now extinct, and it allows to calculate the minimum age of a determinate taxon. Apart from this, they provide accurate data on the order of events in phylogeny (Benton and Hitchin 1996, 1997; Benton 1998). The quality of fossils depends mostly on ecological and sedimentary features of the depositional environments (Carnevale and Pietsch 2006). Many authors have described fossil lophiiformes; *Antennarius monody* from the upper Miocene, north-east Algeria (Carnevale and Pietsch 2006); *Sharfia mirabilis*, a new genus and species of lophiid anglerfish from the Eocene of Monte Bolca, Italy, represents the oldest member of the teleost family

Lophiidae (Pietsch and Carnevale 2011). Bannikov 2004 described a new genus and species of anglerfish (Lophiidae), *Eosladenia caucasica* from the middle Eocene of the Northern Caucasus Russia. *Caruso*, a new genus of lophiid anglerfishes from the Eocene of Monte Bolca (Carnevale and Pietsch 2012). Together with *Sharfia, Caruso* is the oldest member of the teleost family Lophiidae. Fossil ceratioid (linophrynidae and oneirodidae) anglerfishes are described from the Upper Miocene (upper Mohnian) deposits of the Puente Formation, Los Angeles Basin, California (Carnevale *et al.* 2008). It is assumed that the basal family of the order, appeared in the Eocene.

1.3 Indian Lophiiformes: Relevance of the Study

The taxonomy of Indian deep-sea fishes was documented by the outstanding works of Alfred William Alcock, a British systematist, through his publications (1889-1907). Some of his works were published in "Zoological Gleanings from the R.I.M.S. ' Investigator,' " in the form of Scientific Memoirs by Medical Officers of the Army of India. He worked on Fishes, Decapod Crustacea, and Deep Sea Madreporarian Corals and published his papers in the Journal of the Asiatic Society of Bengal, the Annals and Magazine of Natural History as well as catalogues of the Indian Museum. In his "Illustrations of the Zoology of the R.I.M.S. ' Investigator', Alcock described three species from Lophiidae family and seven species from Ogcocephalidae., even though taxonomic ambiguity still persist and many species needs taxonomic updation or re-description.

Later, R.E. Lloyd (1909) and, Annandale and Jenkins (1910) described few more species of lophiiformes from Indian waters.

Subsequently many authors, Tholasilingam *et al.* (1964, 1968); Sudarsan *et al.* (1988); Sivakami (1989); Ninan *et al.* (1992); Jayapraksh *et al.* (2006); Somvanshi *et al.* (2009); Sajeevan *et al.* (2009); Venu (2009, 2013); Hashim (2012) attempted to explore the deep-sea resources from Indian waters. However, they didn't record or described any new species except redescription of *Lophiodes triradiatus* (Lloyd, 1909) from Arabian Sea (Ho *et al.* 2014). To date no work has been carried out on the taxonomy, feeding habit and distribution patterns of this group from Indian waters and information regarding the ecological aspects of Order Lophiiformes are not known. It is well known fact that the Indian lophiiformes are least studied and demands further investigations to explain its systematics and biology, specially for following reasons.

- Though the five suborders of Lophiiform fishes are represented by 18 families, 71 genera and 348 species globally, only limited number of species have been reported from Indian EEZ (Exclusive Economic Zone) so far; 7 families, 13 genera and 21 species.
- The most species rich suborder Ceratioidei (166 species globally) is represented only by 4 species from Indian EEZ.
- Nothing is known about the length weight relationship, food and feeding, distribution patterns, reproductive biology, otolith morphology, functional traits and DNA barcodes of this order from Indian EEZ.
- Studies conducted in Indian waters so far were mostly restricted to the Continental shelf.

1.4 Objectives

i) To investigate the taxonomy, systematics, diversity and distribution of deep-sea angler fishes in the Indian EEZ.

ii) To study the biology of Lophiiformes

  a) Estimation of biomass

  b) Length-weight relationship

  c) Food and feeding

  d) Reproductive biology

  e) Ololith morphology and morphometrics

  f) Ecomorphological differentiation of Lophiiformes.

iii) To generate the DNA barcodes of Lophiiformes

1.5 Outline of the Thesis

Chapter 1 General introduction to the research topic. Definitions, key characteristics, systematics and phylogenetic relationship, economic importance and global distribution are provided. A review of literature on Indian Lophiiformes is also provided to reveal the relevance of the present study. Objectives of the present work are explained.

Chapter 2 Study area, sampling stations and methodology adopted for sampling and analysis are detailed in this chapter. Methods and analysis used to perform the biology of Lophiiformes are outlined.

Chapter 3 Provide a brief systematic account of the species collected from the study area. Taxonomically updated check list of the Order Lophiiformes from the EEZ is provided. Previously Indian Lophiiformes were known from 7 family, 13 genera and 21 species. Present study updated the diversity to 8 families, 17 genera and 36 species. Among them present study contributes 7 new records (21 area wise new records—from Arabian Sea 8; Bay of Bengal 3 and Andaman Sea 10) and 8 species new to the science are reported from Indian EEZ.

Chapter 4 Biomass estimation, length weight relationships, food and feeding, and reproductive biology of selected species are outlined. Relationship between otolith variables and fish size, elliptical Fourier shape analysis and description of otolith morphology of selected species are provided. Ecomorphological differentiation of lophiiformes fishes are also briefed in this chapter.

Chapter 5 Molecular taxonomy of lophiiform fishes encountered during the study are explained in this chapter.

Chapter 6 Salient findings of the study and conclusion are outlined in this chapter.

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Chapter 2

STUDY AREA, SAMPLING METHODOLOGY AND ANALYSIS

Contents

2.1 Study Area

India has a coastline 8129 km in length, an EEZ (Exclusive economic Zone) of 2.02 million sq. km and continental shelf of 0.5 million sq. Km. The potential yield from the EEZ is estimated to be 4.42 million tons (Abdussamad 2017). The study area cover 3 major ecosystems namely, the Arabian Sea Ecosystem (ASE) extending from Lat 7^0 N to 24^0 N, within which is located the Lakshadweep Sea Ecosystem (LSE); Bay of Bengal Ecosystem (BoBE) extending from 10^0 N to 20^0 N and the Andaman Sea Ecosystem (ANE) extending from 6^0 N to 14^0 N (Fig. 2.1). These Ocean basins are unique in their environmental and geographical settings. Arabian Sea has an area (including Lakshadweep) of 0.93 million sq. km; Bay of Bengal 0.52 million sq. km and the Andaman Sea has an area of 0.57 million sq. km. Estimated marine fish landings in India during 2016 are 3.63 million tonnes (CMFRI 2017). Pelagic fishery contributes 52%, demersal fishery 29%, crustaceans 12% and molluscs 7%.

The Arabian Sea is regarded as a biogeographical sub-region of the Indian Ocean (Sheppard *et al.* 1992). It is one of the major upwelling systems of the world. Upwelling takes place along this coast during the summer monsoon months from May to September, which enhances fishery production (Ramamirtham and Patil 1965; Smitha *et al.* 2008). Arabian Sea known for its rich primary and secondary production, contributes nearly 50% to the total Indian marine fish landings (Vivekanandan *et al.* 2003; Smith and Madhupratap 2005).

Bay of Bengal (BoB) forms the north east arm of Indian Ocean. BoB also strongly influenced by monsoonal winds and receives enormous quantities of fresh water from river discharge (Gauns 2005). Both this tropical basins, AS and BoB occupy the same latitude but are separated by land mass of Indian peninsula. Both are influenced by seasonally reversing monsoon winds, southwesterly during summer monsoon and northeasterly during November to February (Rao *et al.* 2014). Compared to AS, BOB is less productive due to absence of strong upwelling and the strong thermocline stratification caused by the fresh water inputs (Gauns 2005).

The Andaman-Nicobar group of islands is regarded as one of the major biodiversity hot spots in terms of terrestrial as well as in marine biodiversity. Geographically, the islands are part of the long Island Arch extending from the Arakan Yoma hill range of Myanmar to the Sumatran range of Indonesia. Andaman Sea is characterized by relatively extensive basin with a maximum depth of 4360 m and uneven bottom topography (Priyaja *et al*. 2016).

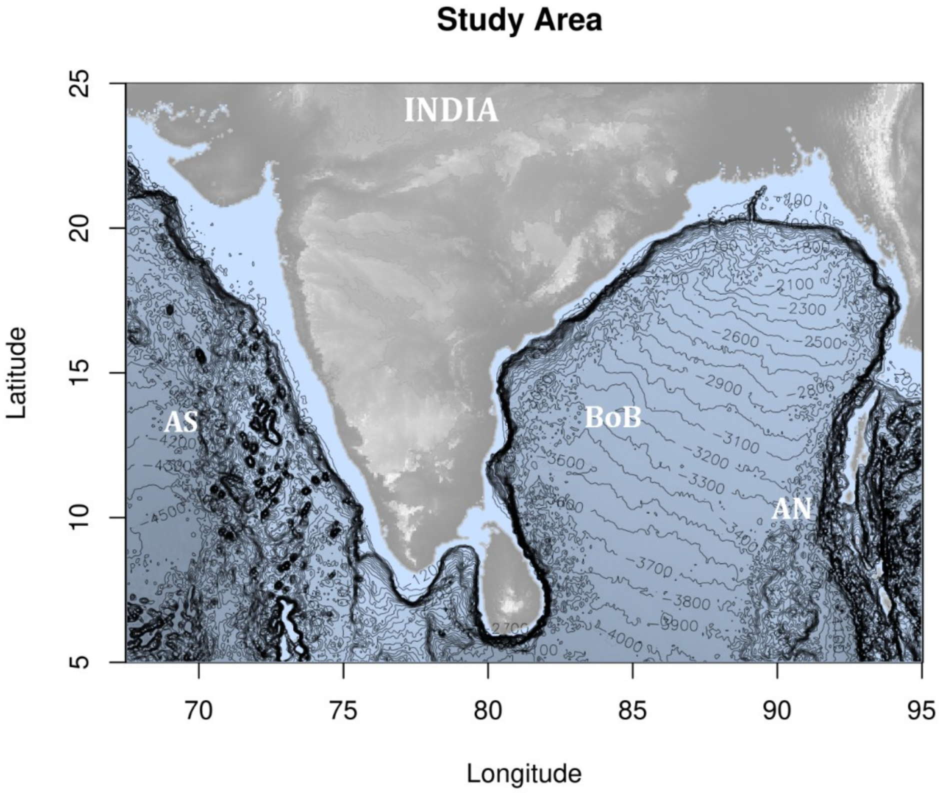

Figure 2.1. Study area, AS—Arabian Sea; BoB—Bay of Bengal; AN—Andaman Sea.

2.2 Sampling

Bottom trawl operations were conducted on onboard Fishery Oceanographic Research Vessel *Sagar Sampada* (FORV- SS) in the continental slope areas of Indian EEZ (Fig. 2.2). A total of 19 survey's were conducted at depths ranging from 200 m to 1337 m (Fig. 2.4). (Arabian Sea- 12 cruises and 33 stations; Bay of Bengal- 2 cruises and 13 stations; Andaman Sea 5 cruises and 32 stations. Station details are given in Table 2.1). 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.

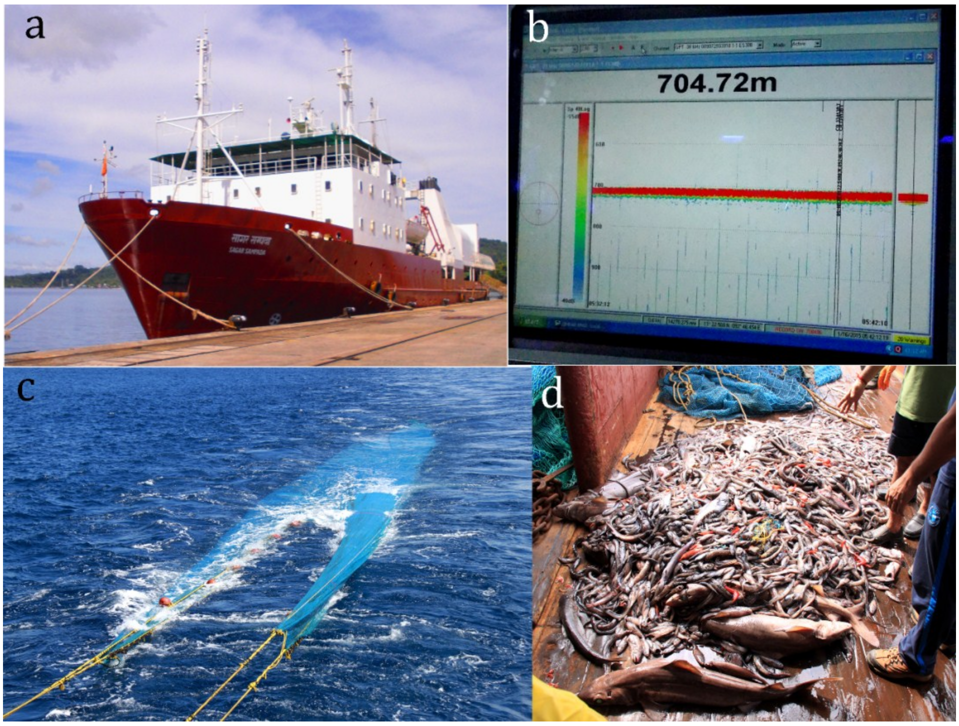

Figure 2.2. a— FORV *Sagar Sampada*; b—Screen shot of Echo sounder during bottom scanning; c—HSDT CV net while end of trawling; e—Catch onboard.

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 for sampling along the continental slope region of Indian EEZ. HSDT is a 2-warp twin-otters bottom trawling net, 58.6 m in total length with a head rope length of 38 m, foot rope of 44.5 m and cod-end with a stretch mesh size of 30 mm, gradually increasing to 130 mm in the front trawl sections. EXPO has a total length of 79.4 m, with a head rope length of 45.6 m, foot rope 55.8 m and cod-end with a stretch mesh size of 30 mm, increasing up to 400 mm in the belly and wing sections of the trawl. HOT I of 50 m. headline and with foot rope length of 57 m. was also occasionally used for operations. Specifications of the sampling gears are given in Figure 2.3.

Vertical opening at trawl mouth was monitored by Integrated Trawl Instrumentation (ITI) system fitted with remote sensing transducers (SIMRAD FR500 Trawl Eye System). For all operations, perfect (Denmark) economy model V-shaped otter boards of 285x126 cm, approximately weighing 2800 kg per set were connected to the net mouth with a wire rope length of 50 m. Trawling operations were carried out with ship speed of 2-3 knots depending on the depth and water currents. Warp out (wire paid out) ratio was approximately 1:3 (depth: wire rope released). All trawl operations were carried in day light.

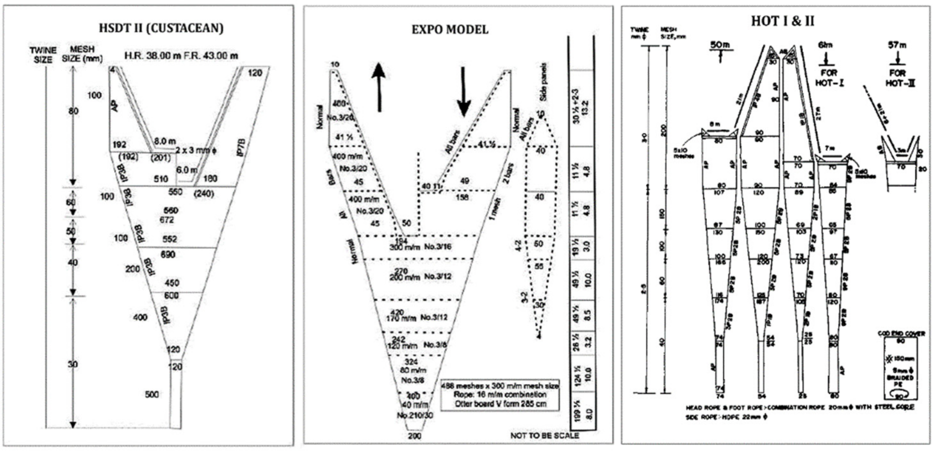

Figure 2.3. Schematic representation of sampling gears HSDT CV; EXPO; HOT.

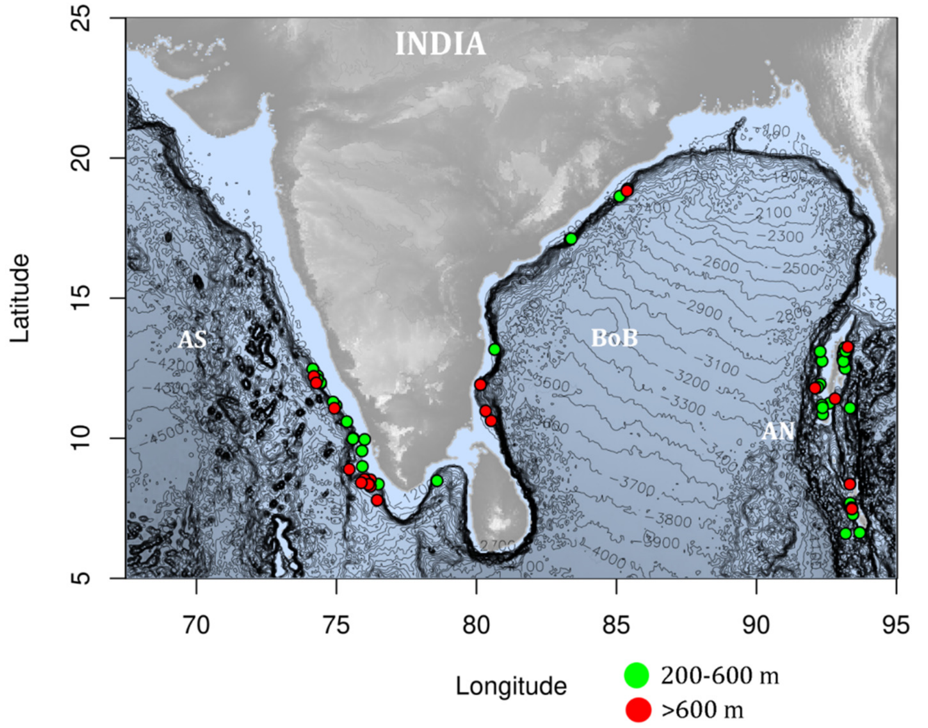

Figure 2.4. Explains sampling locations; green dots represents station depth between 200-600m; red dots represents >600 m up to 1337 m; AS- Arabian Sea; BoB- Bay of Bengal and AN- Andaman Sea.

Table 2.1. Details of sampling locations in the study area

Station	Area	Latitude (°)	Longitude (°)	Depth (m)	Gear	Date	Time
278 01	AS	9.98	75.59	238	HSDT	08-08-2010	07.00
278 07	AS	11.17	74.98	200	HSDT	10-08-2010	11.24
279 11	BoB	13.17	80.65	307	HSDT	29-08-2010	11.23
279 23	BoB	17.12	83.39	567	EXPO	02-08-2010	07.30
279 24	BoB	17.10	83.35	550	EXPO	02-08-2010	10.45
279 25	BoB	17.09	83.34	550	EXPO	02-08-2010	15.10
280 11	AN	13.03	93.10	278	EXPO	16-09-2010	07.10
280 15	AN	12.81	93.08	323	EXPO	17-09-2010	08.00
280 17	AN	11.15	92.33	514	EXPO	19-09-2010	15.40
280 37	AN	6.64	93.68	321	EXPO	24-09-2010	08.08
280 38	AN	7.52	93.40	567	EXPO	24-09-2010	08.20
281 01	AS	8.52	76.21	995	HSDT	12-10-2010	09.42
281 03	AS	8.36	76.17	995	HSDT	15-10-2010	11.11
288 09	AS	11.99	74.43	201	HSDT	08-08-2011	09.28
288 17	AS	10.00	75.60	191	EXPO	10-08-2011	14.40
291 02	BoB	18.63	85.11	580	EXPO	28-10-2011	11.15
291 03	BoB	18.84	85.39	561	EXPO	29-10-2011	09.30
291 05	BoB	18.83	85.38	628	HSDT	30-10-2011	09.35
291 06	BoB	18.90	85.40	500	HSDT	30-10-2011	14.35
291 10	BoB	11.92	80.15	650	EXPO	05-11-2011	10.10
291 11	BoB	11.91	80.15	645	EXPO	05-11-2011	14.30
291 13	BoB	10.97	80.33	651	EXPO	06-11-2011	14.32
291 15	BoB	10.62	80.52	648	EXPO	07-11-2011	12.15
291 17	BoB	11.91	80.14	652	EXPO	09-11-2011	08.20
292 06	AN	11.18	92.34	526	EXPO	22-11-2011	09.40
292 34	AN	13.19	93.14	299	HSDT	27-11-2011	09.30
292 38	AN	12.95	93.10	308	HSDT	28-11-2011	11.15
292 83	AN	6.63	93.69	337	HSDT	10-12-2011	14.27
292 89	AN	7.50	93.42	580	HSDT	11-12-2011	16.10
292 90	AN	7.69	93.35	384	HSDT	13-12-2011	09.25
292 91	AN	8.36	93.33	621	HSDT	14-12-2011	09.35
305 01	AS	8.29	76.21	1059	HSDT	19-08-2012	15.45
305 04	AS	11.98	74.43	206	HSDT	20-08-2012	10.25

305 05	AS	12.22	74.33	236	HSDT	21-08-2012	16.15
305 06	AS	12.21	74.19	923	HSDT	22-08-2012	11.55
316 01	AS	8.29	76.21	1055	HSDT	14-07-2013	15.30
316 02	AS	7.79	76.46	1337	HSDT	15-07-2013	09.25
316 09	AS	8.41	75.89	1241	HSDT	17-07-2013	11.50
317 01	AS	9.96	76.01	200	HSDT	30-07-2013	10.30
318 01	AS	12.47	74.15	444	EXPO	24-08-2013	09.30
318 10	AS	12.10	74.32	320	EXPO	26-08-2013	09.09
318 18	AS	11.29	74.88	249	EXPO	28-04-2013	09.30
318 25	AS	10.59	75.37	318	EXPO	29-04-2013	16.19
321 20	AS	8.53	76.00	1045	HSDT	12-12-2013	10.35
322 02	AS	11.07	74.92	1000	HSDT	08-01-2014	8.47
322 04	AS	11.97	74.28	1000	HSDT	09-01-2014	8.33
322 05	AS	11.96	74.43	200	HSDT	09-01-2014	15.25
322 07	AS	8.99	75.92	200	HSDT	11-01-2014	10.39
322 08	AS	8.89	75.45	1000	HSDT	11-01-2014	9.00
322 10	AS	8.36	76.50	200	HSDT	13-01-2014	8.35
322 12	AS	8.48	78.59	200	HSDT	15-01-2014	13.36
331 01	AS	9.55	75.91	394	HSDT	02-11-2014	11.54
331 02	AS	8.50	76.02	1024	HSDT	03-11-2014	11.26
334 01	AN	10.86	92.37	363	HOT	26-01-2015	8.36
334 04	AN	6.60	93.19	332	HOT	01-01-2015	9.30
334 08	AN	11.82	92.19	299	HOT	14-01-2015	14.15
334 10	AN	11.25	92.60	392	HOT	15-01-2015	6.02
334 11	AN	11.08	93.34	530	HOT	15-01-2015	12.24
334 12	AN	11.41	92.81	907	HOT	16-01-2015	6.24
334 16	AN	13.10	92.27	398	HOT	18-01-2015	7.20
334 17	AN	12.75	92.34	328	HOT	18-01-2015	7.16
345 02	AS	8.29	76.21	1000	HSDT	29-10-2015	10.30
345 03	AS	9.55	75.91	394	HSDT	02-10-2015	11.30
345 06	AS	12.21	74.19	400	HSDT	07-10-2015	9.45
349 01	AN	11.09	92.36	576	HSDT	04-04-2016	9.40
349 02	AN	7.48	93.41	650	HSDT	04-04-2016	4.05
349 03	AN	8.37	93.34	591	HSDT	05-04-2016	11.55
349 05	AN	12.53	93.15	300	HSDT	10-04-2016	11.50
349 06	AN	12.74	93.11	332	HSDT	10-04-2016	4.30

349 07	AN	13.24	93.16	332	HSDT	11-04-2016	6.59
349 08	AN	13.11	93.19	411	HSDT	11-04-2016	14.28
349 09	AN	11.93	92.28	290	HSDT	12-04-2016	7.21
349 10	AN	11.18	92.34	520	HSDT	14-04-2016	7.38
366 01	AS	8.36	76.14	1062	HSDT	20-10-2017	10.14
366 03	AS	7.28	93.44	588	HSDT	21-10-2017	7.55
367 05	AN	12.49	93.17	314	HSDT	25-11-2017	10.40
367 08	AN	13.26	93.26	635	HSDT	26-11-2017	6.36
367 15	AN	11.79	92.09	646	HSDT	28-11-2017	7.24

AS- Arabian Sea, BoB- Bay of Bengal, AN- Andaman Sea, Lat. and Long. in Decimal Degree

2.3 Taxonomic Analysis

Trawl catches were first weighed for total weight, sorted to groups and then group wise catches were recorded. Bottom trawl samples were sorted onboard either to genus or species level. Specimens were photographed (using Nikon D750) onboard, immediately after capture, without losing their body color. From the sorted samples, representative species were preserved in 8 % formaldehyde solution, and brought to CMLRE for further taxonomic clarification. Taxonomic identifications are based on morphometric measurements taken from preserved specimen with aid of digital caliper with an accuracy of 1mm. For taking measurements and meristic counts of each family, appropriate taxonomic keys or other illustrations were followed. Specimens, already preserved and deposited in the Referral Centre of CMLRE were also considered for taxonomic study. Drawings and illustrations of teeth pattern, body spines etc. were made with Inkscape (2007) software (Inkscape is a free and open-source vector graphic editor). All the measurements and counts of each species were compared with their type specimen (if available) or with other illustrations such as re-descriptions. After the taxonomic clarification, species name were matched or updated with World Register of Marine Species (WoRMS 2018) and FishBase (Froese and Pauly 2018). Each species deposited in the Referral Centre were assigned unique identification code. All materials examined for taxonomic study were generally labeled with 5 digit numeric code; first 3 digits representing cruise number and the next 2 digits representing the station number. Further digits if present, denotes species code. Alphabet A, B, C etc. followed by numeric code represents different samples of the same species.

2.4 Biomass Estimation

Samples collected from bottom trawl were sorted up to species level (for lophiiformes) and species or genus level for other groups. Number of lophiiformes fishes (Cn) present in each station was counted to get its numerical abundance. Catch in weight (Cw) from each station as well as weight of lophiiformes fishes from each station were recorded using a marine balance with an accuracy of 0.1 g. Biomass estimation is done following Sparre and Venema (1998) and expressed in kg/km^2.

Numerical abundance was calculates as,

Numerical abundance (n)= Cn/a ; unit—$Individuals/km^2$

Where Cn= Number of individuals in catch (Individuals); a = swept area (km^2)

Biomass (b)= Cw/a kg/km^2

Where; Cw = Catch in weight (kg); a = swept area (km^2)

The "*swept area*" or the "effective path swept" is defined as the area which is the length of the path times the width of the trawl. The swept area (a) is estimated as: $a = D \times hr \times X^2$

Where: D = Distance covered by trawl (estimated in nm and converted to km). The distance covered by the trawl (D) was estimated in units of nautical miles (nm) and calculated using the formula:

$$D=60 \times \sqrt{(Lat1-Lat2)^2 + (Lon1-Lon2)^2 \times \cos2\,(0.5 \times (Lat1+ Lat2)}$$

Where:

Lat1 = latitude at start of haul (degrees)

Lat2 = latitude at end of haul (degrees)

Lon1 = longitude at start of haul (degrees)

Lon2 = longitude at end of haul (degrees)

hr = Head-rope length; 38 m for HSDT, 45.6 m for EXPO and 50 m for HOT 1

X^2 = the fraction of the head-rope length, (hr), which is equal to the width of the path swept by the trawl. The ($hr*X^2$), known as "wing spread" is the effective horizontal trawl opening. The ‘wing spread’ varies with hauling speed, weather conditions, current velocity and direction etc. Hence in the present study the value of the fraction of head-rope length, X^2 is taken as 0.5, suggested as the best compromise for tropical waters by Pauly (1983). Biomass was calculated separately for all the sampling stations; area wise, such as AS, BoB and AN and depth wise, 200-600 m depth zone and >600 m zone. Similarly numerical abundance for lophiiormes (Ind/km^2) were also estimated.

2.5 Length Weight Relationship, Food and Feeding, and Reproductive Biology

Length-weight relationships for all species abundant in the catch were established. Standard length and weight of the fish was taken with an accuracy of 0.1 cm and 0.1 g using digital vernier caliper and electronic balance, respectively. The relationship between the length and weight is expressed by the regression equation $W = a\ L^b$ (Froese 2006; Froese *et al.* 2014; Le Cren 1951; Zar 1999; Ricker 1973) where W is the body weight, L is standard length and '*a*' and '*b*' are constants (Beverton and Holt 1957). The strength of the relationship was ascertained by coefficient of determination (r^2). The detailed methodology is discussed in Chapter 4.

Stomach contents analyzes is based on *Frequency of Occurrence* method (Hyslop 1980).

Frequency of Occurrence $Oi= P/ Ji$;

Where, 'Ji' is number of fish containing prey 'i' and 'P' is the number of fish with food in their stomach.

Maturity stages and relative fecundity were examined following Qasim (1973); Kurup and Samuel (1991) and Bagenal (1978), respectively. Sex ratio was also performed for selected species. Each species was separated into male and females and the ratio was calculated as Male: Female (M: F). Detailed methodology is discussed in Chapter 4.

2.6 Otolith Morphology and Morphometrics

For otolith studies, right otolith were dissected out and photographed with stereo zoom trinocular microscope (Leica model No. S8APO with attached camera). Images were digitized using image analyzing software ImageJ. Otolith morphometrics were taken from the digitized image; shape indices (aspect ratio and roundness) were measured following Avigliano *et al.* (2014, 2015). Otolith weights (OW) were taken using an electronic balance with accuracy of 0.001g. Linear regression method was used to estimate the relationship between fish morphometrics and otolith morphometrics. Analysis of Covariance (ANCOVA) was used to determine inter species variations in the regression slopes (Zar 1999).

For shape analysis digitized image was converted to gray scale by adjusting the threshold to produce black-and-white images using adobe photoshop (7.0) software. For the elucidation of otolith shapes Elliptical and r Fourier analysis were carried out using the R package “Momocs” (Bonhomme *et al.* 2014). Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) were carried out in momocs for analyzing the otolith shape variation among the species. Detailed methodology is explained in the respective Chapters. Otolith morphology is described from photographed images and terminologies follows Smale *et al.* (1995) and Tuset *et al.* (2008).

2.7 Ecomorphological Studies

Ecomorphology is a science that deals with relationships between environmental factors (both physical and biotic) and body shape at species level (Wainwright *et al.* 2002; Lombarte *et al.* 2003). The functional traits which are calculated from the body measurements are good predictors to understand the species performance and ecology (Hooper *et al.* 2005; Ville´ger *et al.* 2008; Mouillot *et al.* 2011). In the course of the present study, ecomorphorphological differentiation of five dominant deep-sea anglerfishes were carried out using functional traits measured from the fish. Sixteen morphological variables were measured based on Keast and Webb (1966), Gatz (1979), Watson and Balon (1984), and Beaumord and Petrere Jr. (1994). From these measurements, a total of eleven ecomorphological atttributes (or functional traits) correlated to food acquisition, swimming performances and food preferences were estimated. Ecomorphological variations among species were derived by principal component analysis (PCA). To test any significant differences among the species, Bonferroni's correction for post-hoc pairwise multiple comparison were tested using Multivariate Analysis of Variance (MANOVA). Detailed methodology is explained in respective Chapters.

2.8 Molecular Identification of Lophiiformes

Approximately 100 mg of white muscle tissues or gill tissues were collected from each species using sterile scissors and preserved in 95% ethanol and kept at -20 °C after proper labelling. Whole genomic DNA from the samples was isolated following the protocol of Miller *et al.* (1988) with minor modification (detailed in Chapter 5). DNeasy (Qiagen) kit, following manufacturer's instruction, was also used to extract DNA from samples. Mitochondrial DNA, Cytochrome c oxidase I (COI) was amplified by employing specific universal primers. PCR (polymerase chain reaction) product was sequenced using both forward and reverse amplification primers. The resulting DNA fragments were cleaned before sending to the sequencing facility.

The raw DNA sequences were edited and aligned using BioEdit sequence alignment editor version 7.0.5.2 (Hall 1999). The sequence divergence values within and between species were calculated using Kimura 2-parameter (K2P) distance model implemented in MEGA 5 (Tamura *et al.* 2011) software. Neighbor-joining (NJ) trees of K2P distance were created to provide graphic representation of divergence with 1000 replications. Detailed methodology explained in Chapter 5.

2.9 Data Analysis

Statistical software, PRIMER 6+ (Plymouth Routines in Multivariate Ecological Research; Clarke and Warwick 2001) was used primarily for data analysis. Total catch, catch composition, individual species abundance were used as input data for PRIMER analysis. Sampling sufficiency of each area was estimated using species accumulation plot. This plot shows the number of new species added to the total species list with addition of samples. From the curve pattern in the species accumulation plot, species predictors (like Chaos1, Jacknife1 and Bootstrap) were used to calculate the number of species which could be add if the sampling performs up to infinity (Magurran 2013). ANCOVA, PCA, LDA, *t* test, Chi square test, MANOVA analysis were performed in R package (ver. 1.2.9; Bonhomme *et al.* 2014), PAST (PAlaeontoloical Statistics, version v1.81; Hammer *et al.* 2001) and SPSS 20. R package and Ocean Data View (ODV 4, Schlitzer 2011) were primarily used for plots. Molecular taxonomy sequence analysis was performed in BioEdit 7.0.5.2 (Hall 1999) and MEGGA 5 (Tamura *et al*. 2011) software.

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Chapter 3

LOPHIIFORMES OF THE INDIAN EEZ: SYSTEMATICS AND DIVERSITY

Contents

3.1 Introduction

Indian Deep-sea exploratory survey's in India were initiated by the Royal Indian Marine Steamer R.I.M.S. *Investigator* during the period from 1884 to 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, which forms the first detailed report of Indian Deep-sea fishes. RIMS Investigator's deep-sea surveys (1884-1914) covered 711 stations in the Indian Ocean up to depths of 3,652 m and documented a total of 169 deep-sea fish species. This was followed by the *Valdivia* expedition in the Bay of Bengal area during the period from 1898 to 1899 covering 12 stations at depths of 296-2500 m. Further additions to the Indian Deep-sea fauna came from the John Murray expedition (1933-1934), on-board the Research Vessel Mabahiss which surveyed 212 stations in the north-west Indian Ocean up to the depths of 4,793 m. The steamer 'Golden Crown'

(1908-1909) surveyed many areas in Bay of Bengal and published the details as *Report on the Fishes taken By the Bengal Fisheries Steamer 'Golden Crown'*.

More than a century ago Alcock described four new species coming under the family Lophiidae from Indian waters; *Lophius gracilimanus* described from off the Malabar Coast (68 to 148, and 100 fathoms); *Lophius mutilus* from Bay of Bengal (128 fathoms); *Lophius lugubris* from off Colombo and *Lophius indicus* from Bay of Bengal (24 fathoms). Caruso reviewed the genus *Lophiodes* in 1981; *Lophiomus* and *Lophius* in 1983 based on the osteological and morphological characters. Based on this review, Caruso designated *Lophius gracilimanus as Lophiodes gracilimanus* (Alcock, 1899); *Lophius indicus* as *Lophiomus setigerus* (Vahl, 1797) and *Lophius mutilus*, *Lophius lugubris* as *Lophiodes mutilus* (Alcock, 1893). Caruso (1981) treated *L. lugubris* as junior synonym of *Lophiodes mutilus*. However, in a recent study (Ho *et al.* 2016b) it was recognized that *Lophiodes lugubris* is a valid species. The present study also supports this fact because all the specimens examined had four dorsal spines (three cephalic and one post cephalic) along with other diagnostic characters and DNA barcode. Later, Lloyd (1909) described *Lohius triradiatus* from Laccadive Sea at a depth of 300 fathoms. Caruso (1981) reassigned the species to the genus *Lophiodes*. Recently, Ho *et al.* (2014) rediscovered the species from Arabian Sea.

The first *Chaunax* species (family- Chuancidae) recorded from India was *Chaunax pictus* (Lowe, 1846) by Alcock in 1899. Alcock recorded the species from Bay of Bengal at depths of 193, 272 and 145 to

250 fathoms and from off Colombo (142 to 400, 480 fathoms). However, Caruso (1989a) is of the view that *C. pictus* is restricted to Atlantic Ocean and all other records represents some other species. Second *Chaunax* species recorded from Indian Ocean was *Chaunax apus* (Lloyd, 1909) described from Bay of Bengal.

Major contributions for the family Ogcocephalidae came from studies of A.W. Alcock and R. E. Lloyd. *Halieutaea coccinea* Alcock, 1889; *Halieutaea fumosa* Alcock, 1894; *Halieutaea nigra* Alcock, 1891; *Halieutaea stellata* (Vahl, 1797); *Halieutaea indica* Annandale and Jenkins, 1910; *Dibranchus nasutus* Alcock, 1891; *Malthopsis lutea* Alcock, 1891; *Halicmetus ruber* Alcock, 1891 and *Dibranchus micropus* Alcock, 1891 (now accepted as *Coelophrys micropa* (Alcock, 1891) based on the studies of Bradbury 1967, 1988). Lloyd (1909) described *Dibranchus nudiventer* from Bay of Bengal at depths of 1100 fathoms. Later, Bradbury (1999) reviewed the genus *Dibracnhus* and assigned the species as *Halieutopsis nudiventer* (Lloyd, 1909). *Malthopsis triangularis* Lloyd, 1909 is now accepted as *Malthopsis mitrigera* Gilbert and Cramer, 1897.

Alcock (1890) described a new species (now under the family-Diceratiidae) *Paronirodes* (=*Paroneriodes*) *glomerosus*, from Bay of Bengal and later, Alcock (1899) renamed it as *Oneirodes glomerosus*, which is now accepted as *Diceratias bispinosus* (Günther, 1887) after the studies of Regan (1912) and Uwate (1979). Lloyd (1909) described a new genus and species (family- Oneirodidae), *Lophodolos indicus* from Arabian Sea (888 fathoms) based on a single specimen of 66 mm long.

Recent taxonomic descriptions on lophiiformes from Indian EEZ are reported by Jayapraksh *et al*. (2006); Venu (2009); Hashim (2012) and Ho *et al*. (2014). Occurrence of *Ceratias uranoscopus* Murray, 1877 (family- Ceratiidae) reported by Venu (2009) and *Melanocetus johnsonii* Günther, 1864 (family- Melanocetidae) from Arabian Sea by Jayaparaksh *et al*. (2006) and Hashim (2012). Ho *et al*. (2014) redescribed *Lophiodes triradiatus* (Lloyd, 1909) from Arabian Sea.

Previous studies have reported a total of 21species of lophiiformes under 7 families from the Indian EEZ. Of these; 5 species are from family Lophiidae; 1 species from Chaunacidae; 11 species from Ogcocephalidae and 1 species each from Diceartiidae, Oneirodidae, Melanocetidae and Ceratiidae.

3.2 Methodology

Suborder LOPHIOIDEI —Methods for the taxonomic identification follows Caruso (1981, 1983). All the measurements expressed in mm; unless mentioned otherwise. The terminology for discussing the angling apparatus follows Bradbury (1967). Abbreviations used are Standard length (SL); Head length (HL); Illicial length (IL); 2 nd dorsal spine length (DS2); 3rd dorsal spine length (DS3); 4 th dorsal spine length (DS4); 5 th dorsal spine length (DS5); 6th dorsal spine length; Tail Length (TL); Caudal fin length (CFL); Head width (HW); Head depth (HD); Snout length (SNL); Snout width (SNW); Distance between inner sphenotic spines (ISP); Distance between frontal spines (IF); Distance between pterotic & left sphenotic spines (PTSP); Distance between lower quadrate

& anterior palatine spines (QPAL); Distance between opercular & sub opercular spines (OPSOP).

Suborder CHAUNACOIDEI— Methods for taking measurements and counts follows Caruso (1989a) and some measurements are added from Ho *et al.* (2013). Counts of lateral-line neuromasts and angling apparatus follows Caruso (1989a). All measurements are expressed in percent of Standard Length (SL).

Suborder OGCOCEPHALOIDEI—Methods for taxonomic identification of Ogcocephalids are based on Bradbury (1980, 1988, 1999); Shimazaki *et al.* (2004); Ho and Shao (2008); Ho *et al.* (2008a, b; 2009). Descriptions on angling apparatus follows Bradbury (1967). Measurements include —Skull length (SKL); Orbital diameter (OD); Interorbital width (IO); Mouth width (MW); Illicial cavity width (ICW); Post -anus length (PAN); Pre-anal length (PAL); Disc margin length (DM); Pectoral fin length (PF); Anal fin length (AF) and Caudal fin length (CFL)

Suborder CERATIOIDEI—Methods for making counts and measurements of diceratiids (Diceratiidae) follow Uwate (1979) and Pietsch *et al.* (2004) and for ceratiids (Ceratiidae) methodologies were adopted following Pietsch (1986). Terminology used to describe the various parts of the angling apparatus follows Bradbury (1967). Melanocetidae follows Pietsch and Duzer (1980); Pietsch (2009). Oneirodids (Oneirodidae) measurements were made following Pietsch (1974a, b) and himantolohphids (Himantolophidae) following Pietsch (2009).

3.3 Results

A total of 36 species of lophiiformes were recorded from the Indian EEZ during the course of the present study that includes 21 previously known species. The updated check-list of lophiiformes in the Indian EEZ is given in Table 3.1. The check-list have 8 species new to science and 7 new records of species from Indian EEZ. Area wise new records includes Arabian Sea (8 species); Bay of Bengal (3 species); Andaman Sea (10 species). Arabian Sea have 28 species; Bay of Bengal 13 species and Andaman Sea 22 species (including previously known species). Among them only 9 species were found common to the Arabian Sea, Bay of Bengal and Andaman Sea.

3.3.1 Sampling Sufficiency

The sufficiencies of sampling from the study area (Arabian Sea (AS), Bay of Bengal (BoB) and Andaman Sea (AN) were tested by the species accumulation curve plots (PRIMER plots- detailed in Chapter 2). Species estimators were calculated to determine the number of species likely to be found in the study area with unlimited sampling. The plot depicts the species observed (Sobs); and curves from species extrapolators (Chao 1, Jacknife 1 and bootstrap) that attempts to predict the total number of species that would be observed as the number of samples progress to infinity (asymptote curves). These are nonparametric approaches, depending on simple functions of the number of species seen only in 1 or 2 samples (Jacknife 1) or the number of species that have only 1 or 2 individuals in the entire pool of samples (Chao 1), or the set of proportion of sample that contain each species (bootstrap).

In the species accumulation curve for Arabian Sea, the Sobs show exponential growth beyond the 21 species observed in the present study. The trend of Sobs curve indicates that with more intensified sampling effort, more number of species are likely to be obtained. Estimators like Chao 1, Jacknife 1 and bootstrap predicts the expected number of species up to 34 ±12; 36 and 25 respectively upon intensified sampling in the Arabian Sea (Fig. 3.1A; Table 3.2).

Sobs curve for Bay of Bengal reach the asymptote when species number reaches 7 which indicate that the area is well sampled in the present study. Predictors such as Chao 1, Jacknife 1 and bootstrap indicates the possible number of species to be 7; 9 and 8 respectively upon intensified sampling (Fig. 3.1B; Table 3.3). Sobs curve for Andaman Sea reach the asymptote when species number reaches 17. Chao 1, Jacknife 1 and bootstrap predict 19 ±3; 19 and 18 numbers of species respectively (Fig. 3.1C; Table 3.4).

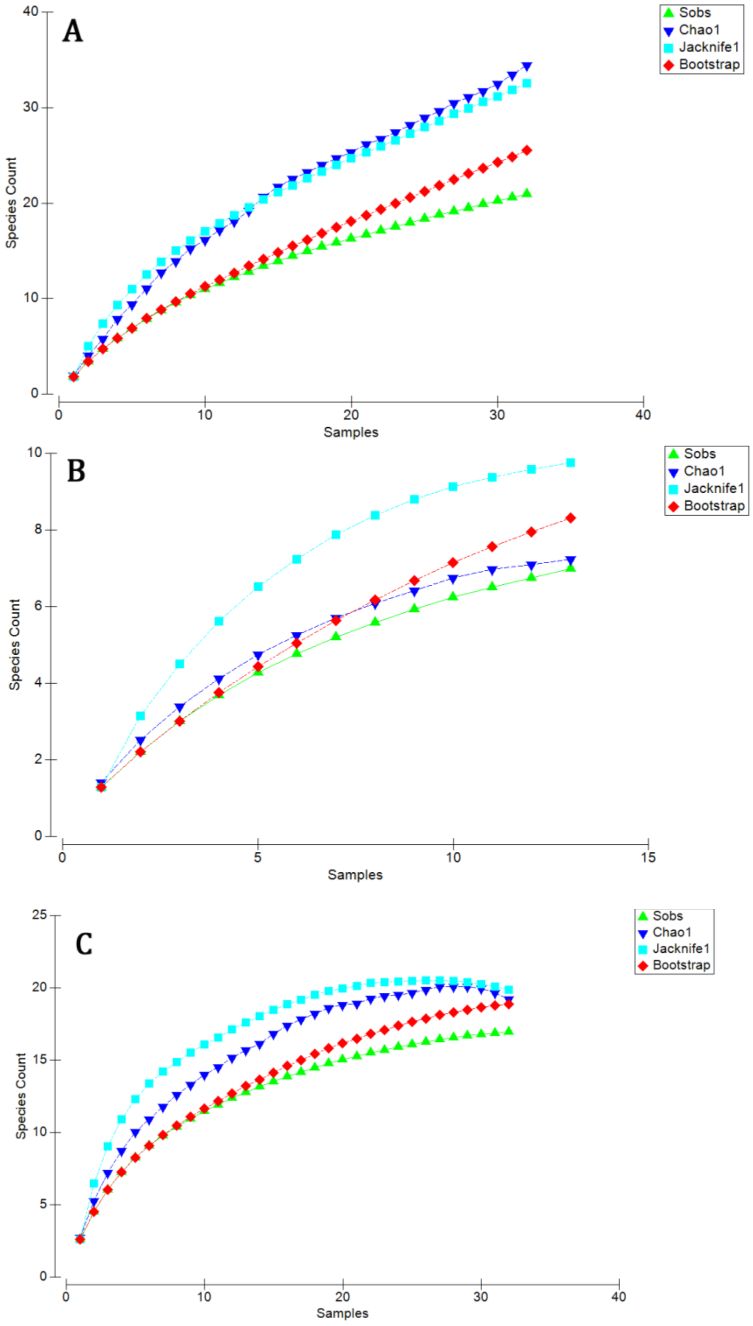

Figure 3.1. Species accumulation plot on estimating sampling sufficiency of Arabian Sea (A), Bay of Bengal (B) Andaman Sea (C).

Table 3.2. Values of species estimator—AS

Arabian Sea	**Number**	**% of sampling sufficiency**
Species observed	21	
Estimators predictions		
Chao 1	34 ± 12	61.8
Jacknife 1	36	58.3
Bootstrap	25	84

Table 3.3. Values of species estimator—BoB

Bay of Bengal	**Number**	**% of sampling sufficiency**
Species observed	7	
Estimators predictions		
Chao 1	7 ± 0.7	100
Jacknife 1	9	77.8
Bootstrap	8	87.5

Table 3.4. Values of species estimator—AN

Andaman Sea	**Number**	**% of sampling sufficiency**
Species observed	17	
Estimators predictions		
Chao 1	19±3	89.5
Jacknife 1	19	89.5
Bootstrap	18	94.4

3.3.2 Systematics and distribution of Lophiiformes along the Indian EEZ

i. Suborder—LOPHIOIDEI
Family—LOPHIIDAE Rafinesque, 1810**.**
The monkfishes or goose fishes

Diagnosis—Head and body depressed; skin loose without scales; tendrils or cirri present along the lateral margins of head and body; mouth large, upper and lower jaws bearing long, slender, recurved teeth; lower jaw projecting well beyond upper. Vomer, palatine, ceratobranchial V, and pharyngobranchials II-IV toothed. Gill filaments present on first three branchial arches, absent on fourth. Dorsal surface of head with numerous spines and ridges; frontal bone with well-developed supraorbital ridge, bearing two to four, dorsolaterally directed spines; a frontal ridge running forward from supraorbital ridge to tip of snout; one to three sphenotic spines; a single pterotic spine; palatine with two well-developed spines at tip of snout; interopercle with one to three spines. Gill openings extending below and behind or below, behind, and in front of bases of pectoral fin. Spinous dorsal fin primitively of six spines, divided into cephalic (two or three spines) and post-cephalic portions (one to three spines); illicium and second dorsal-fin spine inserted close together on common pterygiophore. Esca variable in size and shape. Pelvic fins present. Olfactory organs which is present at base of the eyes are strongly sexually dimorphic, highly developed in males (Caruso 1975). Coloration uniform gray, brown to dark brown usually without any pattern (dorsal surface of head and body spotted in *Sladenia*).

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. 3.7)

Genus *Lophiodes* Goode and Bean, 1896

Diagnosis—*Lophiodes* is unique among the lophiidae in having a moderately depressed head and body and two well-developed articular spine, placed anterior and posterior to jaw joint. Frontal ridge smooth without spines or knobs; gill openings extending below, behind and in front of pectoral fin base; esca variable in size and shape; cephalic portion of spinous dorsal fin have three spines; post cephalic portion of spinous dorsal fin variable, consisting of one to three spines, some or all of which may be imbedded or absent; soft dorsal fin with eight to nine rays; anal fin with six rays; sphenotic spine present, inner one is well developed, outer one is blunt; quadrate with single lower spine; subopercular with single spine; interopercular with one or two spines; humeral spine well developed, but variable in shape. Genus represents 17 valid species of which 4 species are represented in Indian waters.

Lophiodes lugubris (Alcock, 1894)

Figs. 3.2. A—B, Table 3.5
Synonyms—*Lophius lugubris* Alcock, 1894

Syntypes—ZSI F13467 (1) (Lost), 670/1 (1), 671/1 (1), 13.5 miles north 64° west of Columbo Light House, Sri Lanka; Investigator station 151, 259-731 m. (Alcock 1894).

Materials Examined—ZSI F670/1, SL 100 mm, Off Colombo, 261; 2801731, SL-153 mm, Andaman Sea, 11.15° N, 92.33° E; off South Nicobar, 514 m., EXPO, September 2010; 2801531, 165 mm SL,12.81° N, 93.08° E, 323 m., EXPO, September 2010, 2928312 A & B (SL-132 mm, 135 mm) Andaman Sea 6.84° N , 9.05° E, 337 m., HSDT- CV, December 2011; 2920613 A & B (SL-185, 152 mm), 11.15° N, 92. 39° E, 526 m., EXPO, November 2011; 34910 (SL-136 mm), 11.18° N, 92.34° E, 520 m., HSDT-CV; April 2016. 32207 (SL-100 mm) Arabian Sea,15.13° N, 80.55° E, 230 m., EXPO, January 2014; 34906, 95 mm SL, 12.7° N, 93.1° E, Andaman Sea, 332 m., HSDT, April 2016. 34502, 1000 m., 5 specimens (SL- 115mm, 92 mm, 65 mm, 79 and 68 mm) Arabian Sea. 29115, 55 mm SL, 70 mm SL, 10.6° N, 80.5° E, Bay of Bengal, 648 m., EXPO, November 2011. 29117 70 mm SL, 11.9° N, 80.3° E, 700 m., EXPO, November 2011.

Diagnosis—A species of *Lophiodes* genus, moderately depressed head and body, cephalic portion with III dorsal fin spines and post cephalic with I slender spine

Description—Moderately depressed head and body and two spine on the articular region, one anterior and one posterior to jaw joint; gill openings extending below, behind and in front of pectoral fin base; spinous dorsal fin on the cephalic portion well developed, with three (third one is the largest and stout with small black tendrils); post cephalic with one short slender spine; illicium slender, devoid of tendrils, with small narrow bulb like esca, frontal ridge and outer surface of premaxilla smooth; two sphenotic spines present, inner spine sharply pointed and long, outer spine broad and low; humeral spines trifid; (bifid in 34906 specimen); eyes small, directed dorsolaterally; teeth on premaxilla large, forming two or three irregular rows, those on maxilla small and single row, three irregular rows on lower jaw, innermost large and recurved, vomer and palatine present; peritoneum black; anal fin reaches upto the base of caudal fin.

Colour—Uniform light to dark brown on dorsal and ventral surface; all fins are pigmented as body (dark brown), small darker, brown cirri present along the lateral margins of the head and body, ventral pale; buccal floor pale brown or white, peritoneum black.

