Benthic Communities of Mesophotic Coral Ecosystem off Pondicherry, the East Coast of India

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The shallow coral reef ecosystems along the Indian coast are threatened by the anthropogenic global ocean warming and increased frequency of coral bleaching in the recent past. Identification and conservation of deeper reef habitats is essential as they serve as a source of larvae and livestock to replenish the shallow reef habitats. Information on the location and spatial extent of MCEs and their biodiversity is poorly known in the continental shelf of the east coast of India. In this study, we documented the species diversity of MCEs at a depth of 30 to 40 m off Pondicherry along the east coast of India. In total, 12 species of corals including 5 black coral and 16 octocorals, 4 species of sponges, and 31species of coral associated benthopelagic fish species were recorded. *Subergorgia* sp. was the most dominant octocorals species and found extensively as gorgonian forests. The MCEs reported in this study raises important questions about the origin and connectivity of the coral populations in this region to the other major coral reef ecosystems along the east coast. Understanding the physical processes and hydrographic features around the MCEs, off Pondicherry will reveal more information about the distribution and colonization of coral communities and their vulnerability to changes in future.

Key words: Mesophotic Coral Ecosystems, benthic communities, hard-bottom, east coast of India

Introduction

Mesophotic Coral Ecosystems (MCEs) are a highly productive and stable, providing a variety of habitats to a wide range of benthic organisms. MCEs are characterized by low solar irradiance with blue spectral enrichment, low wave disturbance, reduced temperatures and rich nutrients upwelled water[1,2]. Light is the primary physical parameter that limits the distribution of coral reefs across the depths and habitats. The sharp differences in the irradiance over depth gradient, on spatial scales of ten meters have major consequences for the distribution of corals. Photosynthetic corals are often found at depths ranging from 0 to 150 m in clear waters of the tropics[3]. However, several species of corals interfaces between the shallow and deep sea environments around the world[1,2,4,5]. In general, MCEs occur at a depth of 30 to 150 m of the euphotic zone in tropical regions[4,5]. The MCEs, situated off Pondicherry from the east coast of India is considered to be unique one which show all the features mentioned above.

Biotic assemblages in MCEs are considered to be extensions of shallow-water coral ecosystem assemblages due to their unique depth range[4]. In addition, a number of unique or depth-restricted species occur in these habitats. These diverse groups of benthic assemblage in MCEs hold a rich biodiversity and chemical reservoirs[2] which is of high, ecological and economic value[6]. Knowledge on MCEs is scarce while little is known about their functional aspects. Advanced technologies may enable to connect and overcome the logistical challenges to bridge this knowledge gap and allow resource managers to make informed decisions on conserving MCEs[2]. The most important knowledge gap pertains to the species diversity and ecological role of

organisms in MCEs. While intensive efforts were taken to study MCEs in different parts of the world, we don't have concerted effort to study the MCEs in India. This is a first attempt to study the MCEs off Pondicherry.

The potential importance of MCEs as refugia for shallow coral ecosystems and rich source of novel compounds prompted the scientists and managers to study the MCEs extensively. MCEs are well described in the western Atlantic and reported in Pacific and Indian Oceans[7]. In India, MCEs and their associated fauna have been described in the Angria Bank along the west coast (Personal communication). The shallow coral ecosystems are exposed to a range of threats, especially high sea temperature and solar radiation that cause coral bleaching and lead to mass mortality of corals[8]. In contrast, MCEs are protected from these threats due to greater depth of the overlying water column and reduced light irradiance[9]. Most importantly, MCEs serve as the source of coral larvae and other important marine organisms to the shallow reef environments enabling them to recover post disturbances. Therefore the conservation of MCEs is critical for the persistence of corals and their associated fauna under the futuristic climate scenarios. Recently the studies on Mesophotic Coral Ecosystems in Japan reviewed the knowledge on MCEs in different domains such as their distribution, biodiversity, their occurrence in the fossil record, and future directions of MCEs[10]. Considering the above factors we have taken up a short term study of MCEs, off Pondicherry to understand biodiversity of corals and associated fauna. Results of this study enrich the knowledge of biodiversity of MCEs in India and also serve as a baseline for evaluating the futuristic changes.

Materials and Methods

Study Area

The MCEs, situated off Pondicherry in the east coast of India is composed of a hard substratum with is corals and associated biota. MCEs were located on a raised platform or wall which is 2.5 km long and 0.05 Km wide covering an area of ~ 12.5 hectares (0.125 km^2). The width of the wall was ~7 m in the depth range between ~30 and 40 m (Figure 1).The MCEs comprises patchy coral habitats dominated by gorgonians. Data collection *In-situ* observations on species diversity was carried out on a random transect by SCUBA diving during February and March 2017 at10 stations along the wall (Table 1). The depth of the sampling stations ranged from 30 to 40 meters. The organisms encountered under the transect were photographed using a mounted digital camera (Nikon D7000 DSLR with AF-S 18-105mm VR Kit Lens) bearing a flash at a depth-range of 33–40 m. Fishes were collected for identification using hooks and bait and from the local fishermen. Nudibranchs were collected manually during *in-situ* observations. Specific depth-ranges for the species collected have been given along with photographs taken *in-situ* and *ex-situ* to differentiate morphologically similar species and to show the variety of color morphs.

Different Species were identified using high resolution photographs and videos following the keys described by Huang *et al.*[11] for the coral species belonging to families Merulinidae, Montastraeidae, and Diploastraeidae; Cairns[12] and Kitahara[13] for azooxanthellate scleractinian; Laborel[14] and Neves *et al.*[15] for zooxanthellate scleractinian; Castro *et al.*[16] and Pérez *et al.*[17] for octocorals. Soft corals and sea fans were identified at the genus level following Fabricius and Alderslade18; Antony[19]. Fishes were identified using the keys described by Smiths Sea fishes[20]

and FishBase[21]. The flat worms were identified following Newman and Cannon[22] and Sea snake by Rasmussen[23].

Results and discussion

Depth

The depth of MCEs observed in the present study ranged from 30 to 40 m. comparatively this was the lowest depth so far reported. Globally, the occurrence of MCEs below 50 m depth were reported from U.S. Virgin Islands[24], Bermuda[25], Caribbean (from 50 -100)[26], Puerto Rico[27,28], Australia[29], Bahamas[30], Brazil[31], Japan's Ryukyu archipelago (above 100 m) [32] and Hawaii[33]. The MCEs, off Pondicherry possess a variety of organisms composed of at least 77 species from 41 families. The detailed list of species recorded from visual surveys in MCEs is provided in the Table 2.

Corals

The hard-bottom of shelf-margin was dominated by the slow-growing plate coral *Leptoseris explanata* Yabe & Sugiyama, 1941 and *Pachyseris speciosa* (Dana, 1846) (Figure 2). Rooney *et al.*[34] have reported *Leptoseris* spp. as restricted to extreme low-irradiance environments such as MCEs. Similarly, Luck *et al.*[435] noted that the distribution of *Leptoseris papyracea* and *L. hawaiiensis* was restricted to deeper water (more than 100 m) and habitat on shady conditions such as crevices, caves and overhangs[36,37,38]. Leaf corals were dominated by medium-to-large colonies of *Pavona minuta* Wells, 1954 and *Pavona maldivensis* (Gardiner, 1905). Other hard corals such as *Tubastraea micranthus* (Cairns and Zibrowius, 1997) and *T. coccinea* Lesson, 1829 were commonly known as the Black Sun Coral, which lacks zooxanthellae (symbiotic

algae) and rely on zooplankton captured with their tentacles for their nutrition. These azooxanthellate corals possess a slower growth rate compared to the zooxanthellate and they are usually adapted to the environments with strong current. The azooxanthellate corals were native to the tropical Indo-Pacific, ranging from the Red Sea and Madagascar to Japan, Hawaii and Tonga (Table 2).