Remarks—All the specimen having III- I dorsal fin spines pattern; but some degree of variation in the length of dorsal spine is noticed. Generally 1st dorsal spine reaches up to the base or beyond the origin of the 3rd dorsal spine; 2nd dorsal stout and reaches beyond the origin of 3rd dorsal; 3rd is the longest, reaching well beyond the end of soft dorsal, tendrils present only in the 3rd dorsal spine. In 349 06 specimen (95 mm SL), first dorsal spine not reaching up to the origin of 3rd dorsal spine (may be degenerating); In 345 06 (SL 65 mm) 349 07 A & B, (122 mm & 90 mm) 3rd dorsal spine reaching only up to the middle the of soft rays.

Alcock (1894) described *Lophius lugubris* (now under *Lophiodes lugubris*) on the basis of three specimens collected from off Colombo and *L. mutilus* from Bay of Bengal in 1893. Caruso (1981) reviewed the genus *Lophiodes* and synonymized six other nominal species with *Lophoides mutilus* including *L. lugubris* and commented the variation in the size and number of the post cephalic dorsal spines does not warrant in distinguishing the species within the *mutilus* group. Recently Ho *et al.* 2016b examined the validity of *L. lugbris* and *L. mutilus*, and confirmed their distinct species status. Present study also substantiate the above observation, i.e. all the *L. lugubris* specimen examined having four dorsal fin spine (Three cephalic and one post cephalic) and whereas *L. mutilus* have three cephalic and two post cephalic dorsal fin spines. Our study confirmed with DNA barcodes of these two species.

Distribution—Arabian Sea (Alcock 1894); present study (34502, 5 nos.) reports the species from greater depth of 1000 m., Andaman Sea (present study- new record). Indo-West Pacific, recorded from off Sumatra, Indonesia, Taiwan, Australia, Tasman Sea and South Africa at depth of 230-526 m. (Ho *et al.* 2016b).

Table 3.5. Morphometric and Meristic data of *Lophiodes lugubris* (SD=Standard deviation)

Measurements	**32207**	**292 8312 A**	**292 8312 B**	**280 1731**	**292 0613A**	**292 0613B**	**349 10**	**280 1531**	**Mean**	**Range**	**SD**
SL (mm)	100.8	132.6	135	153.3	185	152	136	165		100.8- 185	
% SL											
HL	44.0	32.2	37.6	38.6	34.6	36.5	41.9	40.0	38.2	32.2-44.0	3.8
IL	25.5	29.4	28.0	17.3	27.0	29.6	30.1	29.7	27.1	17.3-30.1	4.2
DS2	30.8	27.5	23.7	23.6	18.9	25.0	25.7	17.6	24.1	17.6-30.8	4.3
DS3	62.9	49.3	52.5	52.0	40.1	46.1	52.2	44.8	50.0	40.1-62.9	6.8
TL	30.0	32.5	29.6	29.0	31.0	32.0	29.0	31.0	30.5	29.0-32.5	1.3
CFL	35.9	34.7	34.8	33.2	36.8	36.2	35.3	33.3	35.0	33.2-36.8	1.3
% HL											
HW	56.4	58.4	50.5	54.2	57.8	59.6	52.6	53.0	55.3	50.5-59.6	3.2
HD	61.1	61.2	61.1	62.5	64.5	65.0	61.4	56.1	61.6	56.1-65.0	2.7
SNL	58.0	62.3	57.9	60.0	58.7	61.9	50.9	53.0	57.8	50.9-62.3	4.0
SNW	16.6	20.2	16.7	17.7	15.7	15.2	19.0	18.0	17.4	15.2-20.2	1.7
ISP	41.3	48.0	43.0	39.2	44.8	41.8	40.4	51.5	43.8	39.2-51.5	4.2
IF	40.6	45.7	39.2	36.7	35.1	36.6	35.1	36.4	38.2	35.1-45.7	3.6
PTSP	21.9	20.9	20.5	18.6	21.4	20.7	17.5	20.2	20.2	17.5-21.9	1.4
QPAL	63.2	64.5	65.2	65.6	68.0	66.0	65.0	69.0	65.8	63.2-69.0	1.9
OPSOP	44.6	46.4	46.1	43.1	50.1	43.0	43.0	42.0	44.8	42.0-50.1	2.7
Meristics											
Dorsal fin spines	III, I	III,I	III,I	III,I	III,I,	III,I	III,I	III,I		III,I	
Dorsal fin rays	9	8	8	9	9	9	8	8		8-9	
Pectoral fin rays	15	15	16	15	15	16	17	17		15-18	
Anal fin rays	6	6	6	6	6	6	6	6		6	
Ventral fin	I,5	I,5	I,5	I,5	I,5	I,5	I,5	I,5		I,5	
Caudal fin rays	8	9	8	9	8	9	9	9			

Lophiodes triradiatus **(Lloyd, 1909)**

Figs. 3.3. A—B, Table 3.6

Synonyms—*Lophius triradiatus* Lloyd, 1909; *Lophiodes infrabrunneus* Smith and Radcliffe, 1912; *Lophiodes abdituspinus* Ni, Wu and Li, 1990

Holotype—ZSI 878/1, 10.1° N, 75.6° E, Laccadive Sea, Investigator station 259, 549 m. (Lloyd 1909).

Materials examined—3212003A, 271 mm SL, 8.50° N, 76.02° E, off Trivandrum, Arabian Sea, 1043 m., HSDT CV, December 2013; 3212003B, SL-245 mm, 9.3° N, 76.15° E, off Trivandrum, Arabian Sea, 1050 m., HSDT CV, December 2013; 2810311, 243 mm SL, 8.51° N, 76.21°, Arabian Sea, 995 m, October 2010; 34909B, SL-121 mm, 11.93° N, 92.28°E, Andaman Sea, 290 m, HSDT CV, April 2016; 36715, 470 mm SL, 11.9° N, 92.09° E, Andaman Sea, 646 m, HSDT CV, November 2017 (maximum length recorded from Indian water).

Diagnosis—A species of *Lophiodes* with three dorsal spines, postcephalic spine absent; illicium relatively short with a leaf-like esca; tendrils present on the 3 rd dorsal fin spine; anal fin reaches beyond the base of the caudal fin; peritoneum black.

Description —Relatively depressed head and body and two spine on the articular region, one anterior and one posterior to jaw joint; two blunt spines on palatine, the posterior spine larger than the anterior spine; frontal ridge and outer surface of premaxilla smooth; inner frontal spine absent in all specimen expect 102 mm SL specimen; two sphenotic spines present, inner spine sharply pointed and long, outer spine blunt;

pterotic spine present, humeral spines strong; gill openings extending front of pectoral fin base; spinous dorsal fin on the cephalic portion well developed, with three spines; post-cephalic dorsal-fin spines absent; illicium slender with leaf like esca, reaching up to the sphenotic spine (length of the dorsal spines shows some degree of variation in all the specimens; third one is the largest in 271 mm and 121mm specimen), tendrils present on the 3rd dorsal fin spine, small darker brown cirri present along the lateral margins of the body and head; dorsal body uniformly deep brown with dark brown fins, ventral surface dark brown.; caudal fin relatively long (about one third of SL) in all specimens; dorsal fin spines 3; dorsal fin rays 8; pectoral fin rays 13-16; anal fin rays 6; caudal fin rays 9.

Colour—Both dorsal and ventral surface having uniform dark brown colour; all the fins are much darker than body colour; mouth cavity pigmented like body colour.

Distribution—Andaman Sea (present study- new record) and Arabian Sea. Northwestern Australia, the Philippines, South China Sea, East China Sea, Japan, and western Indian Ocean, at depths 208–1412 m. (Ho *et al.* 2014).

Table 3.6. Morphometric and Meristic data for *Lophiodes triradiatus*

Measurements	321 2003 A	321 2003 B	281 0311	349 09B	Mean	Range	SD
SL (mm)	271	245	243	102	215.3	102-271	76.6
% SL							
HL	37.1	36.2	35.7	34.2	35.8	34.2-37.0	1.2
IL	17.8	15.9	17.7	15.1	16.6	15.1-17.7	1.3
DS2	10.5	16.3	15.6	17.3	14.9	10.5-17.3	3.0
DS3	19.0	13.7	11.3	12.8	14.2	11.3-19.0	3.3
TL	31.3	32.0	33.3	32.0	32.2	31.3-33.3	0.8
CFL	31.9	36.6	35.7	34.0	34.5	31.9-36.5	2.1
% HL							
HW	54.2	51.5	59.2	53.1	54.5	51.5-59.2	3.3
HD	60.7	68.3	71.2	62.3	65.6	60.7-71.2	5.0
SNL	52.1	52.1	55.4	53.7	53.3	52.1-55.4	1.6
SNW	15.6	17.6	19.5	17.0	17.4	15.6-19.5	1.6
ISP	39.0	39.1	40.3	41.5	40.0	39.0-41.5	1.1
IF	28.1	40.9	32.2	33.0	33.6	28.1-40.9	5.4
PTSP	22.6	23.2	20.0	19.5	21.3	19.5-23.2	1.8
QPAL	63.7	63.8	68.9	63.2	64.9	63.1-68.9	2.7
OPSOP	37.4	35.8	44.0	39.0	39.1	35.8-44	3.5
Meristics							
Dorsal fin spines	III	III	III	III		III	
Dorsal fin rays	8	8	8	8		8	
Pectoral fin rays (both sides)	14/15	16/15	13/13	16/16		14-16	
Anal fin rays	6	6	6	6		6	
Ventral fin	I, 5	I, 5	I, 5	I, 5		I, 5	
Caudal fin rays	9	9	9	9		9	

Lophiodes mutilus (Alcock, 1894)

Figs. 3.4. A—B, Table 3.7

Synonyms—*Lophius mutilus* Alcock, 1893; *Chirolophius mutilus* (Alcock, 1894); *Chirolophius apanicus* Kamohara, 1938.

Holotype—ZSI 13438 (lost), 88.3 mm, 15.0° N, 80.4° E, Investigator station 137, Bay of Bengal, 234 m. (Alcock 1894).

Materials examined—2911516, SL-230 mm, 10.62° N, 80.52°E, Bay of Bengal, 650 m, EXPO, Nov. 2011; 34909A, SL-115 mm, 11.93° N, 92.28° E, Andaman Sea, 290 m, HSDT CV, April 2016; 36708, 200 mm SL, 13.26° N, 93.26° E, Andaman Sea, 635 m. HSDT, November 2017; 34503, 138 mm SL, Off Kollam, 9.5° N, 75.9°, 330 m., Arabian Sea, October 2015.

Diagnosis—Species of *Lophiodes* with moderately depressed head and body; well-developed 3 cephalic and 2 post cephalic dorsal fin spines, peritoneum black.

Description—Moderately depressed head and body; eyes large, directed dorsolaterally, two spines on the articular region, one anterior and one posterior to jaw joint; two spines on palatine, the posterior spine larger than the anterior spine; frontal ridge and outer surface of premaxilla smooth, two sphenotic spines present, (straight not recurved) inner spine sharply pointed and long, outer spine blunt; inner and outer frontal spines present; humeral spines strong and bifid or trifid; illicium simple, devoid of tendrils, esca simple, lightly pigmented bulb without any cirri. Illicium and 2nd dorsal spine extends over the 3rd spine, 3rd is almost reaching the end of soft rays with tendrils, 4th reaches beyond the base of the soft rays, 5th dorsal usually small, (embedded in 115 mm SL specimen) but its presence can be detected peripherally. 3rd dorsal fin spine is the longest in all the three specimen examined; three irregular rows of teeth on upper and lower jaws, innermost row is large and recurved in lower jaw; vomerine and palatine present; anal fin reaches upto the base of caudal fin. 8 caudal fin rays, branched expect 1st and 8th; cirri present along the dorsal surface of the head, body and lateral margin, which have same colour as body; mouth cavity white; species can be easily distinguished from other Indian specimens by the number of cephalic and post cephalic fin spines.

Colour—Head and dorsal surface of the body uniform light brownish black, ventral having same colour as dorsal, but lighter. All the fins are brownish black, pectoral fins with pale tips. In preservative, dorsal surface having uniform pale brown and whitish ventral; all the fins are pale.

Distribution—Arabian Sea (new record from present study), Bay of Bengal and Andaman Sea. Indo-West Pacific, Philippines, East Africa and Australia at depth of 230-650 m. (Ho *et al*. 2016b).

Table 3.7. Morphometric and Meristic data for *Lophiodes mutilus*, compared with previous records

Measurements	**2911516**	**34503**	**34909A**	**36708**	**Caruso 1981 (Range)**
SL (mm)	230	138	115	200	55-311.5
% SL					
HL	36.1	42.0	38.9	34	35.3-43.8
IL	27.0	26.1	29.6	31.5	24-35.4
DS2	23.5	23.2	27.8	broken	20.5-30.4
DS3	48.3	60.1	43.5	46.5	35.9-64.0
DS4	13.9	9.4	10	12	
DS5	8.3	4.3	embedded	3	
TL	29.4	29.0	16.5	0	25.0-33.5
CFL	32.6		34.8	30	
% HL					
HW	54.2	60.3	58.2	52.3	51.3-60.9
HD	64.3	63.8	62.9	62.3	61-68.8
SNL	56.6	51.7	54.1	54.4	51.8-59.9
SNW	16.9	19.0	38.3	16.1	16.2-19.7
ISP	47.0	43.1	17.2	42.6	39.3-46.5
IF	36.1	36.2	40.3	36.8	36.3-46.5
PTSP	20.4	20.7	19.5	22.0	16.1-21
QPAL	76.1	77.6	69.4	68.4	66.6-78.7
OPSOP	41.0	40.9	42.4	41.3	39.5-49.8
Meristics					
Dorsal fin spines	III, II	III, II	III, II	III, II	
Dorsal fin rays	8	8	8	8	
Pectoral fin rays	14	15	15	14	
Anal fin rays	6	6	6	6	
Ventral fin	I,5	I,5	I,5	I,5	
Caudal fin rays	8	8	8	8	

Lophiodes gracilimanus **(Alcock, 1899)**

Figs. 3.5. A—B, Table 3.8

Synonyms—*Lophius graclimanus* Alcock, 1899

Lectotype—ZSI 490/1, 68.1 mm; Paralectotypes: ZSI F488/1-489/1 (2), F672/1 (1) Malabar coast of India, 124-270 m., vessel- Investigator (Alcock 1899).

Material examined—349 02A, ♀, 270 mm SL, off Andaman Coast of India, 7.5° N, 93.4° E, April 2016, 650 m. 367 05, ♀,185 mm SL, 12.49° N, 93.17° E, 314 m, Andaman Coast of India, HSDT, December 2017.

Diagnosis—A species of *Lohiodes* with characters of *L. naresi* species group. Esca with pennant- like flap, long cirri, translucent bulb, and usually with dark, stalked, eye like appendages, cephalic and post cephalic portion of spinous dorsal fin with well-developed spines, III cephalic and III post cephalic fin spines; peritoneum light.

Description— A species of *Lohiodes* with characters of *L. naresi* species group; moderately depressed head and body, spines on the articular region well developed, one anterior and one posterior to jaw joint, gill openings extending below, behind and in front of pectoral fin base; spinous dorsal fin on the cephalic portion well developed, with three spines, post-cephalic also with three spines; frontal ridge and outer surface of premaxilla smooth; two sphenotic spines present, inner one sharply pointed, outer one blunt. Inner frontal spine absent, narrow head and snout; supraorbital ridge elevated and forming a deep U-shaped trough between eyes; subopercle with a single spine, interopercular with two spine, humeral spine well developed with bifid end; cirri present on lateral margin of the head, body, and dorsal surface of body including pectoral fins; illicium simple filament, devoid of tendrils, just reaching to parietal spines when retracted, small leaf like esca; second dorsal spine longest in 270 mm specimen, (third dorsal fin spine is longest in 185 mm SL specimen) reaching up to origin of fourth spine, bearing tendrils, third dorsal spine stout and bearing many tendrils reaches base of soft dorsal; fourth, fifth, sixth also well-developed and pigmented as third, with tendrils; caudal fin rays 8; teeth on alveolar process of premaxillary straight in arrangement; teeth in outer premaxillary row (one half) 20-25 including rudimentary. Vomerine and palatine present.

Colour—Head, dorsal surface of the body and pectoral fins uniform dark brown; ventral surface light brown; ray tips light colour except caudal fin.

Distribution—Known from Arabian Sea, off the Malabar Coast of India and Andaman Sea (New record from present study) at depth range of 125 to 650 m. Also occurs in Indonesian waters.

Remarks—Alcock described *Lophius graclimanus* in 1899 from three specimen collected from Indian Ocean off Malabar Coast of India at depth ranging from 125 to 300 m. Later, Caruso (1981) examined 24 specimen and provided detailed information regarding the species. After that no specimen were recorded from the Indian waters. The present study reports *L. gracilimanus* from Andaman Sea which provides greater latitude and depth distributions (650 m.) than previously known.

Table 3.8. Morphometric and Meristic data for *Lophiodes gracilimanus* compared with previous study

Measurements	34902A	36705	Caruso 1981
SL (mm)	204	185	43.6-165.4
% SL			
HL	36.8	39.5	36.3-44.3
IL	29.4	27.6	23.6-36.6
DS2	35.8	32.4	31.5-63.1
DS3	34.3	35.1	30.9-43.8
TL	31.9	27.0	25.6-31.8
CFL	29.9	33.5	
% HL			
HW	53.3	50.6	45.1-53.0
HD	48.0	59.8	50.7-63.5
SNL	60.0	56.1	55.6-64.6
SNW	14.7	17.9	14.9-18.7
ISP	41.3	42.7	36.0-45.4
IF	30.7	32.4	26.2-33.0
PTSP	20.0	19.2	14.5-19.3
QPAL	76.0	72.5	64.3-74.0
OPSOP	34.7	36.9	31.5-40.9
Meristics			
Dorsal fin spines	III, III	III, III	III, III
Dorsal fin rays	8	8	8
Pectoral fin rays	14	15	14-16
Anal fin rays	6	6	
Caudal fin rays	8	8	

Genus *Lophiomus* Gill, 1883

Diagnosis— *Lophiomus* genus is unique among the lophiidae in having the frontal ridge and outer surfaces of the maxilla dentary. Head and body strongly depressed and broad; gill openings extending below and behind pectoral fin base; spinous dorsal fin of six spines, cephalic and post-cephalic portions well developed; inner and outer sphenotic spines well developed, a third posterior sphenotic spine frequently present; epiotic spines well developed; articular with a single spine anterolateral to jaw joint; quadrate with a single lower spine; subopercle with a single spine; interopercle with two spines; humeral spine well developed. Genus is monotypic.

Lophiomus setigerus **(Vahl, 1797)**
Figs. 3.6. A—B, Table 3.9

Synonyms—*Lophius viviparus* Bloch and Schneider, 1801; *Lophiomus longicephalus* Tanaka, 1918 (type lost) *Lophius indicus* Alcock, 1889*;* *Chirolophius laticeps* Ogilby, 1911; *Chirolophius malabaricus* Samuel, 1963 (specimen lost).

Syntypes— AMS I.25832-004 (Vahl, 1797). syntypes: MNHN 1890-0341 (1), ZSI F12450-51 (2), 261/1-263/1 (3), 12504 (1), 13216 (1), 413/1 (1); Investigator station 43 , Bay of Bengal. 45-78 m. (Alcock 1889).

Materials examined—3170113, 191 mm SL, 9.95° N, 76.00° E, Arabian Sea, 200 m., HSDT, August, 2013; 27807, 130 mm SL, 11.1° N, 74.9° E, 200 m. Arabian Sea, August 2010; 2881718, 180 mm SL, 9.99° N, 75.6° E, 200 m, Arabian Sea, October 2011.

Diagnosis—A species of *Lophiomus* with strongly depressed head and body; frontal ridge and outer surfaces of the maxilla dentary; esca with leaf like flap and two black bulb like appendages; peculiar pattern (small ring like) on the dorsal body.

Description— Head and body strongly depressed, head and anterior portion of body forming almost rounded disk; tail muscular, depressed. Dorsal surface of frontal ridge and premaxilla dentary; palatine with two spines, posterior spine is stronger than anterior; posterior end of each premaxilla with a bifid spine; blunt symphysial spine on lower jaw; two sharp spines on posterior margin of frontals; sphenotic spines well developed, outer one is larger than inner. Inner frontal spine also present; hyomandibular spine small; pterotic spines blunt with broad base; preopercle and posterior end of subopercle possess a sharp spine; single epiotic spine well developed; humeral spine well developed, with assemblage of four spines; anal fin not reaching upto the caudal fin base.

Illicium slender, long devoid of tendrils, reaches up to the sphenotic spines. 2nd fin spine stout, bearing numerous tendrils, reaching up to the sphenotic spines; 3rd is slender, long, devoid of tendrils and reaches 5th dorsal fin spine when retracted; 4th and 5th are developed, devoid of tendrils; 6th reduced (developed in 278 specimen). Esca well-developed flap like, long cirri, at the base of the esca two short black filaments are present (well seen in 288 specimen, others are somewhat dried); cirri present on head, dorsal body, lateral side of the body including pectoral fin surface; peritoneum black.

Colour—Dorsal surface dark brown; with small circular pattern; All fins are dark brown (same as body colour) with black tips, ventral surface light brown; mouth cavity same as body colour. In preservative body retains the pattern and colour as fresh, but faded.

Distribution—Bay of Bengal, Arabian Sea and Andaman Sea (Alcock 1889). Widespread in Indo-west Pacific Ocean, Japan, Indonesia, east coast of Australia, off New South Wales, Madagascar at depth ranges of 72-970 m (Caruso 1983).

Remarks—Alcock 1889 described *Lophius indicus* from Bay of Bengal at depth of 45 m (ZSI-12450, 65 mm). Later, Caruso (1983) synonymized with *Lophiomus setigerus* (Vahl, 1797).

Table 3.9. Morphometric and Meristic data for *Lophiomus setigerus*, compared with previous study

Measurements	**3170113**	**27807**	**2881718**	**Caruso 1983**
SL (mm)	191	130	180	70-277
% SL				
HL	37.6	39.2	41.7	32.1-41.7
IL	29.8	22.9	30.0	23.-41.7
DS2	20.8	19.2	17.8	13.2-20.8
DS3	21.4	22.0	20.0	13.5-25.3
DS4	6.2	7.7	12.2	
DS5	5.0	3.4	3.7	
DS6	1.0	3.0	1.0	
TL	34.7	31.5	31.4	31.5-39.0
% HL				
HW	53.4	51.7	58.7	52.2-58.4
HD	70.0	69.7	61.3	66.4-74.7
SNL	59.3	56.9	53.3	53.7-59.0
SNW	23.0	22.7	25.3	20.7-25.1
ISP	44.5	41.2	38.7	36.7-44.3
IF	35.4	31.4	32.0	31.5-38.4
PTSP	12.7	13.1	15.1	11.4-15.2
QPAL	62.0	71.4	71.6	62.3-72
OPSOP	51.5	49.0	49.3	47.8-54
Meristics				
Dorsal fin spines	III, III	III, III	III, III	III, III
Dorsal fin rays	8	8	8	8
Pectoral fin rays	23	24	23	21-25
Anal fin rays	6	6	6	6
Ventral fin rays	I, 5	I, 5	I, 5	I, 5
Caudal fin rays	9	9	9	9

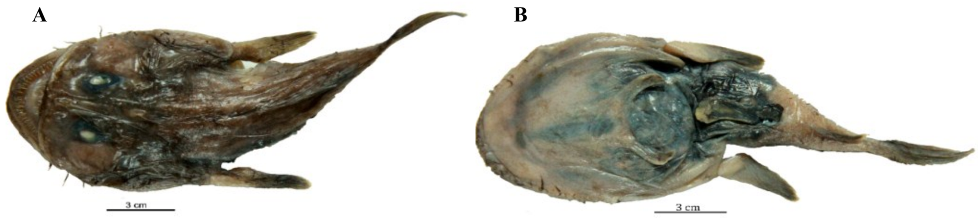

Figure 3.2. *Lophiodes lugubris* (34906), A—dorsal view B—ventral view New record from Andaman Sea, 332 m depth

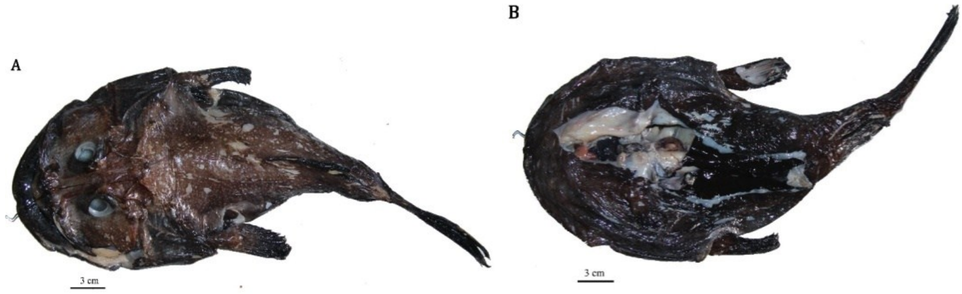

Figure 3.3. *Lophiodes triaradiatus* (36715), A—dorsal view, B—ventral view New record from Andaman Sea, 646 m depth

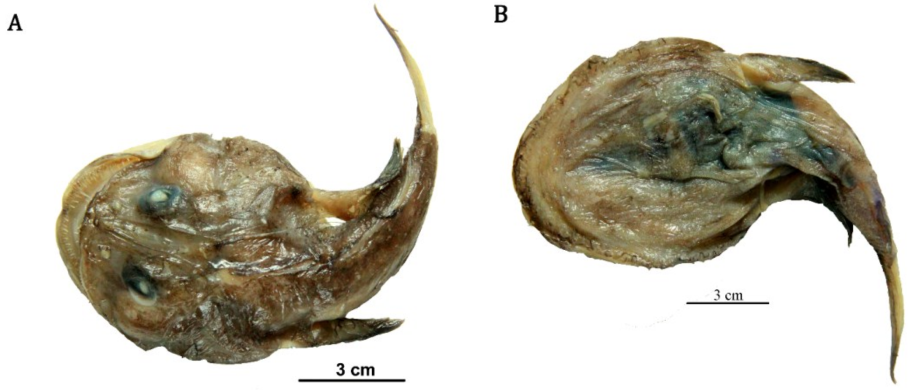

Figure 3.4. *Lophiodes mutilus* (34503), A—dorsal view, B—ventral view New record from Arabian Sea, 330 m depth

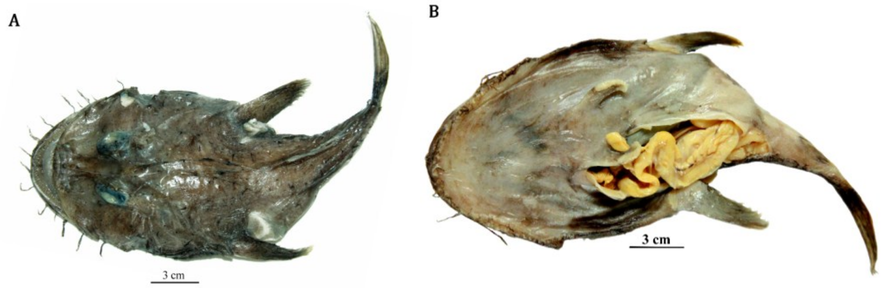

Figure 3.5. *Lophiodes gracilimanus* (349 02A) A—dorsal view, B—ventral view Rediscovery of species after 35 years from Indian waters; collection location— Andaman Sea, 650 m depth

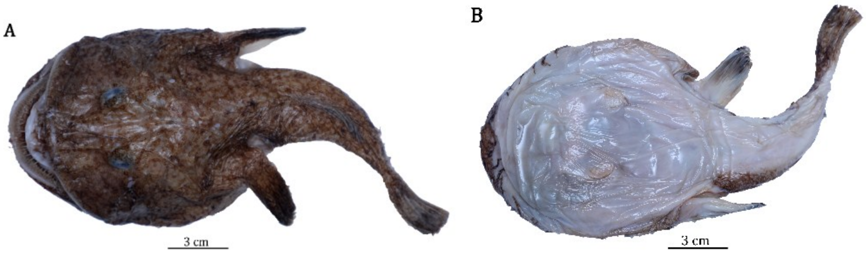

Figure 3.6. *Lophiomus setigerus* (27807), A—dorsal view, B—ventral view

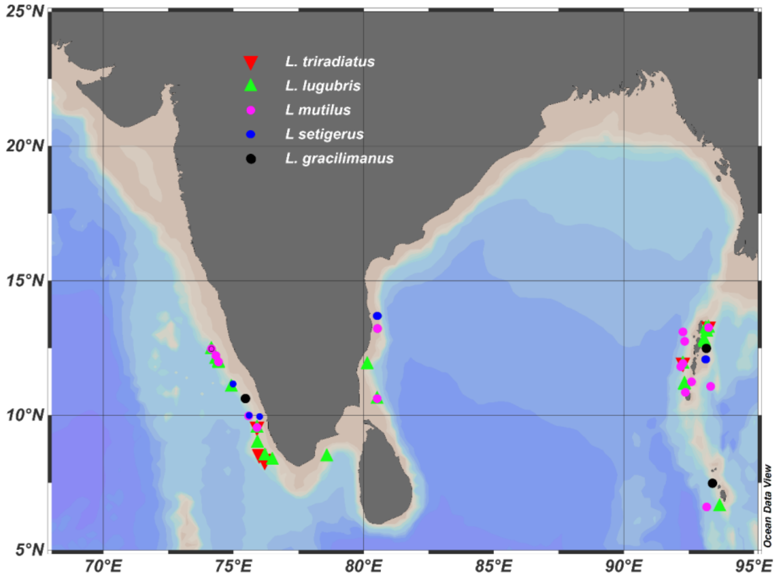

Figure 3.7. Map showing distribution of Family Lophiidae in the Indian EEZ Species—*Lophiodes triradiatus*; *Lophiodes lugubris*; *Lophiodes mutilus*; *Lophiomus setigerus* and *Lophiodes gracilimanus*.

ii. Suborder—CHAUNACOIDEI

Family—CHAUNACIDAE Gill, 1863

Sea toads or coffinfishes

The family Chaunacidae is a group of medium sized, benthic fishes found from 200 m to more than 2000 m depths along the continental slopes of major oceans.

Diagnosis—Head large globose, body rounded and moderately compressed, with very loose, flaccid skin, which is densely covered by minute, prickle-like scales; body tapering to a small rounded tail. Head and body with a conspicuous network of open sensory canals, and a single open lateral-line canal extending posteriorly along a moderately compressed trunk and tail. The angling apparatus consists of a short illicium, with a terminal esca comprising of a dense cluster of short cirri, which is retractable into a scaleless illicial trough immediately behind it. Two additional dorsal cephalic fin spines are present as embedded, post cephalic fin spines absent. They are generally pink, reddish, orange, or rose-colored; some species with yellow or green spots or patches on the dorsal body. Dorsal fin rays with 10 to 12 rays, anal fin with 5 to 7; pectoral fins paddle like with 10 to 15 rays. Caruso (1989a) reviewed the family and included all the *Chaunax* species within two species groups based on morphological characters. *Chaunax fimbriatus*-species group and *C. pictus* species group. Later, Ho and Shao (2010) added a third group, the *C. abei* species group, formerly included in the *C. fimbriatus* species group. Sexual dimorphism is common in Chaunacidae family, male usually with large nostrils sometimes equal to eye size, whereas female with small nostrils.

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. 3.12).

Genus Chaunax Lowe, 1846

Diagnosis- Anal-fin rays 6 or 7 (usually 7); 12 dorsal fin-rays; relatively high number of lateral line neuromast counts; usually thickly packed dermal spinules; narrow intersphenotic space.

Chaunax multilepis Ho HC, Meleppura RK and Bineesh KK, 2016

Indian spotted coffinfish
Figs. 3.8. A—B, Table 3.10
New species described
Holotype—CMLRE 2923417A (130 mm SL), 13.26° N, 93.17° E; off North Andaman, Andaman Sea, 295–323 m, FORVSS, EXPO, November 2011.

Materials examined**—**Holotype; Paratypes- 2923417B (1, 107 mm SL) and 2923417C (1, 105 mm SL), 2923812A & B (140, 126 mm SL), 13.00° N, 93.10° E; Andaman Sea, 325–350 m. 3050 01 (122 SL); 3050503 A and B (134 mm SL, 122 mm SL), 12.22 N, 74.33 E, Arabian Sea; 238-245m. 2911113, 142 mm SL, 11.9° N, 80.1° E, 650 m., EXPO, November 2011. For taxonomic studies more number of specimen were examined. 29111, 3 specimens (80, 85, 101 mm SL), 11.9° N, 80.1° E, 645 m., Bay of Bengal, November 2011.

Diagnosis—*Chaunax multilepis* is a species under *Chaunax abei* species group that is distinguished from congeners in the species group by having a continuous tooth patch on vomer, not divided into two patches, and four or five neuromasts in the lower preopercular series. It can be further separated by the following combination of characters: large green spots on dorsal surface; simple spinules on dorsal surface; 12 pectoral-fin rays; 13–16 neuromasts in pectoral series; 30–37 neuromasts in lateral-line proper; typically four neuromasts on caudal-fin base; typically 7 neuromasts in mandible; typically 12 gill rakers on second gill arch; gill chamber and buccal cavity pale; and peritoneum black.

Description-Morphometric and meristic data are given in Table 3.10; data for holotype are provided below followed by the range for paratypes in parentheses. Head length 2.3 (2.3–2.5) in SL; head width 6.5 (6.5–7.0) in SL, 2.8 (2.7–3.0) in HL; predorsal length 1.9 (1.9–2.1) in SL; pre-gill opening length 1.6 (1.5–1.7); pre-preopercular length 3.4 (3.4–3.8) in SL, 1.5 (1.5–1.7) in HL; upper jaw 4.8 (4.6–5.5) in SL, 2.1 (1.9–2.4) in HL; illicial length 10.0 (9.4–12.9) in HL; illicial trough length 6.1 (5.8–7.9) in HL; eye diameter 5.3 (4.6–6.0) in HL; post-dorsal fin length 5.3 (4.9–5.6) in SL, 2.3 (2.0–2.3) in HL; post-anus length 3.1 (2.8–3.4) in SL, 1.4 (1.2–1.5) in HL; post-anal fin length 6.2 (4.8–6.6) in SL, 2.7 (2.0–2.9) in HL; caudal peduncle depth 5.7 (5.3–5.9) in HL; caudal fin length 3.7 (3.4–3.8) in SL, 1.6 (1.5–1.6) in HL.

Head globular, skull slightly elevated posteriorly; trunk cylindrical, slightly compressed, tapering posteriorly; skin thin, loose and flaccid; interorbital space broad; caudal peduncle relatively long and slender, slightly compressed, tapering posteriorly. Eyes rounded, directed dorsolaterally, covered by dermal membrane broadly connected to adjoining skin, forming clear ‘window’. Illicium short and stout; esca with large central tongue bearing many thin brownish cirri; second dorsal-fin spine close to illicium, embedded under skin; third dorsal-fin spine situated at about mid-point of pre-dorsal distance, embedded under skin. Illicial trough oval-shaped, flat, relatively short and narrow, smaller than pupil, and longer than wide.

Two nostrils anterior to eye, anterior nostril surrounded by fleshy membrane, posterior part higher than anterior part, posterior nostril a simple round hole; mouth relatively wide, terminal, opening nearly vertical; lower jaw slightly protruding in front of upper jaw; maxilla tapering above, broad below; blunt symphyseal spine on lower jaw symphysis. Broad transparent membrane on first gill arch; first ceratobranchial broadly connected to opercular wall; gill filaments on second to fourth gill arches, two rows of gill filaments on second and third gill arches, single row of gill filaments on fourth gill arch; those on inner row of third and fourth gill arch subequal to those of other arches inner surface of fourth gill arch completely connected to body. Single row of 16 (15–17) rakers on first gill arch, 4 (3 or 4) on upper limb and 12 (12 or 14) on lower limb, 12 (11–13) paired rakers on second arch, 11 (11 or 12) paired rakers on third arch and single row of 9 (9 or 10) rakers on fourth arch.

Distribution—Known from the type series collected in the Andaman Sea at depths of 295–350 m; off the southwestern coast of India, Arabian Sea, between Mangalore and Kollam at depths of 200–350 m and Bay of Bengal.

Table 3.10. Morphometric and Meristic data for *Chaunax multilepis*

	Holo -type	**Additional specimens *Chaunax multilepis***									
Measurements	**292 3417A**	**292 3417B**	**292 3417C**	**292 3812A**	**292 3812B**	**305 0503A**	**305 0503B**	**291 1113**	**Mean**	**Range**	**SD**
SL (mm)	130	107	105	140	126	134	122	142			
% of SL											
Head length	43.9	42.5	41.3	42.4	44.0	41.0	39.8	39.1	41.7	39.1-44	1.8
Preopercular length	29.3	27.1	26.4	27.0	29.6	26.2	26.2	27.0	27.3	26.2-29.6	1.3
Interspenotic width	15.5	15.6	15.1	14.4	14.2	16.6	16.7	14.5	15.3	14.2-16.7	1.0
Eye diameter	8.3	9.4	9.0	7.1	8.5	7.9	8.1	8.9	8.4	7.1-9.4	0.7
upper jaw length	20.7	19.8	19.6	19.6	18.3	20.6	20.3	20.0	19.8	18.3-20.7	0.8
Illicial length	4.4	3.9	4.4	4.5	4.1	4.9	5.6	4.8	4.6	3.9-5.6	0.5
Illicial trough length	7.2	7.3	7.2	6.6	5.5	5.3	6.1	6.4	6.4	5.3-7.3	0.8
Pre dorsal length	52.4	50.7	50.0	49.1	46.9	52.5	50.7	52.2	50.6	49.1-52.5	1.9
Pre-gill opening	61.5	65.4	64.5	58.6	57.2	57.0	56.1	58.7	59.9	56.1-65.4	3.5
Post dorsal length TL 1	18.7	20.1	18.0	19.6	18.8	18.6	18.7	18.0	18.8	18.0-20.1	0.7
Post anus length TL 2	31.9	32.2	31.7	31.1	29.3	32.1	29.2	34.0	31.4	31.1-34.0	1.6
Post anal length TL3	16.1	20.9	20.4	15.9	15.3	15.4	15.4	19.0	17.3	15.3-20.9	2.4
Caudal peduncle depth	7.7	8.0	7.4	7.4	7.5	7.9	7.4	7.9	7.7	7.4-8.0	0.3
Caudal fin length	26.9	26.2	26.4	27.9	26.8	27.4	27.1	29.1	27.2	26.2-29.1	0.9
Meristics				-	-	-	-	-	-	-	-
Dorsal fin rays	12	12	12	12	12	12	12	11		11-12	
Pectoral fin rays	12	12	12	12	12	11	10	10		10-12	
Anal fin rays	7	7	7	7	7	7	7	7		7	
Caudal fin rays	9	9	9	9	9	9	9	9		9	
Neuromasts counts										n=15	
AB	12;12	11;12	12;12	12;12	12;12	11;11	11;12	12:12		11-12	
AC	8;8	8;8	8;8	8;8	8;8	8;8	8;8	8;8		8	
BD	3;3	3;3	3;3	3;3	3;3	3;3	3;3	4;4		3-4	
CD	6;6	6;7	6;6	6;6	6;6	6;6	6;6	6;6		6-7	
DG	4;4	4;4	4;4	3;4	4;4	3;3	3;3	4;5		3-5	
EF	6;7	6;6	7;7	6;7	7;7	7;7	6;7	7:7		6-7	
FG	3;3	3;3	3;4	3;3	4;3	3;4	3;4	4:4		3-4	
GH Pectoral	14;14	14;14	13;13	14;15	15;15	13;13	14;14	13;13		13-15	
BB'	5;5	5;5	5;4	5;5	4;4	5;4	4;4	5:5		4-5	
BI	36; 37	36;37	35;35	36;32	36;39	39;37	38;37	39;38		35-39	
Gill rakers										n=8	
GRI	16	17	15	16	15	16	16	17		15-17	
GRII	12	12	11	12	13	12	12	13		11-13	
GRIII	11	12	11	11	13	11	11	12		11-13	
GRIV	9	10	10	10	10	9	10	10		9-10	

Chaunax sp. A

Figs. 3.9. A—B, Table 3.11

New species

Material examined—CMLRE 30501 (196 mm SL) 8.28° N, 76.20° E; 1050-1100 m, Arabian Sea, Southwest coast of India, northern Indian Ocean; FORVSS, August 2012.

Diagnosis—A species belonging to *C. fimbriatus* species group that is distinguished from congeners in the species group by having 3-4 neuromasts on upper preopercualar series; 4 neromasts on lower preopercular series; 14-15 on pectoral series; 11 gill rakers on 2nd and 3rd gill arches; uniform red colour all over the body including all the fins without any marking.

Description—Dorsal fin rays III, 12; pectoral fin rays 13; anal fin rays 7; caudal fin rays 8. Head globular, skull slightly elevated posteriorly; trunk cylindirical, slightly compressed, tapering posteriorly to caudal-fin base; ventral surface of belly flattened; skin loose and flaccid; interspace between eyes broad, flat, not convex; eyes large, rounded, directed dorsolaterally; covered by dermal membrane connected to adjoin skin, forming clear window.

Illicium short (3.7 in SL), esca depressed, forming a large central plate with many deep red, thin cirri; illicial trough notably broad and oval shape bearing many thin cirri on the outer margin of the entire trough second dorsal fin spine close to the illicium, embedded under skin; third dorsal fin spine located just in front of the origin of dorsal fin rays, both spines are embedded under the skin. Soft dorsal originating from slightly behind midpoint of body; pectoral fin originating from the midpoint of the body laterally; pelvic fin ventrally positioned well anterior to pectroral; anus located ventrally below in front of the origin of anal fin.; caudal fin relatively strong, 9 fin rays, all are branched except outer most two.

Nostrils anterior to eye; mouth wide, nearly vertical, lower jaw protruding slightly in front of upper jaw; symphysis of lower jaw bearing a blunt symphyseal spine; 4 rows of irregular teeth on upper and lower jaws. Jaws and body margin covered with simple cirri; entire dorsal surface covered by scattered cirri, relatively dense on supraocular membrane, lower portion of maxilla and preopercular area. All the cirri have the red colour same as body. First ceratobranchial well connected to opercular wall and first epibranchial entirely free of opercular wall; gill filaments present on second to fourth gill arches, two rows of gill filaments in second and third gill arches, single filaments on fourth gill arch; first gill arch without any filaments, inner surface of the fourth gill arch completely fused with body. Dorsal surface covered by mixed simple and bifurcated, recurved spinnules, except for eye window, ventral surface of pectoral fin, entire pelvic fin, entire anal fin, membranes of dorsal fin rays and anus. Bifurcated spinnules more in the area under eyes. Caudal fin rays bearing spinnules. Ventral surface covered by minute simple spinules.

Lateral line neuromasts well prominent, 3-4 pairs of short spines bridging each neuromast. Supraorbital (AB) =10:11; premaxillary (AC)= 8; upper preopercular (BD)=4:3; inraorbital (CD)=6; lower preopercular (DG)=4; mandibular (EF)=6; hyomandibular (FG)=3; pectoral (GH)=14:15; anterior body proper (BB')=4; supratemporal (BB)=5 and body proper (BI)=35 including on caudal fin.

Colour—When fresh, pale red on dorsal surface, including the ventral surface. All the fins are dark red. Illicium colour same as that of body, esca with deep red ciiri. When preserved dorsal body, ventral surface and all the fins are uniformly pale; illicium pale, cirri on esca pale with dark brown tips, gill chamber, buccal cavity and gill rakers pale; peritoneal membrane uniformly brown.

Distribution—Known from collection locality only, Arabian Sea, Southwest coast of India, northern Indian Ocean, 1050-1100 m depth.

Discussion—*Chaunax* sp. A can easily distinguished from *C. africanus*, having uniform red colour vs. complicated reticulate colour pattern even in preserved specimen; 11 rakers on second gill arch vs. 8-9; illicial trough large oval shape vs. small; black spotted gill chamber vs. pale; BD=4:3 vs. 2. New species is most similar to *C. flammeus* having similar body colour and proportion but it can be easily distinguished by the following characters, all the four gills having relatively high number of rakers, Gr i-12 vs. 14; Gr ii-9 vs. 11; Gr iii-9 vs. 11; Gr iv- 8 vs. 9, further neuromasts BD= 2 vs. 3:4; GH 10 vs. 14:15. New species can be distinguished from *C. hollemani* in having the following characters, pre-preopercle length 33.7 % vs. 26.8–28.5% SL; (peritoneum same in both species–brown colour); 4:3 neuromasts in upper preopercular series (BD) vs. 2; Gr ii 11 vs. 7; post anus length (TL1) 35.2 vs. 15.2-19.4; post dorsal length (TL 2) 22.4 vs. (28.9-31.8).

New species differ from *C. nebulosus* in having uniformly pale red vs. dorsal dusky colour pattern overlaid with five brownish eye-sized spots on the dorsal surface.; 11rakers on second gill arch vs. 8–9; illicial trough broad and oval shaped vs. elongate; BD = 4:3 vs. 2; GH =14:15 vs. 10:12.

Table 3.11. Morphometric and meristic data for *Chaunax* sp. A. compared with other members of *C. fimbriatus* group. (n= no. of specimen examined)

		Ho & Ma 2016		**Ho & Last 2013**	
	***Chaunax* sp. A CMLRE 30501**	***C. flammeus***	***C. hollemani*** **Mean (Range)**	***C. nebulosus*** **Mean (Range)**	***C. africanus***
SL (mm)	196 (n=1)	95.7 (n=1)	114.9-178.7 (n=5)	106–212 (n=12)	227, 142 (n=2)
In % of SL					
Head Length	44.9	43.4	39.7 (39.1-40.5)	41.1 (39.3–43.2)	43.6 43.7
Head width	18.9	20.7	17.2 (16.0-18.5)	19.0 (17.8–21.0)	23.8 24.6
Pre-opercular length	33.7	30.7	27.5 (26.8-28.5)	27.8 (26.2–29.5)	28.9 29.6
Eye diameter	13.7	10.4	7.7 (7.3-8.4)	7.4 (6.2–8.1)	6.5 7.0
Illicial length	3.7	5.2	4.9 (4.2-5.6)	4.1 (3.2–4.9)	4.4 2.8
Illicial trough length	8.0	10.4	7.5 (7.1-7.9)	-	-
Pre-illicial trough length	1.0	1.8	3.4 (2.2-3.9)	-	-
Upper jaw length	17.3	27.2	21.6 (20.8-23.0)	19.6 (17.9–21.3)	22.5 21.8
Pre-dorsal length	53.1	50.6	48.0 (46.0-50.0)	52.3 (48.5–56.4)	50.2 52.1
Pre-gil opening length	61.7	62	62.1 (60.7-63.9)	62.9 (60.5–65.0)	65.2 64.1
TL 1 (Post anus)	35.2	34.1	17.7 (15.2-19.4)	28.3 (25.1–30.3)	35.7 31.7
TL 2 (Post-dorsal length)	22.4	18.5	30.3 (28.9-31.8)	16.5(15.7-17.3)	16.3-17.6
TL 3 (Post-anal length)	19.9	16.9	14.9 (13.7-15.9)	14.1 (12.8–15.2)	11.5 13.7
Caudal peduncle depth	8.7	10	8.7 (8.4-9.0)	9.3 (8.8–9.9)	9.7 10.0
Caudal fin length	28.1	32.9	29.9 (27.8-31.5)	31.0 (28.8–34.0)	27.8 28.9
Meristic values					
Dorsal fin rays	lll, 12		lll, 12	lll,11-12	12
Pectoral fin rays	12	13	12:13	13:14	13:14
Anal fin rays	7		7	7	6-7
Caudal fin rays	8		9	9	9
Neuromasts (*counts expressed both sides when it differ)*					
AB	10:11	11	11	10:12	11
AC	8	8	8	8	8
CD	6	6	6	5:7	6:7
BD	4:3	2	2	2:3	2
DG	4	4	3	3	3
EF	6	6	6	4:7	6
FG	3	3	3	3:4	3
GH	14:15	10	11:14	10:12	10:12
BB'	4	5	4	3:5	4
BB	5	6	6	6	6
BI	35	31	33-38	29:35	31-32
Gill rakers					
Gr i	14	12	13-15	11:14	12:13
Gr ii	11	9	9	8:10	8:9
Gr iii	11:9	9	9:10	8:9	9
Gr iv	9	8	7:8	6:8	7-8

- Not mentioned

Chaunax apus Lloyd, 1909

Figs. 3.10. A—B, Table 3.12

Holotype—ZSI F2404/1; Bay of Bengal, off Akyab coast, Myanmar, Investigator station 379, depth 969 m. (Lloyd 1909).

Materials examined—34902A and B 225, 195 mm SL 7.5° N, 93.4° E, Andaman Sea, 650 m., HSDT CV, April 2016; 34908A and B, 100, 104 mm SL, 12.1° N, 93.2° E, 411 m., HSDT CV, April 2016 ; 2928324, 138 mm SL, 6.8° N, 93.1° E, 337 m., December 2011; 2910511, 96 mm SL, 18.8° N, 85.4° E, Bay of Bengal, 620m., HSDT CV, October, 2011 ; 3050507 91 mm SL, 12.2° N, 74.3° E, Arabian Sea, 245 m., HSDT CV, August 2011.

Diagnosis—Belongs to the *Chaunax abei*-species group, which is characterized by its lack of filaments on the dorsal surface of the head and flap-like cirri laterally on the body associated with the lateral line. Uniform red colour in fresh turning creamy white on preservation. Relatively small head, dermal spinules slender and curved; long tail, especially TL2 (post anus length 32.4-36.9 5 % SL), relatively short caudal fin; gill rakers on second gill arch; GR ii=11 or 12; lateral-line neuromasts: 3 neuromasts on upper preopercular (BD), 14-17 on pectoral series (GH), 33-38 on body series (BI).

Description—Head globular, relatively small, skull slightly elevated posteriorly; trunk cylindrical, slightly compressed, tapering posteriorly; skin thin, loose and flaccid; caudal peduncle relatively long and slender, slightly compressed, tapering posteriorly. Eyes rounded, directed dorsolaterally, covered by dermal membrane broadly connected to adjoining skin, forming clear window.

Illicium short and slender; esca with large central tongue bearing many thin pinksh cirri; second dorsal-fin spine close to illicium, embedded under skin; third dorsal-fin spine situated at about mid-point of pre-dorsal distance, embedded under skin. Illicial trough oval-shaped, flat, relatively short and narrow, smaller than pupil, and longer than wide.

Two nostrils anterior to eye, anterior nostril surrounded by fleshy membrane, posterior part higher than anterior part, posterior nostril a simple round hole; mouth relatively wide, terminal, opening nearly vertical; lower jaw slightly protruding in front of upper jaw; maxilla tapering above, broad below; blunt symphyseal spine on lower jaw symphysis. Broad transparent membrane on first gill arch; first ceratobranchial broadly connected to opercular wall; gill filaments on second to fourth gill arches, two rows of gill filaments on second and third gill arches, single row of gill filaments on fourth gill arch; those on inner row of third and fourth gill arch subequal to those of other arches inner surface of fourth gill arch completely connected to body. Single row of 15 (14–16) rakers on first gill arch, 4 on upper limb and 12 (10 to 12) on lower limb, 11 (11–12) paired rakers on second arch, 11 (11 or 12) paired rakers on third arch and single row of 9 (9 or 10) rakers on fourth arch.

Distribution—Bay of Bengal (type locality), new record from Arabian Sea and Andaman Sea. Widespread in Indo-west Pacific, South and East Africa to Madagascar and Kenya; Myanmar and Indonesian water at a depth ranging from 195–969 m (Ho and Last 2013; Ho *et al.* 2015; Ho and Ma 2016).

Table 3.12. Morphometric and meristic data for *Chaunax apus* compared with previous study

Measurements	**34902 A**	**34902 B**	**292 8324**	**291 0511**	**305 0507**	**349 08A**	**349 08B**	**Mean**	**Range**	**SD**	**Ho & Ma 2016 Mean (Range)**
SL (mm)	225	195	138	96	91	100	104				106-234(n=4)
% of SL											
Head length	40.0	38.7	37.8	37.5	37.4	37.9	37.6	38.1	37.4-40.0	0.9	38.9 (37.3-40.6)
Head width	16.0	15.9	15.2	14.6	14.8	14.7	14.2	15.1	14.2-16.0	0.7	15.4 (14.0-16.7)
Pre-dorsal length	47.6	46.2	45.7	45.8	44.0	45	43.6	45.4	44.0-47.6	1.4	46.4 (44.4-48.1)
Pre-gill opening length	61.3	60.0	59.4	57.3	57.1	58	56.3	58.5	56.3-61.3	1.8	59.0 (57.5-61.3)
Preopercular length	26.7	26.2	26.8	25.0	25.3	26	25.3	25.9	25.0-26.7	0.7	25.9(25.0-27.4)
Upper-jaw length	21.3	20.0	19.6	18.8	18.1	19	18.9	19.4	18.1-21.3	1.0	19.6(18.7-21.3)
Illicial length	3.1	3.1	3.6	2.6	2.9	2.9	2.9	3.0	2.6-3.6	0.3	3.1 (2.8-3.4)
Illicial trough length	6.2	6.2	5.8	4.2	4.9	4.9	4.9	5.3	4.2-6.2	0.8	5.7 (4.5-6.3)
Eye diameter	8.0	8.2	8.7	6.7	6.6	7	7.0	7.5	6.6-8.7	0.8	8.0 (6.3-9.0)
Post-dorsal fin length	20.0	20.0	18.8	17.7	17.6	18	17.9	18.6	17.6-20.0	1.1	19.2 (17.3-20.2)
Post-anus length	36.9	35.4	36.2	34.2	32.4	35	34.1	34.9	32.4-36.9	1.5	34.7 (33.1-38.7)
Post-anal length	17.8	18.7	16.7	14.0	13.7	16	16.1	16.1	13.7-18.7	1.8	16.2 (13.4-18.0)
Caudal-peduncle depth	8.4	7.6	7.2	7.2	7.0	7.3	7.7	7.5	7.0-8.4	0.5	7.7 (7.1-8.1)
Caudal fin length	28.4	27.6	27.2	26.7	26.4	26.9	26.3	27.1	26.3-28.4	0.8	29.5 (26.5-28.9)
Meristic values											
Dorsal-fin rays	12	12		12	12	12;12	12;11				12
Pectoral-fin rays	13;13	13;13		13;13	13	13;13	12:13				11-13
Anal-fin rays	7	7	7	7	7	7	7				7
Caudal fin rays	8	8	8	9	9	8	8				9
Gill rakers											
GR i	15	15	15	16	15	14	14				14-16
GR ii	11	11	11	12	12	11	11				11-12
GR iii	12	11	11	12	12	11	11				11-12
GR iv	10	9	9	10	10	9	9				9-10
Neuromasts (*counted on both sides*)											
AB	11;12	11;12	11;11	12;12	12;12	11;11	11				11-12
AC	8;7	8;8	8;8	8;8	8;8	8;8	8;8				8
BD	3;3	3;3	3;3	3;3	3;3	3;3	3;3				3
CD	6;6	6;7	6;6	6;6	5;6	6;6	5;6				5-7
DG	3;3	3;3	3;3	4;4	3;3	3;3	3;3				3-4
EF	6;6	6;6	6;6	6;6	6;6	6;6	6;7				6-7
FG	3;3	3;3	3;3	3;3	3;3	3;3	3;4				3-4
GH	14;15	14;14	14;16	14;15	14;14	17;16	14;14				14-17
BB’	4;4	4;4	4;4	4;4	4;5	4;4	4;4				4;4
BI	41;40,	39;37	35	34;34	35	39	39				34-41

Chaunax penicillatus **McCulloch, 1915**

Figs. 3.11. A—B, Table 3.13

Synonyms—*Chaunax tosaensis* Okamura and Oryuu, 1984

Holotype—AMS E.5488; paratype: AMS I.13605 (1); type locality: 60 km SW of Cape Everard, Victoria, Australia, depth 293–366 m.

Materials examined—2803730, 113 mm SL (female) 6.6° N, 93.7° E, Andaman Sea, 321 m. September 2010; 2928323 A & B, 165 mm SL and 118 mm SL respectively (female), 6.8° N, 93.1° E, Andaman Sea, 337 m., December 2011.

Diagnosis—A species in the *C. pictus*-species group with a black and very deep illicial trough, an extremely short illicium and esca. Cirri on esca black anteriorly and bright white posteriorly. Dorsal-fin rays III, 12; anal-fin rays 7; pectoral-fin rays 13. GRi= 12-13, GRii=9; GRiii= 9-10, GRiv=7 and lateral-line neuromasts: BD= mainly 2, GH=10–11 mainly 11, BI=34–35. Body orange in colour with irregular yellowish vermicular patches. Uniform creamy white on preservation.

Description—Head globular, relatively narrow, skull slightly elevated posteriorly; trunk cylindrical, slightly compressed, tapering posteriorly; skin thin, loose and flaccid; interorbital space broad; caudal peduncle relatively long and slender, slightly compressed, tapering posteriorly; relatively short tail. Eyes rounded, directed dorsolaterally, covered by dermal membrane broadly connected to adjoining skin, forming clear window.

Very short Illicium and esca with black deep llicial trough; esca with numerous stout black (anterior portion) and pale (posterior portion) cirri; Illicial trough somewhat round-shaped, deeply concave. Second dorsal-fin spine close to illicium, embedded under skin; third dorsal-fin spine situated at about mid-point of pre-dorsal distance, embedded under skin. Two nostrils anterior to eye, anterior nostril surrounded by fleshy membrane, posterior part higher than anterior part, posterior nostril a simple round hole; mouth relatively wide, terminal, opening nearly vertical; lower jaw slightly protruding in front of upper jaw; maxilla tapering above, broad below; blunt symphyseal spine on lower jaw symphysis. Broad transparent membrane on first gill arch; first ceratobranchial broadly connected to opercular wall; gill filaments on second to fourth gill arches, two rows of gill filaments on second and third gill arches, single row of gill filaments on fourth gill arch, those on inner row of third and fourth gill arch subequal to those of other arches; inner surface of fourth gill arch completely connected to body. Single row of 13 rakers on first gill arch, 3 (3 or 4) on upper limb and 10 (9 or 10) on lower limb, 9 paired rakers on second arch, 10 paired rakers on third arch and single row of 7 rakers on fourth arch (relatively low number of gill rakers).

Colour—Colour of the Indian specimen in fresh, unknown. Generally dorsal with orange to reddish with irregular yellowish vermicular or spotty patterns; sometimes large black patches also found. Preserved specimens uninform creamy white except illicial trough, which is black.

Remarks—*Chaunax penicillatus* is the only member in the *C. pictus* group that occurs outside the Atlantic Ocean and showing widest distribution in the Indo-Pacific region.

Distribution—Andaman Sea, at depths of 321-337 m. (Present study- new record). *Chaunax penicillatus* is widespread in the Indo-west Pacific, including Kenya, South Africa, Madagascar, Japan, Taiwan, South China

Sea, Australia and New Zealand. Bathymetric range 293–620 m (Ho *et al.* 2013).

Table 3.13. Morphometric and meristic data of *Chaunax penicillatus*

	Present study						**Ho *et al.* 2013**	
Measurements	**292 8323A**	**292 8323B**	**280 3730**	**Mean**	**Range**	**SD**	**Mean (Range)**	**SD**
SL (mm)	165	118	113		113-165		97-197 (n=9)	
% of SL								
Head length	44.2	36.7	43.5	41.5	36.7-44.2	3.4	41.0 (37.8-45.2)	2.2
Head width	18.9	19.3	20.1	19.5	18.9-20.1	0.5	18.2(17.0-20.4)	1.0
Pre-dorsal length	50.6	49.0	54.1	51.2	49.0-54.1	2.1	49.4(45.6-53.4)	2.4
Pre-gill opening length	58.5	60.9	59.4	59.6	58.5-60.9	1.0	63.1 (58.3-67.7)	3.0
Pre-preopercular length	28.5	27.9	30.0	28.8	27.9-30.0	0.9	28.3 (27.4-29.5)	0.7
Upper-jaw length	20.8	19.6	20.9	20.4	19.6-20.9	0.6	20.7 (19.3-22.1)	0.9
Illicial length	2.1	2.2	2.4	2.2	2.1-2.4	0.1	1.9 (1.5-2.2)	0.3
Illicial trough length	5.5	5.7	5.4	5.5	5.4-5.7	0.1	4.1 (3.6-5.3)	0.6
Eye diameter	6.9	8.5	7.9	7.8	6.9-8.5	0.6	7.8 (6.8-8.7)	0.7
Post-dorsal fin length	15.6	16.6	18.7	16.9	15.6-18.7	1.3	16.9 (15.0-18.7)	1.4
Post-anus length	30.3	28.5	31.2	30.0	28.5-31.2	1.2	29.1 (26.5-31.8)	1.9
Post-anal length	15.2	14.7	15.1	15.0	14.7-15.2	0.2	14.3 (13.0-15.3)	0.7
Caudal peduncle depth	8.3	7.8	8.4	8.2	7.8-8.4	0.2	8.8 (7.4-9.5)	0.6
Caudal fin length	30.3	29.7	32.8	30.9	29.7-32.8	1.3	30.2 (27.5-32.2)	1.7
Meristics								
Dorsal fin rays	12	12	12		12		11-12	
Pectoral fin rays	13	13	13		13		11-13	
Anal fin rays	7	7	7		7		6-7	
Gill rakers								
GR i	12	13	13		13		13-14	
GR ii	9	9	9		9		8-10	
GR iii	10	10	9		10		8-11	
GR iv	7	7	7		7		7-8	
Neuromasts (*counted on both sides*)								
AB	10;11	11;11	11:11		10-11		10-12	
AC	8;8	7;8	8;8		7-8		8:8	
BD	2;2	2;2	2;2		2-3		2:3	
CD	7;7	6;7	7;7		6-7		6:7	
DG	3;3	3;3	3;3		3-5		3:4	
EF	6;6	6;6	6;6		6-6		3:5	
FG	3;3	3;3	3;3		3-3		3:4	
GH	11;11	10;11	11;11		11-13		10:13	
BB’	4;4	5;5	4;4		4-5		4:5	
BI	35;35	34;35	34;35		36-37		35:40	

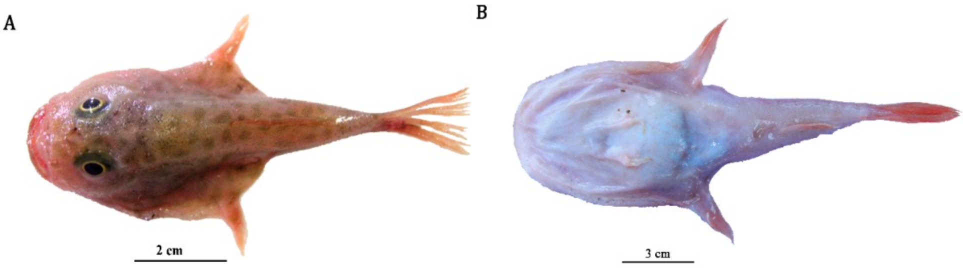

Figure 3.8. *Chaunax multilepis*, A—dorsal view, B—ventral view
New species described, Holotype—CMLRE 2923417A, 130 mm SL, 13.26° N, 93.17° E; off North Andaman, 295−323 m, also present in Arabian Sea and Bay of Bengal

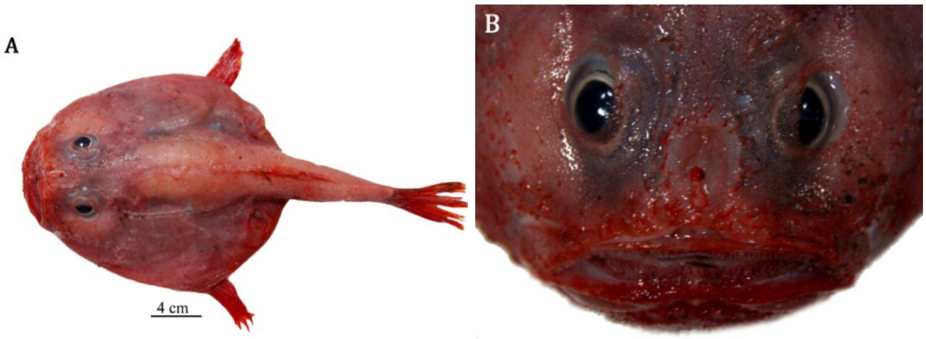

Figure 3.9. *Chaunax* sp. A, A—dorsal view, B—enlarged view of head showing illicium
New species, Material—CMLRE 30501, 196 mm SL, 8.28° N, 76.20° E; 1050-1100 m, Arabian Sea

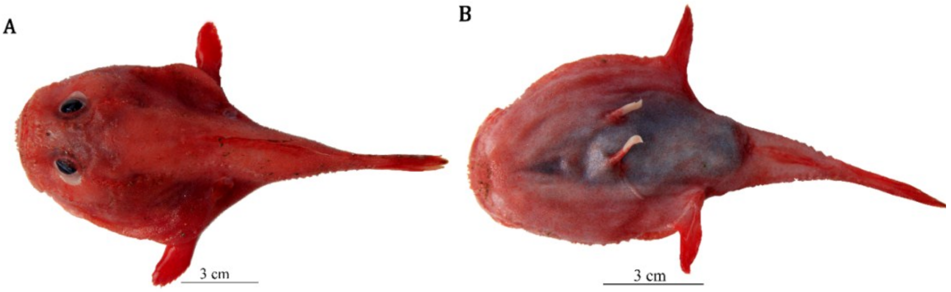

Figure 3.10. *Chaunax apus* (34902A) A—dorsal view, B—ventral view
New record from Arabian Sea and Andaman Sea, 650 m depth. This is one of the oldest nominal species of *Chaunax*

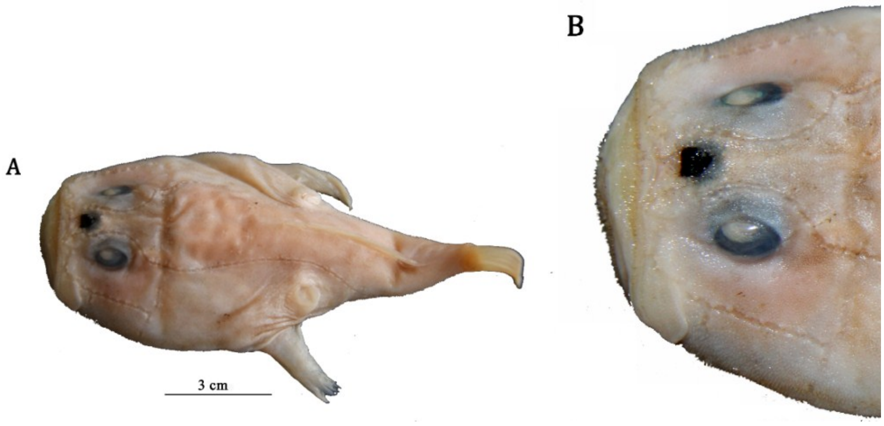

Figure 3.11. *Chaunax penicillatus* (2803730). A—dorsal view, B—enlarged view of head showing illicium.
New record from Andaman Sea, 321 m depth, only member in the *Chaunax pictus* group that occurs outside the Atlantic Ocean

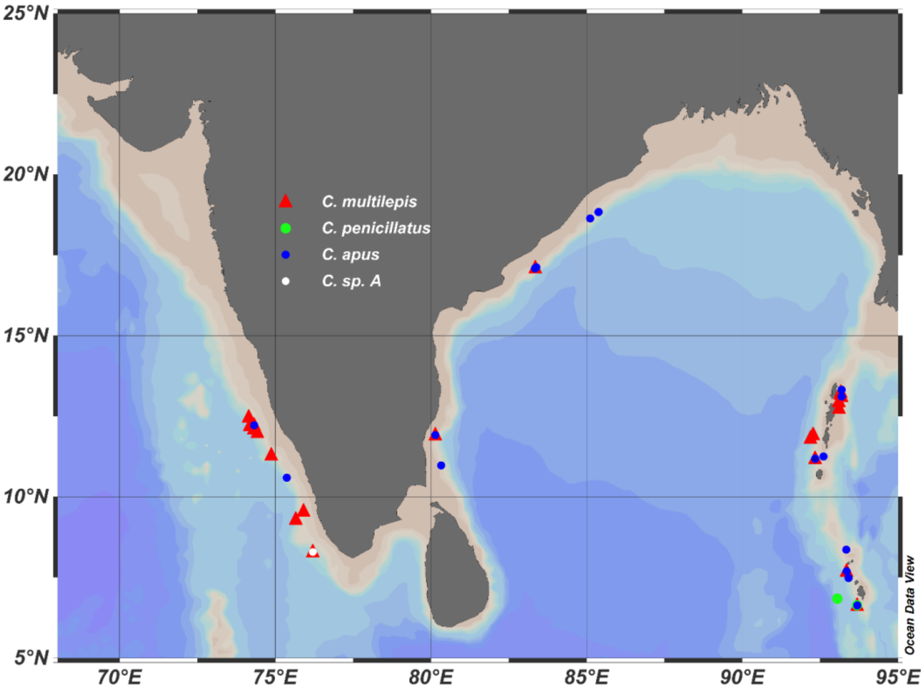

Figure 3.12. Map showing distribution of Family Chaunacidae in the Indian EEZ Species—*Chaunax multilepis*; *Chaunax penicillatus; Chaunax apus* and *Chaunax* sp. A (new species)

iii. Suborder—OGCOCEPHALOIDEI

Family—OGCOCEPHALIDAE Gill, 1893

Bat fishes

Diagnosis—The members of family Ogcocephalidae of Order Lophiiformes are generally termed as Bat fishes. They are marine bottom-dwellers that feed on small invertebrates and fishes, characterized by large head, triangular or circular in outline, forming a disc. Strongly depressed body disc, triangular, sub-triangular or rounded in dorsal view (except box-like in the genus *Coelophrys*); tail tapering; scales are modified to form conical tubercles, minute prickles to large strong spiny structure; first dorsal fin spine is modified to form a short illicium placed within a cavity just above the mouth; fleshy escal bub usually present at tip of the illicium; dorsal margin of the illicial cavity possess a rostrum, it may be long in some genera; second spine is highly reduced. Mouth sub-terminal, in front of body disk. Jaw teeth minute, palatines and vomer with or without teeth. Pectoral fins are leg like, attached to the latero-posterior edges of the disc, usually with 10-19 rays; pelvic fins are present on the ventral surface of the disk, anterior to pectoral fins usually with 1 spine and 4 rays; dorsal fin-rays 2-7 (totally absent in *Halicmetus ruber*); anal fin rays 3-4.

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.

Halieutopsis Garman, 1899

Diagnosis—Head moderately to greatly depressed, no teeth on palate, two or more lateral line scales with neuromasts on either side of anus, the illicial bone relatively simple and spine like; its base not perforated by foramina; no teeth on vomer and palatine; teeth on tongue not forming two large patches; gills two. 3 species of *Halieutopsis* were encountered during the study, among them, two species is new to science and 1 is new record from the area. Distribution of *Halieutopsis* spp. from Indian EEZ explained in the Figure 3.16.

Halieutopsis stellifera (Smith and Radcliffe, in Radcliffe, 1912)

Figs. 3.13. A—B; Table 3.14
Synonyms—*Dibranchus stellifer* Smith and Radcliffe, 1912

Holotype—USNM 70273, 71.2 mm SL, 05°36' S, 120° 49' E, Flores Sea off coast of Celebes, Indonesia, Albatross station 5660, 1266 m.

Material examined—2928922 A, B and C, 51, 55, 56 mm SL respectively, 7.53° N, 93.25° E, 480-580 m., HSDT CV, December 2011; 31601, 50 mm SL, 8.3° N, 76.2° E, 1337 m., DSDT CV, July 2017 (Specimen Damaged).

Diagnosis—A species of *Halieutopsis* with wide inter-orbital distance, tubercles present on ventral surface of disk, three lateral-line scales on pre-opercular series.

Description—Head not as broad as long, elliptical, disk depressed; moderately arched. Mouth moderate, jaws comparatively long, narrow and delicate; narrow bands of villiform teeth on jaws; palate and tongue without any teeth. Nostrils large; inter-orbital space broad and flat; rostrum scarcely projecting beyond the jaws; illicium ending in two large globular lobes and a narrow bifurcated lobe; illicial cavity having a well-marked dorsal median notch. Skin translucent especially on belly portion. Dorsal surface covered with stellate tubercles; usually having six facets, each consists of one weak spine; those on lateral margin of the disk comparatively strong and bifid. Ventral surface of the disk and tail covered with tubercles; but the spine on ventral surface of the disk is minute. Sub-opercular spines slightly developed.

Fins moderately sized, weak; fin membranes and rays are delicate. Origin of dorsal fin just above anal opening. Dorsal fin with six rays; pelvic fin with five; pectoral with fifteen; pectoral fin reaching upto the origin of caudal fin. Anal fin with four rays; its insertion under or slightly behind posterior base of dorsal; caudal fin with nine soft rays.

Colour in life—Dorsal surface of the body uniform yellowish brown; all fins are dark brown.

Colour on preservation—In preserved specimens dorsal surface of the body uniform dark brown in one specimen and moderately dark brown in the other two specimens. All the fins are dark brown.

Distribution—Andaman Sea (New record– present study) at depth of 480-580 m. Madagascar; Indonesia to Philippines, north to southern Japan, south to New Caledonia at depth of 410-1372 m.

Table 3.14. Morphometric and meristic data of *Halieutopsis stellifera* compared with previous study

Measurements	**292 89 22A**	**292 89 22B**	**292 89 22C**	**Mean**		**Range (Bradbury 1988)**
Standard Length (mm)	51	55	56			
In % of SL						
skull length	32.4	34.2	31.6	32.7	327	247-358
Head depth	25.3	19.5	18.2	21.0	210	
Orbital diameter	9.9	12.2	11.3	11.1	111	105-154
Interorbital width	17.8	17.0	16.9	17.2	172	140-192
Mouth width	30.1	28.7	24.4	27.7	277	228-280
Jaw length	14.5	27.7	15.9	19.4	194	156-208
Illicial cavity width	13.1	13.2	12.1	12.8	128	
Pre-dorsal length	71.1	68.5	65.6	68.4	684	661-767
Post-anus length	70.2	67.3	69.3	68.9	689	594-696
Pre-anal length	76.3	74.2	73.4	74.6	746	717-774
Disk margin length	43.5	45.6	47.1	45.4	454	415-479
Pectoral fin length	32.5	28.2	27.2	29.3	293	280-347
Pelvic fin length	19.7	15.5	19.0	18.1	181	-
Anal fin length	21.7	22.3	19.2	21.1	211	-
Dorsal fin length	22.9	22.7	23.0	22.9	229	-
Caudal fin length	30.8	32.4	31.5	31.6	316	-
Neuromasts counts						
Supra-orbital series	6	8	6			6-8
Body series	9	10	9			9-10
Pre-opercular series	3	3	3			3-4
Sub-opercular series	5	5	6			5-6
Tail series	10	10	11			11-14

***Halieutopsis* sp.** A

Figs. 3.14. A—B, Table 3.15

New species

Common name—Indian black batfish

Material examined—CMLRE 36603, 125 mm SL, 8.36° N, 76.24° E, Arabian Sea, 934 m. HSDT, October 2017.

Diagnosis—A species under *Halieutopsis* with uniform deep black, simple spine on dorsal and ventral surfaces; sub-opercle with complex spines; pectoral and caudal fin lengths almost equal.

Description—Body depressed; disk subtriangular, broader, skull slightly elevated from disk surface, rostrum broad, anterior part of the rostrum slightly projects from the margin of the disk and overhanging on mouth. Illicial cavity broad on anterior surface of head, between olfactory sacs. Its width is almost equal to the inter-orbital width. Illicial cavity fully visible from ventral view. Eye small, oval in shape. Esca moderately large, depth greater than width, with two spherical ventral lobes and a median leaf like dorsal lobe, anterior margin of the median dorsal lobe with 2 small cirri. Mouth large, terminal; minute villiform teeth on both jaws, no teeth on palate and tongue; teeth present on V^{th} ceratobanchial; gill filaments present on second and third branchial arches; pectoral fin length is almost equal to caudal fin length; pectoral-fin lobe attached to body.

Dorsal surface covered with numerous simple spines (small and large spinules) with star shaped bases (Fig. 3.14. C); ventral surface also covered with numerous spines, but minute compared to dorsal surface. Eye membrane also covered with minute spines. Gill cavity devoid of spines.

Esca trilobed, with well developed, rounded two ventral lobes and a flap like median lobe with two cirri on tip; illicial cavity, esca and cirri completely black. Disc margin, lateral line associated neuromasts and tail having slightly larger spine with bifurcation; subopercle forked and divided into 5 spines (Fig. 3.14. D); no cirri on either lateral margin of the body or tail; buccal cavity and peritoneum black.

Colour—Entire body is uniform deep black including all the fins.

Distribution—Known from only collection locality, Arabian Sea at a depth of 934 m.

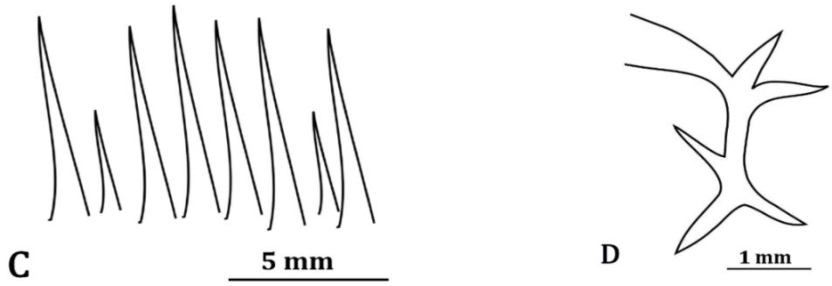

Figure 3.14. C—D. Dorsal spinule pattern (C), subopercle spine (D) of *Halieutopsis* sp. A

Table 3.15. Morphometric and meristic data of *Halieutopsis* sp. A

Morphometric	36603
Standard Length (mm)	125
% SL (mm)	
Head length	37.6
Eye diameter	6.4
Orbital diameter	13.6
Inter orbital width	12
Rostrum length	8.8
Rostrum width	9.6
Disc margin length	41.6
Illicial cavity width	10.4
Illicial cavity depth	7.2
Pre dorsal length	64.8
Pre anal length	69.6
Upper jaw length	11.2
Lower jaw length	12
Mouth width	20
Lower jaw to anus	52
Pectoral fin length	27.2
Pelvic fin length	22.4
Caudal fin length	26.4
Body width	17.6
Body depth	12.8
Caudal peduncle length	21.6
Caudal peduncle depth	6
Meristics	
Dorsal fin rays	6
Pectoral fin rays	14
Anal fin rays	4
Pelvic fin rays	6
Caudal fin rays	8
Neromasts counts	
Preopercle	5
Subopercle	12
Cheeck	3
Ventral	3
Tail	12

Halieutopsis sp. B

Figs. 3.15. A—B, Table 3.16

New species

Indian red bat fish

Material examined—36715A, 90 mm SL; 36715B, 72 mm SL, 11.8° N, 92.1° E; 646 m; 36708, 70 mm SL, 13.3° N, 93.3° E, 635 m, Andaman Sea, HSDT CV, November 2017

Diagnosis—A species under *Halieutopsis* with uniform red colour all over the body; spinules on the dorsal body serrated tip with star shaped bases; well-developed suopercular buckler with complex spines.

Description—Body depressed; disk subtriangular, broader than long, skull slightly elevated from disk surface, rostrum broad, anterior part of the rostrum slightly projects from the margin of the disk and overhanging on mouth; dorsal surface with both large and small spinules, tips are serrated; ventral surface also with same pattern of spinules but are small (Fig. 3.15. C); llicial cavity broad on anterior surface of head, between olfactory sacs, its width is almost equal to its length; illicial cavity fully visible from ventral view, eyes small, oval in shape, illicium slender, esca trilobed, with two spherical ventral lobes and a median dorsal lobe, median dorsal lobe without any cirri; mouth large, terminal; minute villiform teeth on both jaws; vomer absent; teeth present on tongue (small rounded patches), teeth present on Vth ceratobanchial; gill filaments present on second and third branchial arches; pectoral fin length is almost equal to caudal fin length; pectoral-fin lobe attached to body;

subopercular buckler well developed with complex spine, 8 or 9 spines directed randomly (Fig. 3.15. D).

Colour in fresh—Uniform red colour all over the body including ventral surface; all the fins are bright red.

Colour in preservative—Creamy white including the fins.

Remarks—Present specimen can easily be distinguished from *Halieutopsis* sp. A by its unique red colour all over the body (vs deep back colour); serrated spinules on body (vs simple spinules)

Distribution—Known from collection locality only, Andaman Sea at depths of 635 and 646 m.

Figure 3.15. **C—D**. Dorsal spinule pattern (C), subopercle spine (D) of *Halieutopsis* sp. B

Table 3.16. Morphometric and meristic data of *Halieutopsis* sp. B.

Measurements	36715A	36715B	36708	Range	Mean	SD
SL (mm)	90	72	70			
% SL						
Predorsal length	62.2	66.7	65.7	62.2-66.7	65	2.3
Preanal length	75.6	70.8	72.9	70.8-75.6	73	2.4
Head length	31.1	34.7	32.9	31.1-35.7	33	1.8
Disk length	33.3	35.4	35.7	33.3-35.7	35	1.3
Body width	16.7	18.1	17.1	16.7-18.1	17	0.7
Body depth	12.8	13.2	12.9	12.8-13.2	13	0.2
Eye diameter	6.7	6.9	7.1	6.7-7.1	7	0.2
Orbit diameter	10.0	10.4	10.0	10.0-10.4	10	0.2
Interorbital width	11.1	12.5	10.0	10.0-12.5	11	1.3
Mouth width	24.4	27.8	22.9	22.9-27.8	25	2.5
Upper jaw length	15.0	14.0	17.1	14.0-17.1	15	1.6
Illicial cavity width	7.2	6.9	7.1	6.9-7.2	7	0.1
Illicial cavity depth	5.6	5.6	7.1	5.6-7.1	6	0.9
Rostrum length	11.1	11.1	11.4	11.1-11.4	11	0.2
Rostrum width	8.9	9.7	6.4	6.4-9.7	8	1.7
Pectoral fin length	23.9	23.6	22.9	22.9-23.9	23	0.5
Pelvic fin length	15.6	13.9	17.1	13.9-17.1	16	1.6
Caudal fin length	24.4	27.8	27.1	24.4-27.8	26	1.8
Caudal peduncle length	17.8	18.1	19.3	17.8-19.3	18	0.8
Caudal peduncle depth	5.6	5.6	7.1	5.6-7.1	6	0.9
Meristics						
Dorsal fin rays	6	6	5			
Pectoral fin rays	14	14	15			
Pelvic fin rays	6	6	6			
Anal fin rays	4	4	4			
Caudal fin rays	8	8	8			
Neuromasts counts (both sides)						
Pre-opercle	4;4	4;4	3;4			
Sub-opercle	4;4	4;4	4;4			
Dorsolateral branch of sub- opercle	2;2	2;2	2;2			
Ventral	3;3	2;2	3;3			
Tail	11;12	10;11	14;14			

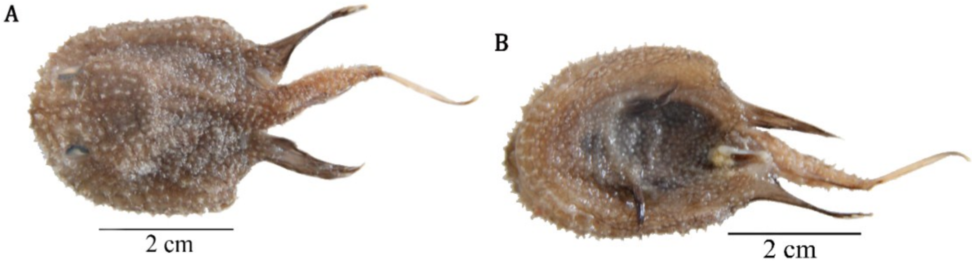

Figure 3.13. *Halieutopsis stellifera* (2928922 A), A—dorsal view, B—ventral view
New record from Andaman Sea, 580 m depth

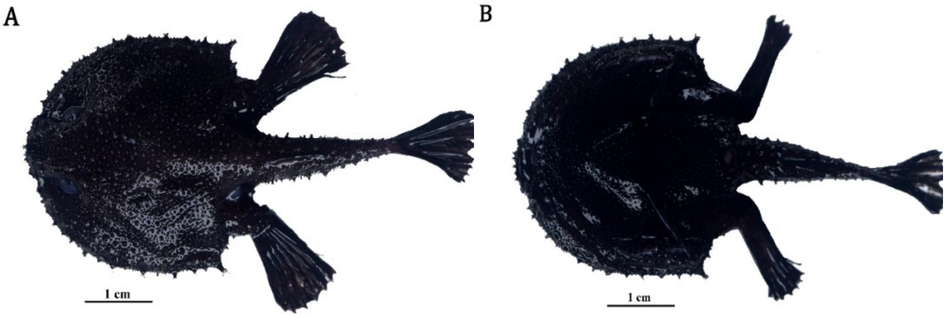

Figure 3.14. *Halieutopsis* sp. A, A—dorsal view, B—ventral view
New species, common name—Indian black batfish, Material—CMLRE 36603, 125 mm SL, 8.36° N, 76.24° E, Arabian Sea, 934 m.

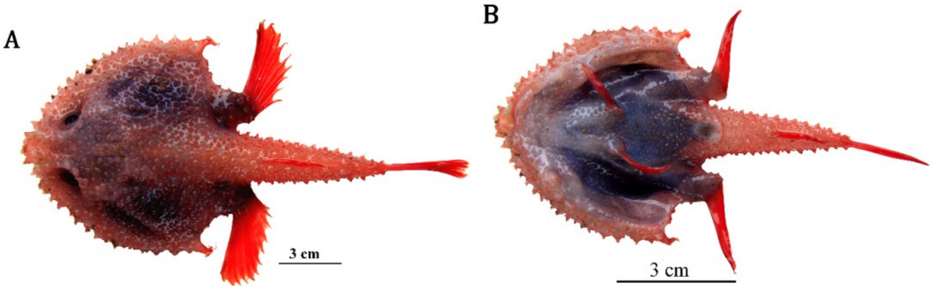

Figure 3.15. *Halieutopsis* sp B, A—dorsal view, B—ventral view
New species, common name— Indian red bat fish, Material—36715A, 90 mm SL; 11.8° N, 92.1° E, Andaman Sea, 646 m.

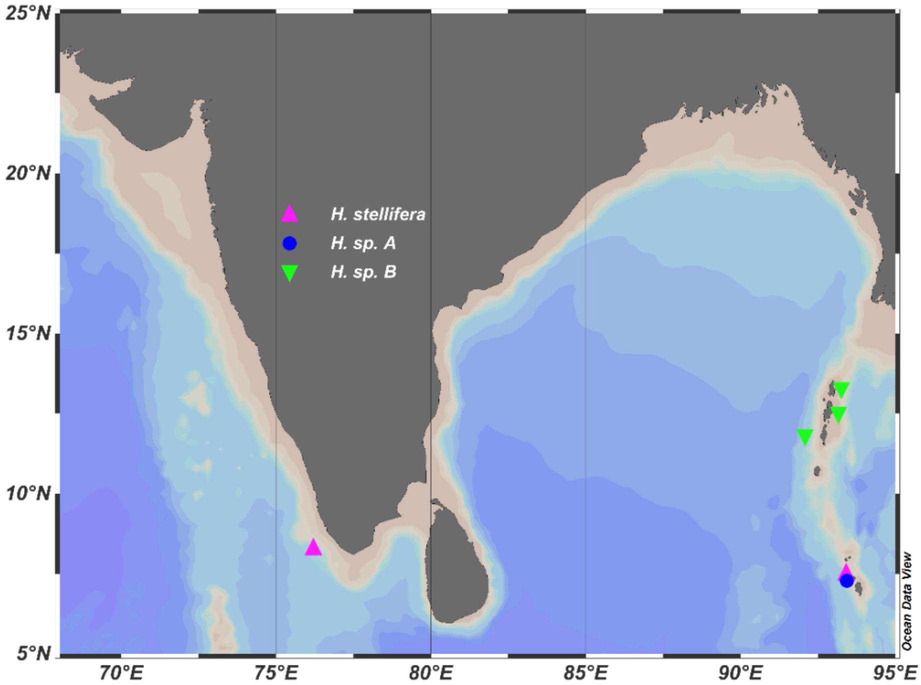

Figure 3.16. Map showing distribution of *Halieutopsis* spp. in the Indian EEZ Species—*Halieutopsis stellifera; Halieutopsis* sp. A and *Halieutopsis* sp. B

Halieutaea Valenciennes, 1837

Diagnosis-Head relatively or strongly compressed; disk margin is rounded in dorsal view; rostrum may or may not project over the disk; generally trilobed esca; dorsal surface covered with principle tubercles, these are needle like or stout; in between the principle tubercle tiny spinules may or may not be present; ventral surface covered with granules, small stout spines or naked; teeth on tongue forming two patches, each has an elongated inner projection; body with uniform pinkish to reddish colour when fresh, with or without black pattern or spots of various arrangement on dorsal surface; black bands either present or absent on the fins. Currently comprise 9 valid species and 4 species from India including one new species (Fig. 3.21).

***Halieutaea* sp. A**

Figs.3.17 A, Table 3.17

New species

Indian spiny batfish

Material examined—2881736, 118 mm SL, Arabian Sea, 9.99° N, 75.60° E, 150-200 m., HSDT, October 2011.

Diagnosis—Dorsal fin rays 5; pectoral fin rays 14; caudal fin rays 9; anal fin rays 4. Well developed strong spines on the dorsal body, peculiar arrangement of black patches on the dorsal surface, small eyes, peritoneum white.

Description—Cephalic disk circular; head relatively elevated from body anteriorly; rostrum not projecting over front of disk, esca visible from dorsal view; trilobed, ventral lobes having cirri on the distal end. Dorsal surface possess needle like well-developed, long spines (dorsal spinules), naked area between the spines (Fig. 3.17. B); ventral surface covered with minute spines widely distributed (low number); noticeably small eye (8.8 5% SL); lateral line associated spines are bifid, trifid and multifid, also well prominent. Teeth on tongue forming two small patches, each has an anterior and posterior pointed ends (Fig.3.17. C); both jaws having minute teeth; inter-orbital slightly concave.

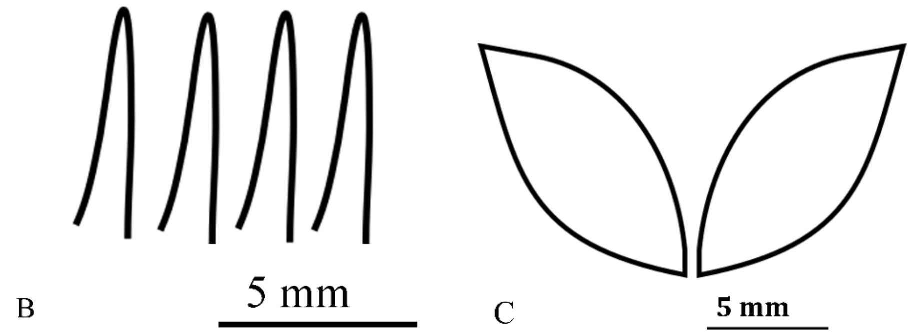

Figure 3.17. B—C. Pattern of dorsal spinule (B) and teeth pattern on tongue (C) of *Halieutaea* sp. A

Colour in fresh—Dorsal surface having rosy colour with small black patches; all the fins having pale red colour with black band on tips; anterior margin of the caudal fin also having a black band; dorsal and anal fin completely black.

Colour in preservative—After preservation dorsal surface retains black patches, arranged symmetrically; all the fins are pale with black edge except pelvic fins.

New species differs from its congeners having combination of following characters such as, well developed, long, strong, relatively thickly placed spines on the dorsal surface; dorsal body having rosy colour with small black patches; all the fins except dorsal and anal having pale red colour with black band on tips; anterior margin of the caudal fin also having a black band; dorsal and anal fin completely black.

Table 3.17. Morphometric and meristic data of *Halieutaea* sp. A

Measurements	2881736
SL (mm)	91
% SL	
Head length	59.3
Eye diameter	8.8
Interorbital space	12.1
Intersphenotic length	11.0
Rostrum length	14.3
Disc margin length	50.5
Illicial cavity length	5.5
Mouth width	37.4
Upper jaw length	22.0
Lower jaw length	20.9
Pre-dorsal	78.0
Pre-anal	80.2
Lower lip to anus	63.7
Anus to caudal fin base	36.3
Pectoral fin length	26.4
Caudal fin length	27.5
Caudal peduncle depth	7.7
Gill opening length	5.5
Meristics	
Dorsal	5
Pectoral fin rays	14
Anal fin rays	4
Caudal fin rays	9
Neuromasts counts	
Pre-opercular	4
Sub-opercular	8
Tail series	9

Halieutaea stellata **(Vahl, 1797)**

Figs. 3.18. A—B, Table 3.18

Minipizza batfish

Synonyms—*Lophius stellatus* Vahl, 1797; *Halieutaea maoria* Powell, 1937.

No type known, original from China

Material Examine**d**—34910, 140 mm SL, 11.18° N, 92.34° E, 520 m. HSDT-CV, April 2016; 349 01B, 102 mm SL, 12.48 N, 92.39 E, 576 m, HSDT CV, April 2016; 349 06, 118 mm SL, 12.74° N, 93.10° E, 332 m, HSDT CV, April 2016; 34907, 125 mm SL, 13.2° N, 93.2° E, Andaman Sea, 332 m., HSDT CV, April 2016; 317 01, (2) 98, 103 mm SL, 9.6° N, 76.0° E, Arabian Sea, 200 m., HSDT CV, July 2013.

Diagnosis—Dorsal fin rays 5-6; pectoral fin rays 14; caudal fin rays 9 and anal fin rays 4. Dorsal surface having simple major spines and minute spinules giving a velvet appearance; ventral surface with widely distributed spines, peritoneum black.

Description—Head relatively elevated from body anteriorly; rostrum not projecting over front of disk, esca trilobed, visible from dorsal view; with lots of cirri on the distal margin of the ventral lobes. Dorsal surface covered with needle-like principal tubercles; tiny, simple (without any bifurcation) spinules present everywhere on body surface forming a velvet skin between those principal tubercles; Ventral surface also covered with spine having star shaped base, but widely distributed, between the spines naked space. Bifid and multifid spines are present along the margin of the disk, lateral line system and tail. Teeth on tongue forming two large patches, each has a outer pointed prolongation (Fig. 3.18. C). Inter-orbital space slightly concave.

Colour—Body uniformly pinkish to reddish in colour when fresh with black symmetrical lineate pattern on dorsal surface, all fins with black edge or not.

Colour in preservative—Both dorsal and ventral with pale colour; symmetric black pattern on dorsal surface. Ventral also pale. Caudal fin with a black stripe on the distal end.

Distribution—Bay of Bengal, Arabian Sea at depth ranging 68-200 m. (Alcock 1899). Andaman Sea (present study- new record) 332 -576 m. Widespread in the western Pacific off Japan, Taiwan, South China Sea, the Philippines, Indonesia, New Caledonia, Australia and north New Zealand. Depth 95-474 m (Ho and Shao 2008).

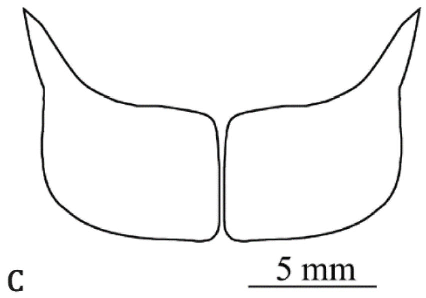

Figure. 3.18. C. Teeth pattern of *Halieutaea stellata*

Table 3.18. Morphometric and Meristic data of *Halieutaea stellata*

Measurements	**34910**	**34901B**	**34906**	**Mean**	**Range**	**SD**
SL (mm)	140	102	118		102-140	11.0
% SL						
Head length	57.1	52	53.6	54.2	52-57.1	2.6
Eye diameter	7.9	9.8	10.2	9.3	7.9-10.2	1.2
Interorbital space	10.7	13.7	11.9	12.1	10.7-11.9	1.5
Intersphenotic length	8.6	12.7	8.5	9.9	8.5-12.7	2.4
Rostrum length	12.1	14.7	6.8	11.2	6.8-14.7	4.0
Disc margin length	43.6	59.8	50.0	51.1	43.6-59.8	8.2
Illicial cavity length	7.1	9.8	8.5	8.5	7.1-9.8	1.3
Mouth width	31.4	40.2	38.1	36.6	31.4-40.2	4.6
Upper jaw length	20.0	24.5	24.6	23.0	20-24.6	2.6
Lower jaw length	18.6	23.5	22.9	21.7	18.6-23.5	2.7
Pre-dorsal	62.9	77.5	72.9	71.1	62.9-77.5	7.5
Pre-anal	62.1	78.4	78.8	73.1	62.1-78.8	9.5
Lower lip to anus	54.3	67.6	66.9	63.0	54.3-67.6	7.5
Anus to caudal peduncle	45.7	32.4	34.7	37.6	32.4-45.7	7.1
Pectoral fin length	20.7	22.5	21.2	21.5	20.7-22.5	1.0
Caudal fin length	22.1	25.0	27.1	24.8	22.1-27.1	1.4
Caudal peduncle depth	6.4	8.8	7.6	7.6	6.4-8.8	1.2
Gill opening length	6.4	4.9	6.8	6.0	4.9-6.8	1.0
Meristics						
Dorsal fin rays	6	5	5			
Pectoral fin rays	14	14	14			
Anal fin rays	4	4	4			
Caudal fin rays	9	9	9			
Neuromasts counts						
Pre-opercular	3	3	4			
Sub-opercular	8	9	8			
Tail series	9	10	9			

Halieutaea coccinea Alcock, 1889

Figs. 3.19. A—B, Table 3.19

Scarlet seabat

Holotype—ZSI F11741, Andaman Sea, Investigator station 13, 484 m. (Alcock 1899)

Material Examined—Holotype, ZSI, F 11741, Andaman Sea, 338-465 m; 34901A, 112 mm SL, 12.5° N, 92.4° E, Andaman Sea, 576 m. HOT, April 2016; 33401 B, 154 mm SL, 33401C, 117 mm SL, 10.99° N, 92.27° E, Andaman Sea, 363 m, HOT, January 2015; 34905, 6 specimens 5.5-6.5 mm SL, 12.5° N, 93.2° E, Andaman Sea, 300 m, HSDT CV, October 2016; 30501, 130 mm SL, 8.31° N, 76.16° E, Arabian Sea, 1075 m; 288 09, 94 mm SL, 11.99° N, 74.42° E, Arabian Sea, 200 m., August 2011; 29106, 96 mm SL, 18.9° N, 85.4° E, Bay of Bengal, 500 m, HSDT CV, October 2011.

Diagnosis—Dorsal fin rays 5; pectoral fin rays 13-14; anal fin rays 4; caudal fin rays 9. Dorsal surface with simple spines; thickly packed stellate spine on the ventral surface, peritoneum black.

Description—Head distinctly elevated from body anteriorly; rostrum not projecting over front of disk, esca trilobed, visible from dorsal view, cirri on the distal margin of the ventral lobes; dorsal surface covered with needle-like simple principal tubercles, without any bifurcation; tiny spinules present everywhere on body having star shaped bases. Teeth on tongue forming two large patches, each has a outer pointed prolongation (like *H. stellata* Fig. 3.18. C), both jaws having minute villiform teeth. Bifid and multifid spines are present along the margin of the disk, lateral line system and tail. Interorbital space slightly concave. Black band on the caudal fin edge. 2nd, 3rd gill arches having filaments, 4th hemibranch.

Colour—Body uniformly light reddish in colour when fresh with black symmetrical lineate pattern on dorsal surface, all fins with black edge or not.

Colour in preservative—Both dorsal and ventral with pale colour; symmetric black pattern on dorsal surface. Some specimen retains a black stripe on the distal end of caudal fin.

Halieutaea coccinea differ from *H. stellate* in having thickly packed well developed stellate spine on the ventral surface, ventral surface completely covered with small spinules with star shaped bases, feels rough on touch.

Distribution—Arabian Sea, 1075 m. (present study- greater depth), Bay of Bengal (present study- new record) and Andaman Sea, (363 m). South Africa, Madagascar, Indonesia and Australia (Ho and Shao 2008).

Table 3.19. Morphometric and Meristic data of *Halieutaea coccinea*

Measurements	**349 01A**	**334 01B**	**334 01C**	**305 01**	**Mean**	**Range**	**SD**
Standard Length (mm)	112	154	117	130		112-154	18.8
% of SL							
Head length	53.1	62.5	55.6	59.2	57.6	53.1-62.5	4.1
Eye diameter	8.9	7.8	11.1	9.2	9.3	7.8-11.1	1.4
Interorbital space	13.4	13.6	12.8	13.1	13.2	12.8-13.6	0.4
Intersphenotic length	9.8	8.4	12.0	11.5	10.4	8.4-11.5	1.6
Rostrum length	15.2	13.0	12.8	12.3	13.3	12.3-15.2	1.3
Disc margin length	56.3	49.4	52.7	53.8	53.0	49.4-56.3	2.9
Illicial cavity length	8.9	12.3	8.5	8.5	9.6	8.4-12.3	1.9
Mouth width	39.3	35.1	37.2	39.2	37.7	35.1-39.3	2.0
Upper jaw length	25.0	22.1	24.8	23.8	23.9	22.1-25	1.3
Lower jaw length	23.2	23.4	22.2	22.3	22.8	22.2-23.4	0.6
Pre-dorsal	75.9	77.9	73.5	76.9	76.1	73.5-77.9	1.9
Pre-anal	82.1	79.9	81.2	90.8	83.5	79.9-90.8	4.9
Lower lip to anus	70.5	68.2	66.7	70.0	68.8	66.7-70.5	1.8
Anus to caudal fin base	29.5	32.5	33.3	30.0	31.3	29.5-33.3	1.9
Pectoral fin length	22.3	20.2	23.1	24.6	22.6	20.2-24.6	1.8
Caudal fin length	27.7	26.7	27.4	26.2	27.0	26.2-27.7	0.7
Caudal peduncle depth	8.9	5.8	8.9	7.7	9.2	5.8-8.9	3.7
Gill opening length	6.3	13.6	12.0	8.5	10.1	6.3-13.6	3.3
Meristics							
Dorsal fin rays	5	5	5	5		5	
Pectoral fin rays	14	13	13	13		13-14	
Anal fin rays	4	4	4	4		4	
Caudal fin rays	9	9	9	9		9	
Neuromasts counts							
Pre-opercular	5	4	5	5		4-5	
Sub-opercular	8	8	9	8		8-9	
Tail series	11	10	11	11		10-11	

Halieutaea indica Annandale and Jenkins, 1910

Figs. 3.20. A—B, Table 3.20

Indian handfish

Synonyms—*Lophius muricatus* Shaw, 1804; *Lophius faujas* Lacepède, 1798; *Halieutea spicata* Smith, 1965; *Halieutaea spicata* Smith, 1965; *Halieutaea sinica* Tchang and Chang, 1964; *Astrocanthus stellatus* Swainson, 1839.

Syntypes—ZMA 112980 (1), ZSI F2207/1, 4142/1, 4143/1, 4145/1, 2205/1, 2206/1, 3545/1, 4192/1. Bay of Bengal. (Annandale and Jenkins 1910).

Material examined—ZSI, F 2207/ 1; 288 09, 74 mm SL, Arabian Sea, 11.99° N, 74.42° E, 200 m., August 2011.

Diagnosis—Dorsal fin rays 4; pectoral fin rays 14; anal fin rays 4; caudal fin rays 9; rostrum projects over the margin of the disk, esca invisible from dorsal view; relatively long spines on the dorsal surface, most of them are bifid; peritoneum white.

Description—Head compressed, rostrum projects over front of disk so that esca invisible or hardly visible from dorsal view; dorsal surface covered with sharp and slender principal tubercles, no spinules in between the principal tubercles; many of the principal tubercles are bifid (Fig. 3.20. C); ventral surface with minute scattered spines. Teeth on tongue forming two large, long patches, rather than broad, each has a pointed tip on both ends (Fig. 3.20. D), both jaws having minute villiform teeth.

Mostly trifid spines present along the edges of the disk and lateral line system.

Colour—In fresh unknown, according to Annandale dorsal surface having reddish to pink colour with minute black spots which together form lines and recirculated patterns. In preserved specimens uniform creamy colour on both dorsal and ventral surface, dorsal surface retains some black spots.

Halieutaea indica mainly differs from its congeners in the following characters, rostrum projects over the margin of the disk; relatively long spines on the dorsal surface, most of them are bifid; naked area between principal tubercles; white peritoneum.

Remarks—This species represents rediscovery from Indian water after 108 years of its original description by Annandale and Jenkins in 1910.