Six black coral species was observed in the study area and dense populations were observed in the study area (Figure 3). Roark *et al*.[39] observed the black corals are sessile benthic suspension feeders, slow-growing species, potentially indicating the oldest living animals on Earth, with colonies dated to over 4,000 yr old. They are important components of the mesophotic benthic communities. They are considered to be ecosystem engineers, providing valuable three-dimensional habitat for numerous associated fauna, fish, and invertebrate species[40,41]. A total of 16 species of octocorals were identified belonging to 2 sub-orders, 7 families. Photographic identification of individuals was up to genus level except for *Dichotella gemmacea* (Milne Edwards & Haime, 1857). *Subergorgia* sp. was dominant among octocoral communities forming gorgonian forests (Figure 3).

Sponges

The sponges are major components in most coral reef ecosystems, including MCEs. Here we observed the limited number of species, with 4 distinct taxa such as Bob Marley sponge *Pipestela candelabra* Alvarez, Hooper & van Soest, 2008, *Axinella corrugate* (George & Wilson, 1919), Orange Lumpy Sponge *Acanthella acuta* Schmidt, 1862, Row Pore Rope Sponge *Aplysina cauliformis* (Carter, 1882) (Figure 4).

Fishes

A total of 31 fish species belonging to 16 families were identified in the study area. Malabar grouper *Epinephelus malabaricus* (Bloch & Schneider, 1801), emperor angelfish *Pomacanthus imperator* (Bloch, 1787) and *Neopomacentrus filamentosus* (Macleay, 1882) were the most common species. Fifteen reef fish species were observed, with the dominant species being *Odonus niger* (Rüppell, 1836) known as red-toothed triggerfish (Figure 3), and the cleaner wrasse *Labroides dimidiatus* (Valenciennes, 1839). These fish species play key ecological roles, major mobile components and show high species diversity within MCEs[6,42,43,44]. The lionfish *Pterois volitans* (Linnaeus, 1758) originally native to the Indian, Pacific Oceans, and the Red Sea was recorded. They rapidly spread over the past decade, from their few initial sightings to colonizing on mesophotic reef habitats across the Western Atlantic[45,46] (Figure 4).

Other taxa

The polyclad flatworms *Thysanozoon nigropapillosum* (Hyman, 1959) collected from the study area have a characteristic white margin with colourful yellow-tipped papillae. These flatworms are obvious inhabitants of coral reefs throughout tropical and subtropical oceans and are reported from various reef environments at, Maldives, Sri Lanka, Indonesia, New Guinea and Solomon Islands[47,48] (Figure 4). The Varicose Wart Slug *Phyllidia varicose* Lamarck, 1801 is widely distributed throughout the Indo-West Pacific Oceans, the central Pacific and the Red Sea. The Honeycomb Oyster *Hyotissa hyotis* Linnaeus 1758 has a wide native range in the Indian and Pacific oceans. *Pteria penguin* (Röding, 1798) commonly known as the penguin's wing oyster and native to the western and central Indo-Pacific region was also recorded (Figure 4). The Crab *Quadrella maculosa* (Alcock, 1898) was found associated with black coral *Cupressopathes abies*

(Linnaeus, 1758). The other crab *Dromia dromia* (Linnaeus, 1763) were found associated with the sponges and they are widely distributed across the Indo-Pacific region. The feather Star *Cenometra bella* (Hartlaub, 1890) was found in the study area which is a common inhabitant of the deeper reef habitats. The Arabian Gulf sea snake *Hydrophis lapemoides* (Gray, 1849) was observed and identified by its striking patterning, comprising 33 to 35 dark bands along the length of the body. It is well-adapted for entire life-cycle in the marine environment. They feed on eels and other types of bony fish are the main source of prey it locates amongst crevices in rocks and coral reefs[49].