Distribution—Arabian Sea at a depth of 200 m. (present study-new distributional record). Species were widely distributed in Indo-west Pacific from off South Africa, Madagascar, Seychelles, Western Australia, the Philippines, Indonesia, Taiwan, China and Japan (Ho and Shao 2008)

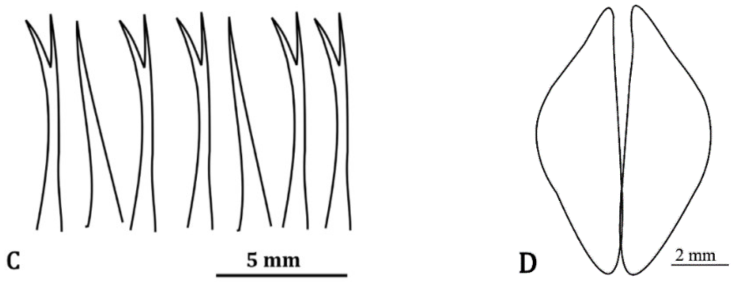

Figure 3.20. C—D. Dorsal spinule pattern (C) and teeth outline (D) of *Halieutaea indica*

Table 3.20. Morphometric and meristic data of *Halieutaea indica*

Measurements	28809
Standard Length (mm)	74
% SL	
Head length	32.4
Head width	18.9
Eye diameter	6.8
Inter-orbital space	9.5
Inter-sphenotic length	25.7
Rostrum length	9.5
Disc margin length	51.4
Illicial cavity length	6.8
Mouth width	32.4
Upper jaw length	18.9
Lower jaw length	17.6
Pre-dorsal	74.3
Pre-anal	81.1
Lower lip to anus	63.5
Post anal	6.8
Anus opening to origin of anal fin	13.5
Anus to caudal peduncle	33.8
Pectoral fin length	28.4
Caudal fin length	31.1
Caudal peduncle depth	8.1
Gill opening length	8.1
Meristics	
Dorsal fin rays	4
Pectoral fin rays	14
Anal fin rays	4
Caudal fin rays	9
Neuromasts (both sides)	
Pre-opercular	4;4
Sub-opercular	7;8
Tail series	5;6

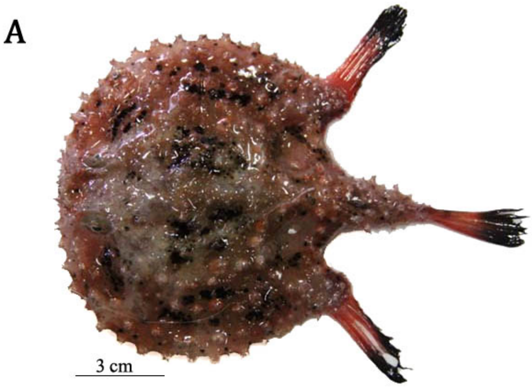

Figure 3.17. *Halieutaea* sp. A, Dorsal view New species, common name—Indian spiny batfish Material—2881736, 118 mm SL, 9.99° N, 75.60° E, Arabian Sea, 150-200 m

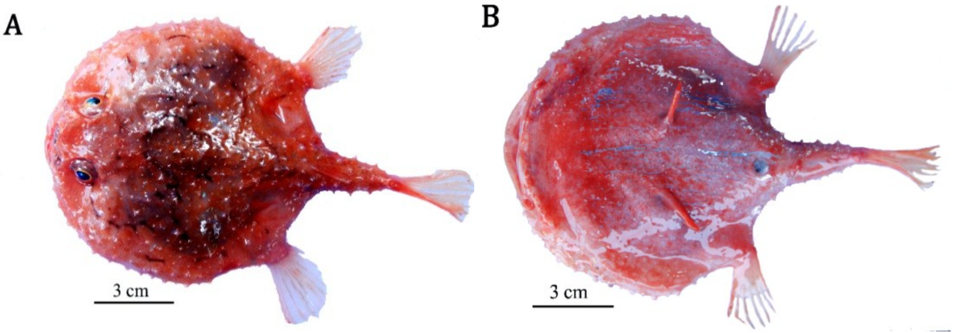

Figure 3.18. *Halieutaea stellate* (34910), A—dorsal view, B—ventral view New record from Andaman Sea, 520 m depth

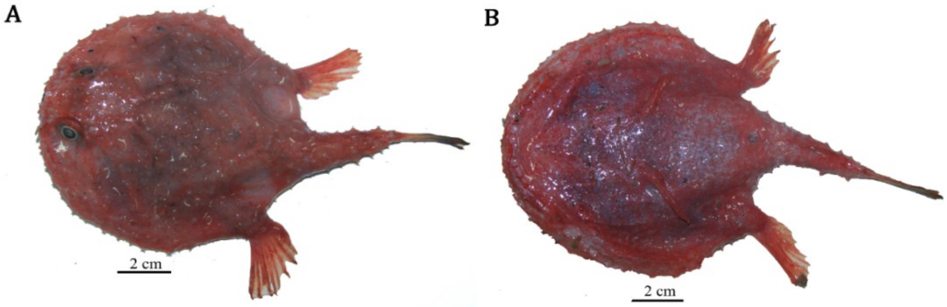

Figure 3.19. *Halieutaea coccinea* (29106), A—dorsal view, B—ventral view New record from Bay of Bengal; specimen collected from Arabian Sea is the deepest known depth (1075 m)

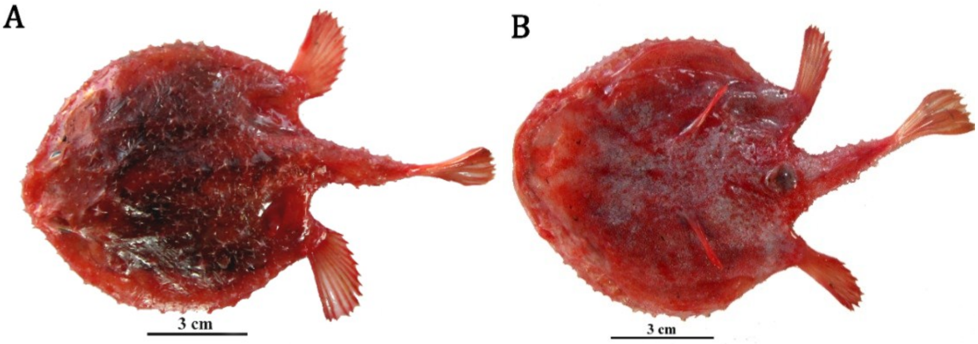

Figure 3.20. *Halieutaea indica* A—dorsal view, B—ventral view Material—288 09, 74 mm SL, Arabian Sea, 11.99° N, 74.42° E, 200 m. The species represents rediscovery from Indian waters after 108 years of its original description by Annandale and Jenkins in 1910

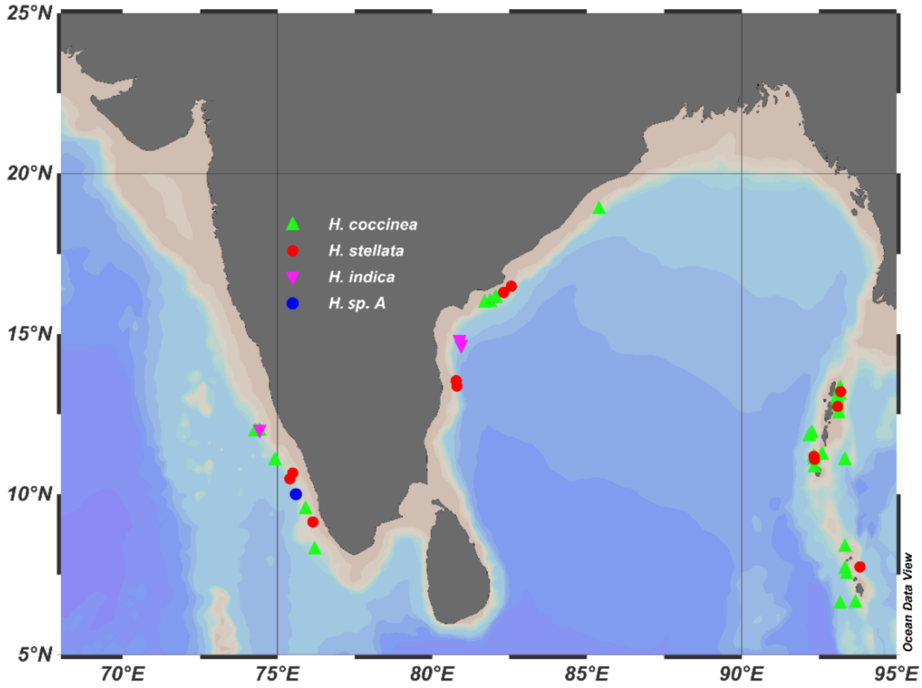

Figure 3.21. Map showing distribution of *Halieutaea* spp. in the Indian EEZ Species—*Halieutaea coccinea; Halieutaea stellate; Halieutaea indica* and *Halieutaea* sp. A

Halicmetus Alcock, 1891

Diagnosis—Body depressed; disk subtriangular; broader than long, dorsal fin present or absent; lower jaw slightly overhanging upper jaw; entire body covered with minute bucklers with simple, bifid or trifid ends; dorsal surface with or without colour pattern; all fins are either with black bands or completely black. Presently genus contains 4 valid species, only 1 species is represented from India (Fig. 3.24).

Halicmetus ruber Alcock, 1891

Figs. 3.22. A—B, Table 3.21

Syntypes—ZSI F13025-26 (2), 11°31'40"N, 92°46'06", Andaman Sea, Investigator station 115, 343-402 m (Alcock 1891).

Material examined—27911A, 97 mm SL, 13.22° N, 80.59° E, Bay of Bengal, 307 m, HSDT CV, August 2010; 32208A, 76 mm SL, 32208 B, 102 mm SL, 8.94° N, 75.46° E, Arabian Sea (SEAS), 1000 m, January 2014; 36603A, 85 mm SL. 36603B, 80 mm SL, 8.36° N, 76.24° E, Arabian Sea, 950 m, October 2017; 2928312 SL-78 mm, Andaman Sea, 6.84° N, 9.05° E, 337 m., HSDT- CV, December 2011.

Diagnosis—A species under *Halicmetus* with absence of dorsal fin; body surface uniformly light pink; single or bifid tubercles present everywhere; relatively small buckler present on dorsal surface especially in the anterior region of the orbit, along the midline and tail; all fins are black; peritoneum black.

Description—Body strongly depressed; skull elevated, disk sub-triangular and truncated anteriorly, disk relatively wide; rostrum not extending beyond mouth; mouth visible from dorsal view. Lower jaw slightly overhanging upper jaw, mouth visible from dorsal view; illicial cavity small, triangular in outline; esca a small flat lobe, trilobed, ventral lobes not well separated; dorsal fin absent; teeth on vomer forming a square patch, palatine teeth forming quadrangular patch (Fig. 3.22. C); two long equal sized teeth on tongue (Fig. 3.22. D). Sub-opercle with multiple spine. Both upper and lower jaw having small villiform teeth band. Body thickly covered with minute, simple spines, which are visible only under microscope. Ventral surface also having minute spines with same size as dorsal. Edges of the disk and lateral line associated neuromasts having multifid spines. Bucklers preset along the orbit, edge of the disk, midline of the body and tail.

Colour—In fresh specimen's dorsal and ventral surface uniformly pale red. All fins are pale pink with black edge.

Colour in preservative—Uniform creamy colour, without any trace of colour, but some specimen (32208, 102 mm SL) retains light red colour. All the fins are white with black edges.

Distribution—Bay of Bengal (Present study- new record) Arabian sea and Andaman Sea (Alcock 1891) at depth ranging from 307 to 1000 m. Indian Ocean at depth 280-1000 m.

Remarks —CMLRE 32208 B specimen have uniform yellow colour, all the fins are same as body colour. More specimens needed to clarify as to whether the specimen is a new sp.

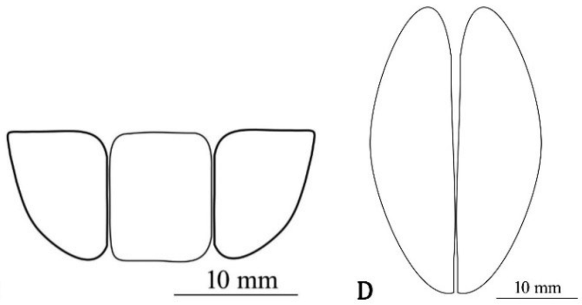

Figure 3.22. C—D. Vomer and palatine teeth (C); Tongue teeth (D) of *Halicmetus ruber*

Table 3.21. Morphometric and meristic data of *Halicmetus ruber* compared with previous study

Morphometric	**279 A**	**292 8312**	**322 08 A**	**322 08 B**	**366 03 A**	**366 03 B**	**Ho *et al.* 2008 Range (mean)**
SL (mm)	97	78	76	102	85	80	49.6 - 71.3
% of SL							
Skull length (SKL)	28.9	28.2	27.9	29.4	27.3	27.5	21.6 - 28.1 (26.7)
Orbital diameter (OD)	8.2	7.7	9.2	8.8	9.4	7.5	8.8 - 10.5 (9.6)
Interorbital width (IO)	5.2	6.4	6.6	6.9	7.1	6.3	5.1 - 6.4 (5.7)
Mouth width (MW)	13.4	14.1	17.1	16.7	15.3	16.3	15.4 - 18.2 (16.6)
Illicial cavity width (ICW)	6.19	6.4	7.9	8.8	8.2	8.8	4.8 - 6.4 (5.5)
Post anus length (PAN)	54.1	51.0	51.0	54.0	52.0	52.1	50.2 - 54.3 (52.2)
Pre-anal length (PAL)	73.0	71.0	75.2	75.7	75.4	75.4	72.4 - 76.0 (74.3)
Disc margin length (DM)	41.2	47.4	46.1	40.2	49.4	43.8	42.9 - 47.4 (44.9)
Pectoral fin length (PF)	15.5	20.5	23.7	21.6	22.4	21.3	16.4 - 22.1 (19.4)
Anal fin length (AF)	13.4	14.1	17.1	15.7	14.1	15.0	12.7 - 17.0 (15.1)
Caudal fin length (CL)	20.6	21	23.6	21.5	23.5	23.2	20.0 - 24.0 (21.6)
Meristics							
Dorsal fin rays	0	0	0	0	0	0	0
Anal fin rays	3	3	3	3	3	3	3-4
Caudal fin rays	9	9	9	9	8	8	-
Pectoral fin rays	12	12	12	12	12	12	12-13
Pelvic fin rays	5	5	5	5	5	5	-
Neuromasts counts							
Premaxillary series	0	0	0	0	0	0	
Cheek series	4	3	4	5	3	3	
Pre-opercular series	2	2	2	2	2	2	
Sub-opercular series	8	8	8	9	5	8	
Dorsolateral branch of sub-opercular series	2	2	2	2	2	2	
Ventral series	1	2	1	2	2	2	
Tail series	11	10	13	13	10	10	

Coelophrys Brauer, 1902

Diagnosis—Head box-like, rostrum flat and broad, slightly overhanging on mouth; pelvic fins greatly reduced in size; illicial cavity large, simple tubercle densely covered all over the dorsal body. Presently genus, *Coelophrys* comprises 7 species; 1 represented from India (Fig. 3.24).

Coelophrys micropa (Alcock, 1891)

Figs. 3.23. A—B Table 3.25

Synonyms—*Coelophrys micropus* (Alcock, 1891); *Dibranchus micropus* Alcock, 1891; *Halieutopsis micropa* (Alcock, 1891); *Dibranchus micropus* Alcock, 1891.

Syntypes—ZSI F13029-30 (2), Bay of Bengal, 15°5 6' 50" N, 81° 30' 30" E, Investigator station 120, depth 438-504 m. (Alcock 1891).

Material examined—Syntypes- ZSI F13029-30 (2). 34901, 66 mm SL, 12.48° N, 92.39° E, 576 m, HSDT CV, April 2016; 34910A & B (62 mm SL, 25 mm SL) 11.18° N, 92.34° E, Andaman Sea, 520 m., HSDT-CV, April 2016; 31601, 93 mm SL, 8.29° N, 76.21° E, 1300–1350 m, Southwest coast of India (Arabian Sea), July 2013; 29115, 75 mm SL 10.62° N, 80.52° E, Bay of Bengal, 650 m, EXPO, November 2011.

Diagnosis—A species under *Coelophrys* with box-like head, relatively long caudal peduncle; greatly reduced pelvic fins; 5 dorsal fin rays; 14-15 pectoral fin rays; 4 anal fin rays.

Description—Head box-like, anterior portion ends in a frontal bridge, forming rostrum which is flat and broad, slightly projecting beyond jaws; body slightly depressed, surface of body flat; pelvic fins greatly reduced in size; illicial cavity large, less than interorbital width; eyes invisible from the dorsal view; esca, with two ventral lobes which are not well separated and a flap like dorsal lobe. Entire skin translucent; dorsal surface thickly covered with numerous simple spinules with star shaped bases; edges of the disk and tail having relatively longer bifurcated spines, ventral surface covered with spinules but much smaller than dorsal; subopercular spine multifid; minute teeth on jaws; no teeth on tongue, vomer and palatines; peritoneum black.

Colour—In fresh uniform blue black, all the fins are much darker than body.

Distribution—Arabian Sea, Bay of Bengal and Andaman Sea (Alcock 1899) at depth of 430-1350 m. Off South Africa, Taiwan, Japan, the Philippines, Madagascar and Australia at depth range of 400-1400 m.

Table 3.25. Morphometric and meristic data of *Coelophrys micropa*

Morphometric	**34901**	**349 10 A**	**349 10 B**	**291 15**	**31601**	**Mean**	**Range**	**SD**
SL (mm)	66	62	58	75	93		(58-93)	
% SL								
Head length	54.5	54.8	55.2	56.0	60.2	56.2	54.2-60.2	2.3
Head depth	25.8	22.6	19.0	25.3	23.7	23.3	19-25.8	2.7
Head width	30.3	29.0	25.9	29.3	26.9	28.3	25.9-30.3	1.8
Snout length	13.6	16.1	15.5	14.7	16.1	15.2	13.6-16.1	1.1
Eye diameter	10.6	8.1	6.9	12.0	8.6	9.2	6.9-12	2.0
Inter orbital width	22.7	24.2	22.4	22.4	19.4	22.2	19.4-24.2	1.8
Pre dorsal	68.2	69.4	63.8	64.0	53.8	63.8	53.8-69.4	6.1
Pre anal	75.8	74.2	72.4	70.7	71.0	72.8	70.7-75.8	2.2
Lower lip to anus	62.1	56.5	60.3	52.0	53.8	56.9	52-62.1	4.3
Disc margin	42.4	40.3	41.4	40.0	39.8	40.8	39.8-42.4	1.1
Illicial cavity length	15.2	16.1	12.1	14.7	15.1	14.6	12.1-16.1	1.5
Upper jaw length	18.2	17.7	15.5	18.7	14.0	16.8	14-18.7	2.0
Lower jaw length	16.7	19.4	13.8	18.7	12.9	16.3	13-19.4	2.9
Mouth width	27.3	29.0	25.9	24.0	24.7	26.2	24-29	2.0
Pectoral fin length	25.8	24.2	22.4	25.3	16.1	22.8	16.1-25.8	3.9
Caudal fin length	27.3	29.0	25.9	28.0	21.5	26.3	21.5-26	2.9
Caudal peduncle depth	7.6	8.1	8.6	6.7	6.5	7.5	6.5-8.6	0.9
Gill opening	6.1	9.7	6.9	6.7	6.1	7.1	6.1-9.7	1.5
Anal fin end to caudal peduncle	20.1	19.4	19.0	18.7	21.5	19.7	18.7-21.5	1.1
Meristics								
Dorsal fin rays	5	5	5	5			5	
Pectoral fin rays	15	14	15	15			14-15	
Anal fin rays	4	4	4	4			4	
Caudal fin rays	8	8	8	8			8	
Neuromasts counts								
Pre-opercle	4	3	3	4	3		3-4	
Sub-opercle	6	7	6	6	6		6-7	
Tail series	8	10	9	9	9		8-10	
Supra orbital	8	7	8	8	8		7-10	

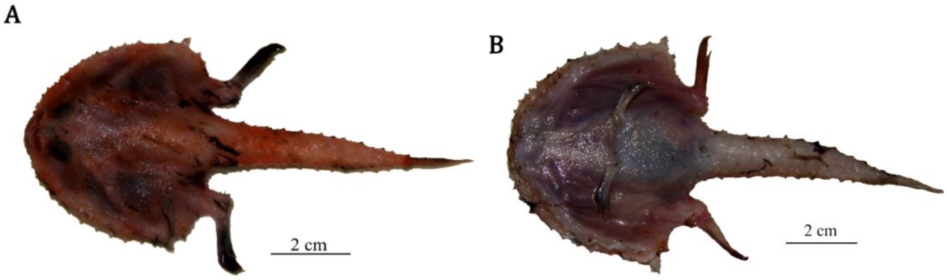

Figure 3.22. *Halicmetus ruber* (27911A) A—dorsal view, B—ventral view New record from Bay of Bengal, 307 m depth

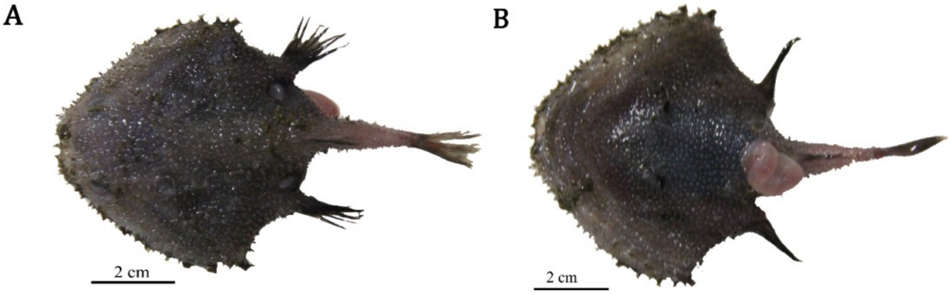

Figure 3.23. *Coelophrys micropa* (31601) A—dorsal view, B—ventral view

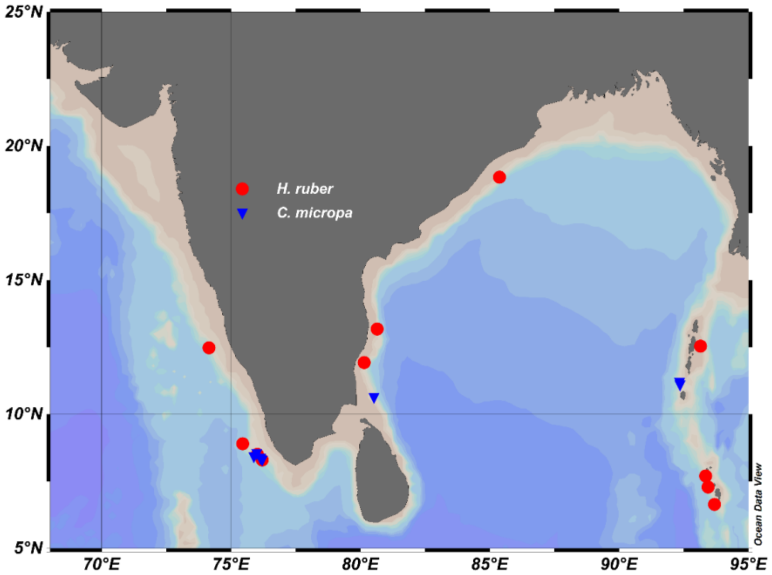

Figure 3.24. Map showing distribution of *Halicmetus ruber and Coelophrys micropa* in the Indian EEZ

Malthopsis Alcock, 1891

Diagnosis—Head and anterior part of the body forming depressed sub-triangluar disk; dorsal surface covered with pyramid like principal bucklers, small spinule may or may not be present in between principal bucklers; ventral surface having few small bucklers; rostral spine sharp or blunt, directed forward or upward; subopercle buckler with or without well-developed spines; dorsal surface with or without markings. Currently comprises 13 species (Ho 2013) and 3 represented from India, including 1 new species and 1 new record (Fig. 3.28)

Malthopsis lutea Alcock, 1891

Figs. 3.25. A—B, Table 3.22

Longnose seabat

Synonyms—*Malthopsis luteus* Alcock, 1891

Lectotype—BMNH 1898.7.13.6 [ex. ZSI F13024]. Paralectotypes: BMNH 1891.9.2.2, 51.8 mm SL, Andaman Sea, 11°31'40"N, 92°46'06"E, Investigator station 115, 343-402 m (Alcock 1891).

Materials examined—34909, 55 mm SL, 11.93° N, 92.28° E, 290 m. HSDT, April 2016; 34907, 49 mm SL, 13.23° N, 93.17°E, 332 m, HSDT CV, April 2016; 34902A & 34902B, 62 mm, 56 mm SL, 7.48° N, 93.41°E, Andaman Sea, 650 m HSDT CV, April 2016; 30505, 65 mm SL, 12.2° N; 74.3° E, Arabian Sea, 200-400 m, HSDC CV, August 2017.

Diagnosis—Subopercle buckler with blunt spines; rostral spine small directed upward; 2-3 brown rings present on the dorsal body.

Description—Body relatively depressed, disk triangular in shape from dorsal view; head portion slightly raised from rest of the body; caudal peduncle tapering posteriorly; rostrum pointed; conical, directed upward and forward, eyes are dorsolaterally directed; interorbital space narrow; illicial cavity forms a small triangular groove; esca bearing medial bulb; mouth terminal, small; small villiform teeth on jaws forming narrow band; relatively large quadrangular and triangular teeth on vomer and palatine respectively; two long patches of teeth present on tongue; dorsal surface with principal buckler and small bucklers in between them, all bucklers are low; ventral surface, except under the disk bears low number of small bucklers; subopercle spine blunt with 3 spines.

Colour in fresh—Dorsal body uniformly brownish with 2-3 yellowish rings, ventral with creamy white.

Distribution—Presently known from Arabian Sea (new record) and Andaman Sea at depth ranging from 290-740 m.

Table 3.22. Morphometric and meristic data of *Malthopsis lutea*

Measurements	**349 09**	**349 07**	**349 02 A**	**349 02B**	**Mean**	**Average**	**SD**
Standard Length (mm)	55	49	56	62			
% SL							
Head width	14.5	16.3	15.0	22.6	17.1065	14.5-22.6	3.72438
Orbital diameter	14.5	12.2	14.3	12.9	13.4948	12.2-14.5	1.10176
Interorbital width	6.5	6.1	7.0	5.8	6.35966	5.8-7	0.50412
Rostral length	5.5	5.7	5.4	6.5	5.7444	5.4-6.5	0.49499
Mouth width	12.7	12.2	12.5	12.9	12.5938	12.2-12.9	0.28524
Illicial cavity width	3.6	6.1	5.4	4.8	4.98867	3.6-6.1	1.04442
Pre-dorsal length	63.6	69.4	67.9	71.0	67.9623	63.6-71	3.15116
Post anus length	50.9	51.0	53.6	54.8	52.5849	50.9-54.8	1.94155
Pre-anal length	80.0	83.7	80.4	80.6	81.1689	80-83.7	1.69041
Disc margin length	43.6	46.9	46.4	45.2	45.5413	43.6-46.9	1.47347
Pectoral fin length	32.7	28.6	26.8	24.2	28.0695	24.2-32.7	3.58784
Anal fin length	16.4	12.2	17.9	16.1	15.6487	12.2-16.4	2.39478
Dorsal fin length	16.4	10.2	12.5	12.9	12.9927	10.2-16.4	2.54233
Caudal fin length	29.1	26.5	26.8	25.8	27.0534	25.8-29.1	1.42024
Meristics							
Dorsal fin rays	5	5	5	5			
Anal fin rays	4	4	4	4			
Pectoral fin rays	11	12	12	12			
Caudal fin rays	9	9	8	8			

***Malthopsis gigas* Ho and Shao, 2010**

Figs. 3.26. A—B, Table 3.23

Giant triangular batfish

Holotype—ASIZP 63084, 24°48´N, 122°25.2´E, NE Taiwan, 210-340 m. (Ho and Shao 2010).

Materials examined—29234, 68 mm SL, 13.22° N, 93.18° E, Andaman Sea, 300 m, HSDT CV, November 2011; 29238, 62 mm SL, 13.01° N, 93.11° E, Andaman Sea, 308 m, HSDT CV, November 2011.

Diagnosis—Rostral spine directed almost vertically; wide interorbital space; well-developed large bucklers on tail; anal fin reaches beyond caudal fin base when fully laid back.

Description—Body depressed, disk triangular in outline; skull elevated slightly raised from rest of the body; caudal peduncle tapering posteriorly; rostrum pointed; directed almost vertically; eyes are dorsolaterally directed; interorbital space wide (7.4-8.1% SL); illicial cavity forms relatively wide triangular groove; esca bearing medial bulb; mouth terminal, small; small villiform teeth on jaws forming narrow band; relatively large quadrangular and triangular teeth on vomer and palatine respectively; tongue teeth also present; dorsal surface with well-developed principal bucklers coupled with small bucklers in between them; ventral surface, except under the disk bears low number of small bucklers; subopercular spine blunt with 2 spines, one directed forward and other one backward.

Colour—In preserved specimen, dorsal surface with uniform light brown colour with one or two small black patches, ventral with pale brown; all fins brown, but anal with white.

Distribution—Andaman Sea at a depth of 300-308 m. (present study - new record). Indian and Pacific oceans off Madagascar, Somalia, Japan, Taiwan, Australia, Fiji, Vanuatu, New Caledonia, French Polynesia and New Zealand (Ho and Shao 2010) at depth ranging from 210-650 m.

Table 3.23. Morphometric and meristic data of *Malthopsis gigas* compared with previous study

Measurements	**Present study**		***M. gigas* (n=64) Ho & Shao 2010**
	29234	**29238**	
Standard Length (mm)	68	62	52.3-118.5
% SL			
Head width	22.0	21	20.0-29.7
Head depth	20.6	22.6	19.5-27.5
Orbital diameter	11.8	12.9	10.1-13.8
Interorbital width	7.4	8.1	6.5-9.7
Rostral length	5.9	8.1	5.2-11.5
Mouth width	13.2	14.0	13.4-17.4
Illicial cavity width	4.4	6.5	4.0-6.4
Pre-dorsal length	64.7	66.1	63.8-75.0
Post anus length	52.9	53.2	52.2-62.7
Pre-anal length	82.4	82.3	76.5-85.3
Disk margin length	45.6	48.4	40.0-51.8
Pectoral fin length	19.1	22.6	16.2-27.7
Anal fin length	17.6	19.4	17.4-24.2
Dorsal fin length	17.6	17.7	17.6-29.5
Caudal fin length	25.0	24.2	21.6-29.8
Meristics			
Dorsal fin rays	5	5	5-6
Anal fin rays	4	4	
Caudal fin rays	9	9	
Pectoral fin rays	12	11	11-14
Pelvic fin rays	5	5	

Malthopsis **sp. A**

Fig. 3.27. A, Table 3.24

Andaman triangular batfishes

Material examined—33416, 55 mm SL, 13.3° N, 93.1° E, Andaman Sea, 398 m, HOT, January 2015.

Diagnosis—A species of *malthopsis* genus with uniform rose colour, relatively large, upwardly directed rostral spine; subopercle buckler with well-developed spines.

Description—Compressed body, triangular disk,; rostral spine relatively long, pointed and directed upwardly, length 5.5% SL; illicial cavity forms relatively wide triangular groove; esca bearing medial bulb; mouth terminal, small; small villiform teeth on jaws forming narrow band; large quadrangular vomerine teeth; palatine teeth triangular shape, both are arranged serially (Fig. 3.27. B); two large patches of teeth on tongue (Fig. 3.27. C); dorsal surface with low number of well-developed principal bucklers, rest of the space with small bucklers; ventral surface of the disk bears low number of bucklers except under the disk; tail with thickly packed well developed bucklers; subopercle spine well developed with 3 spine.

Colour—Uniform rosy colour all over the body including ventral surface; all the fins are same in colour as body.

This species can be easily distinguished from *M. lutea* by the following characters low number of principal buckler (vs. high number of bucklers); body with uniform rose colour without any markings (vs. grey colour with distinct yellow marking); relatively long rostral spine (vs.

short rostral spine). It can be distinguished from *M. gigas* in the colour pattern and subopercle spine (subopercle spine well developed in new species, but blunt in *M. gigas*)

Distribution—Known from collection locality only (Andaman Sea).

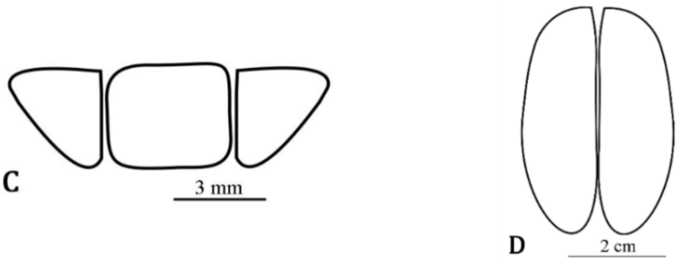

Figure 3.27. *Malthopsis* sp. A. vomer and palatine teeth (C); tongue teeth (D)

Table 3.24. Morphometric and meristic data of *Malthopis* sp. A

Measurements	334 16
SL (mm)	55
Head width	14.5
Head depth	27.3
Orbital diameter	14.5
Interorbital width	6.5
Rostral length	5.5
Mouth width	12.7
Illicial cavity width	36.4
Pre-dorsal length	63.6
Post anus length	50.9
Pre-anal length	80.0
Disc margin length	43.6
Pectoral fin length	32.7
Anal fin length	16.4
Dorsal fin length	16.4
Caudal fin length	29.1
Meristics	
Dorsal fin rays	5
Anal fin rays	4
Caudal fin rays	9
Pectoral fin rays	11
Pelvic fin rays	5

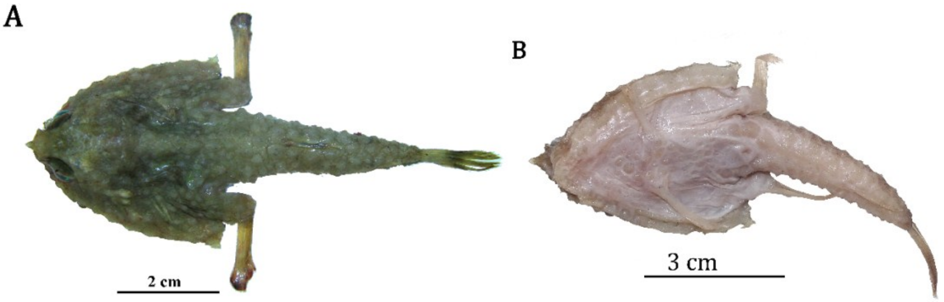

Figure 3.25. *Malthopsis lutea* (30505) A—dorsal view, B—ventral view
New record from Arabian Sea, 400 m depth

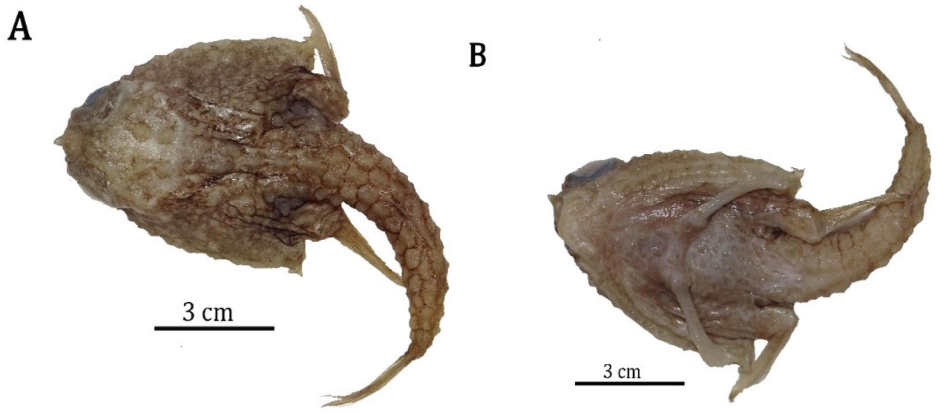

Figure 3.26. *Malthopsis gigas* (29234) A—dorsal view, B—ventral view
New record from Andaman Sea, 300 m depth

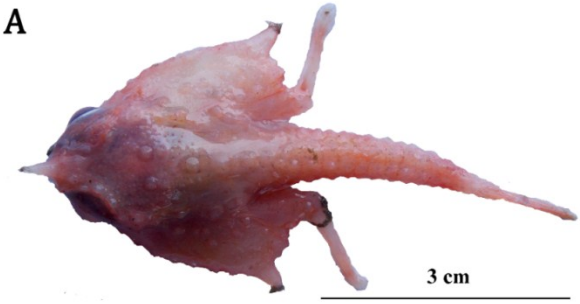

Figure 3.27. *Malthopsis* sp. A, dorsal view.
New species, common name—Andaman triangular batfish, Material—33416, 55 mm SL, 13.3° N, 93.1° E, Andaman Sea, 398 m

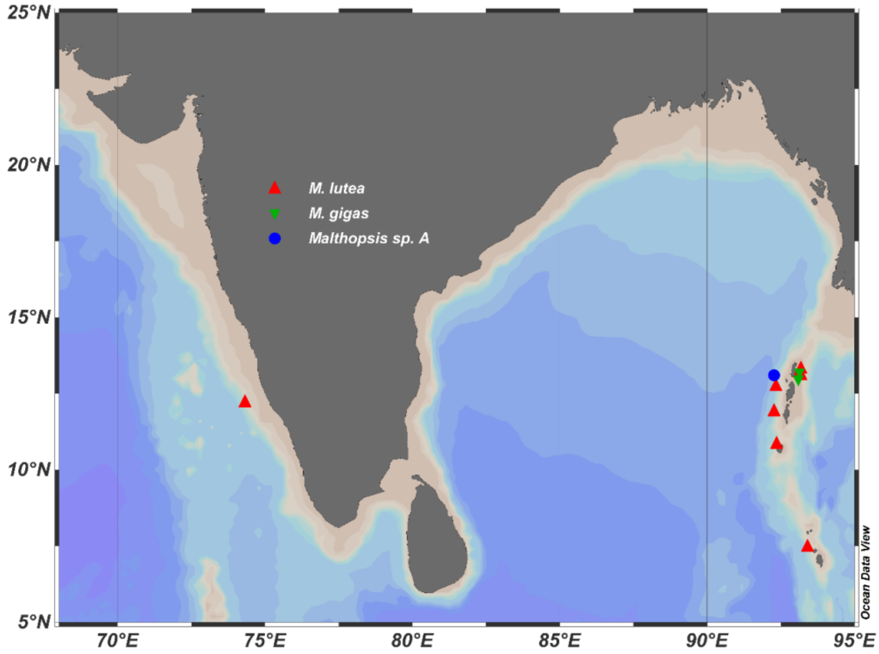

Figure 3.28. Map showing distribution of *Malthopsis* species in the Indian EEZ. Species—*Malthopsis lutea; Malthopsis gigas; Malthopsis* sp. A

iv. Suborder—CERATIOIDEI

Family—CERATIIDAE Gill, 1861

Diagnosis (based on females)- Relatively elongated and large sized anglerfishes; cleft of the mouth vertical; two or three caruncles (modified dorsal fin rays, each bearing bioluminescent gland) on the back just anterior to the origin of the soft-dorsal fin; posterior end of the pterygiophore of the illicium originates from the dorsal midline just anterior to the caruncles; postmaxillary process well developed; anterior maxillomandibular ligament present; supraethmoid present; sphenotic spines absent; parietals present; pterosphenoid present; branchiostegal rays 6; pharyngo-branchial I present or absent; pharyngobranchials II and

III well-developed and toothed; pharyngobranchial IV absent; epibranchial and ceratobranchial teeth absent; opercle bifurcate; subopercle elongate; upper jaw teeth slender, recurved; lower jaw teeth larger and more in number than upper jaw; vomerine teeth may be present or absent; esca without dermal denticles; skin covered with dermal spines; dorsal fin rays 3-5, mostly 4; anal fin rays 4; caudal fin rays 8-9 (8 in *Cryptopsaras*).

The males of the ceratiidae differs from other ceratioid families in having the following characters: adults are obligatory sexual parasites; free-living adolescent stages with a pair of large denticular teeth on snout; two pairs of denticular teeth on tip of lower jaw; premaxillae degenerate; eyes large, directed laterally, pupil larger than lens; olfactory organs minute; caruncles absent; skin naked and without pigmentation in adolescent stages, spinulose and pigmented in parasitic stages; dorsal-fin rays 3-5, mostly 4; anal fin rays 4; caudal fin rays 8-9 (Bertelsen 1951; Pietsch 1986).

Larvae of ceratiids can be differentiated by: hump-backed body; skin inflated; mouth subvertical; females with caruncles (modified dorsal fins) on dorsal midline of trunk; pectoral fins small; pelvic fins absent; sexual dimorphism evident, females with caruncles and distinct illicial rudiment; fin ray count same as females; metamorphosis take place between 8-10 mm SL (Bertelsen 1951). A total of 9 ceratioid species were encountered during the study with 5 new records and 2 new species new to the science. Distribution of ceartioid from Indian waters were explained in Figure 3.37.

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.

Genus- *Ceratias* Krøyer, 1845

Diagnosis- Unique in absence of a spine on the anterodorsal margin of the subopercle; relatively long illicium; nine caudal fin rays, the lowermost greatly reduced; two club shaped caruncles on the dorsal midline of the trunk just anterior to the origin of dorsal fins. Escal bulb of females with or without one or two distal appendages; if present, escal appendages simple or bearing 1-8 lateral filaments (Bertelsen 1951, Pietsch 1986). 2 species were represented from the study area, both of them are new records.

Ceratias uranoscopus Murray, 1877

Fig. 3.29, Table 3.26

Synonyms—*Typlopsaras shufeldti* Gill, 1883; *Mancalias xenistius* Regan and Trewavas, 1932; *Manchalias uranoscopus* (Murray, 1877).

Holotype—BMNH 1887.12.7.15, 57 mm, CHALLENGER Sta. 89, between Canary and Cape Verde islands, ca. 20°13' N, 20°13' W, 0-4392 m.

Material examined—Andaman Sea (Eastern Indian Ocean- Present study, new record), 3341210, ♀, 93 mm SL, 11.4° N, 92.8° E, 850–900 m, HOT, Jan. 2015; 3440412, ♀, 150 mm SL, 8.1° N, 71.8° E, 304-600 m, HOT, Sept. 2015, Cosmos trawl (specimen collected from western Indian Ocean).

Diagnosis-—Illicium length 14.0–28.8% of SL; simple esca, escal bulb lacking escal appendages; two club-shaped caruncles on the dorsal midline of the trunk anterior to the origin of the soft dorsal fin, absence of vomerine teeth.

Description—Relatively long and slender body; unique in lacking a spine on the anteriodorsal margin of the subopercle; two club-shaped caruncles (modified dorsal fin rays) bearing a bioluminescent gland on the dorsal midline of the body anterior to the origin of the soft dorsal fin, illicium length 17% of SL, escal bulb darkly pigmented except at tip, distal portion oval in shape, proximal portion tapering into stem of illicium; vertical mouth; jaws equal anteriorly; lower jaw with well-developed symphysial spine; jaw teeth slender and recurved; teeth in lower jaw considerably larger and slightly more numerous than those in upper jaw; anterior maxillomandibular ligament present; supraethmoid and pterosphenoid present; two nostrils on each side on distal surface of a rounded papilla; eye small; six branchiostegal rays; bifurcated opercle; subopercle elongate; caudal fin rays 8, inner most four rays are bifurcated; vomerine teeth absent. Skin covered with close- set dermal spine except esca.

Colour in preservative—Dark black over entire surface of the body except for the distal portion of escal bulb.

Distribution—Andaman Sea (present study- new record) and Arabian Sea (Venu 2009). *Ceratias uranoscopus* is well represented in the Atlantic and Pacific, but little known from the Indian Ocean; one from off Durban, South Africa and the other in the central Arabian Sea (Pietsch 1986).

Table 3.26. Morphometric and meristic data of *Ceratias uranoscopus* compared with previous study

	C. uranoscopus		**Pietsch 1986 (2)**	**Murray, 1877 (Original description)**
Measurements	**3341210**	**3440412**		
Standard Length (mm)	93	150	19.5-240	57
In % of SL				
Illicium length	17	Broken	14.0-28.8	
Counts				
Upper jaw teeth			-	-
Lower jaw teeth		30	29	-
Vomerine teeth	Absent	Absent	Absent	-
Dorsal fin rays	4	4	3-5	3
Anal fin rays	4	4	4	4
Pectoral fin rays	16	18	-	10
Caudal fin rays	8	8	8-9	8

Genus- *Cryptopsaras* Krøyer, 1845

Diagnosis—Unique in having a spine on the anterodorsal margin of the subopercle; illicium reduced to a small remnant nearly fully covered by tissue of the esca; only eight caudal rays; three club shaped caruncles just anterior to the origin of dorsal fins.

Cryptopsaras couesi Gill, 1883

Fig. 3.30, Table 3.27

Triplewart Seadevil

Synonyms—*Cryptopsaras couesii* Gill, 1883; *Ceratias carunculatus* Günther, 1887; *Ceratias mitsukurii* Tanaka, 1908; *Cryptopsaras valdiviae* Regan and Trewavas, 1932; *Cryptopsaras pennifer* Regan and Trewavas, 1932; *Cryptosparas normani* Regan and Trewavas, 1932 ; *Cryptopsaras atlantidis* Barbour, 1941.

Holotype—USNM 33558, 30 mm, ALBATROSS Station 2101, Western North Atlantic, 38°18' N, 68°24' W, 0-3085 m.

Material examined—30506, ♀, 110 mm SL, 12.2° N, 74.2° E, Arabian Sea, 923 m., HSDT CV, August 2017.

Diagnosis—Unique in having a spine on the anterodorsal margin of the subopercle. Three club-shaped caruncles on the dorsal midline of the trunk just anterior to the origin of the soft dorsal fin and only eight caudal rays.

Description—Relatively long and slender body; unique in having a spine on the anteriodorsal margin of the subopercle; three club-shaped caruncles (modified dorsal fin rays) bearing a bioluminescent gland on the dorsal midline of the body anterior to the origin of the soft dorsal fin, illicium reduced to a small remnant (nearly fully enveloped by tissue of the esca), escal bulb oval in shape, distal part of the escal bulb having one pair of slender filament. vertical mouth; jaws equal anteriorly; lower jaw with well-developed symphysial spine; jaw teeth slender and recurved; teeth in lower jaw considerably larger and slightly more numerous than those in upper jaw; anterior maxillomandibular ligament present; supraethmoid and pterosphenoid present; two nostrils on each side on distal surface of a rounded papilla; eye small; six branchiostegal rays; bifurcated opercle; skin covered with close-set dermal spines. Number of teeth in lower jaw 25; vomerine teeth present with 3-4, dorsal 4, pectoral 15, anal 4 and caudal 8.

Colour in preservative—Dark black over entire surface of the body including escal bulb and filament.

Distribution—Arabian Sea (Present study- new record); occurring in all three major oceans of the world between approximately 63˚ N and 43˚ S. In the Indian Ocean, this species is known from more than 60 specimens (primarily larvae and males (Pietsch 1986).

Remarks- Monotypy.

Table 3.27. Morphometric and meristic data of *Cryptopsaras couesi* compared with previous study

Measurements	*C. couesi* 30506	Pietsch 1986 (2) (n=378)
Standard Length (mm)	110	5.5-290
Illicium	Rudimentary	Rudimentary
Counts		
Dorsal fin rays	4	4-5
Pectoral fin rays	15	15-17
Anal fin rays	4	
Caudal fin rays	8	8
Upper jaw teeth		
lower jaw teeth	24	42-68
Vomerine teeth	4	2-10

Family Diceratiidae Regan and Trewavas, 1932

Common name**-** Doublespine Seadevils

Specimens of diceratiids are rare; the systematics of the family is based almost solely on metamorphosed adolescent females. Only two larvae, one sexually mature female, and one metamorphosed male are known (Pietsch 2005, 2009).

Diagnosis (Based on females)—The Family Diceratiidae is unique in having an extremely exposed second light-bearing, dorsal-fin spine originating from the head directly behind the base of the illicium; two nostrils on each side; eyes small and subcutaneous; mouth large, cleft extending past eye; lower jaw with well-developed symphysial spine, extending slightly beyond upper jaw; supraethmoid present; vomerine teeth present; parietals present; sphenotic spines well developed; articular spine present; angular spine absent; numerous small, darkly pigmented, round shaped papillae on skin; basal half of escal bulb pigmented; many slender, recurved teeth on both upper and lower jaws; body covered with minute dermal spinules; pharyngobranchial I reduced; pharyngobranchials II and III well developed and toothed; pharyngobranchial IV absent; 6 branchiostegal rays; dorsal fin rays 5-7; anal-fin rays 4; pectoral fin rays 13-16; pelvic fins absent; caudal fin rays 9.

Males (based on a single juvenile male 14 mm)- Relatively large eyes; the olfactory organs are well separated from the eye, the premaxillae and dentaries of the male have irregularly resorbed edges; there is a pair of recurved denticular teeth on the snout just posterior to the symphysis of the upper jaw; there are 9 similar denticular teeth lying slightly behind the tip of the lower jaw; the skin is fully covered with tiny conical dermal spinules; fin ray counts same as females; free living, never parasitic (Pietsch 2005).

Larvae (two known specimens, both females, 7-10.5 mm SL) characters includes—body short, nearly spherical; length of head approximately 60% SL; skin highly inflated; pectoral fin normal size, pelvic fins absent; fin ray counts same as females (Bertelsen 1951).

Diceratiidae contains two genera, namely *Bufoceratias* Whitley, 1931 and *Diceratias* Günther, 1887, and is comprised of seven species (Pietsch *et al.* 2004; Ho *et al.* 2016a). *Bufoceratias* includes *B. shaoi*

Pietsch, Ho and Chen, 2004; *B. wedli* (Pietschmann, 1926), *B. thele* (Uwate, 1979) and *B. microcephalus* Ho, Kawai and Amaoka 2016 and *Diceratias* includes *D. bispinosus* (Günther 1887), *D. pileatus* Uwate, 1979 and *D. trilobus* Balushkin and Fedorov, 1986.

Genus *Diceratias* Günther, 1887

Doublespine Seadevils

Diagnosis- Illicial length 27-47% SL; pterygiophore of the illicium emerging on the snout from between the frontal bone, distance from base of illicium to symphysial cartilage 7-15% SL; pterygiophore elongate with exposed anterior tip; supraethmoid forming 52° angle with horizontal plane of cranium; illicial trough relatively deep.

Diceratias trilobus Balushkin and Fedorov, 1986

Figs. 3.31. A—B, Table 3.28

Holotype—ZIN 47426, 122 mm *SL*, R/V *Shantar*, trawl 28, E of Honshu, Japan, 38 °20.7′ N, 142°31.9′ E, bottom trawl, 1211–1216 m, 28 March 1975.

Material examined—3160107, ♀, 141.87 mm SL, 8.2° N, 76.2° E, Southwest coast of India (Arabian Sea), 1300–1350 m, , July 2013.

Description—The length of the illicium is 27.4 (27.9–33.7)% SL, anterior tip of the pterygiophore of the illicium is exposed, emerging on the snout; the distance between the symphysis of the upper jaw is 8 (7 to 15)% SL. The anterior margin of the supraethmoid forms an angle of 53° (52°). Laterally compressed esca with greatest width of 11.0 (9.6–10.5)% SL, large anterior and posterior escal appendages; margin of the both appendages having smooth edge with two and five tiny slender filaments, respectively. Posterior escal appendage slightly longer than anterior appendage. Dermal spinules of the skin and pigments covering half of the escal bulb and extending almost distal end of the posterior escal filaments, remaining parts of esa and filaments are unpigmented (Fig. 3.31.B); deep illicial trough; body being uniform dark brown in colour.

Distribution—Arabian Sea (present study- new record), Western North Pacific, Australia and eastern Indian Ocean (Pietsch *et al.* 2006; Balushkin and Fedorov 1986).

Table 3.28. Morphometric and meristic data of *Diceratias trilobus* compared with previous study

Measurements	**3160107**	**Holotype (ZIN 47426) Balushkin and Fedorov, 1986; *Pietsch *et al.* 2006**	**Pietsch *et al.* 2006**
Standard Length (mm)	141.87	122	47-140
In % of SL			
Head length	46.9	50*	40.0–50.1
Head width	34.2	27.0	30.7–37.2
Illicium length	27.4	27.1*	27.9–33.7
Esca length	6.4	6.4*	5.8–7.9
Premaxilla length	43.6	47.5	41.2–46.5
Lower jaw length	55.3	60.7	54.4–60
Counts			
Upper jaw teeth	72	75	67–111
Lower jaw teeth	53	60	51–68
Vomerine teeth	6	8	6–10
Dorsal-fin rays	6	5	5–6
Anal-fin rays	4	5	4
Pectoral-fin rays	14-14	15	14–15
Caudal-fin rays	8	9	-

Genus *Bufoceratias* Whitley, 1931

Toady Seadevils

Diagnosis- length of illicium 25–225% SL; anterior tip of pterygiophore of illicium covered with skin; illicium emerging from dorsal surface of head at rear of skull (not from the snout); distance from base of illicium to symphysis of upper jaw 29-61 % SL; illicial trough not deep; dermal spines minute.

Bufoceratias shaoi **Pietsch, Ho and Chen, 2004**

Figs. 3. 32. A—B, Table 3.29

Synonyms—*Phrynichthys thele* Uwate, 1979.

Holotype—ASIZP 61796, 101 mm, off northeast coast of Taiwan, 24°25–50′N, 122°00– 10′E, bottom trawl, 0–800 m, 1999. Paratypes: ASIZP 59952, 2 (56–75 mm), off northeast coast of Taiwan, 24°55′N, 122°04′E, bottom trawl, 0–650 m, 20 March 1998; MNHN 1977–304, 55 mm, Mozambique Channel, 17°36′–22°25′S, 42°59′–43°56.5′E, 0–1200 m.