Threats to the MCEs

Globally, MCEs are vulnerable to environmental disturbances, such as overfishing, bottom fishing gear, capture of aquarium fish, precious coral trade, land-based pollution and invasive species. The MCE off Pondicherry is not an exemption as we observed a discarded fishing net smothering the gorgonids (Figure 4e). Fishing boats operating trawl nets were observed in the study area and the trawl operations will undoubtedly cause a severe destruction to the MCEs communities. Therefore, strong management responses are essential to mitigate the documented threats to prevent future destruction of MCEs. The stress from fishing activities is considered by marine experts to be the greatest threat to benthic habitats[50].

Conclusion

Results of this study provide a baseline on the overall diversity of MCE, off Pondicherry. The high species diversity in the MCEs might play an important role in replenishing the biodiversity of shallow water reef ecosystems and therefore deserve suitable conservation strategies. Given the poor knowledge on the distribution and extension of these habitats, there is a need for

detailed habitat mapping in hard-bottom of the east coast of India. This study has documented the species diversity of the MCEs within this offshore hard-bottom and provides important data for the design of further studies on fish assemblages of MCEs habitats.

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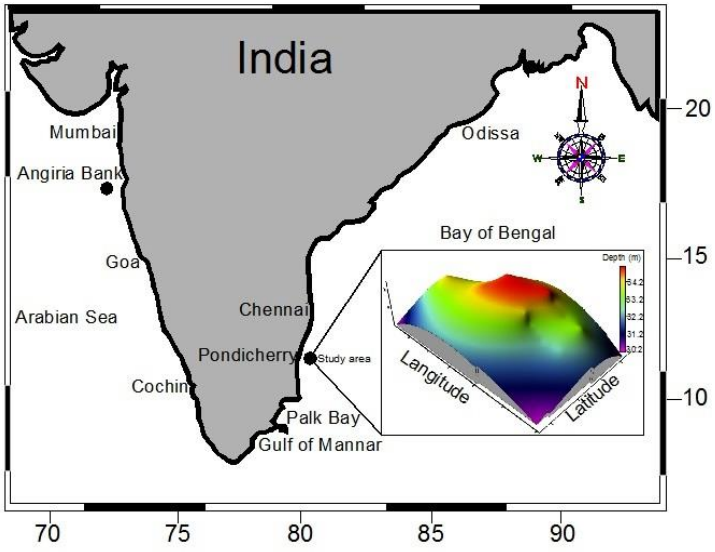

Figure 1. The location of mesophotic coral ecosystems (MCEs), including the present study site in east coast of India.

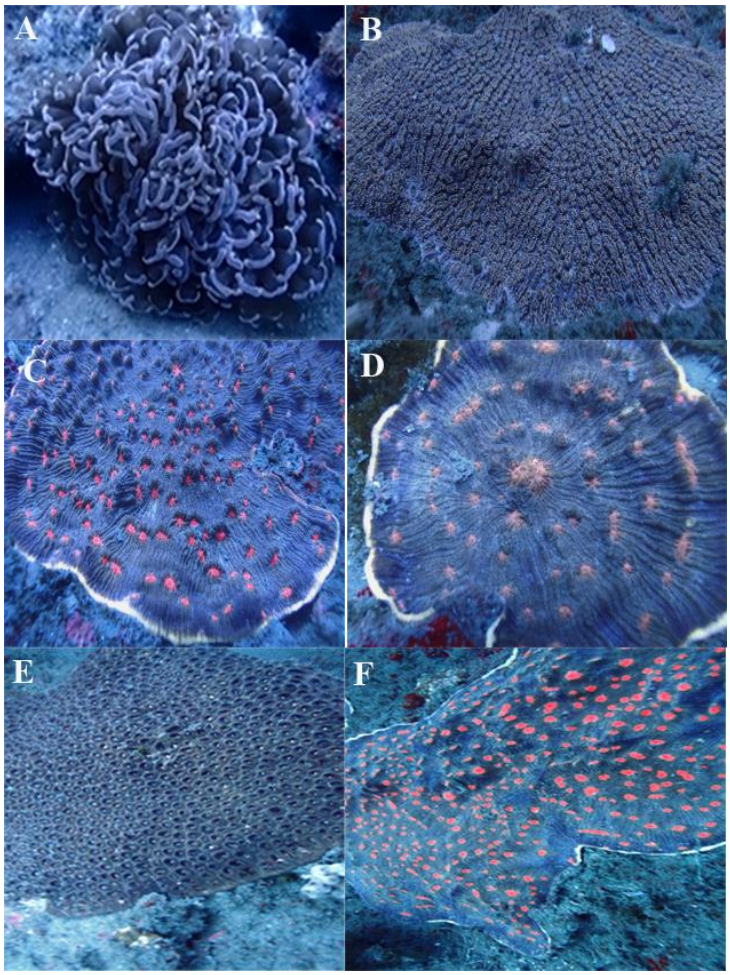

Figure 2. Coral species in the study area: A: *Euphyllia ancora* B: *Psammocora haimiana* C and D: *Leptoseris explanata* E: *Dipsastraea favus* F: *Montipora* sp.

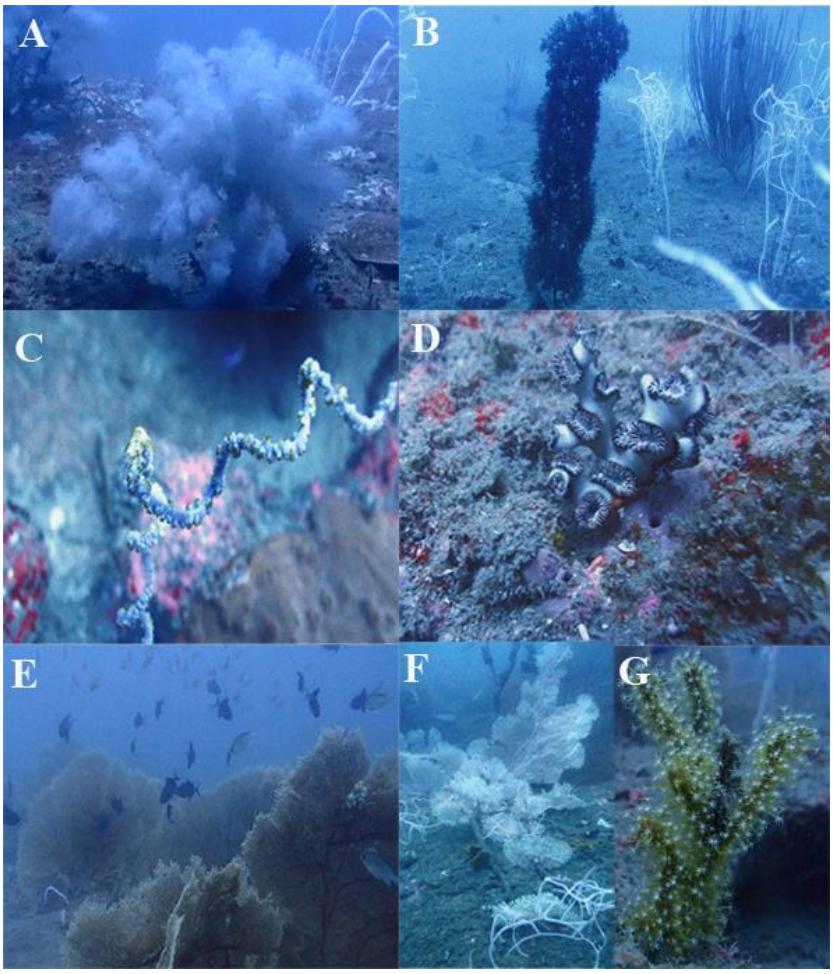

Figure 3. Black coral and Gorgonian species on the study area: A: *Cirripathas spiralis* B: *Cupressopathes abies* C: *Antipathes dendrochristos* D: *Tubastraea micranthus* E: School of fish in the gorgonian forest F: *Eugorgia* sp. G: *Ellisella* sp.