Material examined—3160210, ♀, 153.67 mm (SL), 7.7° N, 76.4° E, Southwest coast of India, 1300–1350 m. July 2013.

Diagnosis—Metamorphosed females of the *Bufoceratias shaoi* have generally shorter illicium (25–40% SL) and a much larger and more complex esca.

Description—Metamorphosed females of the *B. shaoi* are characterized by having a short and stout body, the depth approximately 50% SL; a unique structure of the esca; illicial length 90 (25–40) % SL; distance from base of illicium to symphysis of upper jaw 53.45 (29–61)% SL; anterior margin of supraethmoid forming an angle of approximately 68° (65–74) with horizontal plane of cranium; shallow illicial trough; length from the base of escal bulb to tip of longest escal filaments 43.26 (23–48% SL); mouth large, oral valves well developed, lining inside of both upper and lower jaws; two nostrils on each side, ending in a short tube; eyes small and subcutaneous; oval gill opening, situated just posteroventral to pectoral lobe; numerous slender, recurved, depressible teeth occurring in overlapping sets in both jaws; dermal spines minute; body uniform black in colour.

Longer illicium (90%SL), esca having unpigmented terminal papilla. Anterior escal appendage with seven secondary branches, each bearing numerous slender, elongate filaments. A pair of anterior lateral appendages originating from the anterior region of the escal bulb, also divided into numerous secondary slender filaments. Base of the esca with two laterally situated appendages having four and seven branches each, and containing numerous secondary branches, each branch bearing numerous slender filaments; proximal parts of all appendages and filaments lightly pigmented, distal end unpigmented (Fig. 3.32.B)

Remarks—Pietsch *et al.* (2004) mentioned a considerably shorter illicium (25–40% SL) and a complex esca in all the four *B. shaoi* specimens analyzed; but the present specimen has a much longer illicium (90% SL). However, the length of the illicium of females is highly variable (25–225% SL) in the genus *Bufoceratias*. Males and larvae unknown.

Distribution—Arabian Sea (present study-new record); *B. shaoi* was previously known from only four specimens, three collected from off Taiwan and a fourth in the Mozambique Channel, Western Indian Ocean (Pietsch *et al.* 2004) and recently from Indonesian Waters (Ho *et al.* 2016a).

Table 3.29. Morphometric and meristic data of *Bufoceratias shaoi* compared with previous study

Measurements	3160210	Pietsch *et al.* 2004
Standard Length (mm)	153.67	55-101
In % of SL		
Head length	57.9	49.9-60
Head width	31.0	30.9-38.5
Illicium length	99.6	25.6-36.7
Esca length	43.3	22.9-48.1
Premaxilla length	39.0	33.6-44.9
Lower jaw length	43.0	42.2-51.3
Counts		
Upper jaw teeth	49	34-39
Lower jaw teeth	40	28-30
Vomerine teeth	10	8-10
Dorsal fin rays	6	5-6
Anal fin rays	4	4
Pectoral fin rays	15-15	13-14
Caudal fin rays	9	9

***Bufoceratias thele* (Uwate, 1979)**

Fig. 3.33, Table 3.30

Toady Seadevils

Synonyms—*Phrynichthys thele* Uwate, 1979; *Phrynichthys wedli* Machida and Yamakawa, 990

Holotype—LACM 36077-1; 32.0 mm; type locality: Halmahera Sea, western pacific, Alpha Helix Station- 155; 0° 38.6S, 129° 05.6' E; 680-850 m, 22 May 1975; Paratype, LACM 36076–1, 22 mm, Alpha Helix station 26, Ceram Sea, 2° 46.0' S, 127° 53.7' E, 0–1500 m, 31 March 1975.

Material examined—32202, 72 mm SL, ♀, 11.1° N, 74. 9° E, Arabian Sea, 1000 m., HSDT CV, January 2014.

Diagnosis—A species under the genus *Bufoceratias* with longer illicium and peculiar structure of esca, without any anterior, posterior, and lateral escal appendages.

Description—Body short, globular; pterygiophore of the illicium embedded beneath skin of the head; illicium emerging from dorsal surface of head well beyond the sphenotic spines; distance between upper jaw symphysis and origin of illicium 56.9% SL; Illicium extremely longer than previously reported, 430% SL (112-143% SL (Pietsch *et al.* 2004); 153.8-174.4% SL (Ho *et al.* 2016a). Esca without any anterior, posterior, and lateral escal appendages, its length 10.5% SL; esca with rounded terminal papilla, escal pore present on the base of the terminal papilla. Mouth large, oblique, eyes small, both jaws with fang like teeth, some of them are much longer than others.

Colour—Body with uniform black with minute spine (visible only under microscope) all over the body including fin rays; basal half of the escal bulb also pigmented.

Distribution—Arabian Sea (present study- new record). Previously known from western Pacific, 680- 850 m; Indonesian water 595-768 m.

Remarks—The present specimen show variations in some of the characters from the previously reported specimens (Pietsch 2004; Ho *et al.* 2016a) viz;

illicium much longer than previously reported specimens, 430% SL (112-143% SL, Pietsch *et al.* 2004; 153.8-174.4% SL, Ho *et al.* 2016a); *Bufoceratias* genus shows some variation in their illicial length (25–225% SL, Pietsch *et al.* 2004). Upper jaw length 45.8% SL (38.4–41.4, Ho *et al.* 2016a); distance between upper jaw symphysis and origin of illicium 56.9 % SL (44.1–50.2% SL, Ho *et al.* 2016a). Illicium of the present specimen originating well beyond the sphenotic spines.

Table 3.30. Morphometric and meristic data of *Bufoceratias thele* compared with previous study

	32202	**Ho *et al.* 2016a**	**Pietsch *et al.* 2004**
Measurements			
Standard Length (mm)	72	39.5–127.4 (n=3)	112–143
In % of SL			
Head length	45.8	41.0–48.1	
Head width	34.7	30.5–33.2	
Head Depth	66.7	50.2–66.6	
Illicium length	430.6	153.8–174.4	
Esca length	11.1	9.9–11.1	
Upper jaw length	45.8	38.4–41.4	
Lower jaw length	40.3	40.6–40.8	
Meristics			
Upper jaw teeth	23;24	40–52	12–49
Lower jaw teeth	18;16	33–44	15–48
Vomerine teeth	4;5	6–11	4–10
Dorsal-fin rays	5	6	5-6
Anal-fin rays	4	4	4
Pectoral-fin rays	15	13-15	13-14
Caudal-fin rays	9	9	

Family Himantolophidae Gill, 1861

Football fishes

Diagnosis—Stout globose body with spines; stout, well decorated esca; protruding chin with numerous wart like swellings. Metamorphosed females of himantolophids are charcterised by lack of parietal bones throughout their life; supraethmoid, pterosphenoid, metapterygoid, mesoperygoid and well developed sphenotic spines; quadrate, articular, angular, and preopercular spines absent; Illicium stout and thick, pterygiophore of illicium short, anterior end concealed in skin; large conical dermal spines, with broad rounded bases widely spaced over the head and body; lower jaw projects anteriorly beyond upper; lower jaw, stout and thick with well-developed symphysial spine; pharyngobranchial I reduced; pharyngobranchials II and III toothed; pharyngobranchial IV absent; both jaws having numerous teeth, some of them are long; vomer broad toothless; dorsal fin rays 5-6; anal fin rays 4; pectoral fin rays 14-18; pelvics absent; caudal-fin rays 9.

Metamorphosed males are characterized by series of enlarged dermal spines above and posterior to the upper denticular bone; eyes lateral; olfactory organs large; both upper and lower jaw teeth fused together at the base and forms upper and lower denticular bones respectively; skin densely covered with dermal spinules; pharyngobranchial reduced; pharyngobranchials II and III toothless; pharyngobranchial IV absent; males free-living, never parasitic; fin counts are same as females.

Larvae can be distinguished from other ceratioids by following characters: body short, spherical; skin highly inflated; pectoral fins of normal size, pelvic fins absent; sexual dimorphism clearly found, females with a small, club-shaped illicial rudiment emerging from head; metamorphosis usually take place at lengths between 20 and 33 mm SL (Bertelsen and Krefft 1988).

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.

***Himantolophus* Reinhardt, 1837**

Genus diagnosis same as family

***Himantolophus* sp A.**

Figs. 3.34. A—B

New species

Indian football fish

Material examined—36708, ♀, 150 mm SL, 13.3° N, 93. 3.2° E, Andaman Sea, 635 m., HSDT CV, November 2017.

Diagnosis—A species of *Himantolphus albinares* group, except the presence of a simple, anterior escal appendage; short ilicium 28.9% SL; a pair of simple, slender, short, undivided posterior escal appendages; relatively high number of teeth on both jaws.

Description—Metamorphosed female, body globose, slightly elongated; head length 16.75% SL; head width 22.0% SL; ilicium emerging in between the eyes; distance between upper jaw symphysis and origin of illicium 14%SL; illicium short and stout; distal appendage 32.6% SL; undivided part of distal appendage 6.6% SL; distal escal appendage equally divided and forms two equal main branch, each main branch bifurcated symmetrically at the anterior end (5.3% SL).

Relatively large esca, length of esca 12% SL, depth of esca 6% SL; escal bulb with two lateral lobes, escal pore on posterior margin of bulb in between the lateral lobes; anterior escal appendage (6.65% SL) present just below the escal pore; one pair of undivided posterior escal appendage (6%SL; equal length) placed just above attachment of esca with illicial stem; illicial stem without any filaments; illicium, esca, and base of distal escal appendage covered with tiny, close-set dermal spinules; escal bulb, base of distal escal appendages and bifurcated tip of the distal appendage silvery white (Fig. 3.34.C).

Well-developed sphenotic spines; small eyes; absence of wart-like papillae on snout and chin; large conical dermal spines, with broad rounded bases widely spaced over the head and body except chin and area below the eyes; mouth cleft not reaching eye; oral valve developed, lining inside of both jaws; gill opening large just below the pectoral fin; upper jaw length 30.0% SL; lower jaw length 29.3% SL; dorsal fin rays 6; pectoral fin rays 16; anal fin rays 5; caudal fin rays 9; upper jaw teeth 52; lower jaw teeth 38; vomerine 4 (teeth were counted on both half).

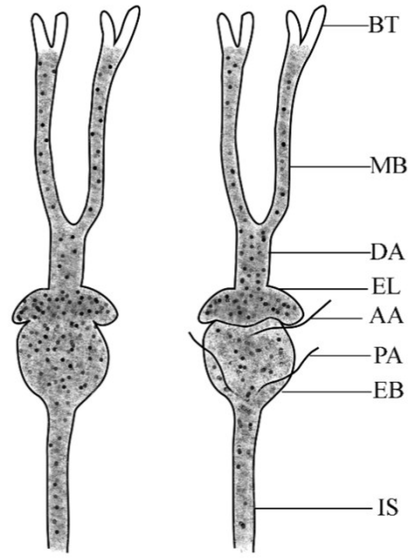

Figure 3.34.C. Diagrammatic representation of Illicial apparatus of *Himantolophus* sp. A;
IS- Illicial apparatus; EB- Escal bulb; PA- Posterior escal appendage; AA- Anterior escal appendage; DA- Distal appendage; MB- Main branch of DA; BT- Bifurcated tip of DA

Remarks—Present specimen compared with all other known specimens of *Himantolophus* (Pietsch 2009). New species mostly agree with *Himantolophus pseudalbinares* (Bertelsen and Krefft, 1988) of *Himantolophus albinares* group except the presence of a small, slender anterior escal appendage. The only group with anterior escal appendage is *H. groenlandicus* group, but the members of this group shows extreme variation in the escal morphology with present specimen.

Colour—Body with uniform purple colour in fresh specimen; dorsal, anal and caudal fins especially, membrane having light pink colour but their edges are black; pectoral fins are dark purple. Illicium black, distal appendage deep blue in colour except distal branched portion and escal bulb which are silvery white.

Distribution— Known only from type locality, Andaman Sea.

Family- Oneirodidae Gill, 1878

Oneirodes Lütken, 1871

Dreamers

Least understood family of suborder Ceratioidei

Diagnosis (based on females)—supraethmoid present; frontals widely separated; parietals present; sphenotic overlapped by anterolateral projection of pterotic; metapterygoid and mesopterygoid present; anterior subopercular spine usually absent; quadrate and articular spines well developed (reduced in Chaenophryne); lower jaw usually with a well-developed symphysial spine (absent in some genera) branchiostegal rays 6; angular and preopercular spines absent; jaws equal anteriorly; jaw teeth present; postmaxillary process of premaxillae absent; anterior-maxillomandibular ligament well developed; pharyngobranchial IV absent; opercle bifurcate; dermal spinules usually absent (except in *Spiniphryne.*) dorsal fin rays 4-8; anal-fin rays 4-7; pectoral fin rays 14-30; caudal-fin rays 9.

Males—Eyes directed laterally, elliptical in shape, axis short, diameter of pupil greater than that of lens; olfactory organs large, anterior nostrils situated close together and opening forwards; posterior nostrils lateral, usually larger than eye; nasal area usually pigmented, sometimes slightly inflated; jaw teeth absent; dermal spinules of snout absent; posterior end of upper denticular remote from anterior end of pterygiophore of illicium; usually free-living, non-parasitic, fin ray counts same as females (Pietsch 2009). The knowledge of oneirodes larvae is limited.

The largest family of suborder Ceratioidei containing 16 genera and 66 species (Pietsch and Sutton 2015; Ho *et al.* 2016a; Rajeeshkumar 2017)

***Oneirodes* sp. A**

Fig. 3.35

New species

Material examined—32202, 65 mm SL, ♀, 11.1° N, 74.9° E, Arabian Sea, 1000 m., HSDT CV, January 2014.

Diagnosis—A species under the genus Oneirodes with relatively short illicium, unique escal morphology, single anterolateral and posterior appendages, absence of lateral and medial appendages and shape of subopercle bone.

Description—Standard length 65 mm, Head length 43% SL; head depth 54% SL; mouth large and mouth cleft extending beyond eye; frontal bone convex, least width 6% SL; distance between the tip of the snout and emergence of illicium 10% SL; llicium short 26% SL; sphenotic spines relatively small, length of 6.2% SL; upper jaw length 42% SL; lower jaw length 38% SL, well-developed symphysial spine; quadrate spine well-developed with length of 7.7% SL; articular spine not distinct; angular spine absent; pectoral fin lobe short and narrow, longest fin measuring 23% SL; posterior margin of opercle deeply notched; subopercle somewhat long, ventral margin rounded (Fig. 3.35. A).

Escal morphology simple, with internally pigmented, single anterolateral and posterior appendage; lateral and medial appendages absent; both appendages are flap like, anterolateral short, posterior appendage long 6.2% SL; rounded terminal escal papilla with single pigment spot (Fig. 3.35.B); pectoral fin rays 16; pelvic absent; anal fin rays 4; caudal fin rays 9, branched except first and last two rays; caudal peduncle depth 15.3% SL; teeth in upper jaw (both half) 26, lower jaw teeth 25, some of them are long and fang like; vomerine 4, 2 on each side; body naked without spines, uniform deep black.

Present species is more similar to *O. alius* (*O. schmidti* group), it differ from *O. alius* by the following characters; anterior appendage absent (vs. present with internal pigment); posterior appendage pigmented (vs. without pigmentation); terminal papilla with single pigment spot (vs. two bilaterally place pigment spots).

Remarks—Dorsal fin damaged in the presented specimen.

Distribution- Known from collection locality only.

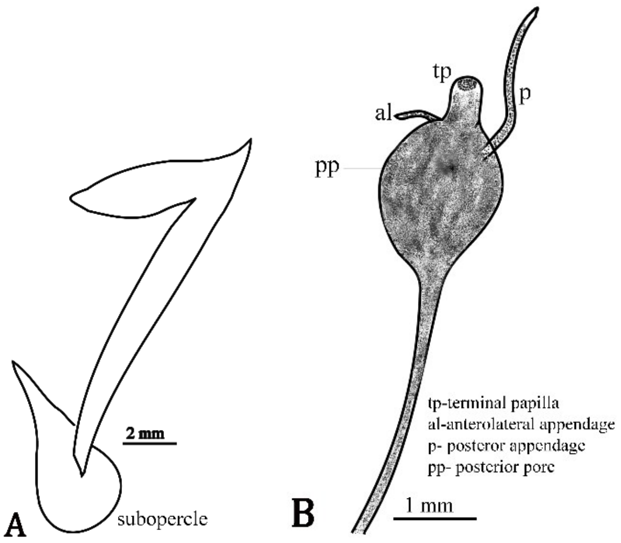

Figure 3.35. A—B. Opercular bone (A) and illicial apparatus (B) of *Oneirodes* sp. A

***Oneirodes* sp.**

Fig. 3.36.

Material examined—30506, 160 mm SL, 12.2° N, 74.2° E, Arabian Sea, 923 m., HSDT CV, August 2017.

Remarks—Specimen totally damaged, not included in the check list. But included in distribution map.

Family Melanocetidae Gill, 1879b

Black Seadevils

Diagnosis—Bathypelagic anglerfishes with globose body, metamorphosed females distinguished from other families by possessing following characters, dorsal fin rays 13-16; anal fin rays 4; large mouth; jaws with numerous long teeth. Frontal bones widely separated; with a well-developed symphysial spine; opeclular birfcate; subopecle long; sphenotic spines; quadrate, articular, angular, and preopercular spines absent; lower jaw pharyngobranchials 1st and 4th absent 2nd and 3rd well developed and toothed; skin with very minute dermal spinules.

Metamorphosed males share common characters with females except olfactory organ large; laterally placed nostrils; jaw teeth absent; upper denticular with 2 or 3 denticles; males usually free-living, never parasitic; fin-ray counts same as metamorphosed females.

Larvae almost spherical shaped, short body, females having a small, club-shaped illicial rudiment emerging from head; fin counts same as metamorphosed females.

Family contains single genus with six valid species.

***Melanocetus* Günther, 1864**

Diagnosis- same as family

***Melanocetus johnsonii* Günther, 1864**

Humpback anglerfish

Synonyms—*Centrocetus spinulosus* Regan and Trewavas, 1932; *Melanocetus cirrifer* Regan andTrewavas, 1932; *Melanocetus ferox* Regan, 1926; *Melanocetus krechi* Brauer, 1902; *Melanocetus megalodontis* Beebe and Crane, 1947; *Melanocetus rotundatus* Gilchrist, 1903; *Xenoceratias braueri* Koefoed, 1944*; Xenoceratias brevirostris* Regan and Trewavas, 1932; *Xenoceratias heterorhynchus* Regan and Trewavas, 1932*; Xenoceratias laevis* Regan and Trewavas, 1932; Xenoceratias micracanthus Regan and Trewavas, 1932.

Holotype—BMNH 1864.7.18.6, Sea of Madeira, eastern Atlantic (Günther 1864).

Material examined—32202, 25.5 mm SL, ♀, 11.1° N, 74.9° E, Arabian Sea, 1000 m, HSDT CV, January 2014.

Diagnosis—Esca is characterized by the presence of crests and a black pigmented area on the top.

Distribution—Tropical to temperate regions of all oceans (Pietsch 2009)

Description—Body short, humpbacked; Head large, HL 45.9% SL, HW 43.3% SL, HD 71.6% SL; upper jaw length 50.8% SL; lower jaw length 69.4% SL; dorsal fin rays 16; pectoral fin rays 18; pelvic fins absent; anal fin rays 4; caudal fin rays 9; upper jaw teeth 49; lower jaw teeth 36; vomerine teeth 8; illicium length 32.3% SL; escal bulb length 11.4% SL; escal bulb slightly compressed, with a rounded prolongation, pigmented spot on top; two crests, anterior one small and compressed, posterior larger and pigmented; body with minute spinules, only visible under microscope.

Colour—Uniformly deep brown, all fins are black.

Distribution—Arabian Sea (present study), tropical to temperate regions of all oceans (Pietsch 2009).

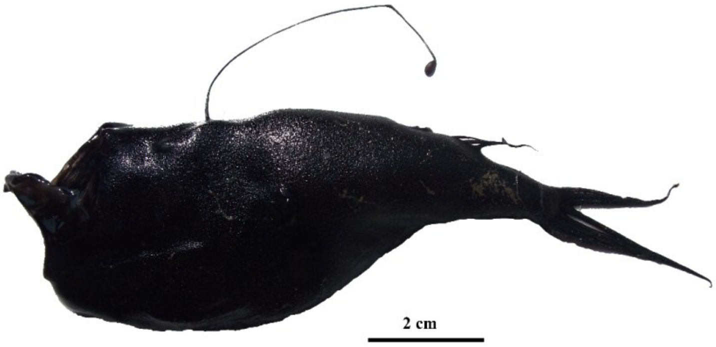

Figure 3.29. *Ceratias uranoscopus* (3341210)
New record from Andaman Sea, 850–900 m depth

Figure 3.30. *Cryptopsaras couesi* (30506)
New record from Arabian Sea, 923 m depth

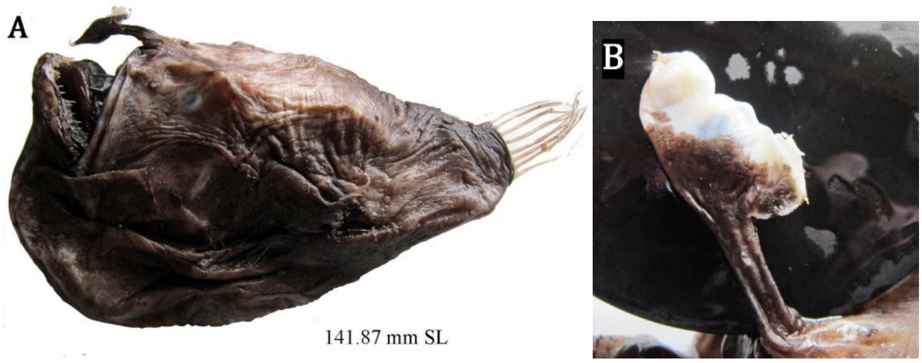

Figure 3.31. *Diceratias trilobus* (3160107), A—lateral view, B—illicial apparatus
New record from Arabian Sea, 1350 m depth

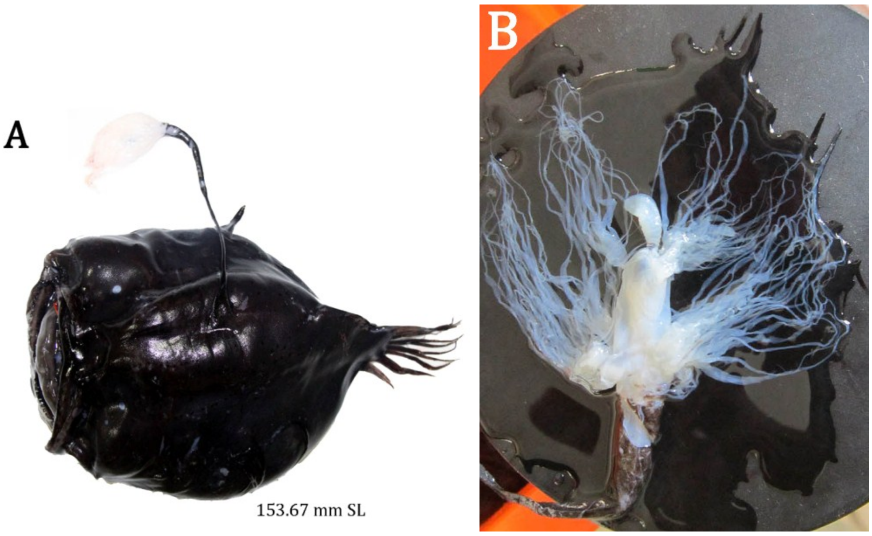

Figure 3.32. *Bufoceratias shaoi* (3160210), A—lateral view, B—illicial apparatus
New record from Arabian Sea**,** 1350 m depth, presented specimen represents fifth known specimen in the world

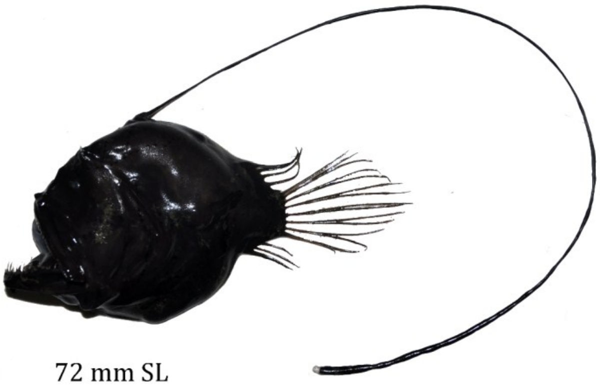

Figure 3.33. *Bufoceratias thele* (32202). New record from Arabian Sea, 1000 m depth

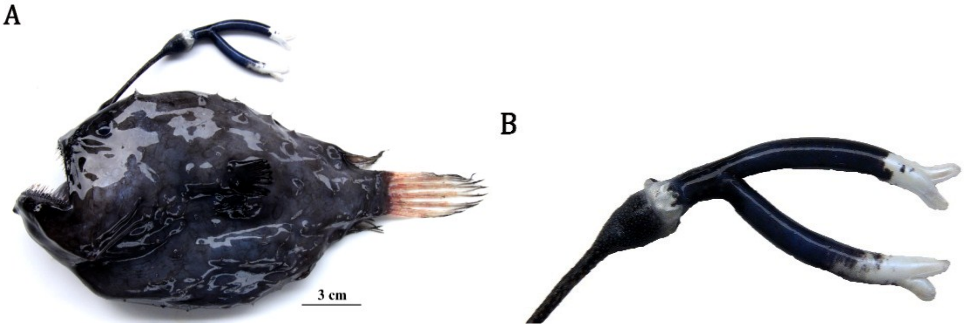

Figure 3.34. *Himantolophus* sp A., A—lateral view, B—illicial apparatus
New species, common name— Indian football fish**,**
Material—36708, ♀, 150 mm SL, Andaman Sea, 635 m depth

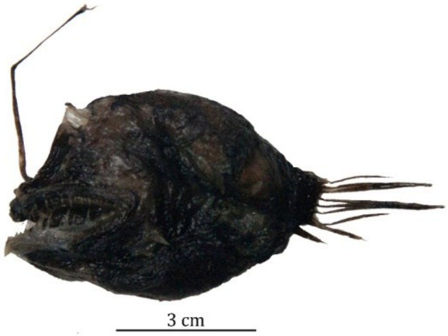

Figure 3.35. *Oneirodes* sp. A, lateral view
New species, common name—Indian dreamer, Material—32202, 65 mm SL, ♀, Arabian Sea, 1000 m depth

Figure 3.36. *Oneirodes* sp.
Material—30506, 160 mm SL, Arabian Sea, 923 m, totally damaged

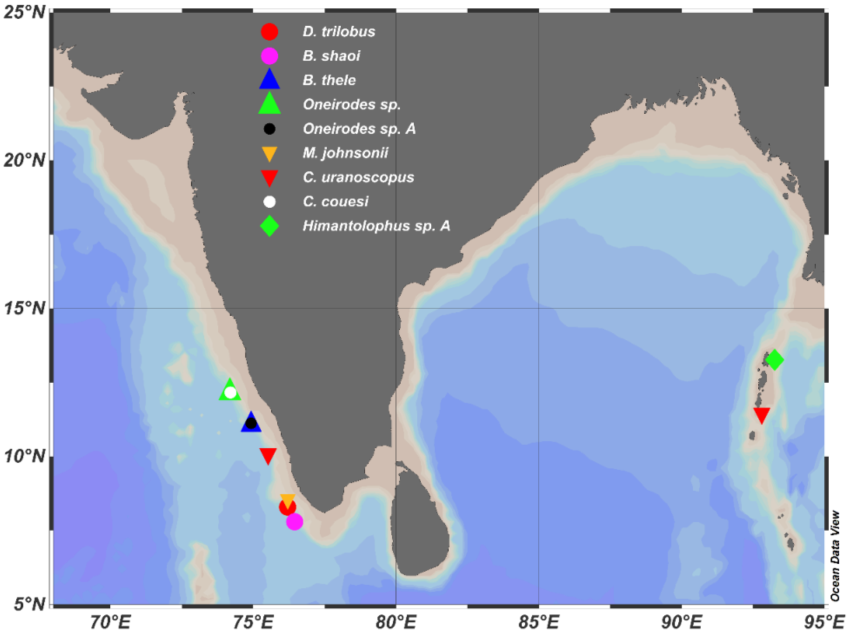

Figure 3.37. Map showing distribution of Ceratiodei species in the Indian EEZ. Species— *Diceratias trilobus*; *Bufoceratias shaoi; Bufoceratias thele; Oneirodes* sp.*; Oneirodes* sp. A; *Melanocetus johnsonii; Ceratias uranoscopus*; *Cryptopsaras couesi* and *Himantolophus* sp. A.

Table 3.1. Updated check list of Lophiiformes fishes in the Indian EEZ

Si No	Family/ Species	Area	Presence	References	Remarks
I	**Lophiidae Rafinesque, 1810**				
1	*Lophiodes lugubris* (Alcock, 1894)	AS	√	Alcock 1894; Present study	
		BOB	√	Present study	New record
		AN	√	Present study	New record
2	*Lophiodes mutilus* (Alcock, 1893)	AS	√	Sajeevan *et al*. 2009; Venu 2009; Present study	
		BOB	√	Alcock 1893; Present study	
		AN	√	Present study	New record
3	*Lophiodes triradiatus* (Lloyd, 1909)	AS	√	Lloyd 1909; Ho *et al.* 2014; present study	
		BOB			
		AN	√	Present study	New record
4	*Lophiodes gracilimanus* (Alcock, 1899)	AS	√	Alcock 1899; present study	
		BOB			
		AN	√	Present study	New record
5	*Lophiomus setigerus* (Vahl, 1797)	AS	√	Alcock 1889; present study	
		BOB	√	Alcock 1889	
		AN	√	Alcock 1889	
II	**Family Chaunacidae Gill, 1863**				
6	*Chaunax multilepis* Ho HC, Meleppura RK & Bineesh, 2016	AS	√	Present study	New species
		BOB	√	Present study	
		AN	√	Present study	
7	*Chaunax* sp. A	AS	√	Present study	New species
		BOB			
		AN			
8	*Chaunax apus* Lloyd, 1909	AS	√	Present study	New record
		BOB	√	Lloyd 1909; present study	
		AN	√	Present study	New record

9	*Chaunax penicillatus* McCulloch, 1915	AS			
		BOB			
		AN	√	Present study	New record
III	**Ogcocephalidae Gill, 1893**				
10	*Halieutopsis stellifera* (Smith & Radcliffe, in Radcliffe, 1912)	AS	√	Present study	New record
		BOB			
		AN	√	Present study	New record
11	*Coelophrys micropa* (Alcock, 1891)	AS	√	Alcock 1891; present study	
		BOB	√	Alcock 1891; present study	
		AN	√	Alcock 1891; present study	
12	*Halicmetus ruber* Alcock, 1891	AS	√	Alcock 1891; present study	
		BOB	√	Present study	New record
		AN	√	Alcock 1891; present study	
13	*Halieutaea* sp. A	AS	√	Present study	New species
		BOB			
		AN			
14	*Halieutaea stellata* (Vahl, 1797)	AS	√	Alcock 1899; Sajeevan *et al* 2009; Venu 2009; present study	
		BOB	√	Alcock 1899	
		AN	√	Present study	New record
15	*Halieutaea coccinea* Alcock, 1889	AS	√	Sajeevan *et al*. 2009; Venu 2009; Present study	
		BOB	√	Present study	New record
		AN	√	Alcock 1889; present study	
16	*Halieutaea indica* Annandale and Jenkins, 1910	AS	√	Present study	New record
		BOB	√	Annandale and Jenkins 1910	
		AN			
17	*Halieutaea nigra* Alcock, 1891	AS	√	Alcock 1891; Sajeevan *et al*. 2009	
		BOB			
		AN	√	Alcock 1891	

18	*Halieutea fumosa* Alcock, 1894	AS	√	Alcock 1894	
		BOB	√	Alcock 1894	
		AN			
19	*Halieutopsis* sp. A	AS	√	Present study	New species
		BOB			
		AN			
20	*Halieutopsis* sp. B	AS			
		BOB			
		AN	√	Present study	New species
21	*Halieutopsis nudiventer* (Lloyd, 1909)	AS			Uncertain
		BOB	√	Lloyd 1909	
		AN			
22	*Malthopsis lutea* Alcock, 1891	AS	√	Present study	New record
		BOB			
		AN	√	Alcock 1891; present study	
23	*Malthopsis mitrigera* Gilbert & Cramer, 1897	AS			
		BOB			
		AN	√	Lloyd 1909	
24	*Malthopsis gigas* Ho and Shao, 2010	AS			
		BOB			
		AN	√	Present study	New record
25	*Malthopsis* sp. A	AS			
		BOB			
		AN	√	Present study	New species
26	*Dibranchus nasutus* Alcock, 1891	AS	√	Alcock 1891	
		BOB			
		AN	√	Alcock 1891	
IV	**Ceratiidae Gill, 1869**				
27	*Ceratias uranoscopus* Murray, 1877	AS	√	Venu 2009	
		BOB			
		AN	√	Present study	New record
28	*Cryptopsaras couesi* Gill, 1883	AS	√	Present study	New record
		BOB			
		AN	√		
V	**Diceratiidae Regan and Trewavas, 1932**				

29	*Diceratias trilobus* Balushkin and Fedorov, 1986	AS	√	Present study	New record
		BOB			
		AN			
30	*Diceratias bispinosus* (Günther, 1887)	AS			
		BOB	√	Alcock 1890	
		AN			
31	*Bufoceratias shaoi* Pietsch, Ho and Chen, 2004	AS	√	Present study	New record
		BOB			
		AN			
32	*Bufoceratias thele* (Uwate, 1979)	AS	√	Present study	New record
		BOB			
		AN			
VI	**Himantolophidae Gill, 1861**				
33	*Himantolophus* sp. A	AS			
		BOB			
		AN	√	Present study	New species
VII	**Oneirodidae Gill, 1878**				
34	*Lohodolos indicus* Lloyd, 1909	AS	√	Lloyd 1909	
		BOB			
		AN			
35	*Oneirodes* sp. A	AS	√	Present study	New species
		BOB			
		AN			
VIII	**Melanocetidae Gill, 1879b**				
36	*Melanocetus johnsonii* Günther, 1864	AS	√	Hashim 2012; present study	
		BOB			
		AN			

AS- Arabian Sea; BoB- Bay of Bengal; AN- Andaman Sea

3.3.3 Discussion

A total of 36 species were recorded and documented in the course of the present study period. Among the 21 species previously known, 7 species were not encountered in the present study; *Halieutopsis nudiventer* (Lloyd, 1909); *Malthopsis mitrigera* Gilbert and Cramer, 1897; *Dibranchus nasutus* (Alcock, 189) and *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 resemble *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, 2003 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.

Present study has contributed 7 new records of species from the entire Indian EEZ (21 new records area wise; AS, BoB and AN) and 8 species new to the science (1 new species, *Chaunax multilepis* and 4 new records, (*Halieutopsis stellifera*, *Diceratias trilobus*, *Bufoceratias shaoi* and *Ceratias uranoscopus*) are published, Annexure 1). Area wise new records includes Arabian Sea (8 species); Bay of Bengal (3 species); Andaman Sea (10 species). 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 them only 9 species were found 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 world wide, Pietsch 2009; Prokofiev 2014; Ho *et al.* 2016a; Rajeeshkumar *et al.* 2017) from the study area. 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 (Rajeeshkumar *et al.* 2017) is described from Western Indian Ocean at depths ranging from 380-600 m. Species not included in the present study hence the study are restricted to Indian EEZ.

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Chapter **4**

BIOLOGY OF LOPHIIFORMES

Contents

4.1 Biomass Estimation

4.1.1 Introduction

Biomass represents the density of a population or a community in a particular area at a given time. It represents organically bound carbon in a particular area (Haedrich and Merrett 1992). Biomass of an ecosystem is directly dependent on the availability of organic matter and its utilization at different trophic levels. Generally high-biomass areas and fisheries occur in shallow waters, on continental shelves and in epipelagic upwelling zones. Exceptions are hydrothermal vents that exclusively depend on chemical or thermal source of energy (de Angelis *et al.* 1993; Norse *et al.* 2012; Dick *et al.* 2013). Deep bottom organisms are dependent upon a meager detritus influx. The detritus sinking towards the bottom become more degradable and only negligible quantities will be available at the bottom (Carney 2001). Information on the distribution of biomass, numerical abundance of species and niche occupied by each species can provide valuable information on the functioning of an ecosystem. Biomass is often estimated by determining the wet weight of the community constituents (either total weight/ km^2 or numerical abundance/ km^2 (Kropp 2004).

4.1.2 Methods and materials

For biomass estimation swept area method was followed. Numerical abundance were calculated as number of individuals per km^2 (Detailed methodology is discussed in Chapter 2). Biomass were calculated for all the 78 stations; average station biomass, biomass of lophiiformes and numerical abundance were calculated separately for AS. BoB and AN. Two depth zones were identified in these study areas representing the 200 to 600 m depth zone and greater than 600 m zone (>600). Biomass and abundance of lophiiformes were estimated for these two depth zone and are expressed in Figures and Tables.

4.1.3 Results

Biomass ranges between 28.4 to 21185.4 kg/km^2 with a mean of 2626.9 kg/km^2. Biomass of lophiiformes ranged between 0.17 to 223.4 kg/km^2 with mean of 28.2 kg/km^2. Numerical abundance ranged between 8 and 1763 individuals per km^2 (Ind /km^2). Area wise (AS, BoB and AN) average biomass of stations, and abundance of lophiiformes are given in Figure 4.1 and Table 4.1. Arabian Sea had an average biomass of 3627 kg/km^2 (27.1 for lophiiformes) from 33 stations; Bay of Bengal had 2128(8) kg/km^2 from 13 stations and Andaman Sea had 1797(37.8) kg/km^2 from 32 stations. Depth wise average biomass of lophiiformes and numerical abundance were also estimated for AS, BoB and AN (Figure 4.2, Table 4.2). Two depth zones were selected for the study, 200 to 600 m and > 600m. In the Arabian Sea biomass of lophiiformes were almost equally distributed within the two depth zones; whereas in BoB depth zone >600 m show much higher biomass compared to the shallower zone. However, Andaman Sea show high biomass in 200-600 m zone than the deeper zone. In the case of numerical abundance of lophiiformes, abundance in all the three study areas was high in the 200-600 m zone compared to the zone above 600 m depth.

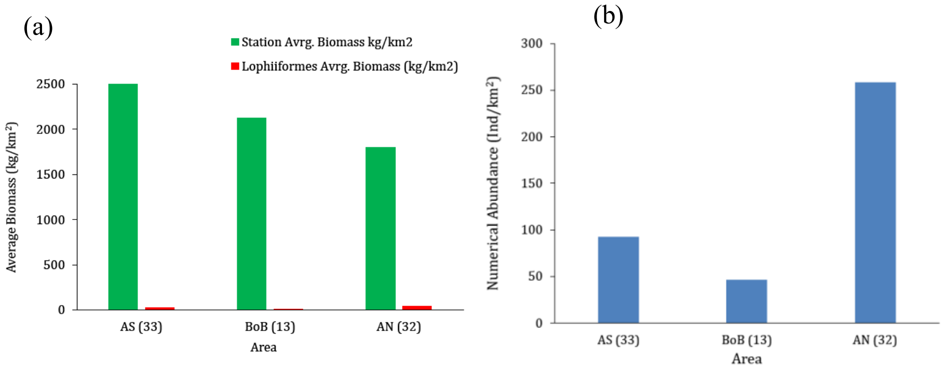


Figure 4.1. Average biomass (a); numerical abundance (b); of lophiiformes

Table 4.1. Details of Average Biomass and Abundance

Area	Station biomass kg/km^2	Lophiiformes biomass (kg/km^2)	Lophiiformes abundance (Ind/km^2)
AS (33)	3627	27.1	92
BoB (13)	2128	8	46
AN (32)	1797	37.8	258

AS- Arabian Sea, BoB- Bay of Bengal AN- Andaman Sea; no. of stations in parenthesis

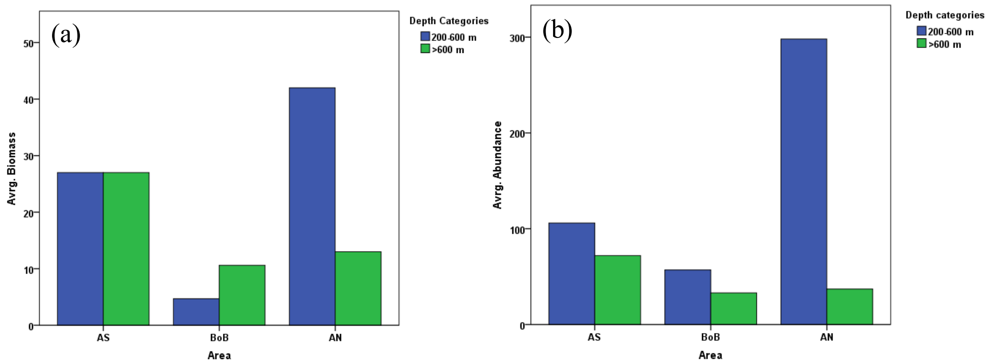


Figure 4.2. Depth wise average biomass (a); numerical abundance (b) of lophiiformes

Table 4.2. Average biomass & abundance of lophiiformes in the two depth strata's

Area	Depth zone (m)	Averg. Biomass (kg/km^2)	Abundance (Ind/km^2)
Arabian Sea	200- 600	27	106
	> 600	27	72
Bay of Bengal	200-600	4.7	57
	>600	10.6	33
Andaman Sea	200-600	42	298
	>600	13	37

4.1.4 Discussion

There is a clear global trend of logarithmic decrease in diversity, numerical abundance and biomass of fish species with increasing depth (Rowe *et al.*1982; Rowe 1983; Gage and Tyler 1991). With increasing distance from the productive surface (euphotic zone) waters, less biomass can be supported and fish populations become scanty. It appears that global fish biodiversity follows this depth-related energy constraint

(Priede and Froese 2013) as only 1-4% of the surface production reaches the deep-sea floor (Lampitt and Antia 1997).

In the present study, near equal biomass distribution in both the depth zones of Arabian Sea were obtained. This may be because of uneven sampling; only 14 trawl operations in the 200 to 600 m zone and 19 in the deeper zone. In BoB, unfavorable conditions (water current, bottom nature) for trawling or poor efficiency of sampling gears might have contributed to the low biomass from the 200-600 m depth zone. Perfect biomass distribution trends for deep-sea environment, ie; decreasing biomass with increasing depth, were obtained for Andaman Sea. Present study shows a decreasing tendency in numerical abundance towards greater depth. Jayapraksh *et al.* (2006); and Venu (2009) observed a trend in decreasing biomass, abundance and diversity of deep-sea fishes with increasing depth from the southwest coast (Arabian Sea) of India. Many authors also observed that a depth wise decrease in the biomass and abundance is a general deep-sea phenomenon (Etter and Grassle 1992; Flach and Heip 1996; Carney 2001; Levin *et al.* 2001; Rex and Etter 2010).

Generally biomass of lophiiformes fishes are comparatively less than other groups obtained in the present study. This may be because of their extremely flattened, small sized body and weight (especially *Malthopsis* sp., *Halieutopsis* sp., *Coelophrys* sp. and other ogcocephalids).

4.2 Length-Weight Relationships (LWRs)

4.2.1 Introduction

A better understanding on the length-weight relationships (LWRs) is important information for the fisheries management. LWRs are widely used in understanding the growth pattern, to predict the weight of the fish from their length (unless age is determined by proper age readings of structures such as scales, otoliths or bones), to estimate weight at age, to assess age structure and function of fish populations (Le Cren 1951; Pauly 1993; Morey *et al.* 2003; King 2007; Froese 2006; Froese *et al.* 2011; Froese *et al.* 2014). It helps morphological comparisons of different population from different regions and caution the methodology in terms of fishing gears, mesh size, season etc. (Froese 2006; Petrakis and Stergiou 1995). However, the main purpose of LWRs is to predict weight from length, because weight determinations on a moving boat or in the field are often difficult or limited.

LWRs provide valuable information on fish species in a given geographic locality. In fish, size is generally more biologically relevant than age, mainly because several ecological and physiological factors are more size-dependent than age-dependent. Therefore, variability in size has important implications for diverse aspects of fisheries science and population dynamics. For instance, the functional regression "*b*" value represents the body form and is directly related to the weight affected by ecological factors such as food supply, gonadal development, spawning conditions and other factors that may include sex, age, fishing time, area etc. The LWR of deep-sea fishes are relatively less known compared to pelagic fish species (González *et al.* 2006; De La Hoz 2016; Kumar *et al.* 2016). Information on the biology, distribution and life history patterns of deep-sea fishes of India are poorly known (Sreedhar *et al.* 2013; Venu and Kurup 2002a, b; 2006b; Hashim 2012; Venu 2009; Vinu 2017). Very few studies have been conducted to understand the LWR of deep-sea fishes from Indian waters (Sreedhar *et al.* 2013; Jayapraksh *et al.* 2006; Kumar *et al.* 2016; Vinu 2017). It is well recognized that not much information is available on the growth characteristics of anglerfishes, especially from the deep-sea waters, globally (Froese and Pauly 2018). The present study provides the first LWR estimates of five deep-sea anglerfishes from the Andaman and Nicobar Sea. Present study is expected to contribute baseline information towards the growth patterns of less studied deep-sea anglerfishes which exhibits unique growth characteristics and to validate the growth parameters of data poor fishes estimated using Bayesian models deposited in FishBase.

4.2.2 Methodology

Samples were collected during the exploratory fishery survey of FORV *Sagar Sampada* of the Centre for Marine Living Resources and Ecology, Ministry of Earth Sciences, Government of India undertaken during April 2016 in the Andaman Sea. High speed demersal trawl II (HSDT II, crustacean version, cod-end mesh size 40 mm) was used for sample collections from depth ranges of 300-650 m. Basic information on depth of operation, trawling duration, catch in weight and its composition were recorded onboard. Samples were identified up to species level following standard identification keys (Alcock 1891;

Bradbury 1967, 1980, 1999; Caruso 1981, 1989). Standard length and weight of the fish were taken at an accuracy of 0.1 cm and 0.1 g using digital vernier caliper and electronic balance, respectively. The samples were preserved in 10% formaldehyde after measurement and weighing.

The relationship between the length and weight is expressed by the regression equation $W = a\,L^b$ (Froese 2006; Froese *et al.* 2014; Le Cren 1951; Zar 1999; Ricker 1973) converted in to its logarithmic form $\mathrm{Log10}\,W = \mathrm{Log10}a + b\,\mathrm{Log10}\,L$ where W is body weight, L is standard length, '*a*' and '*b*' are regression constants (Beverton and Holt 1957). The strength of the relationship was assessed by coefficient of determination (r^2). All the values were converted in to its logarithmic form for excluding the outlier values, if any (Froese *et al.* 2011). In this study curvilinear plots were used with fish standard length and weight to observe the outlier values in the dataset (Froese 2006).

Student's *t-test* was applied to verify whether the *b* value estimated is significantly different from the isometric value 3, indicating the type of growth (Pauly 1993). Analysis of covariance (ANCOVA) was used to determine sexual dimorphism if any in the relationships.

4.2.3 Results

Table 4.3. provide the species name, sample size, minimum and maximum length (SL) and weight (TW), regression parameters *a* and *b*, 95% CL of *a* and *b,* and coefficient of determination, r^2.

Sample size ranged from 43 (*C. apus, L. lugubris*) to 196 (*C. multilepis*). The lowest and highest SL obtained for *H. coccinea* and *L. lugubris* were 3 and 19.5, respectively. Highest total weight was for *L. lugubris* and lowest for *M. lutea* (260 and 8.32 g, respectively). No significant difference in growth pattern among sexes were noticed for all the five species (ANCOVA, P>0.05). Hence sexes were combined to estimate growth parameters. The *b* value of the species varied between 1.8 (*C. mutlilepis*) to 2. 8 (*M. lutea*); r^2 value ranged from 0.97 (*C. multilepis*) to 0.82 (*H. coccinea*). LWRs of five species are given in Fig.4.3.a—f.

4.2.4 Discussion

Even though Indian EEZ is rich in deep-sea resources, adequate knowledge of LWRs of many of the fishes are lacking. LWRs of the five deep-sea anglerfishes presented in this study are the first time estimates from Indian Seas and perhaps first time estimates globally (Froese and Pauly 2018). However, caution need to be exercised when considering the growth characteristics especially on the seasonal and inter-annual variations, since the present study is based on onetime snapshot sampling during April 2016.

Comparison of growth parameters with previous estimates for these species were not possible, as our estimates forms the first information. However, the growth parameter *a* estimated for *Lophius piscatorius* (a=0.263), a sister genus, is comparable with our estimate for *Lophiodes lugubris* (0.4), (Quincoces *et al.* 1998). The *b* value estimated for *L. lugubris* is low (2.1) compared with *L. piscatorius* (2.84). The reason for the observed difference in the b value between the two species may be because previous workers measured the gutted weight for *L. piscatorius* . Contrary to this observation, some researchers report very low *a* and high *b* values for *L. piscatorius* (*a* value range from 0.023-0.046 and *b* value range from 2.70-2.84) from the Atlantic waters (Mahé *et al.* 2016; Ofstad and Laurenson 2007; Silva *et al.* 2013). Differences in these estimations could be regional differences in the growth patterns as confirmed by various authors (Mommsen 1998; Hossain *et al.* 2009). Present study did not find any significant difference between the sexes in growth pattern which is in confirmity with the previous findings of Quincoces *et al.* (1998).

Many deep-sea fishes show negative allometric pattern of growth as observed by various authors (al Sakkaff and Essen 1999; Jayaprakash *et al.* 2006; Sangun *et al.* 2007). Vinu (2017) observed negative allometric growth pattern for *Benthobatis moresbyi,* a dorso-ventrally compressed elasmobranch from the south west coast of India. Growth parameters estimated for *M. lutea* based on Bayesian models are comparable with our observations (Froese and Pauly 2018). There are many factors that affect the LWRs of fishes, such as maturity stages, geographical locality, food supply, physico-chemical properties of water etc. (Mommsen 1998; Thomas *et al*, 2003; Hossain *et al*. 2009; Kumar *et al*. 2016). It is worthy to notice that the congeners *C. multilepis* and *C. apus* show almost similar *b* values (1.80, 1.88) which indicates that both species exhibits same pattern of growth. The use of non-standardized sampling procedures is also reported to influence the estimation of growth parameters (Morey *et al*. 2003). However, snap-shot sampling by far is not adequate to judge on allometry of a species, and long-term observations are suggested. Present work, however is expected to be useful to validate and improve the predictability of LWR estimates of data deficient species using Bayesian Models used in FishBase.

Table 4.3. Length–weight relationships (LWRs) of five deep-sea anglerfishes from Andaman Sea collected during April 2016

		Standard Length (cm)		**Total Weight (gm)**		**Regression parameters**				
	N	**Min**	**Max**	**Min**	**Max**	***a***	***b***	**95% CL *a***	**95% CL *b***	r^2
C. apus	43	5.9	11.5	13	48	0.46	1.88	0.35-0.66	1.76-2.01	0.95
C. multilepis	196	3.8	14.5	11	130	1.23	1.8	1.22-1.34	1.75-1.84	0.97
H. coccinea	113	3	14	4	140	0.22	2.33	0.14-0.32	2.12-2.53	0.82
L. lugubris	43	7.2	19.5	20	260	0.4	2.11	0.20-0.75	1.85-2.37	0.87
M. lutea	49	3.5	7	1.3	8.32	0.04	2.76	0.03-0.06	2.58-2.95	0.95

a and *b* = parameters of the LWR equation; CL-confidence limit; max-maximum; min-minimum; N-sample size; r^2-coefficient of correlation. Tentative estimates due to low sample size or too narrow size range.

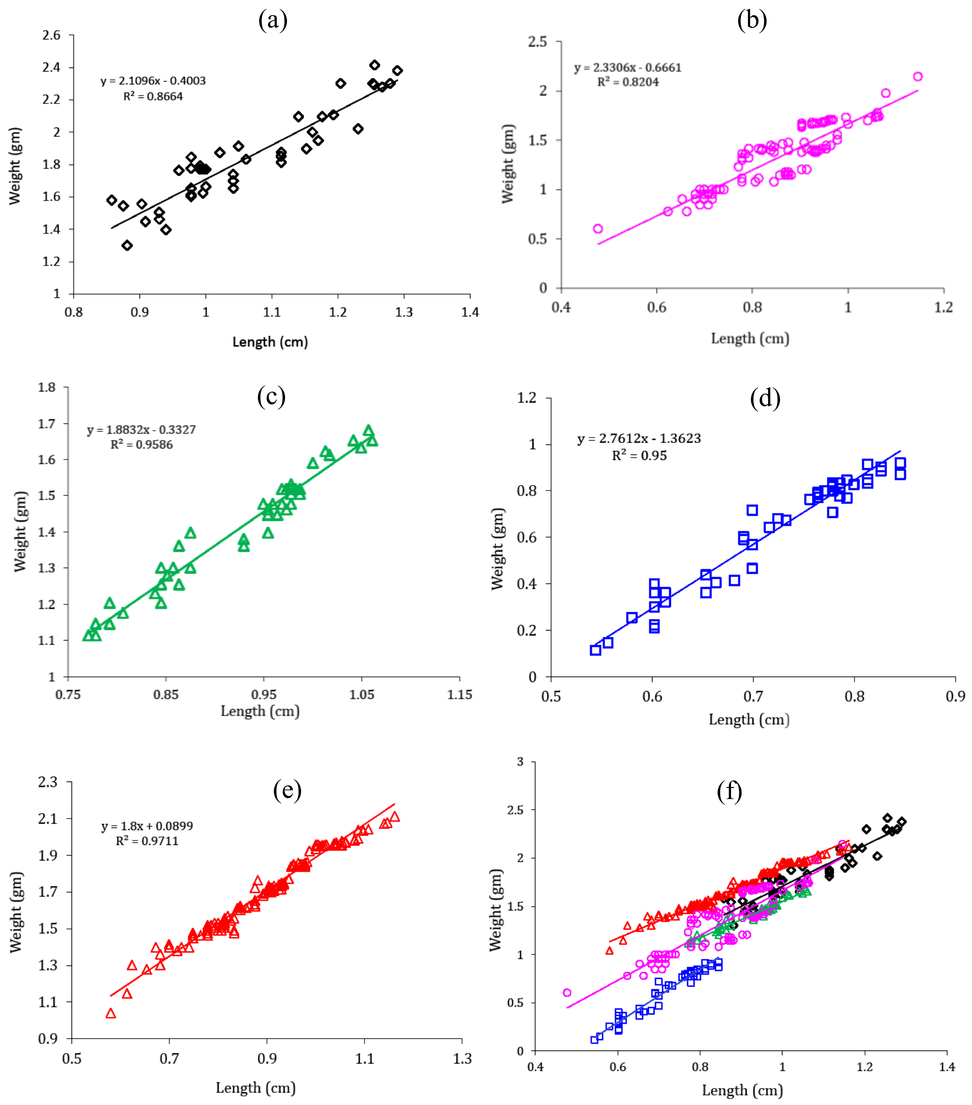


Figure 4.3. LWRs—(a) black diamond *L. lugubris*; (b) violet circle—*H. coccinea*; (c) green triangle—*C. apus*; (d) blue square—*M. lutea*; (e) red triangle—*C. multilepis*; (f) combined LWRs of all the five species.

4.3 Food and Feeding

4.3.1 Introduction

Availability of food is an important factor regulating and influencing growth, fecundity, migration and abundance of fish stocks. Seasonal and diurnal abundance of desired food items may be responsible for the horizontal and vertical movements of the fish stocks (Philip 1994). Feeding is the means by which an organism ingests the food material from its habitat. The food of an organism can be divided into basic food, which is the most preferred food item of a particular organism; occasional food, which is present in the gut occasionally; obligatory food, which is preferred by the organism when available in sufficient quantities; accidental food items which are consumed accidentally when the fish feeds (Srivastava 1999). Food and feeding of fish depends on a number of environmental and intrinsic or biological variables.

Stomach content analyses have long been used to assess diet composition and assign trophic levels in marine organisms (Hyslop 1980; Cortés 1999). Quantitative analyses of stomach contents provide an important tool to understand and elucidate predator-prey interactions, feeding behavior patterns (Preciado *et al.* 2006) and ontogenetic shifts (Armstrong *et al.* 1996). In addition, estimation of prey abundance, frequency of occurrence, weight and relative importance of food items can provide critical ecological information (Joyce *et al.* 2002) and contribute to our understanding of deep water systems (Arendt and Olney 2001, Laurenson and Priede 2005).

Knowledge on food and feeding biology of many deep-sea fishes are presently available globally (Marshall 1965; Percy and Ambler 1974; Golovan 1978; Crabtree *et al*. 1991; Drazen *et al*. 2001; González *et al*. 2006) and many works are also reported from Indian waters (Philip 1994; Venu and Kurup 2002 a, b; 2006 a, b; Karuppasamy *et al*. 2008; Hashim 2009; Vinu 2017). However, comparatively lesser descriptions on lophiiformes are reported from world oceans. Espinoza and Wehrtmann (2008) analyzed the stomach content of the threadfin anglerfish *Lophiodes spilurus* from the central Pacific of Costa Rica. Preciado *et al*. (2006) studied gut content of *Lophius budegassa* from the North Atlantic coast of Spain. Armstrong *et al*. (1996) studied the feeding habit of goose fish *Lophius americanus* from North Atlantic Ocean. Stomach contents of *Lophius gastrophysus* from Brazil were documented by Valentim *et al*. (2007, 2008). However, there are no previous studies on the gut contents of Order Lophiiformes from Indian waters.

4.3.2 Methodology

Gut content analysis were done on five most abundant species from Andaman Sea. (depth 300-500 m., except *M. lutea*, 650 m. April 2016). Stomach content analyzes were performed following the *Frequency of Occurrence* method (Hyslop 1980), in which each stomach content was examined and individual food organisms were sorted and identified. The number of stomachs in which each item occurs is recorded and expressed as a percentage of the total number of stomachs examined.

Frequency of Occurrence **Oi= P/ Ji**

Where, **'Ji'** is number of fish containing prey **'i'** and **'P'** is the number of fish with food in their stomach.

Studies on feeding intensity were performed by analyzing dissected stomachs and examining stomach fullness through visual observation. Stomachs were classified as Full, 3/4 Full, 1/2 Full, 1/4 Full and empty (value given as 1, 0.75, 0 .5, 0.25 and 0 respectively). Stomach fullness in each species was worked out. Maximum number of stomachs were examined (n=196) for *C. multilepis* and minimum (n=29) for *M. lutea*. 43 stomach were examined for *C. apus*; 70 for *L. lugubris* and 129 for *H. coccinea*. Diet similarity among the five species were analyzed with Bray Curtis resemblance.

4.3.3 Results

The stomach fullness of each species are represented in Figure 4.4. Full stomachs were observed in majority (50%) of the fishes examined. Food items in the stomach included fishes, crustaceans and trace quantity of gastropods. Fishes contributes 42%, shrimps 25%, digested matter 21%. In *C. apus* 12% of stomach examined were without any food materials. In *C. multilepis* 52% stomachs examined had digested materials forming the major component followed by shrimps (18%), fishes (16%), crabs and empty stomachs (7%). In the bat fish *M. lutea,* fishes represent 45% food, followed by crustacean (20%). The gut content of *L. lugubris* also show fishes and crustaceans as the most preferred prey items. But in *H. coccinea,* shrimps contributes 45% of the diet followed by fish (16%) diets. Percentage composition of diet in each species is given in Figure 4.5. Diet similarity among the five species were measured by Bray Curtis resemblance (Fig. 4.6), which shows *L. lugubris*, *C. apus* and *M. lutea* sharing common food in their diets. This in turn share 80% similarity with the diets of *C. multilepis* and 75% similarity with *H. coccinea*.

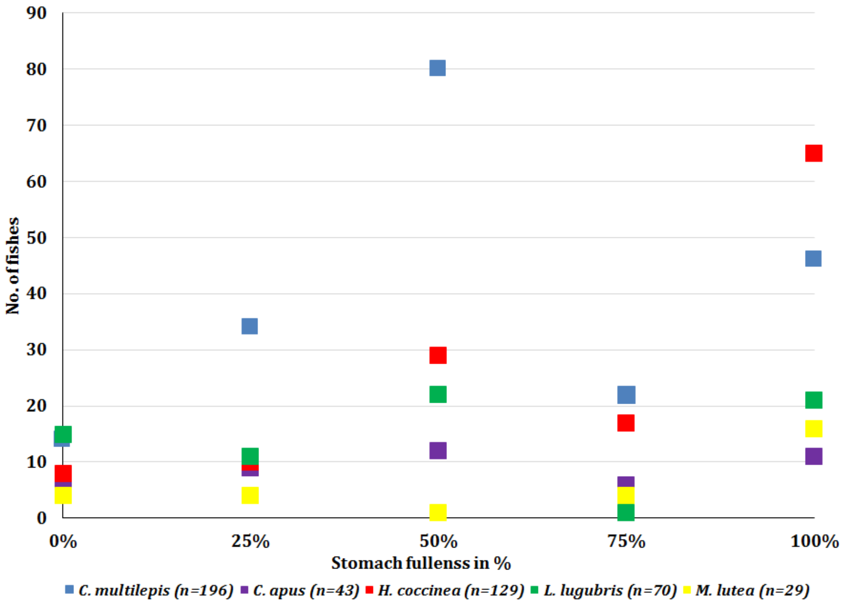


Figure 4.4. Stomach fullness in five species of lophiiformes from Andaman Sea.

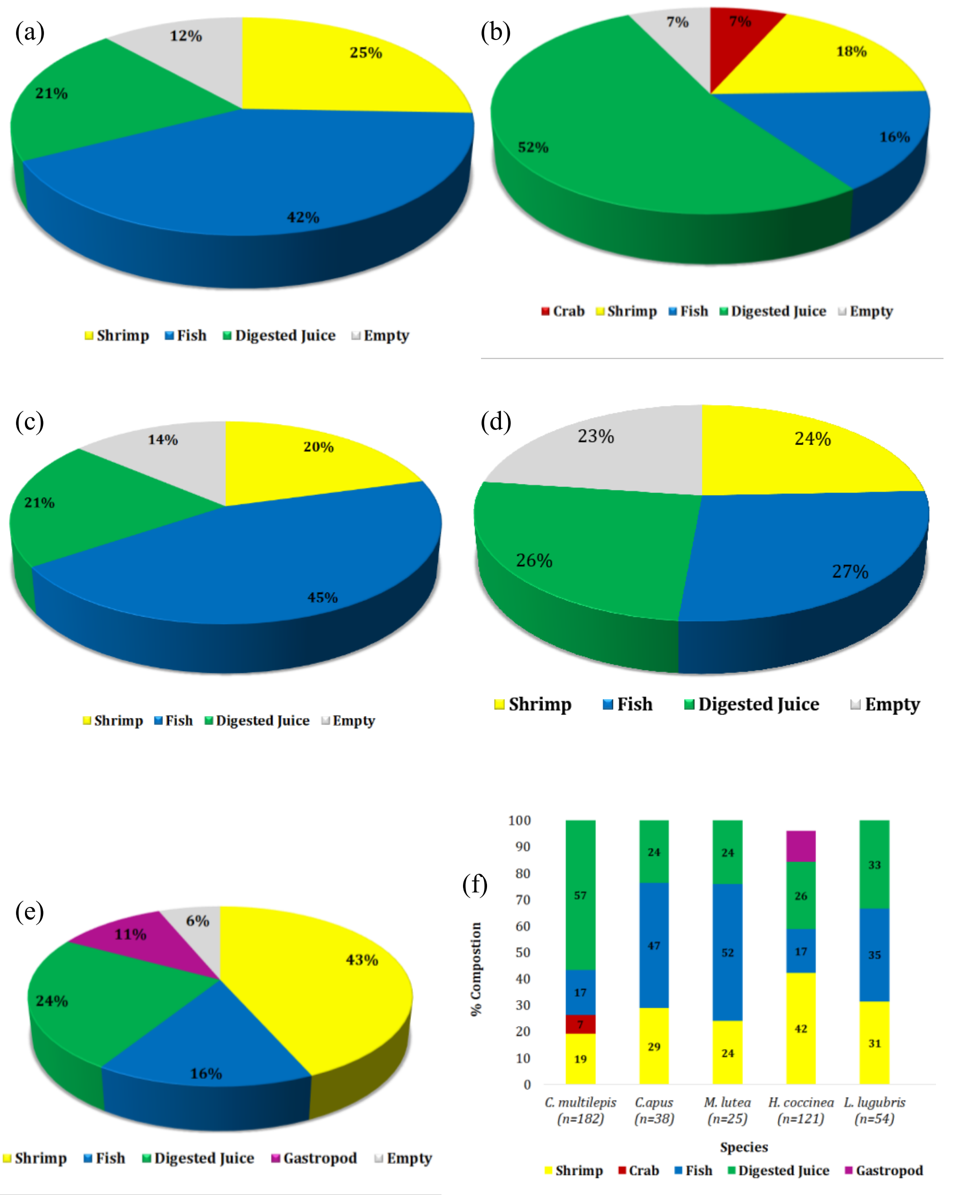


Figure 4.5. Parentage composition of diets, a— *C. apus*; b— *C. multilepis*; c—*M. lutea* d—*L. lugubris*; e—*H. coccinea*; f—summary (fishes with empty stomach excluded)

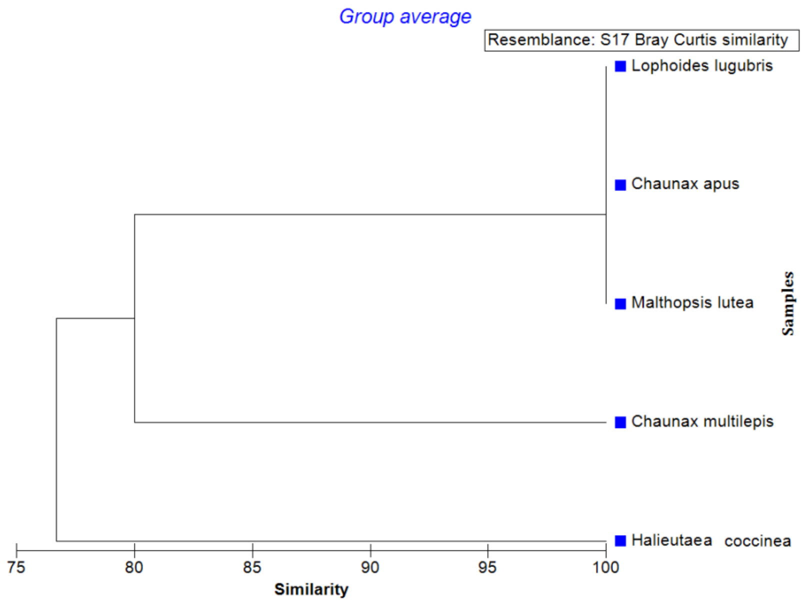


Figure 4.6. Bray Curtis resemblance of diets among five species.

4.3.4 Discussion

Gut content analyses can provide critical information on trophic levels and relationships between organisms in an ecosystem, which in turn helps fishery resource management. What a fish eats as part of its normal diet is often difficult to determine, especially in fishes that are taken from great depths. Fishes trapped in the confined space of cod end of the net, attempt to escape, bite and sometimes swallow each other. Due to the pressure gradient they often regurgitate the stomach contents. In the present study 'net feeding' of *Lophiodes* spp. was observed many times (half swallowed condition, undigested food materials (Fig. 4.7a). All lophiiform fishes studied to date are primarily piscivorous (Bertelsen 1951; Randall 1967; Pietsch and Grobecker 1987) utilizing their lures to attract the prey. Major food items encountered in the stomach contents include fishes and crustaceans; fishes mainly represented by its vertebrae, spines and otolith; whereas crustacean, especially shrimps occur in partially/fully digested state. Though it is not possible to identify the prey items from the digested juice, its colour can give a hint as to whether it contains shrimp or not. Usually, digested shrimps retains its red colour. Digested matter of shrimps found in the stomachs of *H. coccinea* (Fig. 4.7b). *Syngrops* sp., *Gadiiformes* sp., *Heterocarpus* sp., *Arestes* sp. etc were observed from the stomach of *L. lugubris* (Fig. 4.7c). Other fishes encountered from the gut during the study includes *Chlorophthalmus bicornis*, *Cubiceps* sp., *Synagrops japonicus*, *Polymixia fusca* and shrimps mainly *Acanthephyra fimbriata*, *Aristeus alcoki*, *Heterocarpus woodmasonii*, *Plesionika spinipes* etc. Present results are consistent with previous reports on the threadfin anglerfish *Lophiodes spilurus* from the central Pacific of Costa Rica, which revealed that large portion of the stomachs analyzed were empty (52%) and individuals with filled stomachs (n=95) contained exclusively crustaceans (30%) and teleost fish (70%) as the two major components of their diet (Espinoza and Wehrtmann 2008). Preciado *et al.* (2006) found that black anglerfish *Lophius budegassa* from the North Atlantic coast of Spain feed mainly on small benthic fish. Similar results were observed for *Lophius piscatorius* (white anglerfish) from Shetland Islands, UK (Laurenson and Priede 2005). Studies of Valentim *et al.* (2007) showed that *Lophius gastrophysus* from Brazilian waters is essentially piscivorous, with predominance of fish in the stomach contents. Studies of Soares *et al.* (1993); Muto *et al.* (2005) revealed that stomach contents of *Lophius gastrophysus* highlighs the importance of fish in their diet. Tendency for a greater consumption of fish was also observed by different authors for the congeneric species (Crozier 1985; Armstrong *et al.* 1996) of the family, often known as opportunistic feeders or sit-and-wait type feeders, that ambush prey which pass within range or make use of their angling apparatus to actively attract prey to the vicinity of their mouths (Armstrong *et al.* 1996). Evidence of cannibalism was recorded for lophiids, *Lophius americanus* from Northwest Atlantic (Armstrong *et al.* 1996; Johnson *et al.* 2007). Regarding the empty stomachs observed during the study, Fulton (1903) suggested that the frequency of empty stomachs indicates considerable intervals between meals.

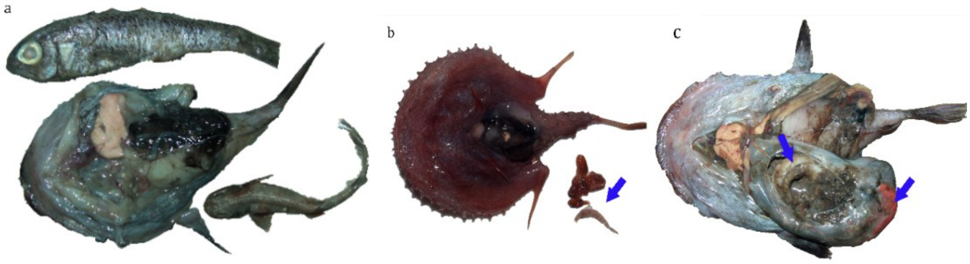


Figure 4.7. (a) Showing net feeding; (b—c) Gut contents of *H. coccinea L. lugubris* respectively

Existing studies on bat fishes (Ogcocephlidae) revels that rather than obvious adaptations for piscivory, their large ventrally directed mouth, enable them to catch small demersal prey such as gastropods, small crustaceans and polychaete worms. The present study examined two species of Ogcocephalids, *H. coccinea* and *M. lutea*. For *H. coccinea* a total of 129 stomachs were examined. Among them shrimps (43%) contributes major share, followed by small fishes (16%), gastropods (11%) and digested juice (24%) and empty stomach (6%). Similarly among the 29 stomach examined in *M. lutea*, major contribution came from small fishes and crustaceans. Previous studies of its congeneric species *Halieutichthys aculeatus*, *Ogcocephalus declivirostris* from Gulf of Mexico recorded that they mainly feed on benthic associated small fishes, crustaceans, gastropods etc. (Nagareda and Shenker 2008). In the family *chunacidae*, their anterodorsally placed mouths enable them to catch benthic associated or demersal prey items especially fishes and shrimps.

Earlier studies reported that most of the stomachs are empty, female ceratioids are predominantly piscivorous, their stomach contains different kinds of meso and bathypelagic fishes, but also traces of several other groups such as crustaceans, cephalopods, holothurians. Feeding and growth of free-living ceratioid males stop at metamorphosis because of denticular jaws and inflexible teeth poorly suitable for capturing prey. Almost all female ceratioids like most of the teleosts, are gap-and-suck feeders. They engulf prey by creating negative pressure (suction pressure) inside the mouth (Liem 1970). Larval forms manly feed on copepods and chaetognaths. During the early stages of life they live and eat within the upper reaches of epipelagic zone (Pietsch 2009).

4.4 Reproductive Biology

4.4.1 Introduction

Maturity stages and fecundity

A variety of reproductive strategies exist among deep-sea fishes due to the extreme challenging environmental conditions. Hermaphroditism, extreme sexual dimorphism and unbalanced sex ratios are very common in the deep-sea environment (Shotton 2005). Generally deep-sea fishes have low metabolic rate, slow growth pattern and long life span. The slow growth rates are also reflected in the high age at maturity. Present study trying to provide a base line information on egg structure and maturity stage of species collected from the present study area.

Not much is known about the reproduction and early life history of lophiiform fishes. Detailed information is available for only a few members of the lophiidae, antennariidae, and many of the ceratioid families (Pietsch and Grobecker 1987; Pietsch 2009). Scattered bits of published data are also available for the tetrabrachiidae, brachionichthyidae, chaunacidae, and ogcocephalidae, but nothing has been reported for the lophichthyidae. Early stage development of escal structure and eyes in some ceratioidei deep-sea anglerfishes were reported by Munk (1964, 1992, 1998, 1999). Observations on courtship and spawning behavior have been reported for only a few antennariids. Eggs and larvae have been adequately described for 2 of the 28 known species of lophiidae (Pietsch 2009). In marine teleosts the structure of the egg is an indication of the systematic status of the species and its morphology is species-specific.

Generally in lophiiform fishes eggs are spawned encapsulated within a non-adhesive, balloon-shaped mucoid mass (Ray 1961) or, typically, a continuous, ribbon-like sheath of gelatinous mucous, often referred to as an "egg-raft" or "veil". These egg-rafts are complex structures that float freely at the surface. Within the ovaries individual egg floats in a separate chambers are provided with openings for the circulation of water (Rasquin 1958; Martin and Drewry 1978). This peculiar structure, differing considerably from any other ovarian product known in fishes, is an excellent device for broadcasting a large number of small eggs over great geographic distances facilitating development in relatively productive surface waters (Pietsch and Grobecker 1980, 1987). The reproductive strategy of black anglerfish (*Lophius budegassa*) is reported from northwestern Mediterranean Sea (Colmenero *et al.* 2013).

4.4.2 Methodology

Maturity stages were examined on four species viz; *L. luguris*; *L. triradiatus*; *M. lutea* and *C. multilepis* collected from Andaman Sea. (depth 300-650 m April 2016). The 5-stage classification of gonad was used to describe the maturity stages, which included visual quantification on the basis of shape and color of the gonads and the extent to which the ovary occupies the gut cavity (Qasim 1973; Kurup and Samuel 1991) (Table 4.4).

Fecundity- Absolute fecundity (AF) is the total number of eggs in the ovaries of a fish prior to spawning (Bagenal 1978). It can be done by direct counting of spawnable eggs in the female ovaries under stereo microscope. Relative Fecundity (RF) was obtained as the number of eggs per unit length (cm) or the number of eggs per unit weight (g) of fish.

Table 4.4. Maturity stages of ovary of deep-sea fishes

I	Immature	Gonad about 1/3 rd the length of the abdominal cavity. Ovaries thin, ribbon like
II	Maturing virgin or Recovering spent	Gonad occupy about 1/2 the length of the abdominal cavity. ovaries pinkish translucent, eggs visible under magnifying glass
III	Ripening	Gonad about 2/3rd of the abdominal cavity. Eggs large and readily seen. Ovary yellowish with granulated appearance
IV	Ripe	Gonad occupies the full abdominal cavity. Ovaries are distended and eggs are clearly seen and easily detachable
V	Spent	Gonad shrunken with loose walls. Ovary may contain few ripe eggs

4.4.3 Results

The egg mass is encapsulated in a huge gelatinous covering. *L. lugubris* (15.5 cm SL) showed maturity stage lll (ripening stage; eggs are relatively large and occupy 2/3rd of the abdominal cavity, eggs are yellowish in colour (Fig. 4.8 a—d Specimen 23.0 cm SL were in stage IV (Ripe stage), ovaries occupy full abdominal cavity, eggs are clearly seen and easily detachable (Fig. 4.8 e—f). Egg diameter varies between 0.24 mm to 0.519 mm, mean 0.34± 0.07. Fecundity in *L. lugubris* varied between 48000 eggs (8 cm SL) to 64320 eggs (12 cm SL). Maximum fecundity was observed in 23 cm SL specimen with 152746 eggs (single count was made).

Four specimens of *L. triradiatus* (6 to 6.5 cm SL) were found to be immature. But 14.7 cm SL were in stage II (maturing stage). Gonads occupy half of the abdominal cavity; eggs are small and strongly attached to the ovarian wall (Fig. 4.8 g—h). The diameter of eggs varies between 0.068 mm to 0.223 mm; mean diameter was 0.18± 0.046.

Eggs of *Chaunax* were also encapsulated in a gelatinous covering. RF value of *C. multilepis* varied from 9000 eggs (100 mm SL) to 40500 eggs (130 mm SL). It is also noted that *C. multilepis* with SL of 125 mm (Fig. 4.8 i—j) was in spent stage with retention of some eggs on the wall of ovary.

Chaunax apus (SL of 100 mm) was in the maturing stage (Specimens 4.3 cm SL and 5.5 cm SL were immature.). Many of the samples collected were either in immature or maturing stages.

Fully matured *M. lutea* (50 mm SL) were encountered during the study (Fig. 4.8. k—l). Egg diameter varied between 0.305 to 0.406 mm. RF was 60000 eggs. Specimen with 30 mm SL where in maturing stage (stage-II).

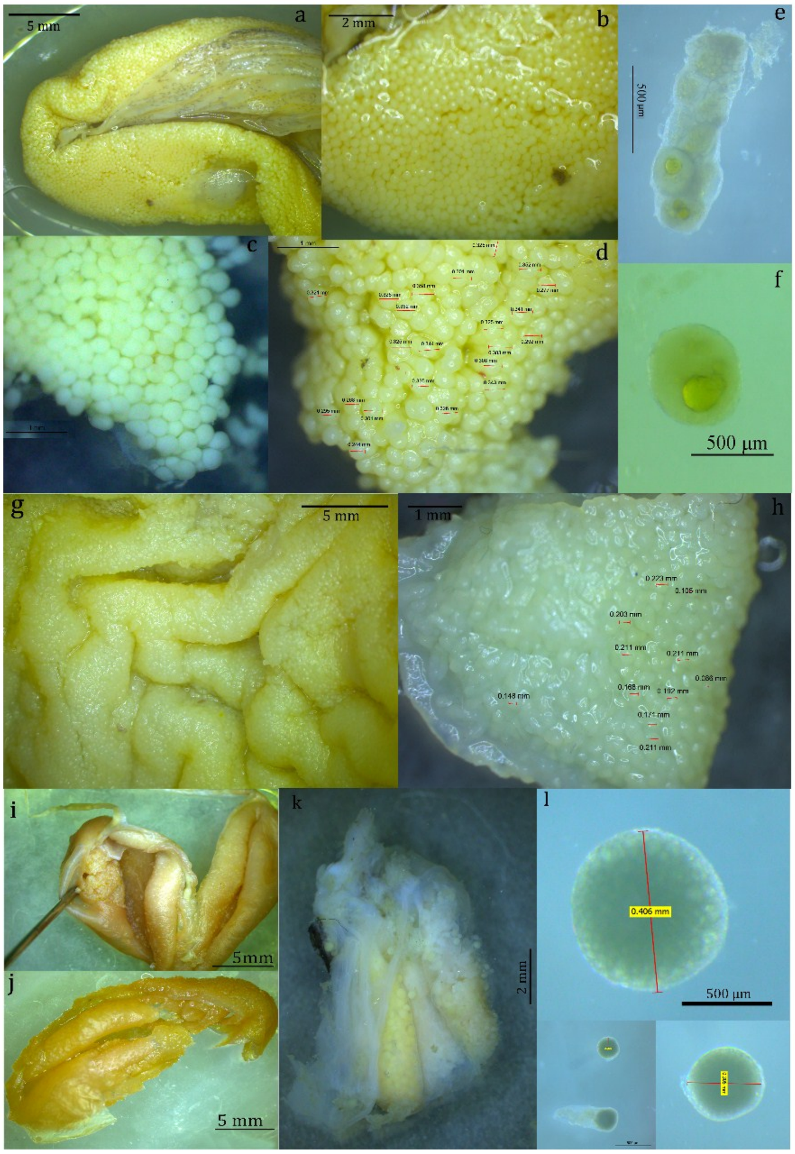


Figure 4.8. a—d gonad showing maturity stage III, e—f gonad in stage IV of *L. lugubris*; g—h, stage II of *L. triradiatus*; i—j spent stage of *C. multilepis*; k—l matured stage and detached egg of *M. lutea*

4.4.4 Discussion

Ovaries of *L. lugubris* at SL 18.5 cm (20.0 cm TL) were in the fully matured stage. Studies by Ofstad and Laurenson (2007) on *Lophius piscatorius* from northeast Atlantic Ocean (this species is one of the commercially exploited one in Atlantic Ocean) revealed that Length at first maturity (L50%) was at 83 cm (TL) for females and 57 cm for males. Most active spawning was recorded during February to April. Similar observations are recorded for *L. litulon* and *L. setigerus* (Yoneda *et al.* 2001).

Lophiodes lugubris from the Indian waters show relatively smaller size than its congeners from outside India; this may be the reason for sexual maturity at 19.0 cm SL in Indian specimens. Sexual maturity is related to gonad development and spawning period or feeding activities (food availability and feeding rate), geographical localities (Wootton 1990) and also attributed to differences in sampling especially length ranges. It is too premature to conclude the length at maturity of present specimens because of insufficient sampling size.

The present study provides a base line data on egg structure and RF of 4 lophiiformes collected from the Andaman Sea. In lophiiform fishes eggs are encapsulated with a gelatinous covering, which enable them to float freely at most productive surface waters. Testis of male is generally white, narrow, tubular in shape with varying sizes. Egg diameter of *L. lugubris* varies between 0.27 to 0.45 mm. In *M. lutea* ova were 0.305 to 0.406 mm in diameter. Approximate egg diameter of some of the certioids ranges from 0.16 to 0.28 mm (diceratiidae), 0.20 to 0.25 mm (melanocetidae); 0.2 to 0.4 mm (centrophrynidae and ceratiidae) (Pietsch 2009). The results presented above are based on a snapshot sampling. Frequent sampling is required for a better understanding of the reproductive strategy.

4.5 Sex ratio

4.5.1 Introduction

Fishes exhibit great diversity in reproductive strategies and associated traits (Helfman *et al.* 1997) such as breeding system, number of partners, gender role, spawning habitat, spawning season, fecundity, etc. Sex allocation theory describes how organisms should divide their resources between male and female for reproduction (Charnov 1982). In deep-sea habitat, chances of finding a pair is uncertain. Deep-sea anglerfishes show a wide variety of methods for reproduction, extreme sexual dimorphism and parasitism is displayed in many ceratioid families. Luring apparatus (esca) plays an important role in reproduction as well is in feeding. In some species it secretes chemically active compounds which may attract opposite sex. However, the complete process still unknown.

4.5.2 Methodology

Sex ratio: Male and females of each species were separated and the ratio was calculated as Male: Female (M:F). The deviation in the sex ratio from the hypothetical value was assessed using chi-square test (Rao and Yoon 1983).

4.5.3 Results

Sex ratio of five species were estimated (Table 4.5). For *C. multilepis* a total of 196 specimens ranging between 38 to 145 mm SL were studied. Sex ratio show 1: 1.3, a value statistically insignificant ($p>0.05$). For *C. apus*, 43 specimens ranging from 13 to 115 mm SL, were selected. Sex ratio was found to be 1: 1.04 ($p>0.05$). A total of 34 specimens of *M. lutea* selected for the study (35 to 67 mm SL) gave a sex ratio of 1:2.7. Ratio was skewed towards females and was statistically significant ($p<0.05$). For *H. coccinea,* (30 to 140 mm SL) specimens were selected and sex ratio was found to be 1:0.64, ($p<0.05$) and for *L. lugubris*, (70 to 98 mm SL) specimens were examined and the sex ratio was found to be 1:0.32 ($p<0.05$).

Table 4.5. Sex ratio

Species	**Male**	**Female**	**Immature**	**Ratio**	**X-square value**	**df**	**P- value**
C. multilepis	50	67	79	1:1.3	2.47	1	>0.05
C. apus	21	22	0	1:1.04	0.02	1	>0.05
M. lutea	9	25	0	1:2.7	7.53	1	<0.05
H. coccinea	77	50	3	1:0.64	5.74	1	<0.05
L. lugubris	28	9	6	1.0.32	9.75	1	<0.05

4.5.4 Discussion

The present study reveals that the species *C. multilepis* and *C. apus* obeys the general sex allocation theory in a population (1:1); where as in *M. lutea* sex ratio is skewed towards female (females dominated in the population). For *H. coccinea* and *L. lugubris* ratio is skewed towards male (male is dominant). Unbalanced sex ratios are very common in deep-sea environment (Shotton 2005). Female dominant population (*Priacanthus* *hamrur*) is reported by many authors (Sivakami *et al.* 2001; Hashim 2009) from Indian water. Similarly male dominant population is also observed in *Bembrops caudimacula* (Hashim 2009). As specimens for the present study were collected from Andaman Sea in April, 2016; seasonal variations if any could not be judged. Ratio may vary according to season, and such seasonal variation in sex ratio have been reported for some deep-sea fishes from Indian waters (Venu 2009).

4.6 Morphology and Morphometrics of otolith

4.6.1 Introduction

Morphometric analysis of Otolith

Otoliths are acellular accretions of calcium carbonate and other inorganic salts developed over a protein matrix (Blacker 1969; Degens *et al.* 1969) and acts as inner ear. Otoliths play significant roles in the sensorial capabilities and maintaining buoyancy (Popper and Fay 1993; Popper and Lu 2000). The sagittal otoliths, the largest among three pair of otoliths (sacculus, utriculus and lagena) present in the inner ear are the candidate specimens for morphometric and morphological analysis (Nielsen *et al.* 2010; Tuset *et al.* 2015; Kumar *et al.* 2017a, b). The sagittal otoliths are extensively used in differentiating population/stocks/species of various fishes owing to their large size and inter-specific variability (Gauldie and Crampton 2002; Sadighzadeh *et al.* 2014; Bostanci *et al.* 2015; Libungan and Palsson 2015; Tuset *et al.* 2015; Afanasyev *et al.* 2017). Previous studies also confirmed the relationship between the otolith size and sound reception capacities in fishes (Paxton 2000; Cruz and Lombarte 2004; Popper *et al.* 2005; Lombarte and Cruz 2007). It is observed that deep-sea fishes possess large otoliths compared to the pelagic species to compensate their limitation in visual communication in light deprived habitats (Deng *et al*. 2011, 2013). These abilities are extensively used by the species in a attracting their mates more efficiently (Sisneros and Bass 2003). It is possible to understand the ecology of fishes from otolith characteristics such as otolith area, sulcus area, aspect ratio etc. which significantly vary according to the prevailing environmental, ontogenic, phylogenetic and ecological factors as observed by various researches (Gauldie and Crampton 2002; Reichenbacher *et al*. 2007; Lombarte *et al*. 2010; Teimori *et al*. 2012; Tuset *et al*. 2011, 2016). Otolith morphology also gives a better insight in to the swimming performance of fishes (Volpedo and Echeverria 2000; Tuset *et al*. 2016). The fast moving pelagic fishes such as tunas and herrings possess relatively small otoliths compared to the deep-sea fishes such as roughies, gadiform and ophidiiform fishes that use otoliths for sensorial and buoyancy requirements (Gauldie and Crampton 2002). Fishes inhabiting in poor light conditions and showing nocturnal feeding habits are found to possess large otoliths (Smale *et al*. 1995; Lombarte and Cruz 2007; Colmenero *et al*. 2010; Tuset *et al*. 2011). The relationship between the otolith structure and morphology of lophiiformes with their ecology is poorly known. Colmenero *et al*. (2010) reported that saccular otoliths were highly variable in *Lophius piscatorius* and *L. budegassa*. These structures are located in the lower part of the inner ear and are related with the hearing ability of the fishes, a fact confirmed by previous researches (Popper and Lu 2000). Colmenero *et al*. (2010) reported that *L. budegassa* which are more active during night and are more acoustically driven when the light is insufficient for the visual communication, possess larger otoliths compared to its congener *L. piscatorius*. This indicate the adaptations of these species to minimize inter-specific competitions. Better understanding on the ecological interpretations of otoliths of these fishes is very much useful to study niche sharing and food web dynamics in detail (Colmenero *et al.* 2010; Tuset *et al*. 2016)

4.6.2 Materials and Methods

Otoliths were collected by making an incision on the cranium and were washed with distilled water to remove the exogenous matter, dried and kept in plastic vials for the further analysis. Only the right otoliths were selected for further analysis as the both right and left otoliths are mirror images of each other (Hunt 1979; Harvey *et al.* 2000; Waessle *et al*. 2003). All the otoliths were weighed (OW) to the nearest 0.001g using the electronic balance (Metler Toledo, ML 503) at an accuracy of 0.001g. The right otoliths were taken for morphometric measurements. The photographs of the otoliths were taken using stereo zoom trinocular microscope (Leica model No. S8APO Camera, Leica DFP-425), with the *sulcus acusticus* oriented towards the observer (Fig. 4.9), and the images were digitised using the image analysing software imageJ. Otolith length (mm), otolith height (mm), area (mm^2), perimeter (mm) (Fig. 4.10) and two shape indices, aspect ratio and roundness were measured for the further analysis according to the terminology used by Avigliano *et al.* (2014, 2015). The shape indices were calculated from the otolith morphometric measurements using specific mathematical equations (aspect ratio (AR) = OH/OL; roundness= $(4A)/(\pi OL^2)$ following Leguá *et al.* (2013). Otolith morphology are described according to Tuset *et al.* (2008).

A linear regression, fitted by power function $Y = aX^b$, was used to estimate the relationship between fish size (SL) and otolith morphometric variables (Froese 2006; Froese *et al*. 2014; Le Cren 1951; Zar 1993). Data were previously transformed to logarithmic values (log10) to remove the possible outliers in the data used for subsequent analysis (Froese *et al.* 2011). The data were recalculated and presented in the results in anti-log format after the linear analysis. Analysis of Covariance (ANCOVA) was undertaken to determine the inter species variations in the regression slopes (Zar 1999).

4.6.3 Results

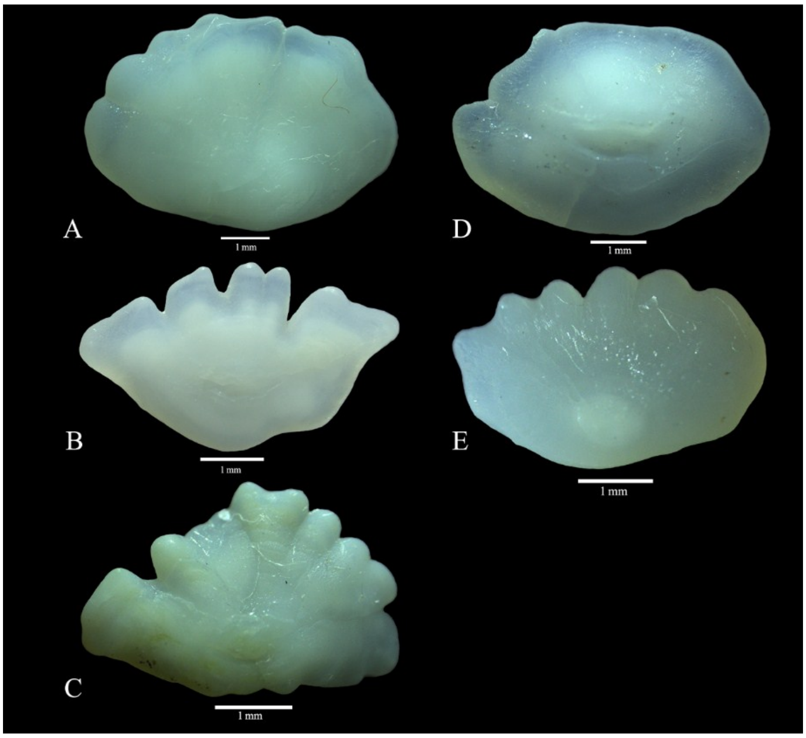


Figure 4.9. Right otoliths of A)—*C. multilepis*; B)—*H. coccinea*; C)—*L. lugubris*; D)—*C. apus*; E)—*M. lutea*

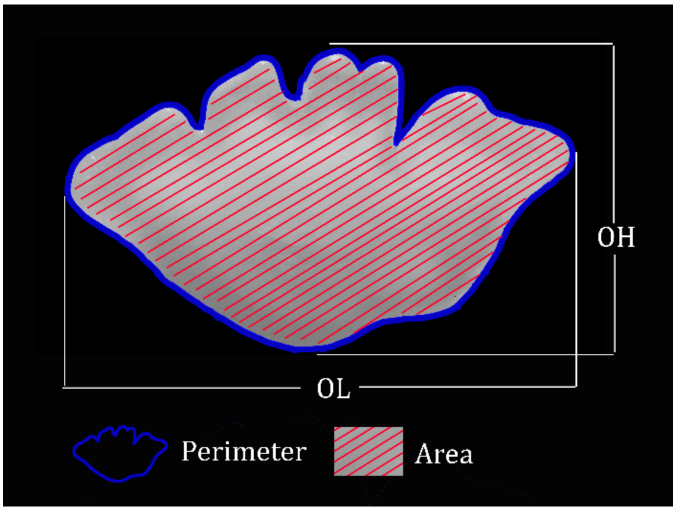


Figure 4.10. Otolith morphometrics; OL—Otolith Length; OH—Otolith Height; OP—Perimeter; OA—Area

4.6.3.1 Otolith morphometric relationships

The descriptive statistics of the all the otolith variables selected for the study are given in the Table 4.6. The number of otoliths taken for the morphometric analysis ranges from 10 for *C. apus* to 16 for *C. multilepis and H. coccinea*. Table provides the details regarding the number of samples analysed, minimum and maximum values of standard length, otolith length, otolith height, otolith weight, area and perimeter for all the five species.

Table 4.6. Descriptive statistics otolith variables of five lophiiformes

Species	Variables	n	Min	Max	Mean	sd
C. apus	SL	10	59	155	85.1	27.64
	OL		4.86	7.93	5.88	0.94
	OH		3.47	5.53	4.19	0.62
	OA		12.3	35	19.15	6.54
	OP		13.2	23.4	16.58	2.98
	OW		0.022	0.099	0.0395	0.022
C. multilepis	SL	16	68	109	92	11.02
	OL		1.62	4.81	5.76	0.5
	OH		3.59	4.53	4.07	0.24
	OA		12.9	22.1	17.83	2.64
	OP		13.3	17.7	15.86	1.28
	OW		0.021	0.048	0.0325	0.007
H. coccinea	SL	16	49	110	75.12	17.46
	OL		2.89	5.19	4.25	0.59
	OH		1.75	3.13	2.51	0.36
	OA		3.47	10.21	7.3	1.78
	OP		11.1	22.1	15.13	3.28
	OW		0.006	0.015	0.01	0.003
L. lugubris	SL	15	91	170	118.5	22.6
	OL		3.69	6.3	4.73	0.93
	OH		2.46	3.52	2.99	0.36
	OA		6.31	15	9.98	3.18
	OP		10.3	16.6	13.13	2.2
	OW		0.006	0.03	0.134	0.007
M. lutea	SL	12	41	67	57.25	7.16
	OL		2.19	2.91	2.59	0.22
	OH		3.48	4.63	4.02	0.3
	OA		6.33	9.69	8	1.18
	OP		9.6	11.96	10.73	0.75
	OW		0.006	0.021	0.016	0.004

Min-minimum; Max-maximum; SL-standard length; OL-otolith length; OH-otolith height; OA-otolith area; OP-otolith perimeter; OW-otolith weight; sd-standard deviation.

Both otolith length and otolith height showed significant relation with the otolith weight (Table 4.6, Fig. 4.11). The relationship between fish size (SL) and otolith morphometric variables are shown in Fig. 4.12. Very high correlations were observed between fish size (SL) and otolith weight of three species (*C. apus, M. lutea* and *H. coccinea* (r^2 >0.90). *L. lugubris* also showed the same pattern, however, the r^2 value was found to be low (r^2=0.87). The *b* values for the relationship ranged from 1.2 to 2.6 for *H. coccinea* and *M. lutea*, respectively. ANCOVA confirmed significant difference in relationship between species (F=78.42, P<0.01). Standard length of *C. multilepis* is correlated more strongly with otolith length compared to other otolith variables (r^2=0.82). It was observed that otolith area and otolith perimeter showed highest correlation with standard length for *C. apus* (r^2=0.96) followed by otolith height and otolith width (r^2=0.95). There is no significant correlations between shape indices (AR and roundness) and fish size (SL). Hence it is not considered for further statistical analysis. Standard length is significantly correlated with the all the other otolith morphometric variables of the five species is confirmed by ANCOVA (Table 4.7).

Table 4.7. Relationship between fish size and otolith variables

	Chaunax apus Lloyd, 1909					*C. multilepis* Ho, Rajeesh & Bineesh, 2016					*Halieutaea coccinea* Alcock, 1894					*Lophiodes lugubris* (Alcock, 1894)					*Malthopsis lutea* Alcock 1891						
Relationship	**n**	***a***	***b***	**SE (*b*)**	**r^2**	***n***	***a***	***b***	**SE (*b*)**	**r^2**	***n***	***a***	***b***	**SE (*b*)**	**r^2**	***n***	***a***	***b***	**SE (*b*)**	**r^2**	***n***	***a***	***b***	**SE (*b*)**	**r^2**	**ANCOVA**	***P***
OL-OW	10	0.31	2.70	0.27	0.93	16	0.49	2.39	0.26	0.86	16	0.73	1.79	0.26	0.77	15	0.54	2.00	0.15	0.93	12	0.38	3.79	0.57	0.81	62.41	<0.01
OH-OW	10	0.57	2.91	0.30	0.92	16	0.50	2.95	0.62	0.61	16	1.91	1.75	0.27	0.76	15	0.60	2.69	0.43	0.88	12	0.42	2.63	1.21	0.79	67.49	<0.01
SL-OL	10	0.51	0.53	0.05	0.94	16	0.34	0.63	0.08	0.82	16	0.34	0.59	0.07	0.85	15	0.05	0.97	0.12	0.83	12	0.29	0.54	0.11	0.72	301.3	<0.01
SL-OH	10	0.48	0.49	0.04	0.95	16	0.75	0.37	0.08	0.63	16	0.23	0.55	0.09	0.73	15	0.24	0.53	0.11	0.65	12	1.26	0.29	0.15	0.28	177.5	<0.01
SL-OA	10	0.17	1.06	0.08	0.96	16	0.15	1.05	0.15	0.79	16	0.07	1.07	0.13	0.83	15	0.01	1.53	0.21	0.8	12	0.23	0.88	0.21	0.63	178.4	<0.01
SL-OP	10	1.21	0.59	0.04	0.96	16	1.22	0.57	0.08	0.77	16	6.34	0.20	0.24	0.05	15	0.27	0.82	0.11	0.8	12	1.70	0.45	0.08	0.78	27.01	<0.01
SL-OW	10	0.05	1.50	0.11	0.96	16	0.04	1.48	0.26	0.7	16	0.05	1.20	0.11	0.9	15	0.00	2.03	0.22	0.87	12	0.00	2.60	0.17	0.95	78.42	<0.01

SL-standard length; OL-otolith length; OH-otolith height; OA-otolith area; OP-otolith perimeter; OW-otolith weight; n-sample size; '*a*' and '*b*'-regression parameters; SE- standard error; r^2- correlation coefficient

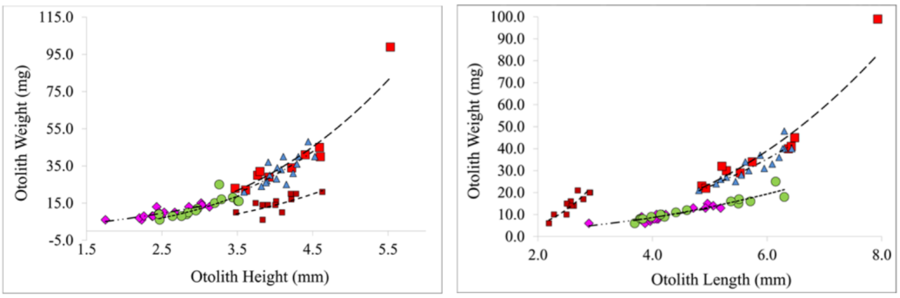


Figure 4.11. Power relationship between otolith length, otolith height and otolith weight of *C. apus* (red square), *C. multilepis* (blue triangle), *H. coccinea* (violet diamond), *L. lugubris* (green circle), *M. lutea* (brown square).

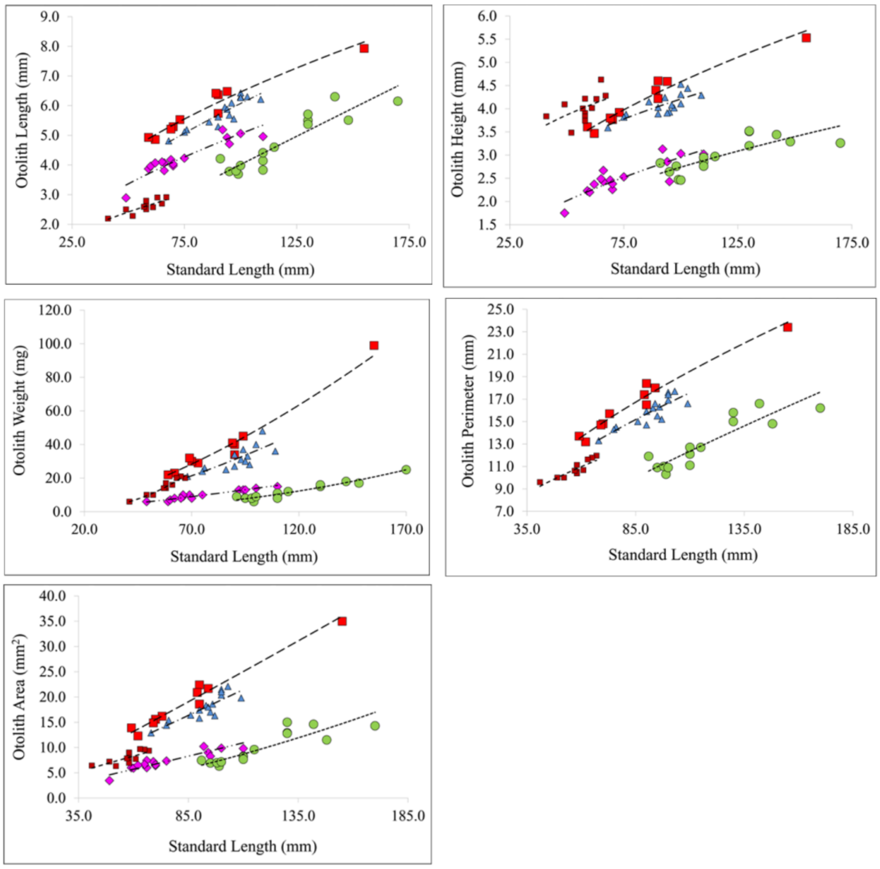


Figure 4.12. Power relationship between fish standard length and various otolith morphometric variables of *C. apus* (red square), *C. multilepis* (blue triangle), *H. coccinea* (violet diamond), *L. lugubris* (green circle), *M. lutea* (brown square).

4.6.4 Discussion

Our studies confirmed the suitability of otolith morphology for the differentiation of lophiiform fishes inhabiting in Indian waters. Otolith morphology and their morphometric relationships varies significantly among the five lophiiform fishes have been confirmed by various researches (Campana 2004; Chang *et al.* 2012). Fishes with deeper bodies (*C. apus, C. multilepis*) those which walk on the bottom and shows a sit and wait mode of feeding have heavy otoliths compared to flattened species (*H. coccinea* and *M. lutea*) which can move faster in bottom and chase the prey (Armstrong *et al.* 1996). Unlike *H. coccinea* and *M. lutea, L. lugubris* are sit and wait predator and can ambush the prey by attracting them with a well-developed angling apparatus called illicium (modified first dorsal fin spine) (Chadwick 1929; Armstrong *et al.* 1996). Our studies also confirmed that otolith area, perimeter and weight are higher for the slow moving fishes compared to fishes with superior swimming capabilities (Parmentier *et al.* 2001; Volpedo and Echeverría 2003; Lombarte and Cruz 2007). Otolith size is considered as a major biological character with profound influence on sensorial ability of fishes (Popper *et al.* 2005; Lombarte *et al.* 2010; Tuset *et al.* 2016). These otolith morphometric characteristics also indicate their capacity to live in higher depths as observed by earlier researches (Lombarte and Cruz 2007; Schulz-Mirbach *et al.* 2008; Tuset *et al.* 2011). Inter-specific variations in the otolith sizes are mainly related to the environment and physical limitations than their phylogeny as observed by various authors (Paxton 2000; Aguirre and Lombarte 2000; Gauldie and Crampton 2002; Lombarte *et al.* 2010). The positive influence of otolith size on hearing ability is discussed by many authors (Paxton 2000; Cruz and Lombarte 2004; Lombarte and Cruz 2007; Monteiro *et al*. 2005). The heavier otoliths possessed by *Chaunax* species have definitely improves their hearing capacities especially at low frequencies which enable them to inhabit more deeper waters and to compensate their limitations in visual communication (Fine *et al*. 1987; Lychakov and Rebane 2000). The otoliths of *C. apus* and *C. multilepis* grows more in size and weight and indicates their adaptations to live in deeper waters (Colmenero *et al*. 2010; Tuset *et al*. 2011, 2015). However, findings of Kéver *et al*. (2014) are not in agreement with this. They reported that hearing capacities of the fishes cannot be predicted based only on sagittal size. Fishes which are more active in night are reported to have larger otoliths compared to diurnal fishes (Colmenero *et al*. 2010). They have reported this phenomenon in *Lophius budegassa* which possess larger otoliths and have nocturnal feeding habits compared to *L. piscatorius* which are not as active in night as the former species. The feeding of these fishes are more acoustically driven when light is insufficient for the visual communications (Colmenero *et al*. 2010). Variations observed in these characters between the fishes also point towards their varied adaptations to temporal segregations in their activity rhythms and reduce interspecific competitions by morphological specialisations in sensory organs which promote their coexistence in resource poor deep-sea ecosystem (Colmenero *et al*. 2010; Kumar *et al*. 2016). Further research need to be carried out with an understanding about the otolith area: sulcus area ratio among the species to elucidate these relationship more clearly. The equations we have derived for predicting the fish size from various otolith morphometric measurements would be useful in studying the food and feeding, population dynamics, paleontological and yield studies of data poor species as observed by Kumar *et al.* (2017b). These relationships are very inevitable to study the trophic relationships between the less studied deep-sea fishery resources of India EEZ.