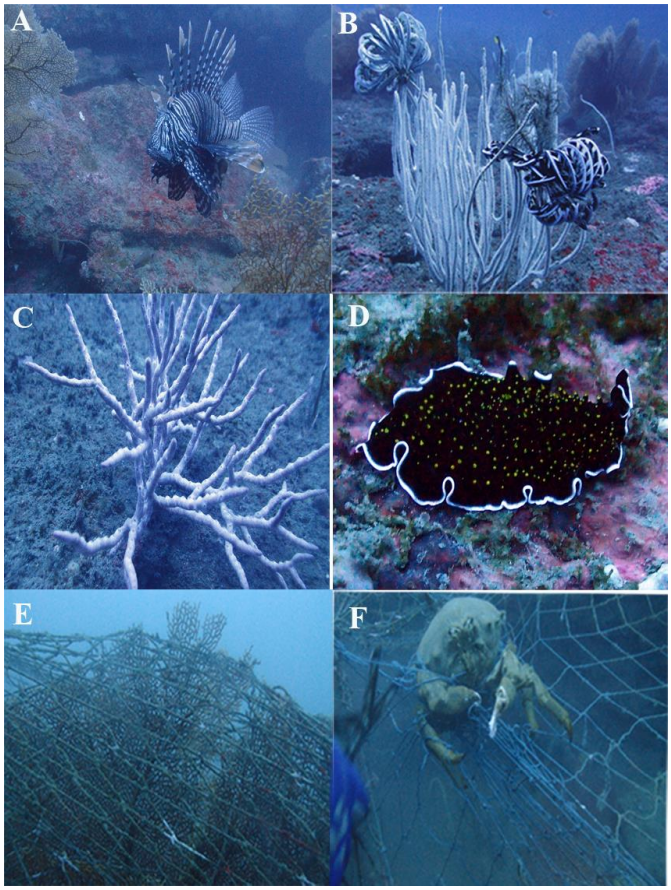

Figure 4. A: *Pterois volitans* B: feather Star *Cenometra bella* on *Eugorgia* sp. C: Row Pore Rope Sponge *Aplysica cauliformis* D: *Thysanozoon nigropapillosum* E: A discarded fishing net was smothering on gorgonids species F: Sponge Crab *Dromia dromia* on the fishing net.

Table 1. Details of SCUBA Diving location

Stations	Latitude	Longitude	Depth
S1	11°48.119'	79°55.403'	32.5
S2	11°48.202'	79°55.395'	32.5
S3	11°48.287'	79°55.389'	32.6
S4	11°48.362'	79°55.419'	33.0
S5	11°48.432'	79°55.426'	33.4
S6	11°48.470'	79°55.429'	34.1
S7	11°48.638'	79°55.428'	34.6
S8	11°48.967'	79°55.453'	34.7
S9	11°49.087'	79°55.431'	34.2
S10	11°49.404'	79°55.412'	34.4