4.7 Description of Otolith Morphology

4.7.1 Introduction

Otolith are species specific and therefore enables fish identification in paleoicthyology (Nolf 1985; Smale *et al.* 1995) and serve as an important tool for prey classification in several dietary studies (Pierce *et al.* 1991; Granadeiro and Silva 2000) as they are quite resistant to digestion. Now a days their use in food and feeding studies has contributed to a better understanding of marine wood web dynamics. Many authors have produced otolith atlases from various parts of the world (Morrow 1979; Hecht 1987; Smale *et al.* 1995; Rivaton and Bourret 1999; Volpedo and Echeverría 2003; Campana 2004; Lombarte *et al.* 2006; Furlani *et al.* 2007; Tuset *et al.* 2008). However, there is no otolith atlas of deep-sea fishes from India. Present study provides a baseline information and an atlas of lophiiformes fishes from Indian waters.

4.7.2 Materials and methods

The otoliths were photographed with a stereo zoom trinocular microscope (Leica model No. S8APO Camera, Leica DFP-425), with the sulcus acusticus oriented towards the observer. Otolith descriptions were made from right otolith using high resolution microscope. Due to insufficient sampling size, description of otolith morphology is restricted to 12 deep-sea anglerfishes. Shape parameters, Otolith Length (OL, mm), Otolith Height (OH, mm), Perimeter (OP, mm) and Area (OA, mm^2), were measured in right otoliths using imageJ software. Shape indices: Circularity ($4\pi \times OA/ OP^2$); Roundness or inverse of aspect ratio ($4 \times OA/3.14\times OH^2$); Aspect ratio (OH/OL%) were calculated. Fish Total length in mm (FTL) and depth of collection locality are also given. R—Indicate right and L—for left otolith.

Detailed methodology (dissection, processing) are discussed in Chapter 2. Terminologies used for the description of otolith morphology follows (Smale *et al.* 1995; Tuset *et al.* 2008). Figure 4.13 explains the terminology used for otolith description, illustration modified from Tuset *et al.* (2008).

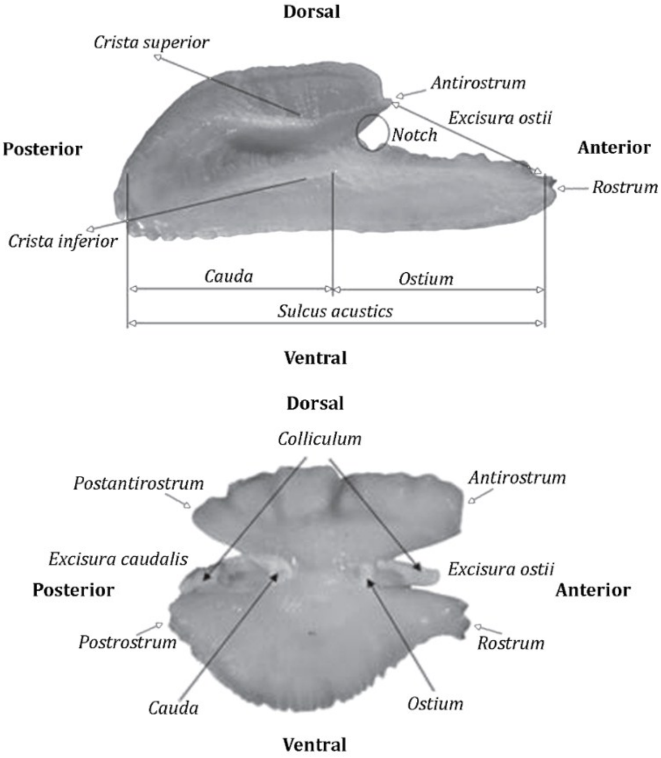


Figure 4.13. Mesial surface of sagittal otolith explains morphological features

4.7.3 Results

Chaunax apus Lloyd, 1909

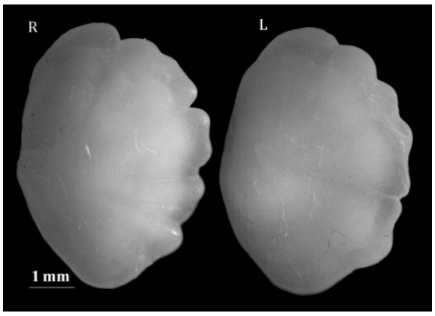


Figure 4.14. Otolith *of Chaunax apus* R—showing mesial surface

FTL-113, Depth-411 m. OL-5.74, OH-4.22, OA-18.6, OP-16.5, AR-74.0, Circularity-0.86, Round-0.71

Shape: Elliptic to oval; *Dorsal margin*: lobed, *Ventral margin*: entire. *Sulcus acusticus*: archaesulcoid, mesial mode of opening, median in position; *Ostium*: round oval; *Cauda*: undifferentiated; *Anterior region*: rounded, *Posterior region*: rounded to flattened.

Chaunax multilepis Ho. HC, Meleppura RK & Bineesh KK, 2016

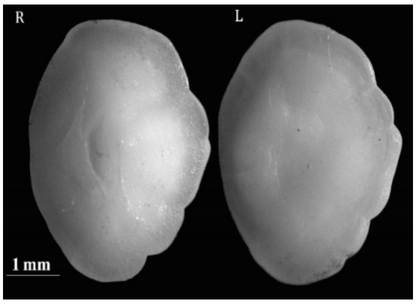


Figure 4.15. Otolith of *Chaunax multilepis* R—showing mesial surface

FTL-121 mm, Depth-411 m. OL-6.09, OH-4.08, OA-18.6, OP-16.3, AR-66.9, Circularity-0.88, Roundness-0.68

Shape: Elliptic to oval; *Dorsal margin*: lobed, *Ventral margin*: entire to irregular. *Sulcus acusticus:* heterosulcoid, mesial opening, median, restricted to middle portion of the otolith; *Ostium*: round oval; *Cauda*: tubular, slightly curved; *Anterior region:* rounded, *Posterior region*: rounded to flattened.

Halieutaea coccinea Alcock, 1889

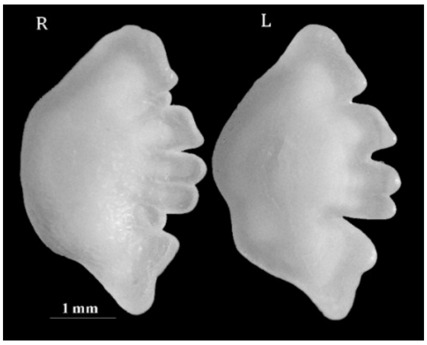


Figure 4.16. Otolith of *Halieutaea coocinea* L—showing mesial surface

FTL-115 mm, Depth-300 m. OL-5.06, OH-3.03, OA-9.88, OP-14, AR-59.8, Circularity-0.64, Roundness-0.61

Shape: Semicircular, *dorsal margin* is lobed, *ventral margin* is irregular; *Sulcus acusticus*: archaesulcoid, pseudo-ostio caudal; median in position; *Ostium*: round oval, *Cauda*: undifferentiated; *Anterior region* and *Posterior region* slightly notched.

Malthopsis lutea Alcock, 1891

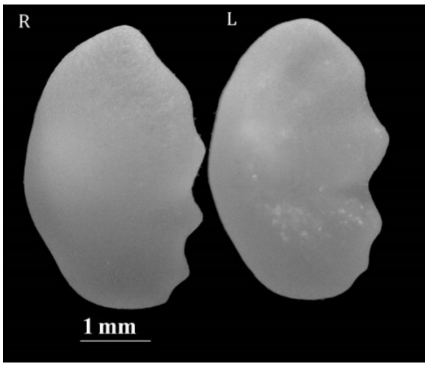


Figure 4.17. Otolith of *Malthopsis lutea* L—showing mesial surface

FTL-75 mm, Depth-650 m. OL-4.02, OH-2.57, OA-7.74, OP-10.67, AR-63.9, Circularity-0.85, Roundness-0.62

Shape: Oval, *dorsal margin* lobed, *ventral* entire; *Sulcus acusticus*: pseudo-archaesulcoid, mesial, infra median; *Ostium*: tubular; *Cauda*: undifferentiated; *Anterior* and *posterior* region round to flattened.

***Coelophrys micropa* (Alcock, 1891)**

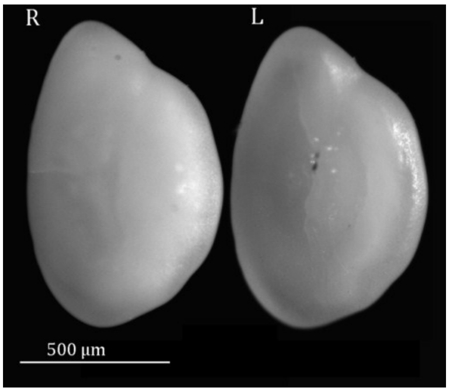


Figure 4.18. Otolith of *Coelophrys micropa* R—showing mesial surface

FTL-65 mm, Depth-520 m. OL-2.5, OH-1.6, OA-3.04, OP-6.5, AR-64, Circularity-0.90, Roundness-0.67

Shape: Oval, *dorsal and ventral margins* entire, without any irregularity; *Sulcus acusticus*: mesial, median, *Ostium*: tubular, *Cauda*: undifferentiated; *Anterior* and *posterior* regions round.

***Halieutaea stellata* (Vahl, 1797)**

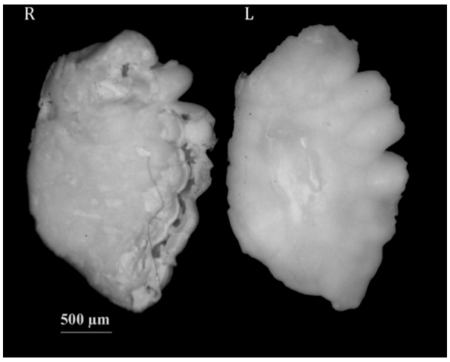


Figure 4.19. Otolith of *Halieutaea stellata* L—showing mesial side

FTL-85 mm, Depth-300 m. OL-2.7, OH-1.8, OA-3.45, OP-7.82, AR-66.7, Circularity-0.71, Roundness-0.67

Shape: Semicircular, *Dorsal margin* lobed, *Ventral* entire; *Sulcus acusticus*: archaesulcoid, mesial mode of opening, infra median in position; *Ostium*: round oval, *Cauda*: undifferentiated; *Anterior and posterior region* blunt.

Halicmetus ruber Alcock, 1891

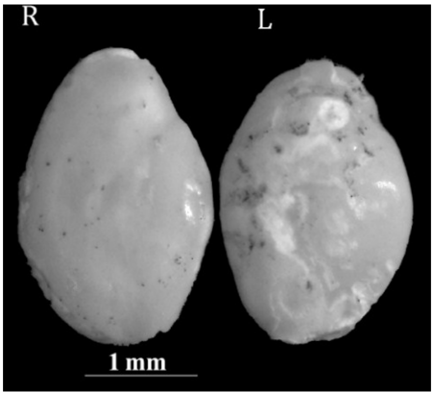


Figure 4.20. Otolith of *Halicmetus ruber*. L—showing mesial surface

FTL-75 mm, Depth-934 m. OL-2.5, OH-1.7, OA-3.25, OP-6.7, AR-68, Circularity-0.90, Roundness-0.68

Shape: Oval, dorsal and ventral region entire; *Sulcus acusticus*: heterosulcoid, mesial, median; *Ostium* and *Cauda* undifferentiated, restricted in the median region; *Anterior* and *posterior* region round.

Halieutopsis sp. B

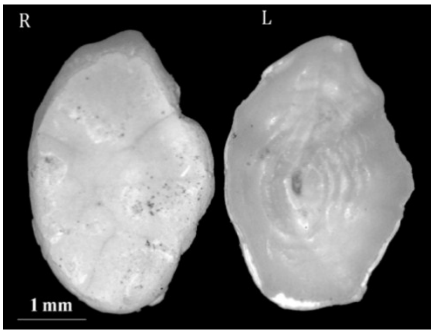


Figure 4.21. Otolith of *Halieutopsis* sp.B R—showing mesial surface

FTL-94 mm, Depth-646 m. OL-4.04, OH-2.78, OA-8.15, OP-10.84, AR-68.8, Circularity-0.87, Roundness-0.68

Shape: Elliptic; *Dorsal margin* slightly lobed, *Ventral* entire; *Sulcus acusticus*: heterosulcoid, mesial, median in position; *Ostium* and *Cauda* round oval; *Anterior region* blunt to peaked, *Posterior* blunt; rostrum and antirostrum not separated.

Lophiodes triradiatus (Lloyd, 1909)

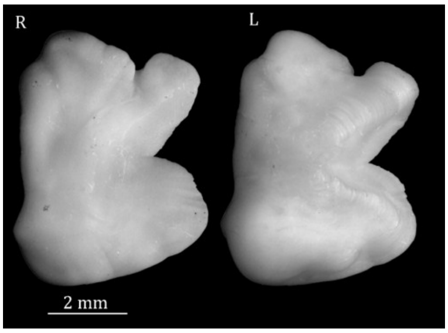


Figure 4.22. Otolith of *Lophiodes triradiatus* R—Showing mesial surface

FTL-420 mm, Depth-646 m, OL-3.21, OH-2.5, OA-5.6, OP-10.4, AR-77.9, Circularity-0.70, Roundness-0.73

Shape: Hour-glass, asymmetric with ventral and dorsal areas almost equally developed, deep notch on dorsal margin, ventral entire; *Sulcus acusticus*: heterosulcoid, mesial, median; *Ostium*: discoidal, *Cauda:* curved slightly; *Anterior region* notched, *Posterior region* blunt.

Lophiodes gracilimanus (Alcock, 1899)

Figure 4.23. Otolith of *Lophiodes gracilimanus* R—showing mesial surface

FTL-240 mm, Depth-314 m. OL-6.4, OH-3.32, OA-14.9, OP-16.5, AR-51.8, Circularity-0.69, Roundness-0.48

Shape: Kidney shaped, *Dorsal margin* irregular, *Ventral* entire; *Sulcus acusticus*: archaesulcoid, mesial, median; *Ostium* and *Cauda* undifferentiated; *Anterior region* peaked, *Posterio*r blunt to peaked.

Lophiodes mutilus (Alcock, 1893)

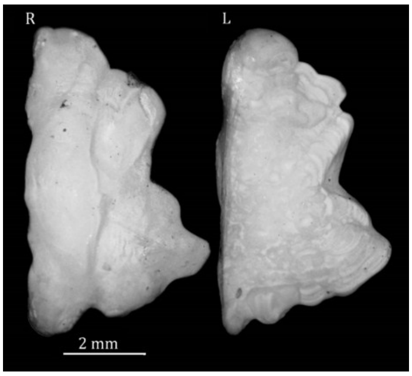


Figure 4.24. Otolith of *Lophiodes mutilus* R—showing mesial surface

FTL-250 mm Depth-635 m. OL-6.7, OH-4.03, OA-17.8, OP-18.9, AR-60.1, Circularity-0.62, Roundness-0.54

Shape: Irregular, *Dorsal margin* is irregular, *Ventral* Sinuate; *Sulcus acusticus*: archaesulcoid, pseudo-ostiocaudal, median in position; *Ostium* and *Cauda*: tubular, narrow; *Anterior* and *Posterior* region notched; rostrum little bit prolonged than antirostrum.

Lophiodes lugubris (Alcock, 1894)

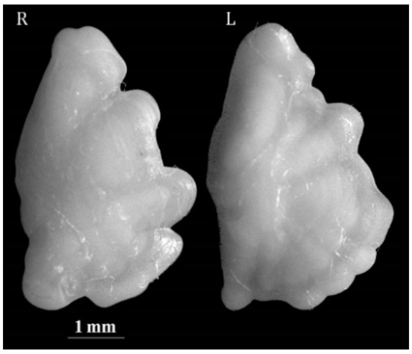


Figure 4.25. Otolith of *Lophiodes lugubris* L—showing mesial surface

FTL-170 mm, Depth-332 m. OL-7.22, OH-4.67, OA-5.2, OP-20.4, AR-64.7, Circularity-0.70, Roundness-0.60

Shape: Irregular, dorsal and ventral margins lobed, but dorsal with deep indentations; *Sulcus acusticus*: pseudo-archaesulcoid, pseudo-ostio caudal, infra median in position; *Ostium*: narrow tubular; *Cauda*: not well differentiated, tubular, slightly curved; *Anterior region* highly irregular than *Posterior*. Rostrum and antirostrum well differentiated.

4.8 Discrimination of Lophiiformes fishes using Otolith Shape

4.8.1 Introduction

Otoliths (earstones) are paired calcified structures located in the inner ear cavity of all teleost fishes, mainly used for balancing and hearing. There are three pairs of otoliths; sagittae, asterisci and lapilli, found in three otolithic end organs; the saccule, lagena and utricule, respectively (Popper and Lu 2000). Traditionally it have been used to find the age and size of fishes. Apart from the age and growth determination, otoliths are widely used in stock discrimination (Campana and Casselman 1993; Neves *et al.* 2011; Yu *et al.* 2014); systematics and species identification (Popper *et al.* 2005; Tuset *et al.* 2003); fish stock identification and environmental reconstruction of the fish habitat (Ladroit 2017); and is an excellent tool for trophic studies (Tuset *et al.* 2012). It can also be used for the evaluation of relationships between the environment and organisms (Campana 1993), paleoecology, paleobathymetry, paleoclimatology, paleobiogeography and biostratigraphy (Nolf 1995).

Otlolith morphology is unique in each and every species (Hossucu *et al.* 1999; Popper *et al.* 2005). This attribute enable use of otolith as an added tool for species identification (Adams 1940; Hernández García *et al.* 2004; Tuset *et al.* 2012). For otolith shape analysis, two main morphometric methods are used: landmark analysis and outline analysis. In outline analysis boundary shapes of otolith are extracted and pattern of the shape variations within or among the species can be evaluated based on large number of independent variables (Bookstein 1985; Rohlf 1993; Marcus 1996; Cadrin 2013; Stransky 2013; Libungan and Pálsson 2015).

Many authors have successfully elucidated the shape of otoliths by using different packages based on elliptical Fourier analysis (Campana and Casselman 1993; Crespo *et al*. 2012; Libungan and Pálsson 2015; Rodgveller *et al*. 2017; Ladroit *et al*. 2017). Otolith shape analysis of some of the lophiiformes fishes were performed by Campana (2004) especially for lophiidae and chaunacidae families and deposited in Anàlisi de FORmes d'Otòlits (AFORO) available online http://isis.cmima.csic.es/aforo/. No attempts were made yet for the contour analysis of otolith from Indian waters.

4.8.2 Materials and methods

Otolith in this study refers to the Sagitta otolith. Five different species of deep-sea anglerfishes (Order Lophiiformes) were collected on April 2016 from Andaman Sea covering depths ranging from 300 to 650 m. Fishes were identified up to species level following standard identification keys and other illustrations. A total of 186 otoliths from five species were taken for the study. After taking morhomtric measurements of the fishes, the sagittal otoliths were removed by making an incision in the cranium. Sagittae were cleaned and stored dry for further analysis.

The otoliths were photographed with a stereo zoom trinocular microscope (Leica model No. S8APO Camera, Leica DFP-425), with sulcus acusticus oriented towards the observer (Fig. 4.26). Otolith with calcite crystallization and other aberrant formation were not included in the study. Otolith morphometrics were taken from the right otolith using the image analysing software, ImageJ (Rueden *et al*. 2017) and the same was used for further analysis.

Fourier shape analyses (Elliptical and rFourier)

Otolith has a complex shape that lack consistent identifiable points or landmarks and therefore may not be viable to describe by its morphometric measurements such as (length, width, area, perimeter). Fourier analyses provide more advantages, because of its ability for accurate description of complex or curved shapes (Tracey *et al.* 2006; Rodgveller *et al.* 2017) which enable accurate discrimination of stocks, subpopulations and species.

Elliptical Fourier analysis is a group of techniques used to describe curves, like those of an otolith, in terms of cosine waves (also called harmonics). A series of radii are drawn at equal angles from a centroid to coordinates along the outer edge. Harmonics are fit to these data to describe the contours in the shape. Harmonics are added until at least 99% of the variance in the otolith shape can be reconstructed (Campana and Casselman 1993; Crampton 1995; Rodgveller *et al.* 2017). In this study a number of ellipses with four Fourier descriptors each are used to describe the shape. Those descriptors can then be examined using a PCA. Elliptical Fourier-based techniques have been widely used to distinguish stocks or species covering many taxa worldwide (Campana and Casselman 1993; Galley *et al.* 2006; Tracey *et al.* 2006; Keating *et al.* 2014) by Fourier analysis mainly elliptical Fourier analysis and Fast Fourier transform (FFT). Present study used elliptical and Radii variation Fourier Transform (rFourier, Claude 2008) analysis to describe the otolith shapes between species.

Right otoliths of 93 specimens (details provided in the Table 4.8) were photographed and each image was converted to a black and weight image (Fig. 4.26) using Adobe Photoshop 7.0 software. Outline of image was extracted using the R package "Momocs" (ver. 1.2.9; Bonhomme *et al.* 2014, R is a free software environment for statistical computing and graphics). The set of outlines were thoroughly checked for alignment to a common center, oriented to remove discrepancies in positioning, and scaled to centroid size using functions built into the package.

Otoliths have strongly irregular, wavy edges that can cause difficulties in fitting the harmonic curves to the shape, requiring a smoothing algorithm to simplify the shapes and to soften the impact of minor variations. Trial runs using 1, 10, 20, and 30 smoothing iterations were conducted, and 30 ellipses selected which produced the optimal discrimination of otolith shapes. These were used for further analysis. After this, an elliptical Fourier analysis was conducted to fit Fourier harmonics to each otolith outline and subsequent analysis were conducted on the set of Fourier descriptors. PCA and LDA tests were carried out in order to demarcate the shape variability of otolith between the species.

4.8.3 Results—Fourier shape analyses

The elliptical Fourier analyses of the smoothed otolith outlines were capable of describing otolith shape using 30 elliptical harmonics, with 4 individual coefficients (a,b,c,d), after three descriptors were removed for adjusting the size and orientation . An effective way of describing the otolith shape of each species is to define the mean shapes, which were extracted from 30 descriptors of each otolith of the given species (Fig.

4.28). These described 99.5% of the variation in shapes; rFourier, analysis were performed on the mean shapes which are described by elliptical Fourier, in order to demonstrate, at which angle the shape variation has occurred (Fig. 4.29a—e). PCA conducted on these descriptors demonstrated that there was some visual separation between the shapes of five otoliths. A comparison of PC1 to PC2 scores provided the most effective separation of shapes. Subsequently an LDA analysis also performed, which shows a clear separation of shapes between the species, especially in the case of lophiodes.

Table 4.8. Descriptive statistics of fish

Species	**Station (no. of specimen parenthesis)**	**Number Of otolith**	**SL (mm)**		**OL (mm)**		**OW (mg)**	
			Min	**Max**	**Min**	**Max**	**Min**	**Max**
C. multilepis	34908 (16), 34910 (19), 34906 (3)	38	38	145	3.1	8.4	7	77
C. apus	34908	10	59	155	4.9	7.9	22	99
M. lutea	34902	12	41	67	3.5	4.6	6	21
L. lugubris	34906	16	72	180	3.2	7.2	4	27
H. coccinea	34905(12), 34909 (4), 34906(1)	17	49	110	2.9	8.3	3	45

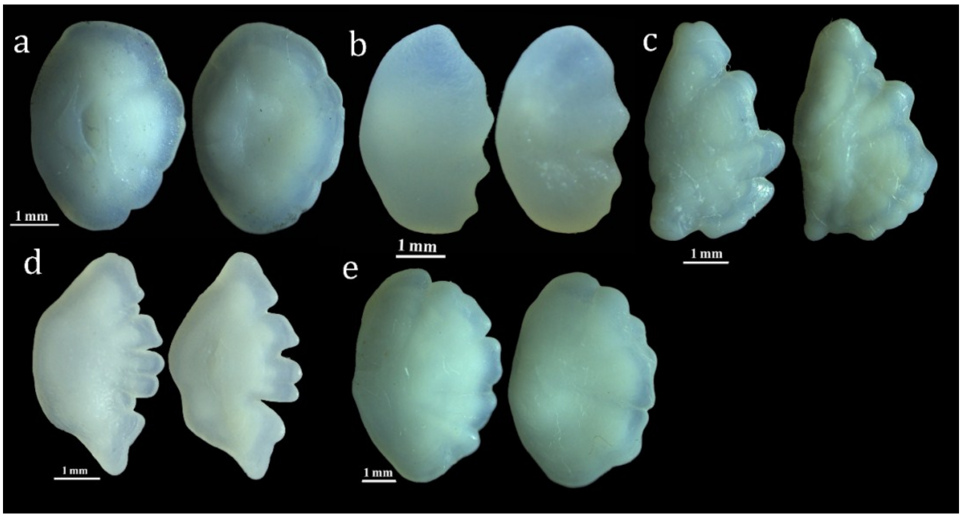


Figure 4.26. Right and Left otoliths of a)—*C. multilepis*; b)—*M. lutea*; c)—*L lugubris*; d)— *H. coccinea*; e)— *C. apus*.

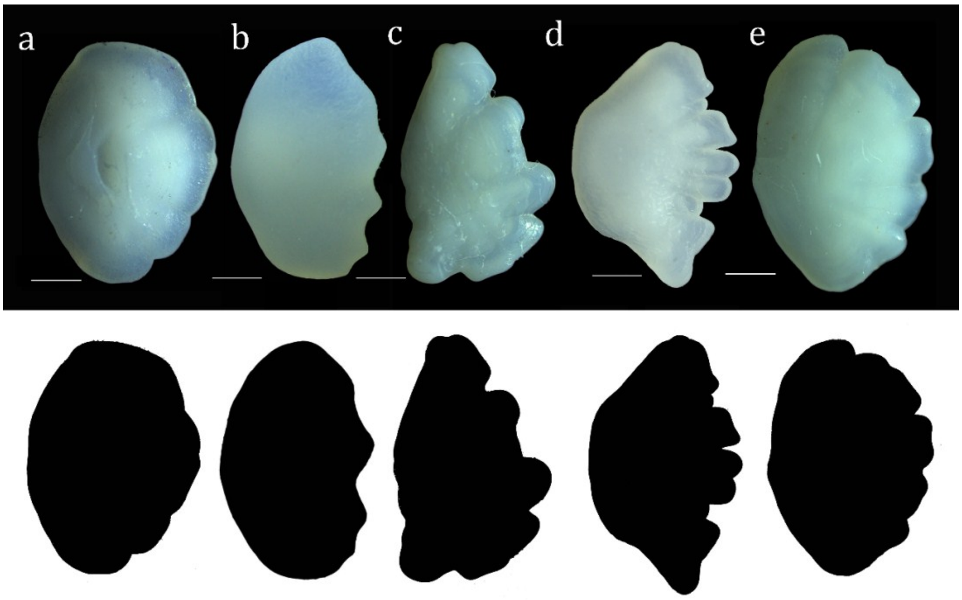


Figure 4.27. Right otolith of five species; respective black and white images (for outline extraction) are given below.

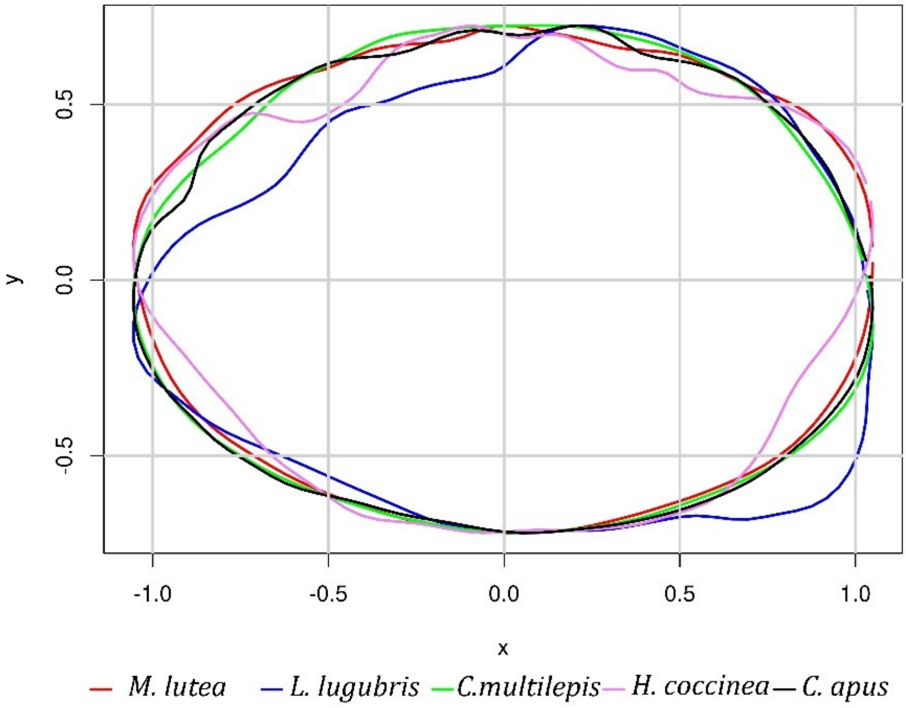
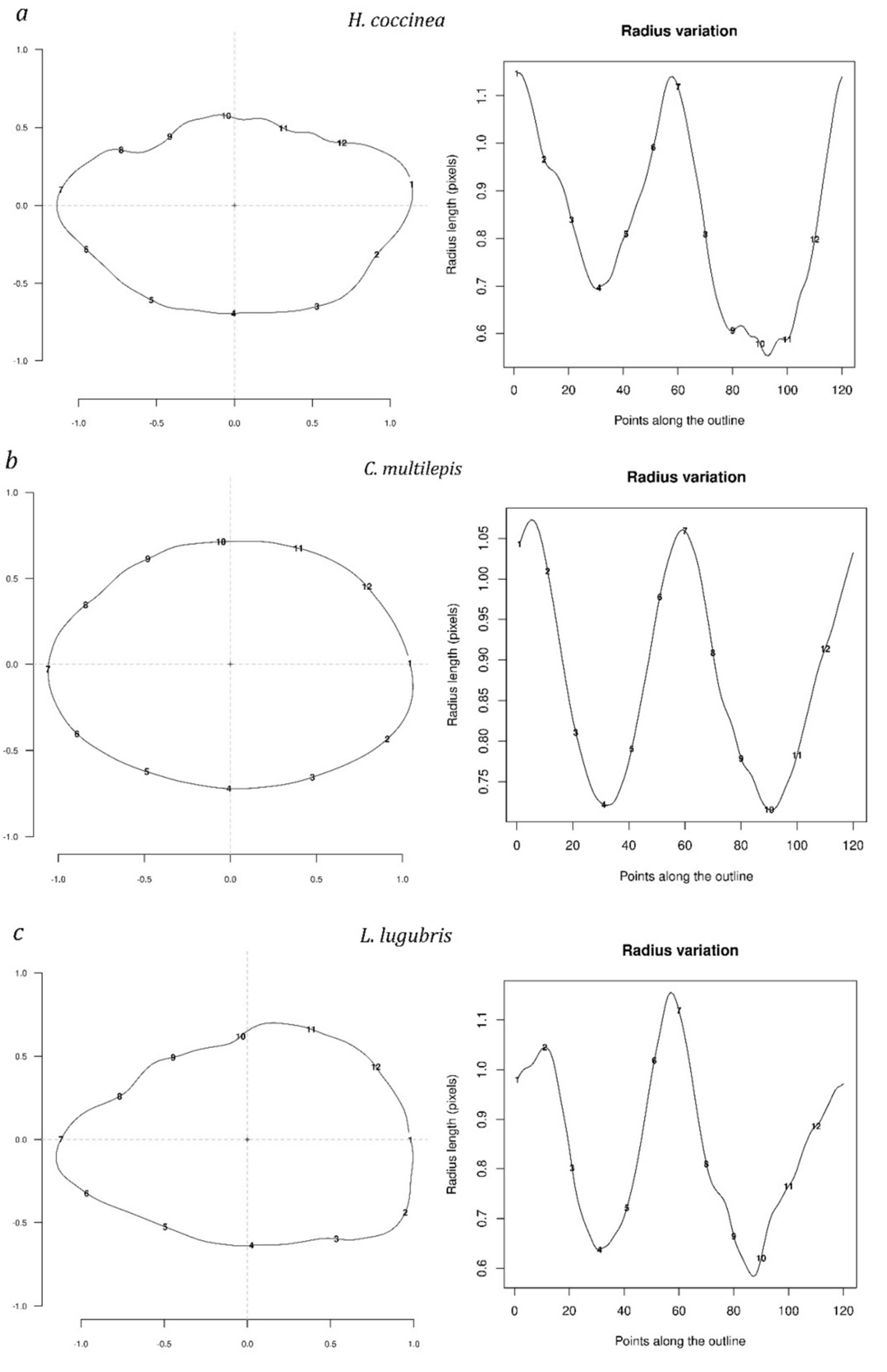


Figure 4.28. Otolith mean shapes of five species; individual mean shape of species are explained using different colours.


a
H. coccinea
Radius variation
Radius length (pixels)
Points along the outline
b
C. multilepis
Radius variation
Radius length (pixels)
Points along the outline
c
L. lugubris
Radius variation
Radius length (pixels)
Points along the outline

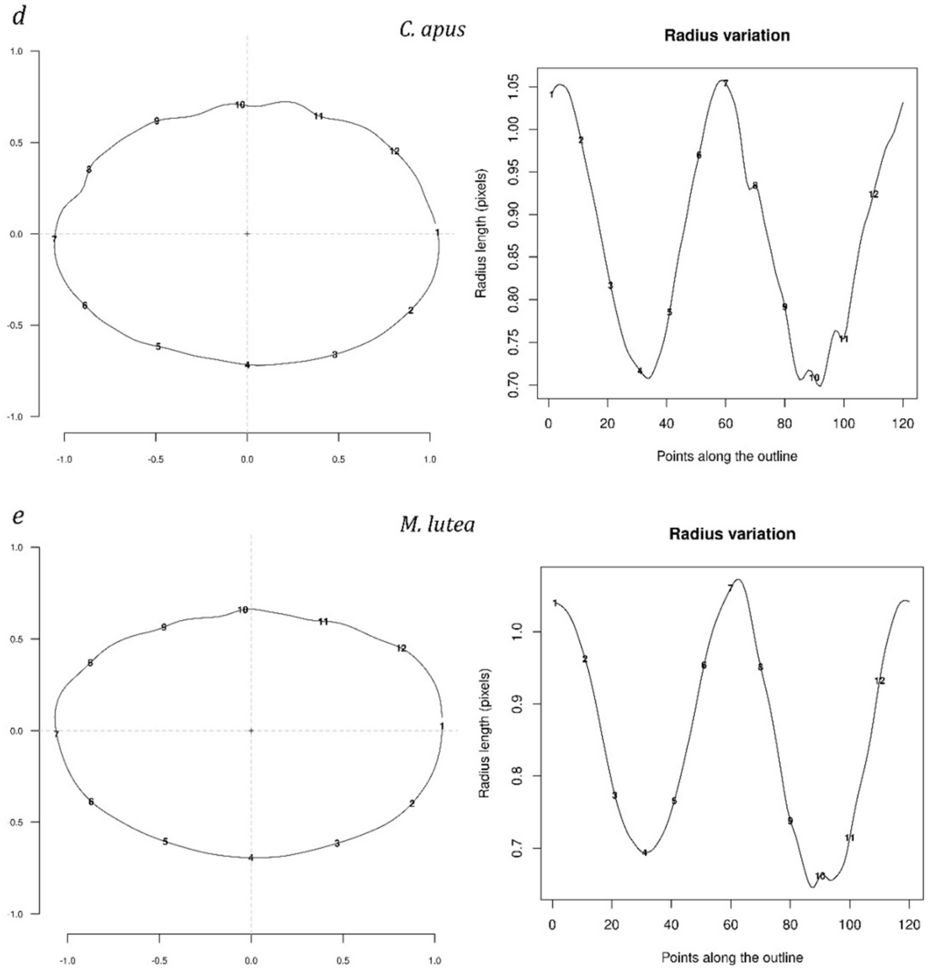


Figure 4.29. a—e; rFourier based mean shape variation of five species.

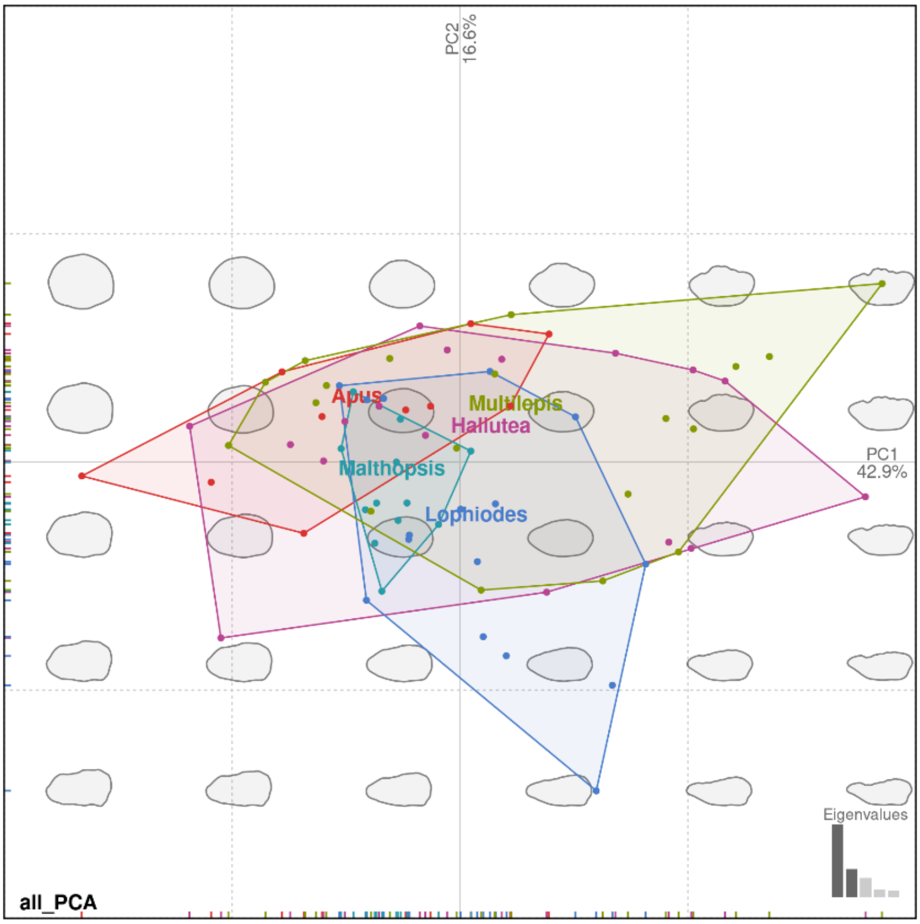


Figure 4.30. Principal Component Analysis (PCA) of elliptical Fourier analysis harmonic descriptors for five otolith shapes (red-*C. apus*, violet- *H. coccinea*, green-*C. multilepis*, cian-*M. lutea*, blue- *L. lugubris*). Vertical and horizontal lines intersect where PC values are both 0.

Figure 4.31. Linear Discriminant Analysis (LDA) of elliptical Fourier analysis harmonic descriptors for five otolith shapes (red- *C. apus*, violet- *H. coccinea*, green-*C. multilepis*, cian-*M. lutea*, blue- *L. lugubris*).

4.8.4 Discussion

Mean shape recreated from elliptical Fourier descriptors shows otolith shape variability among five species of anglerfishes. The shapes are presented in Fig. 4.28. Observable differences in the otolith shape of *L. lugubris, H. cocinea* and *M. lutea* from those of *C. multilepis* and *C. apus*, can be substantiated with PCA and LDA result (Fig. 4.30 and 4.31). It is also noticed that species of *Chaunax* genus, *C. apus* and *C. multilepis* show some similarity in the shape from others. *Lophiodes lugubris* and *H. coccinea* show extreme shape variations, observed by naked eyes. rFourier, analysis clearly demarcates, the portion of the otolith showing variation in shapes. Mean otolith shape of *H. coccinea* is semicircular shape, with lobed dorsal margin (radius variation 6-12, in rFourier) and an irregular ventral margin (2-6; Fig. 4.29 a); *C. multilepis* have otolith of elliptic to oval shape; dorsal margin lobed (8-11; Fig. 4.29 b); *L. lugubris* possess irregular shaped otolith, dorsal and ventral margins lobed, but dorsal with deep indentations (7-12; Fig. 4.29 c); *C. apus* have elliptic to oval shaped otolith; dorsal margin lobed, indicating radius variation 7-12 in rFourier (Fig. 4.29. d); In *M. lutea*, otolith is oval in shape, dorsal margin lobed (8-12) ventral smooth (1-6; Fig. 4.29. e).

Growth rate of species is linked to differences in otolith shapes (Rodgveller *et al.* 2017). Feeding intensity also, highly influence otolith shape; fishes with adequate feed shows relatively wider, multi lobed otolith in the laboratory study (Stransky *et al.* 2008). Otolith of *L. lugubris* is multilobed in shape and can be distinguished by their heavy and large body compared to other four species. Many previous studies (Jónsdóttir *et* *al.* 2006; Stransky *et al.* 2008; Keating *et al.* 2014; Mahé *et al.* 2016) suggests that environmental factors have a major influence in the shape of otoliths. The present study provides base line information on the differentiation of the otolith shapes among five lophiiformes fishes.

The elliptical Fourier analysis illustrated that there were quantifiable differences in the otolith shapes among the five anglerfish species studied. This tool can be effectively used for species with taxonomic ambiguity, to differentiate the species. Otoliths enable identification of species from the shape of otolith obtained from the stomach of a predator, which ultimately contributes to establish the prey predator relationship or trophodynamics of an ecosystem (Pierce *et al.* 1991; Tollit *et al.* 1997).

4.9 Ecomorphological Differentiation of Lophiiformes.

4.9.1 Introduction

Ecomorphology is a science that deals with relationships between environmental factors (both physical and biotic) and morphology at species level (Wainwright *et al.* 2002; Lombarte *et al.* 2003; Papiol *et al.* 2013). The ecomorphological traits which explain the functional property of a species is calculated from the body measurements with specific equations used to predict the feeding patterns, habitat use and ecology of species/communities (Hooper *et al.* 2005; Villéger *et al.* 2008; Mouillot *et al.* 2011; Bohórquez-Herrera 2015; Silva-Júnior *et al.* 2016). Recently, significant number of researches have described the functional diversity of fishes (Albouy *et al.* 2011; Villéger *et al.* 2010, 2012; Mouchet *et al.* 2010; Schmera *et al.* 2017). However, very few studies were carried out on deep-sea fishes (Norton 1995; Kinaley *et al.* 2014; Farré *et al.* 2016; Mindel *et al.* 2016a, b; Romeu *et al.* 2016; Preciado *et al.* 2017) and species exhibiting much diversity in morphology as coral reef fishes (Fulton *et al.* 2013; Binning and Roche 2015). It was well documented that beyond the depth gradient of continental slope, resource availability declines and environment conditions become extreme (Carney 2005). Information on the eco-functional characteristics of deep-sea fishes always remain elusive due to many inherent difficulties in the collection of samples (Kenaley *et al.* 2014). Both internal and external morphology characters are reported to influence resource partitioning among the fishes (Dumay *et al.* 2004; Papastamatiou *et al.* 2006; Silva-Júnior *et al.* 2016).

Previously it was believed that in shallow waters, the distribution of species is follow the theory of limiting similarity (Macarthur and Levins 1967) and environmental filtering is responsible for the sustenance of deep-sea ecosystem where conditions are extreme to coexist (Carney 2005; Bridge *et al.* 2016). Later, it was observed that theory of limiting similarity is also actively involved in deciding species distributions in deep-sea ecosystems (Farré *et al.* 2016; Kumar *et al.* 2016; Romeu *et al.* 2016; Preciado *et al.* 2017). Hence, we can assume that along with the environmental factors (theory of environmental filtering) which is a major factor in deciding the species assemblages in deep-sea ecosystems, many others mechanisms were also synergistically act towards the coexistence of species (eg. theory of limiting similarity) (Macarthur and Levins 1967; Kumar *et al.* 2016). Though anglerfishes are less efficient in their swimming capacities compared to other teleost fishes, this is compensated by their feeding specialities (Gudger 1945; Armstrong *et al.* 1996;

Velasco *et al.* 2008). We believe that the spatial distribution of these fishes are characterised with high degree of specialisation in resource utilisation as postulated by theory of limiting similarity. That is, when availability of food is limited, fish tend to forage on a common food source (Macarthur and Levins 1967; Preciado *et al.* 2006; Colmenero *et al.* 2010; Kumar *et al.* 2016). Even though considerable number of research have been carried out to understand the ecological responses to the environmental parameters based on traits, the extent to which we can predict this, is still an unresolved puzzle (Sutherland *et al.* 2013) which has to be substantiated with further research in this area. Only very limited studies have been carried out on the ecomorphological differentiation of fishes from Indian EEZ (Narayani *et al.* 2015; Kumar *et al.* 2016) despite the rich deep-sea fishery resources in our waters (Venu and Kurup 2002a, b; Jayaprakash *et al.* 2006; Venu 2009; Hashim 2012; Vinu 2017). It is observed from the recent exploratory cruises on-board FORV *Sagar Sampada* that along the Indian waters species diversity is high in Andaman and Nicobar waters, compared to other regions of the Bay of Bengal (Hashim 2012). This is possibly due to its unique geographical settings as the Island is close to Indo-Malayan region and the islands are part of the long Island Arch extending from the Arakan Yoma hill range of Myanmar to the Sumatran range of Indonesia. Also the Andaman and Nicobar waters are connected to Pacific Ocean through Strait of Malacca (Balakrishnan *et al.* 2008; Rajan and Sreeraj 2013).

Under this background, our initial hypothesis is that the ecomorphological traits related to the feeding and locomotion strategies differ among the five deep-sea species that live in resource poor environment (deep-sea ecosystem) and that such strategies are very essential for their coexistence (Albouy *et al.* 2011; Aguilar –Medrano *et al.* 2013, 2016; Azzurro *et al.* 2014; Blasina *et al.* 2016; Bernal-Durán and Landaeta 2017).

The five anglerfishes discussed in our study are common and show much similarity in their feeding pattern and food preferences. However, little is known about the ecological variables that support their coexistence in the food-deprived deep-sea ecosystems. Hence, present study attempts to answer the following questions (1) Are the five dominant deep-sea anglerfishes (*Chaunax apus, C. multilepis, Halieutaea coccinea, Lophiodes lugubris* and *Malthopsis lutea*) separated spatially in their distribution, and in the functional space? (2) the major functional traits responsible for the variation if any.

4.9.2 Materials and Methods

Present study is based on the data collected in cruise no.349 of FORV *Sagar Sampada* (71.5 m LOA: 2285 hp) from Andaman Sea during April 2016, using high speed demersal trawl (crustacean version) at a towing speed of 2.5-3.5 knots (Fig. 4.32). Ten stations were surveyed along the continental margins of Andaman and Nicobar Islands (Lat. 7.29° N-13.76° N and Long. 92.14° E – 93.11° E) at depths ranging from 300- 650m.

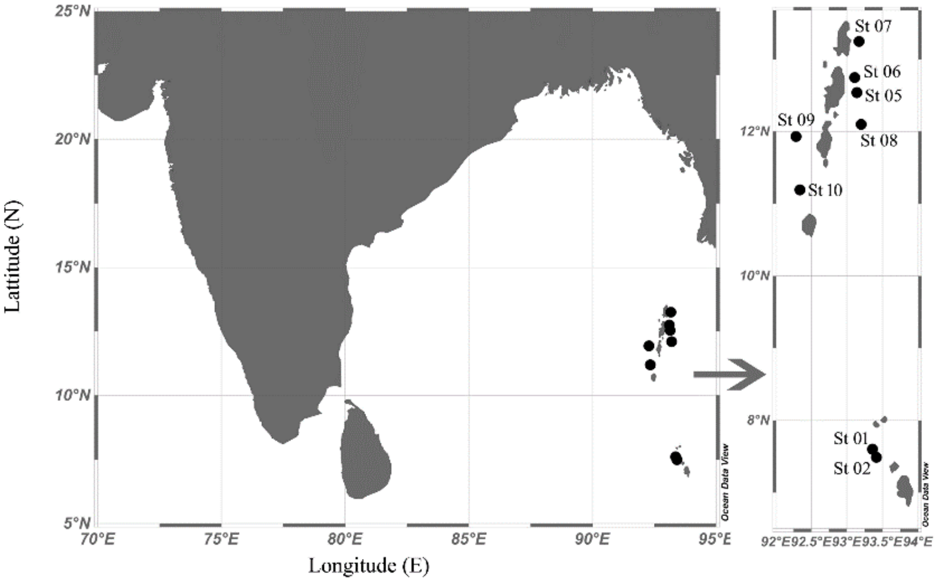


Figure 4.32. Sampling stations in Andaman and Nicobar waters, India

The locations were scanned using SIMRAD EK60 echo sounder before trawling operations and the stations were selected based on the suitability of the trawling grounds. The fishing operations were carried out from 6 am to 6 pm depending upon the weather conditions. Five anglerfish species (Order Lophiiformes) were caught during the fishing operations: *Chaunax apus* Lloyd, 1909 (n= 10), *C. multilepis* Ho HC, Meleppura RK & Bineesh KK, 2016 (n= 16), *Halieutaea coccinea* Alcock, 1894 (n= 20), *Lophiodes lugubris* (Alcock, 1894) (n= 24) and *Malthopsis lutea* Alcock, 1891 (n= 15). Species were identified following standard identification keys referred in Chapter 3. Only non-damaged adult fishes were selected to take the meristic and morphological measurements, and to extract the *sagittae* otolith. The details regarding the percentage contribution of each species to the total CPUE (Catch per Unit Effort) for each stations are shown in Fig. 4.33.

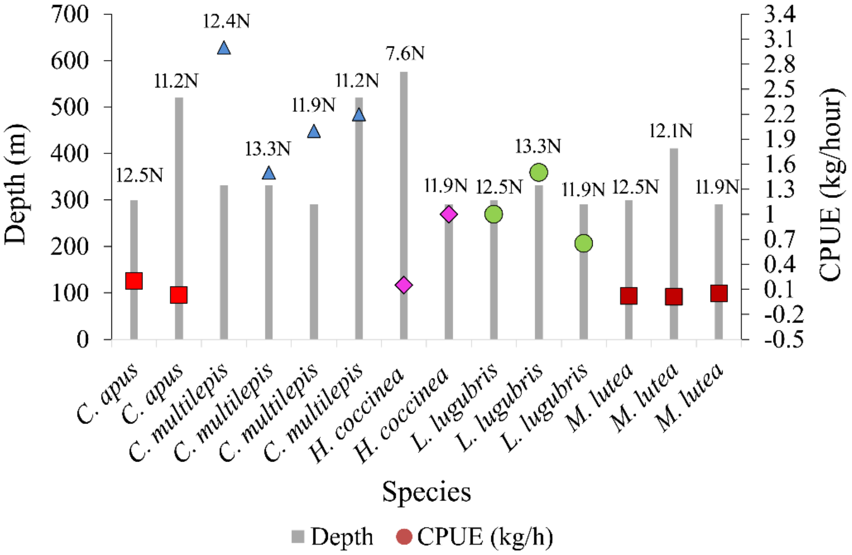


Figure 4.33. The spatial distribution of species along with geographical positions

4.9.2.1 Meristic counts and Morphological data of fish body

Morphological data of the fish

Sixteen morphological variables were measured based on Keast and Webb (1966); Gatz (1979); Watson and Balon (1984) and Beaumord and Petrere Jr. (1994). A numeric vernier calliper (0.1 mm precision) was used to measure: total length (TL), standard length (SL), eye diameter (ED), mouth opening (MO), head depth (HD), eye height (EH), pectoral fin base (PFB), pectoral fin insertion (PFI), pectoral fin length (PFL), pectoral fin surface (PFS), caudal peduncle depth (CPD), caudal fin surface (CFS), caudal fin depth (CFD), body depth (BD), body length (BL), body width (BW), mouth height (MH), and mouth width (MW) (Fig. 4.34).

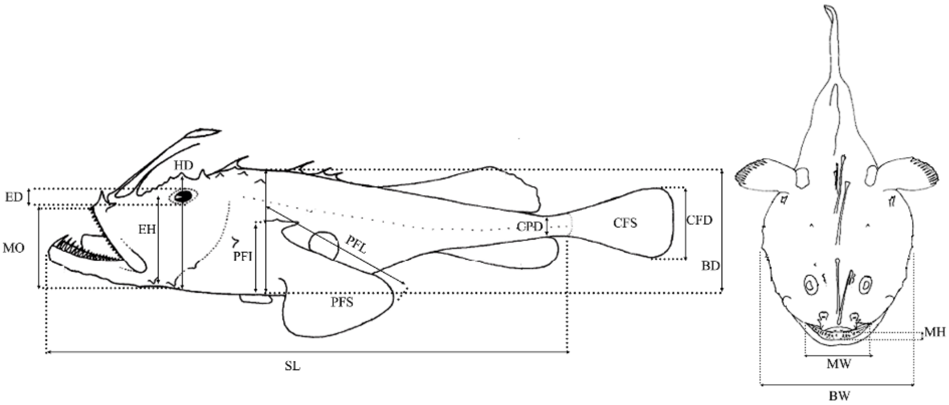


Figure 4.34. Schematic representation of the morphological measurements of the fishes for the analysis (Villéger *et al.* 2011). *BD*, body depth; *BWw*, body width; *CFD*, caudal fin depth; *CPD*, caudal peduncle minimal depth; *ED,* eye diameter; *EH*, distance between the bottom of the head and the eye center along the head depth axis; *HD*, head depth along the vertical axis of the eye; *MH*, mouth height; *MW*, mouth width; *PFB*, body depth at the level of the pectoral fin insertion; *PFI*, pectoral fin length; *PFL*, distance between the insertion of pectoral fin and the bottom of the body; *PFS*, pectoral fin surface (Figures were modified from Caruso 1981, 2002).

From these measurements, a total of eleven ecomorphological attributes (or functional traits) correlated to food acquisition, swimming performances and food preferences were estimated:

Oral gape surface (*Osf*) which indicates the nature/size of the prey captured. Large oral gape ensure the feeding on large prey (following Sibbing and Nagelkerke 2001; Karpouzi and Stergiou 2003; Villeger *et al.* 2017).

Oral gape shape (*Osh*) which defines the method to capture food items (Karpouzi and Stergiou 2003; Wainwright *et al.* 2007).

Oral gape position (*Ops*) which shows the feeding position in the water column. The position of the oral gape reduces the pushing away of the prey during ingestion (following Sibbing and Nagelkerke 2001; Villeger *et al.* 2017).

Eye size (*Edst*) which defines the prey detection efficiency. It also influences the feeding rhythms, predator avoidance and also indicates the availability of the light in the microhabitat (Boyle and Horn 2006; Van der Meer and Anker 1984; Winemiller 1991; Schmitz and Wainwright 2011; Bellwood *et al.* 2014).

Eye position (*Eps*) which displays the vertical position in the water column. High values indicate dorsally located eyes (Gatz 1979; Mahon 1984; Watson and Balon 1984; Pouilly *et al.* 2003; Pease *et al.* 2012; Ribeiro *et al.* 2016).

Body transversal shape (*Bsh*) which indicates the vertical position in the water column as well as hydrodynamic efficiency (Gatz 1979; Sibbing and Nagelkerke 2001; Villéger *et al.* 2017).

Caudal peduncle throttling (*Cpt*) which shows the caudal propulsion efficiency through the reduction of drag (Webb 1984; Villeger *et al.* 2017).

Fin surface ratio (*Fsr*) which indicates the type of propulsion between caudal and pectoral fins.

Fin surface to body size ratio (*Fsb*) which indicates the acceleration and/or maneuvering competence.

Aspect ratio of the pectoral fin (*ArPF*), it is an indicator of swimming ability which helps in sustained swimming. High values indicates long fins, typical character of pelagic fishes which can swim constantly (Fulton *et al.* 2001; Watson and Balon 1984; Wainwright *et al.* 2002; Casatti and Castro 2006).

Aspect ratio of the caudal fin (*ArCF*) indicates the caudal fin use for propulsion and /or direction (Nursall 1958; Gatz 1979; Ovchinnikkov 1971; Webb 1984; Bridge *et al.* 2016; Villeger *et al.* 2017).

All attributes were standardised to remove the allometric effect from the data as it was observed that the functional traits were correlated with the fish size (total weight). We used biomass (total weight) for the allometric correction as it is an indicator of the robust relationship between morphological or metabolic rates and body mass (Dumay *et al.* 2004; Mouillot *et al.* 2005; Kumar *et al.* 2016). The allometric relationship between a trait (x) and mass (M) is $X = aM^{b}$ and the exponent coefficient varied between species. The effect of body mass was eliminated by using the residuals of the common within-group slopes of the linear regressions for each component on body mass.

4.9.2.2 Statistical Analysis

Ecomorphological variations among species were achieved by principal component analysis (PCA). The PC axes which can explain 95% of the total variation were selected (Collar and Wainright 2006). Our hypothesis of significant difference among the species and Bonferroni's correction for post-hoc pairwise multiple comparisons were tested using

Multivariate analysis of variance (MANOVA) (Marcus 1993). Further, a discriminant analysis was done to verify the efficiency of functional traits to predict the species. The leave-one-outcross-validation was used to classify the accuracy of discriminant analysis (Nishimoto *et al.* 2010). All the statistical analysis were performed in PAST (PAlaeontological STatistics, version v1.81; Hammer *et al.* 2001) and R version 3.0.2 (R Foundation for Statistical Computing, Vienna) and results were tested at a significance level of 0.05.

4.9.3. Results

4.9.3.1. Functional space analysis

The first five PCA axes explained 97.9% of the total variation and the first three components showed 93.8% of the variance (Table 4.9). The PC1 axis alone contributed 63.7% of the total variance which was mainly correlated with *Fsb* (r=0.868) (Table 4.10). Positive values were obtained for species with a more dorso-ventrally flattened body and higher swimming capabilities (*M. lutea*, *H. coccinea and L. lugubris*) *versus* species with higher depth body and lesser swimming reaction (*C. multilepis and C. apus*) (Fig. 4.35). The PC2 axis (19.1% of variance) was related to propulsion and acceleration capabilities (*ArCF*, r=0.893). No specific separation was noted, although a small variability was observed between species clustering the PC1 axis.

Table 4.9. Summary of the PCA analysis using functional traits for five lophiiform fishes from Andaman and Nicobar waters. In bold, PC scores considered.

PC scores	**Eigenvalue**	**Variance explained (%)**	**Variance accumilated (%)**
1	**0.433339**	**63.729**	**63.729**
2	**0.1302**	**19.148**	**82.877**
3	**0.0740114**	**10.884**	**93.761**
4	**0.0212467**	**3.1246**	**96.8856**
5	**0.00718458**	**1.0566**	**97.9422**
6	0.00412436	0.60655	98.54875
7	0.00340359	0.50055	**99.0493**
8	0.00287608	0.42297	**99.47227**
9	0.00207029	0.30447	**99.77674**
10	0.00111276	0.16365	**99.94039**
11	0.000404284	0.059456	**99.999846**

Table 4.10. Correlation between PC's components and functional traits. In bold, correlations higher abs (0.3).

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Osf	-0.030	-0.068	0.153	**0.739**	0.253	**0.306**
Osh	-0.034	0.019	0.012	0.120	**0.653**	-0.101
Ops	0.050	-0.084	0.168	0.499	**-0.548**	-0.066
Edst	0.075	0.037	-0.051	-0.149	**-0.302**	0.041
Eps	-0.018	-0.022	0.039	0.233	-0.166	0.061
Bsh	-0.236	-0.012	-0.169	0.056	-0.077	0.215
CPt	-0.084	0.274	0.162	0.182	0.160	**-0.686**
FSr	0.013	0.021	0.137	-0.139	0.212	**0.570**
FSb	**0.868**	0.130	**0.360**	-0.045	0.041	0.035
ArPF	**0.350**	**0.309**	**-0.834**	0.236	0.028	0.026
ArCF	-0.225	**0.893**	0.212	-0.014	-0.109	0.205

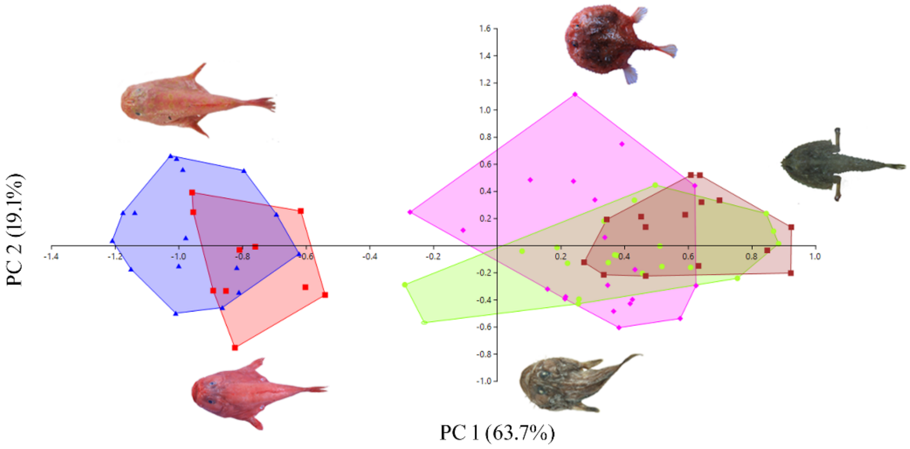


Figure 4.35. Principal Component Analysis of functional traits in five major lophiiform fishes collected from the Andaman and Nicobar waters along the two major axes (*C. apus* (red square), *C. multilepis* (blue triangle), *H. coccinea* (violet diamond), *L. lugubris* (green circle), *M. lutea* (brown square)).

Multivariate analysis of variance confirmed significant difference among the deep-sea anglerfishes (Wilk's Lambda=0.0229, $F=_{44,\ 258.3}=22.88$, P<0.0001). The pair-wise comparison among species using sequential Bonferroni correction indicated significance difference among the species (*P*< 0.0001). Discriminant analysis revealed 92.7% classification success for all the five species studied (Table 4.11).

Table 4.11. Cross-validation for indicating the predictive ability of five lophiiform fishes from Andaman and Nicobar waters: number of cases (percentage of classification).

	C. apus	*C. multilepis*	*H. coccinea*	*L. lugubris*	*M. lutea*	Total
C. apus	10 (100)	0	0	0	0	10
C. multilepis	0	16 (100)	0	0	0	16
H. coccinea	0	0	19 (95)	1	0	20
L. lugubris	0	0	1	17 (89.5)	3	21
M. lutea	0	0	0	1	14 (82.3)	15

4.9.4 Discussion

Our results confirm that the five lophiiform fishes differed significantly based on the functional traits which are related with swimming performance and feeding behaviour. These results are in accordance with the previous findings that the partitioning in the food resources in a resource poor environment such as deep-sea habitat promote the coexistence of the species (Parzefall 1996; Colmenero *et al.* 2010; Preciado *et al.* 2017; Sá-Oliveira *et al.* 2017). The morphological traits are good predictors to understand the ecological habitats of the species under the assumption that adaptation to the environment depends mainly on the resource use based on phenotype (Gatz 1979; Farré *et al.* 2016). In deep-sea habitats, the resource partitioning among the species are mainly based on prey size and swimming capacity near the bottom as observed by various researches (Cartes 1998; Papiol *et al* 2013; Kumar *et al.* 2016). PCA differentiated the species mainly into two groups viz., deep-bodied *Chaunax* spp. (*C. apus* and *C. multilepis*) and dorso-ventrally flattened fishes (*M. lutea*, *L. lugubris* and *H. coccinea*). These two groups are clearly differentiated and separated within the functional groups. The major variations among the two main groups (deep-bodied and dorso-ventrally flattened) are related to the swimming ability to catch the prey and manoeuvrability. The deep-bodied fishes such as *Chaunax* spp. are not good swimmers as the dorso-ventrally flattened species and they prefer to stay in bottom, and wait the prey to come, which are attracted by their well-developed lure (Armstrong *et al.* 1996). They have larger mouth and bigger eyes that enable them to compensate their inferior swimming efficiency with other dorso-ventrally sympatric species. Unlike *Chunaux* species, flattened species (*M. lutea, L. lugubris and H. coccinea*) are superior in their locomotors abilities which enable them to chase the prey more effectively than the former, except *L. lugubris*. Among the three dorso-ventrally flattened species, *L. lugubris* has the largest mouth opening. The variations in their functional morphology for locomotion and manoeuvrability between the species help us to understand the mode of feeding, prey type and the nature of the habitat (Schoenfuss and Blobb 2007; Kumar *et al.* 2016) and to predict the trophic niche of the species (Wainwright and Richard 1995; Colborne *et al.* 2013). Our studies confirmed the understanding that even if the prey items are similar, the ecological strategy for the mode of predation differs significantly, which promote their coexistence by reducing the competition (Kumar *et al.* 2016). Though, *L. lugubris* is morphologically more similar to the *H. coccinea* and *M. lutea*, its mode of feeding is more similar to *Chaunax* species as it is the characteristic feature of fishes inhabiting ecosystems deprived of food resources (Pietsch 2009). Similarly, though all the three flattened species are placed in the same group based on their functional traits, their mode of feeding is dissimilar.

Only limited information is available on the food and feeding habits of lophiiform fishes (Crozier 1985; Azevedo 1996; Laurenson and Priede 2005; Preciado *et al.* 2006). Lophiid fishes are basically sit and wait predators with an ambush behaviour and can attract their prey with angling apparatus or the illicium (Chadwick 1929; Grobecker and Pietsch 1979; Armstrong *et al.* 1996) which are considered as adaptations to live in energy poor habitats (Marshall 1971). Fishes were the major food item in the stomachs of *Lophius* species, a morphologically similar species to

L. lugubris (Crozier 1985; Laurenson and Priede 2005; Preciado *et al.* 2006). These fishes are very active and opportunistic feeders which was evident by the presence of less empty stomachs and variety of prey items (Stagioni *et al.* 2013). Bigger mouth opening of *L. lugubris* enables them to feed on large preys such as fishes compared to other flattened species such as *M. lutea* and *H. coccinea* (Stagioni *et al.* 2013). Shrimps were the major food item observed in *Chaunax* species (Karuppasamy *et al.* 2008). They are mainly ambush predators and have specialised suction mechanisms seen in non-swimmers or occasional swimmers such as ceratioid anglerfishes (Webb 1984). No information is available on the feeding style and prey preferences of *M. lutea* and *H. coccinea*. However, considering their functional similarities these species could be theoretically competing with each other (Kumar *et al*. 2016). Our results indicate that the five deep-sea anglerfishes are vary in their spatial distribution.

Gut content analysis indicate that fishes are the major prey items in the stomach of both the *Chaunax* species. However, instances of shrimps were found in the stomachs of *C. apus*. Our analysis indicates that fin area to body size ratio is higher for *C. multilepis* and the body is more elongated than *C. apus*. These characters make them more active swimmers. These functional differences allow them to share their resources. This clearly suggests that even if the prey is similar for these fishes, the ecological strategy for feeding clearly differs, as observed by Kumar *et al*. (2016). Our studies are in accordance with the previous findings that diet partitioning in deep-sea environments can be predicted from functional as well as morphological characteristics (Parzefall 1996;

Colmenero *et al.* 2010; Kumar *et al.* 2016; Romeu *et al.* 2016 Preciado *et al.* 2017). Feeding behaviour of the two dorso-ventrally flattened species *L. lugubris* and *H. coccinea* are also very dissimilar as inferred from their relative position and size of their mouth. *L. lugubris* have larger mouth opening and show an ambush mode of predation by attracting their prey with their well-developed illicium. The relative size and mouth opening of *H. cocinea* is less compared to the former, but it can swim and chase the prey with a suction feeding. The setbacks from smaller mouth opening and short illicium are overcome by their superior swimming efficiencies. Existence of dissimilar feeding and swimming performances reduce the inter-species competition and promotes coexistence.

Present studies indicate that ecological strategies amongst the species studied clearly differs, even if they have similar prey preferences. Results indicate that the five deep-sea anglerfishes differ in their strategies on feeding and locomotion. This along with the variations in their spatial distribution promotes their coexistence in the resource poor environment of deep-sea habitat. This study confirm the suitability of ecomorphological approach to study the ecology of deep-sea fishes from morphological features. Further studies with more species, better understanding about the preys, and the degree of niche overlap among species, are inevitable to elucidate these relationships more clearly.

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Chapter 5

MOLECULAR IDENTIFICATION OF LOPHIIFORMES

5.1 Introduction

Fish species is traditionally identified on the basis of morphological, meristic and sometimes anatomical characters. But in many cases especially in deep-sea fishes, because of their overlapping meristic characters, high phenotypic plasticity and diverse developmental stages, morphological characters alone is not sufficient to identify the species (Victor *et al.* 2009; Veríssimo *et al.* 2014). This draw back can be overcome with relatively new techniques like DNA (Deoxyribo Nucleic Acid) barcoding. It is one of the power full taxonomic tools as it allows identify all stages of the life cycle (Zhang *et al.* 2004) and quantify considerable intraspecific variations. DNA-based identification techniques are proven to be rapid, accurate and cost-effective in resolving taxonomic ambiguity of species. This relatively new techniques appears to be a promising approach for taxonomic clarification, characterization, and discovery of new species, facilitating biodiversity studies and elucidating evolutionary relationships (Bhattacharya *et al.* 2015). Combined use of DNA barcode along with morphological characters got wide acceptance in taxonomic studies (Ebert *et al.* 2010; Akhilesh *et al.* 2012; Iwatsuki *et al.* 2013; Allen *et al.* 2013; Bineesh 2015).

Globally many authors have successfully generated the barcode life of fishes (Morita 1999; Carr 1999; Miya *et al.* 2001; Hebert *et al.* 2003b; 2003; Ward *et al.* 2005; Lane *et al.* 2007; Teletche 2009; Kochzius 2010; Dasmahapatra 2010; Iglésias *et al.* 2010; Cawthorn *et al.* 2011; Iwatsuki 2013; Lee *et al.* 2013). 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 (Ward *et al.* 2009).

Contributions towards the phylogeny and molecular systematics of angler fishes came from many authors. Lundsten *et al.* (2012) studied the morphological and molecular characteristics of *Chaunacops coloratus* (Garman 1899) from north Eastern Pacific. Pietsch and Orr (2009) demarcated the phylogenetic relationships of deep sea anglerfishes of the suborder ceratioidei based on morphological characters and Miya *et al.* (2010) explained the evolutionary history of Order Lophiiformes through the mitogenomic approach. Shedlock *et al.* (2004) elucidated the molecular systematics and life history evolution of angler fishes from mitochondrial DNA. Arnold *et al.* (2012) established the phylogenetic relationships within the family Antennariidae from mitochondrial 16S and cytochrome oxidase c subunit 1 (COI) genes.

Barcode life of Indian fishes are limited. Major study came from Lakra *et al.* (2009) for commercially important Indian sciaenids species, carangids (Persis *et al.* 2009). Lakra *et al.* (2011) barcoded 115 species of commercially important marine fishes from east and west coasts of India. Other major studies includes Lakra *et al.* (2010); Benziger *et al.* (2011); Lakra *et al.* (2013); Rahman *et al.* (2013); Khare *et al.* (2014); Chakraborty and Ghosh (2014a), and Basheer *et al.* (2014). Recently, comprehensive studies on molecular taxonomy of 82 deep-sea fishes from southern coast of India were documented by Bineesh (2015). It is well noticed that barcode life of Indian lophiiformes is least studied. Present study provides base line information on molecular taxonomy and phylogenetic relationships among Indian lophiiformes.

5.2 Materials and Methods

a. Tissue collections and cataloguing

After the collections, each specimen was washed well, all fins were spread and fixed in formalin before taking high quality photographs. Approximately 100 mg of white muscle tissues or gill tissue was collected from each species and preserved in 95% ethanol in properly labelled sterile 2 ml storage vials and kept at -20 °C until further analysis. Species identification was done based on original description, redescription and other illustrations as explained in Chapter 3.

b. Mitochondrial DNA (mtDNA) analysis

Genomic DNA isolation

The whole genomic DNA from the samples was isolated following the protocol of Miller *et al.* (1988) with minor modifications. DNeasy (Qiagen) kit, following manufacturer's instruction, was used to extract DNA from samples. The quality of DNA isolated was checked through

0.8% agarose gel. The concentration of isolated DNA was diluted to a final concentration of 100 ng/µl after checking with UV spectrophotometer. Mitochondrial DNA (mtDNA), cytochrome C oxidase I (COI) and 16S rRNA were amplified by employing specific universal primers. For COI, more than one set of primers (varied primers) were used depending on the compatibility. Annealing temperatures (Ta) were adjusted depending on the melting temperature (Tm) of the respective primer used.

Each PCR procedure included a negative control (no DNA template). Verification of successful amplification was assessed by 1.8% agarose gel electrophoresis. After successful PCR amplification of the target fragments, amplified products were purified before the template was sequenced in both directions. The cleaned up PCR products were used as the template for sequencing PCR to increase the amount of product linearly with the number of cycles. Nucleotide sequencing was performed by the dideoxy chain-termination method (Sanger *et al.* 1977) using ABI Prism Big Dye Terminator v3.1 Cycle Sequencing kit, (Applied Biosystems, USA). Terminators are dideoxynucleotides labelled with different coloured fluorescent dyes that will present different emission spectra on an electrophoresis gel illuminated by laser. Each PCR product was sequenced using both forward and reverse amplification primers. The resulting DNA fragments were cleaned before sending to the sequencing facility.

c. Amplification and sequencing

The Cytochrome c oxidase I (COI) gene was amplified in a 25 µl reactions volume containing 1X assay buffer (100 mM Tris, 500 mM KCl, 0.1% gelatin, pH 9.0) with 1.5 mM $MgCl_2$ (SciGenom, Kochi), 5 pmoles of each primer, 200 µM of each dNTP , 1.5 U *Taq* DNA polymerase and 20 ng (nanogram) of template DNA. The primer used for the amplification of the partial 16S rRNA gene were 16SAR (5'-CGCCTGTTTATCAAAAACAT-3') and 16SBR (5'-CCGGTCTGAACTCAGATCACGT-3') (Palumbi *et al.* 1991). The thermal profile used was 36 repetitions of a three step cycle consisting of denaturation at 94 °C for 1 min, annealing 50 °C for 1 min and extension at 72 °C for 1.5 min including 4 min for initial denaturation at 94 °C and 7 min for final extension at 72 °C.

The partial sequence of COI gene was also amplified using primers Fish F1 (5' – TCA ACC AAC CAC AAA GAC ATT GGC AC - 3') and Fish R1 (5' – TAG ACT TCT GGG TGG CCA AAG AAT CA - 3') (Ward *et al.* 2005) in 25 µl reactions volume containing 1x assay buffer (100 mM Tris, 500 mM KCl, 0.1% gelatin, pH 9.0) with 1.5 mM $MgCl_2$ (SciGenom, Kochi, India), 5 pmoles of each primer, 200 µM of each dNTP, 1.5 U *Taq* DNA polymerase and 20 ng of template DNA. The thermal condition consisted of initial preheat at 95 °C for 3 min, denaturation at 94 °C for 30 s, annealing at 50 °C for 30 s, extension at 72 °C for 35 s, repeated for 29 cycles, followed by a final extension for 3 min at 72 °C. The PCR products were visualized on 1.5% agarose gels. Samples with intense bands were selected for sequencing. Sequencing reactions used a BigDye Terminator V.3.1 Cycle sequencing Kit (Applied Biosystems, Inc). All samples were sequenced bidirectionally using an ABI3730 capillary sequencer following the manufacture's protocol. Even though both genes are amplified, only COI gene was taken for further analysis due to the bad sequence quality of 16SrRNA gene.

d. Sequence analysis

The raw DNA sequences were edited and aligned using BioEdit sequence alignment editor version 7.0.5.2 (Hall 1999). The extent of sequence differences between species was calculated by averaging pair-wise comparisons of sequence differences across all individuals. The sequence divergence values within and between species were calculated using Kimura 2-parameter (K2P) distance model implemented in MEGA 5 (Tamura *et al.* 2011) software. The number of polymorphic sites and nucleotide diversity (Pi), nucleotide composition and number of transition and transversion between species were determined by DnaSpver 3 (Rojas *et al.* 2006). Neighbour-joining (NJ) trees of K2P distance were created to provide graphic representation of divergence with 1000 replications.

5.3 Results

The sequence data sets generated in the present study from 52 individual sequences, 13 species under 4 families were used for partial sequence analysis of COI gene. Sequences of few additional species (*Lophiodes gracilimanus, Halicmetus ruber, Halieuteae stelleta and Halieutopsis stellifera* etc.) were excluded in the analysis due to bad sequence quality and short sequence size. All sequences were compared with NCBI GenBank and BOLD for identification confirmation. The partial sequences of mtDNA generated in this study were deposited in the GenBank and BOLD public database.

5.3.1 Cytochrome oxidase sub unit I (COI) and Barcoding

A total of 52 fishes belonging to 13 species, 8 genera, 4 families of the Order Lophiiformes were barcoded with a minimum of 615 bp. (Fig. 5.1; Table 5.1).

The collections included 12 fish species that were not previously reported from Indian waters. Five of these taxa were confirmed as putative new species for Indian waters (including *Bufoceratias* sp. which unable to identify due to total damage). All amplified sequences were >650 bp with no insertions, deletions, stop codons and NUMTs. Amplified sequence length varied among species and families but consistent within species. The shortest sequence observed was 598 in *Lophiodes lugubris* and the longest was 678 in *Chaunax multilepis*. Sequences were aligned and multiple alignments resulted in consensus length of 615 bp per taxon was used for analysis. All sequences were compared with NCBI GenBank and BOLD (www.barcodinglife.org, see Ratnasingham and Hebert 2007) for initial identification confirmation. Out of the total 615 sites obtained 324 (49.77%) were constant, 283 (50.23%) variable, 30 singleton and 253 (49.46%) parsimony informative sites. A total of 51 haplotypes were observed across the taxa. Within each species (n=5), minimum number of haplotypes was one (*Lophiodes mutilus*) and maximum was eight in *Halieutaea coccinea*. The overall mean distance of individuals among the lophiiformes fishes under this study was estimated as 0.221 (22.1%). The maximum interspecific K2P distance was 0.32 (32.0%) between *Halieutopsis* sp. A and *Halieutaea coccinea* and minimum was 0.22 (2.2%) divergence between *Bufoceratias thele* and *Bufoceratias* sp. (not included in the taxonomic study, specimen totally damaged). Maximum intraspecific distance observed was 0.12 (1.2%) in *Lophiodes lugubris*.

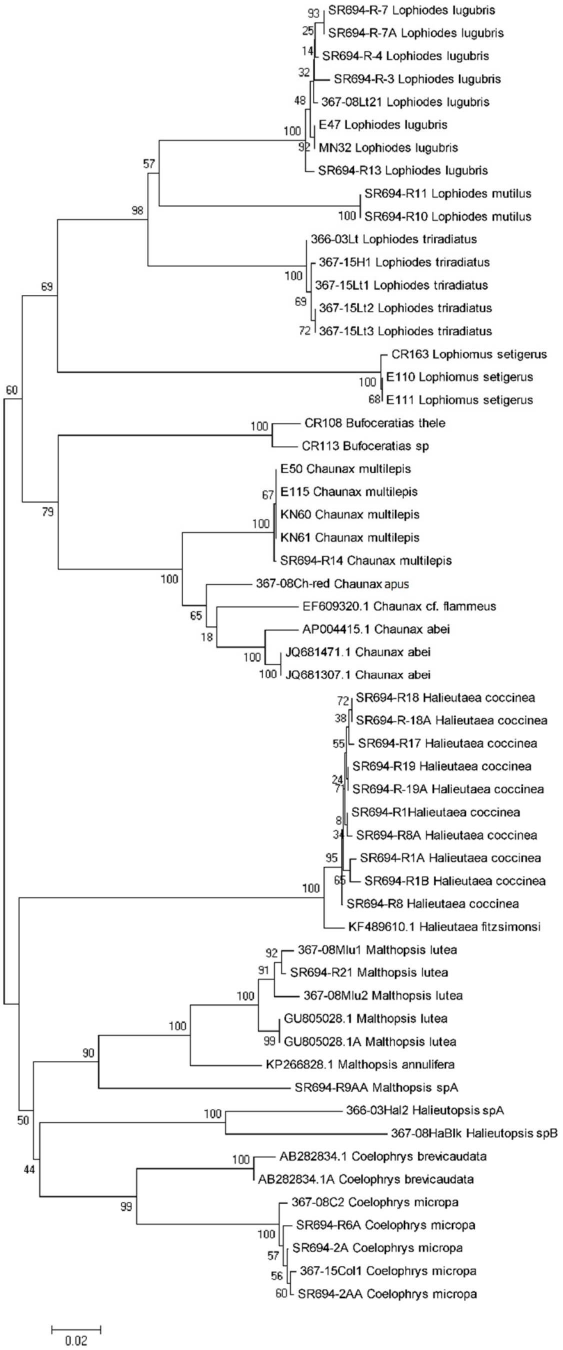

Figure 5.1. Neighbour joining (NJ) phylogenetic tree of fishes belonging to Order Lophiiformes inferred from mitochondrial COI sequence analysis.

5.3.2 Comments on families

a. Lophiidae

Four species under two genera belonging to the family Lophiidae were investigated in the present study. The overall mean distance of individuals showed a high value of 14.1%. The maximum interspecific K2P distance was 28.9% between *Lophiodes mutilus* and *Halieutaea coccinea* and minimum was 13.2% divergence between *Lophiodes triradiatus* and *Lophiodes lugubris*. The minimum intraspecific distance observed was 0.1% in *Lophiomus setigerus* while maximum intraspecific distance observed was 1.2% in *Lophiodes lugubris*. The amplified sequence length varied from 655 bp in *Lophiodes lugubris* to 668 bp in *Lophiodes mutilus*.

A total of 15 haplotypes were observed across the taxa. Within each species (n=5), minimum number of haplotypes was three (*Lophiomus setigerus*) and maximum was 6 in *Lophiodes lugubris*. Four major clades were observed in Neighbour-Joining analysis for the family Lophiidae (Fig. 5.2). All the species were separated from each other forming clusters, indicating sister groups in the family Lophiidae. Taxonomic ambiguity between *L. lugubris* and *L. mutilus* from Indian waters is resolved in this study. All three *Lophiodes* species were seen as one clade and *Lophiomus setigerus* separated into another clade. In the first major clade, *Lophiodes lugubris* and *Lophiodes triradiatus* appear as sister clades. All these clades were supported by high bootstrap values.

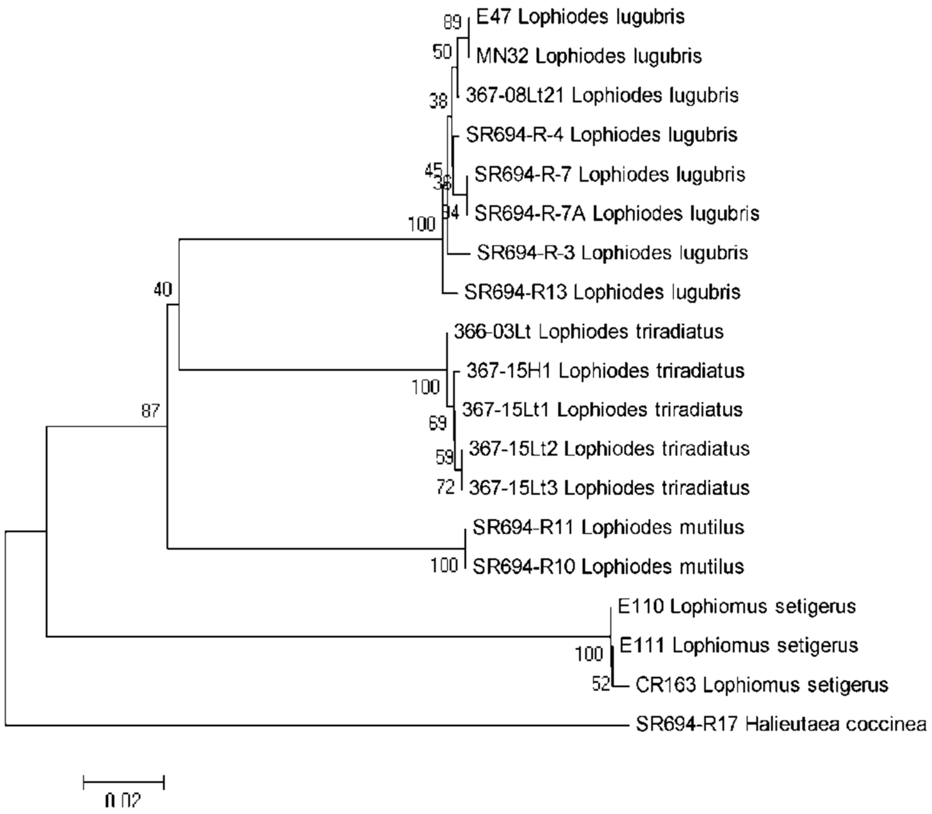

Figure 5.2. Neighbour joining (NJ) phylogenetic tree of fishes belonging to family Lophiidae inferred from mitochondrial COI sequence analysis.

b. Ogcocephalidae

Six species under four genera belonging to the family Ogcocephalidae were investigated in the present study. The overall mean distance of individuals showed a high value of 19.8%. The maximum interspecific K2P distance was 31.8% between *Halieutopsis* sp. A and *Halieutaea coccinea* and minimum was 6.0% divergence between *Halieutopsis* sp. A and *Halieutopis* sp. B. The minimum intraspecific distance observed was 1.8% in *Malthopsis lutea* while maximum intraspecific distance observed was 0.03% in *Halieutaea coccinea*. The amplified sequence length varied from 628 bp in *Halieutopsis* sp. A to 672 bp in *Malthopsis lutea.*

A total of 28 haplotypes were observed across the taxa. Within each species (n=5), minimum number of haplotypes was two (*Malthopsis* sp. A) and maximum was 7 in *Halieutaea coccinea*. Five major clades were observed in Neighbour-Joining analysis for the family Ogcocephalidae (Fig. 5.3). All the species were separated from each other forming clusters, indicating sister groups in the family Ogcocephalidae. All three *Malthopsis* species were seen as one clade and *Halieutaea coccinea* separated into another clade. In the last major clade, a new species of *Halieutopsis* cluster with *Coelophrys micropa* appear as sister clades. All these clades were supported by high bootstrap values.

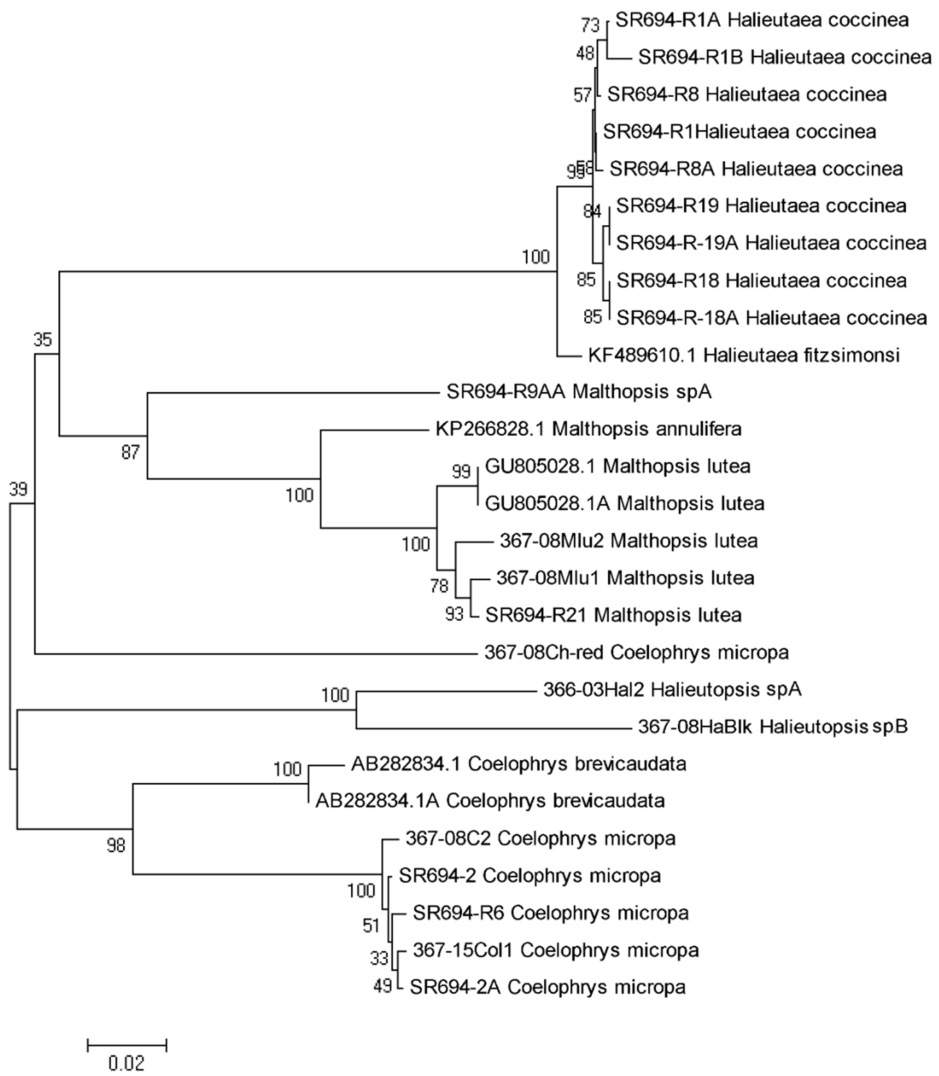

Figure 5.3. Neighbour joining (NJ) phylogenetic tree of fishes belonging to family Ogcocephalidae inferred from mitochondrial COI sequence analysis.

5.4 Discussion

Deep-sea fishes are considered as one of the least studied groups with several taxonomic ambiguities in most of the families. Morphology based taxonomy is problematic in many of the deep-sea fish families and genetic tools have great potential to resolve the taxonomic status and find out the accurate fish diversity and discover new species to science (Zahuranec *et al.* 2012; Gomon *et al.* 2014). Identification of species based on morphological characters is the traditional approach in fishes and the use of modern tools like molecular markers for species identification make it more concrete (Hebert *et al.* 2003a; Ilves and Taylor 2009). Species identification by using DNA barcoding is a simple technique that is based upon the principle that interspecific divergence sufficiently outscores intraspecific divergence and the biological species can be clearly demarcated by a threshold value (Hebert *et al.* 2003a). The present study represents the first molecular survey of deep-sea fish diversity of the Order Lophiiformes using COI gene data from the Indian EEZ including Andaman Sea. This includes generation of COI barcodes for 13 species and confirmation of four species based on morphology and molecular data.

We observed that many species sequenced here show (Fig.5.1) high genetic divergence with sequence in the GenBank and BOLD databases. This may indicates 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 but it requires more samples to describe the species. The distance between *Halieutopsis* sp. A and *Halieutopsis* sp. B (11.8 %) is well above the threshold value proposed by Ward *et al.* (2005). Similarly *Chaunax multilepis* a new species confirmed and described during the present study was found genetically diverged from *Chaunax apus* by 6.4%. We also found *Malthopsis* sp. A clade to be very distinct and different from *Malthopsis lutea* of Indian waters by having 15.5% divergence. This high genetic variation clearly shows the presence of un-described species in the present study. It is also observed that distance between *Malthopsis lutea* from Indian waters and *Malthopsis lutea* (GU805028, from South Africa) was 1.7 %. Further taxonomic studies are needed to find out cryptic species using morphological characters and more molecular markers.

It is concluded that partial sequence information of COI gene can be used as a molecular marker for identification and resolution of taxonomic ambiguity in deep-sea fishes of the Order Lophiiformes. The present study clearly points out the importance to do the morphological taxonomy deep-sea fish families with analysis of COI data to identify the cryptic species and discover new species at faster rate.

Table 5.1. Details of species studied for molecular identification

Si No	Species	Genus	Family
1	*Lophiodes lugubris*	*Lophiodes*	Lophiidae
2	*Lophiodes mutilus*	*Lophiodes*	Lophiidae
3	*Lophiodes triradiatus*	*Lophiodes*	Lophiidae
4	*Lophiomus setigerus*	*Lophiomus*	Lophiidae
5	*Chaunax apus*	*Chaunax*	Chaunacidae
6	*Chaunax multilepis*	*Chaunax*	Chaunacidae
7	*Halieutaea coccinea*	*Halieutaea*	Ogcocephalidae
8	*Coelophrys micropa*	*Coelophrys*	Ogcocephalidae
9	*Halieutopsis* sp. A	*Halieutopsis*	Ogcocephalidae
10	*Halieutopsis* sp. B	*Halieutopsis*	Ogcocephalidae
11	*Malthopsis lutea*	*Malthopsis*	Ogcocephalidae
12	*Malthopsis* sp. A	*Malthopsis*	Ogcocephalidae
13	*Bufoceratias thele*	*Bufoceratias*	Diceratiidae

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Chapter 6

HIGHLIGHTS AND CONCLUSION

- Present study provides a comprehensive report on the Order Lophiiformes from Indian waters. Field surveys were undertaken exclusively on board FORV. *Sagar Sampada* by participation in 19 cruises of the vessel and covering a total of 78 stations ranging from 200 m to 1337 m depths. (Arabian Sea- 12 cruises and 33 stations; Bay of Bengal- 2 cruises and 13 stations; Andaman waters- 5 cruises and 32 stations).

- A total of 36 species were documented in the course of the present study. This include, 8 species new to science, 7 new records of species from the Indian EEZ (21 area wise new records—8 from Arabian Sea; 3 from Bay of Bengal and 10 from Andaman Sea) and 21 species previously known. The 8 new Lophiiformes species discovered through the present study are *Chaunax multilepis, Chaunax* sp. A*; Halieutopsis* sp. A; *Halieutopsis* sp. B*; Malthopsis* sp. A; *Oneirodes* sp. A; *Himantolophus* sp. A and *Halieutaea* sp. A.

- Species identity of *Chaunax multilepis* (Ho HC, Meleppura RK and Bineesh KK, 2016) *Halieutopis* sp. A; *Halieutopis* sp. B and *Malthopsis* sp. A are reconfirmed through DNA barcodes. Another new species of ceratioid, *Oneirodes sanjeevani* Rajeeshkumar, 2017 was also described from Western Indian Ocean during this study. However, this species is not included here as it was collected from outside the study area.

- Further, *Lophiodes gracilimanus* (349 02A and 367 05) reported in this study is the rediscovery of the species after 35 years. *Halieutaea indica* (288 09) represents the rediscovery from Indian water after 108 years of its description by Annandale and Jenkins in 1910.
- Among the 21 species previously known, 7 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). Nevertheless, these species are included in the revalidated check list of Lophiiformes.
- Accordingly the check list of Lophiiformes from Indian EEZ is revalidated to 36 species under 17 genera and 8 families. Of these; 5 species belong to Lophiidae family; 4 species to Chaunacidae; 17 species to Ogcocephalidae; 4 species to Diceartiidae; 2 species each from Ceratiidae and Oneirodidae and 1 species each from Melanocetidae and Himantolophidae. Previous studies had reported a total of only 21 species of Lophiiformes under 13 genera and 7 families from the Indian EEZ. Of these; 5 species were from family Lophiidae; 1 species from Chaunacidae; 11 species from Ogcocephalidae and 1 species each from Diceartiidae, Oneirodidae, Melanocetidae and Ceratiidae.

- A decreasing trend in biomass and numerical abundance with increasing depth is noticed in Lophiiformes. However, biomass of Lophiiformes fishes are less when compared to other groups in the catches obtained. This may be due to their extremely flattened, small sized body and low weight in majority of taxa.
- Length-weight relationships established for Lophiiform fishes in the present study are the first time estimates from Indian Seas, perhaps first time globally (Froese and Pauly 2018). Present study did not find any significant difference in the growth patterns between sexes. Like many other deep-sea fishes, anglerfishes also follow negative allometric growth pattern.
- Gut content analysis reveals that Lophiiformes feed mainly on fish, followed by crustaceans. Generally they are opportunistic feeders. Members of lophiids, ogcocephalids show sit-and-wait type feeding mechanism, that ambush prey which pass within range or make use of their angling apparatus to actively attract prey to the vicinity of their mouths.
- In Lophiiform fishes, eggs are encapsulated with a gelatinous covering, which enable them to float freely in productive surface waters. Present study provides base line information of egg structure and relative fecundity (RF) of some deep-sea anglerfishes. Egg diameter of *L. lugubris* varies between 0.27 to 0.45 mm and for *Malthopsis lutea* from 0.305 to 0.406 mm. RF value of *Chaunax multilepis* was observed to range from 9000 eggs (100 mm SL) to

40500 eggs (130 mm SL). Estimated RF for *M. lutea* was 60000 eggs.

- *Chaunax multilepis* and *Chaunax apus* obeys general sex allocation theory in a population (1:1); where as in *Malthopsis lutea* sex ratio value is skewed towards female and for *Halieutaea coccinea* and *Lophiodes lugubris* towards male.
- Our studies confirm the suitability of otolith morphology for the differentiation of Lophiiform fishes inhabiting Indian waters. Otolith morphology and their morphometric relationships varies significantly among the five Lophiiform fish species studied. The equations we have derived for predicting the fish size from various otolith morphometrics would be useful for studying food and feeding, population dynamics, palaentological and other biological aspects of fishes. These relationships are good tools to study the trophic relationships between the less studied deep-sea fishery resources of India EEZ. Our studies also confirm that otolith area, perimeter and weight are higher for slow moving fishes like Lophiiformes compared to fishes with superior swimming efficiencies.
- Otoliths are species specific and therefore useful in resolving taxonomic ambiguities by identifying the species from the shape of its otolith. Present study describes otolith morphology of 12 deep-sea anglerfishes from the Indian EZZ for the first time.
- Otoliths have complex shapes, lack consistent identifiable points or landmark and therefore may not provide results directly from its morphometric measurements such as (length, width, area,

perimeter). Therefore, elucidation of otolith shape was done through Fourier analyse, because of its ability to provide an accurate description of complex or curved shapes. Elliptical Fourier analysis identified quantifiable differences in the otolith shapes among the five anglerfish species studied. Present study has documented the use of this tool effectively to resolve taxonomic ambiguities or differentiate species.

- The suitability of ecomorphological approach for the better understanding of the ecology of deep-sea fishes is confirmed through the present study. Study reveals that Lophiiform fishes differed significantly based on the functional traits which are related with swimming performance and feeding behaviour. Their ecological strategy clearly differ even if they have similar prey preferences. Ecomorphological approach enables to predict diet partitioning in deep-sea environments from their functional as well as morphological characteristics.

- Partial sequence of COI gene from 13 species belonging to 8 genera and 4 families of Order Lophiiformes were generated through this study. The study represents the first molecular survey of deep-sea fish diversity of the Lophiiformes using COI gene data from the Indian EEZ including Andaman and Nicobar Islands. Study resolved the taxonomic ambiguity between the two *Lophiodes* species, *L. lugubris* and *L. mutilus* from Indian waters and also confirmed four new species based on morphology and molecular data.

- So far, four research papers have been published in international journals using data collected through this study and two papers are communicated for publication.

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Annexure I

List of Publications

[1] **Rajeeshkumar MP**, Meera KM, Hashim M. 2017. A New Species of the Deep-Sea Ceratioid Anglerfish Genus *Oneirodes* (Lophiiformes: Oneirodidae) from the Western Indian Ocean. ***Copeia*** 105, No. 1, 2017, 82–84, DOI: 10.1643/CI-16-467

[2] **Rajeeshkumar MP**, Vinu J, Sumod KS, Sanjeevan VN, Hashim M. 2016. Three new records of rare deep-sea Anglerfishes (Lophiiformes: Ceratioidei) from the Northern Indian Ocean. ***Marine Biodiversity***, Springer, 46:923–928, DOI 10.1007/s12526-015-0437-2

[3] **Rajeeshkumar MP**, Vinu J, Cubelio SS, jayalakshmi KJ, Sanjeevan VN. 2013. First record of the batfish, *Halieutopsis stellifera* (Lophiiformes: Ogcocephalidae) from the eastern Indian Ocean. ***Marine Biodiversity Records***, page 1 of 3. Marine Biological Association of the United Kingdom, 2013 Vol. 6; e84; doi: 10.1017/S1755267213000626.

[4] Hsuan-Ching HO, **RajeeshKumar Meleppura**, Bineesh KK. 2016. *Chaunax multilepis* sp. nov., a new species of *Chaunax* (Lophiiformes: Chaunacidae) from the northern Indian Ocean. ***Zootaxa*** 4103 (2): 130–136. http://doi.org/10.11646/zootaxa.4103.2.3

Other Publications

[1] **RajeeshKumar MP**, Vinu J, Cubelio SS, Sanjeevan VN 2014. First record of *Aphanopus microphthalmus* Norman, 1939 (Teleostei: Trichiuridae) from the Indian Exclusive Economic Zone. ***Check List, Journal of species lists and distribution***. 10(5): 1187–1188. ISSN 1809-127X

[2] **RajeeshKumar MP**, Vinu J, Sumod KS. Hashim M, Sanjeevan VN, Sudhakar M. 2016. Fishes of the family Peristediidae (Pisces: Scorpaeniformes) from Indian waters with four new records. ***South Indian Journal of Biological Sciences*** 2.4 (2016): 404-414. ISSN: 2454-4787

[3] Vinu J, **RajeeshKumar MP**, Usha VP, Sumod KS, Akhilesh KV, Hashim M, Sanjeevan VN. 2017. Redescription and sexual dimorphism of Andaman leg-skate *Cruriraja andamanica* (Chondrichthyes: Rajiformes) with comments on the zoogeography of the genus *Cruriraja*. (2017). ***Journal of Fish Biology*** (2017) 91, 587–602. doi:10.1111/jfb.13371

[4] Vinu J, **Rajeeshkumar MP,** Sumod KS, Meera KM, Hashim M, Sanjeevan VN, Sudhakar M. 2016. Taxonomic clarification and re-description of two deep-sea roughies of genus *Hoplostethus* from the Indian Ocean. ***Marine Biodiversity***, Springer DOI 10.1007/s12526-016-0478-1

[5] Vinu J, **Rajeesh Kumar MP**, Sumod KS, Deepa KP, Hashim M, Sanjeevan VN, Sudhakar M. 2016. First record of deep-sea gigantic pycnogonid *Colossendeis colossea* Wilson, 1881 from the Western Indian Ocean. ***Marine Biodiversity***, Springer DOI 10.1007/s12526-015-0373-1

[6] Vinu J, **RajeeshKumar** MP, Sumod KS, Deepa KP, Hashim M, Sanjeevan VN, Sudhakar M. 2016. Occurrence of a rare gigantic sized deep-sea cod *Lepidion inosimae* (Günther, 1887) in the Northwestern Indian Ocean. ***Marine Biodiversity,*** Springer DOI 10.1007/s12526-016-0476-3

[7] Sumod KS, Vinu J, **Rajeeshkumar MP**, Cubelio SS, Hashim M, Sanjeevan VN, Sudhakar M. 2016. First record of Solitary duckbill eel, *Nettastoma solitarium* Castle & Smith, 1981 (Anguilliformes: Nettastomatidae) from the Andaman Sea. ***Marine Biodiversity***, Springer DOI 10.1007/s12526-015-0438-1

[8] Nikki R, Vijayan AKK, Oxona K, Sileesh M, Deepa KP, **Rajeeshkumar MP**, Hashim M, Sudhakar M. 2018. A range extension of *Diretmoides veriginae* Kotlyar, 1987 (Beryciformes: Diretmidae) from the Nicobar Island, India. ***FishTaxa***, 3(2), pp.460-465. E-ISSN: 2458-942X

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Reprints of Papers Published

[1] A New Species of the Deep-Sea Ceratioid Anglerfish Genus *Oneirodes* (Lophiiformes: Oneirodidae) from the Western Indian Ocean.

[2] Three new records of rare deep-sea Anglerfishes (Lophiiformes: Ceratioidei) from the Northern Indian Ocean.

[3] First record of the batfish, *Halieutopsis stellifera* (Lophiiformes: Ogcocephalidae) from the eastern Indian Ocean.

[4] *Chaunax multilepis* sp. nov., a new species of *Chaunax* (Lophiiformes: Chaunacidae) from the northern Indian Ocean.