Table 2. List of Mesophotic corals and associated species

Family	Species	Family	Species
Algae		**Others**	
Schizymeniaceae	*Titanophora pikeana* (Dickie) Feldmann, 1942	Axinellidae	*Pipestela candelabra* Alvarez, Hooper & van Soest, 2008
			Axinella corrugate (George & Wilson, 1919)
		Dictyonellidae	*Acanthella acuta* Schmidt, 1862
		Aplysinidae	*Aplysica cauliformis* (Carter, 1882)
Hard coral		Pseudocerotidae	*Thysanozoon nigropapillosum* (Hyman, 1959)
Agariciidae	*Leptoseris explanata* Yabe & Sugiyama, 1941	Phyllidiidae	*Phyllidia ocellata* Cuvier, 1804
	Pavona minuta Wells, 1954	Gryphaeidae	*Hyotissa hyotis* (Linnaeus, 1758)
	Pavona maldivensis (Gardiner, 1905)		*Pteria penguin* (Roding, 1798)
	Tubastraea micranthus (Cairns and Zibrowius,		
Dendrophylliidae	1997)	Trapeziidae	*Quadrella maculosa* Alcock, 1898
	Tubastraea coccinea Lesson, 1829	Dromiidae	*Dromia dromia* (Linnaeus, 1763)
Euphylliidae	*Euphyllia ancora* Veron and Pichon, 1980	Colobometridae	*Cenometra bella* (Hartlaub, 1890)
		Elapidae	*Hydrophis lapemoides* (Gray, 1849)
Fungiidae	*Cycloseris* sp.	**Fish species**	
Merulinidae	*Hydnophora rigida* (Dana, 1846)	Torpedinidae	*Torpedo marmorata* Risso, 1810
	Goniastrea pectinata (Ehrenberg, 1834)	Acanthuridae	*Acanthurus nigricauda* Duncker & Mohr, 1929
	Dipsastraea favus (Forskål, 1775)		*Acanthurus thompsoni* (Fowler, 1923)
	Psammocora haimeana Milne Edwards &		
Psammocoridae	Haime, 1851		*Acanthurus xanthopterus* Valenciennes, 1835
Scleractinia			
incertae sedis	*Pachyseris speciosa* (Dana, 1846)	Caesionidae	*Pterocaesio chrysozona* (Cuvier, 1830)
Black coral		Balistidae	*Odonus niger* (Rüppell, 1836)
Antipathidae	*Cirrhipathes spiralis* (Linnaeus, 1758)	Carangidae	*Caranx heberi* (Bennett, 1830)
	Pseudocirrhipathes mapia Bo et al., 2009	Chaetodontidae	*Chaetodon decussatus* Cuvier, 1829
	Antipathes dendrochristos Opresko, 2005		*Heniochus acuminatus* (Linnaeus, 1758
	Antipathes grandis Verrill, 1928	Haemulidae	*Plectorhinchus vittatus* (Linnaeus, 1758)
	Cupressopathes abies (Linnaeus, 1758)	Holocentridae	*Myripristis kuntee* Valenciennes, 1831
Gorgonians			*Myripristis botche* Cuvier, 1829
Gorgoniidae	*Leptogorgia* sp.	Labridae	*Bodianus diana* (Lacepède, 1801)

	Eugorgia sp.		*Bodianus neilli* (Day, 1867)
Ellisellidae	*Ellisella* sp.1		*Labroides dimidiatus* (Valenciennes, 1839)
	Ellisella sp.2		*Thalassoma lunare* (Linnaeus, 1758)
	Ellisella sp.3	Lutjanidae	*Lutjanus bohar* (Forsskål, 1775)
	Junceella sp.		*Lutjanus russellii* (Bleeker, 1849)
	Dichotella gemmacea	Nemipteridae	*Scolopsis vosmeri* (Bloch, 1792)
	Viminella flagellum	Pomacanthidae	*Apolemichthys xanthotis* (Fraser-Brunner, 1950)
Acanthogorgiidae	*Alackagorgia* sp.		*Pomacanthus semicirculatus* (Cuvier, 1831)
Acanthogorgiidae	*Muricella* sp.		*Pomacanthus imperator* (Bloch, 1787)
	Acanthogorgia sp.		*Chromis dimidiata* (Klunzinger, 1871)
Subergorgiidae	*Subergorgia* sp.	Pomacentridae	*Chromis viridis* (Cuvier, 1830)
Plexauridae	*Menella* sp.		*Chrysiptera rollandi* (Whitley, 1961)
	Muricea sp.		*Dascyllus aruanus* (Linnaeus, 1758)
	Echinogorgia sp.		*Neopomacentrus cyanomos* (Bleeker, 1856)
Melithaeidae	*Acabaria* sp.		*Neopomacentrus filamentosus* (Macleay, 1882)
		Serranidae	*Epinephelus malabaricus* (Bloch & Schneider, 1801)
		Scorpaenidae	*Pterois volitans* (Linnaeus, 1758)
		Torpedinidae	*Torpedo marmorata* Risso, 1810