Benthic communities of mesophotic coral ecosystem off Puducherry, east coast of India

P. Laxmilatha[1,*], S. Jasmine[2], Miriam Paul Sreeram[3] and Periasamy Rengaiyan[1]

[1]ICAR-Madras Research Centre of the Central Marine Fisheries Research Institute, Chennai 600 028, India
[2]ICAR-Vizhinjam Research Centre of the Central Marine Fisheries Research Institute, Cochin 695 521, India
[3]ICAR-Central Marine Fisheries Research Institute, Cochin 682 018, India

The shallow coral reef ecosystems along the Indian coast are being threatened by anthropogenic global ocean warming and increased frequency of coral bleaching in the recent past. Identification and conservation of deeper reef habitats are 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 the mesophotic coral ecosystems (MCEs) and their biodiversity is poorly known in the continental shelf of the east coast of India. In this study, we have documented the species diversity of MCEs at a depth of 30–40 m off Puducherry along the east coast of India. In total, 12 species of corals, including 5 black corals and 16 octocorals, 4 species of sponges and 31 species of coral-associated benthopelagic fish species were recorded. *Subergorgia* sp. was the most dominant species of octocorals and found extensively as gorgonian forests. The MCEs reported in this study raise 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 Puducherry will reveal more information about the distribution and colonization of coral communities and their vulnerability to changes in future.

Keywords: Benthic communities, gorgonian forest, mesophotic coral ecosystems, reef habitats.

MESOPHOTIC coral ecosystems (MCEs) are 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 depths and habitats. The sharp differences in the irradiance over depth gradient, on spatial scales of 10 m 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 interface between the shallow and deep sea environments around the world[1,2,4,5]. In general, MCEs occur at a depth of 30–150 m of the euphotic zone in tropical regions[4,5]. The MCEs, situated off Puducherry the east coast of India are considered to be unique, showing 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 are of high, ecological and economic value[6]. Knowledge on MCEs is scarce, while little is known about their functional aspects. Advanced technologies may enable us to connect and overcome the logistic 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 do not have concerted efforts to study MCEs in India.

The potential importance of MCEs as refugia for shallow coral ecosystems and the rich source of novel compounds prompted scientists and managers to study them extensively. MCEs are well described in the western Atlantic and reported in the Pacific and Indian Oceans[7]. In India, MCEs and their associated fauna have been described in the Angria Bank along the west coast (pers. commun.). 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

*For correspondence. (e-mail: laxmil@yahoo.com)

futuristic climate scenarios. Recent studies on MCEs in Japan have reviewed the knowledge on MCEs in different domains such as their distribution, biodiversity, occurrence in fossil records and future directions[10]. Considering the above factors we had taken up a short-term study of MCEs, off Puducherry, to understand the 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 Puducherry in the east coast of India, are composed of a hard substratum with 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 ha (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 comprise patchy coral habitats dominated by gorgonians. *In situ* observations on species diversity were carried out on a random transect by scuba diving during February and March 2017 at ten stations along the wall (Table 1). The depth of the sampling stations ranged from 30 to 40 m. The organisms encountered under the transect were photographed using a mounted digital camera (Nikon D7000 DSLR with AF-S 18–105 mm 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. Photographs taken *in situ* and *ex situ* were used to differentiate morphologically similar species.

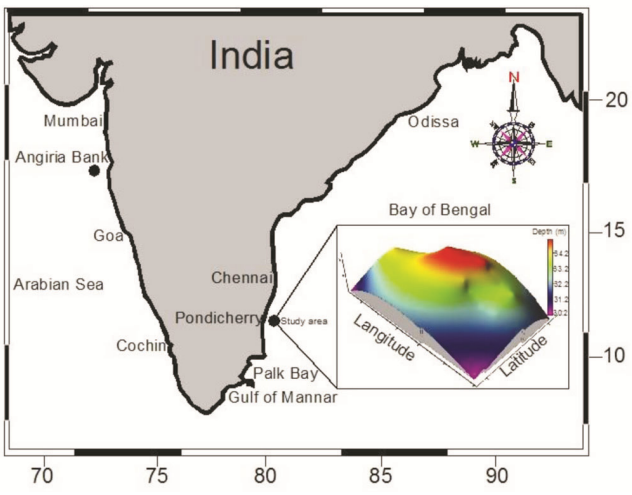

Figure 1. Location of mesophotic coral ecosystems, including the present study site on the east coast of India.

Different species were identified using high-resolution photographs and videos following the keys described by Huang *et al.*[11] for 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 and 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 Alderslade[18] and Antony Fernando[19]. Fishes were identified using the keys described by Smith[20] and FishBase[21]. The flatworms 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 is the lowest depth so far reported. Globally, the occurrence of MCEs below 50 m depth was reported from US Virgin Islands[24], Bermuda[25], the Caribbean (from 50 to 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 Puducherry possess a variety of organisms composed of at least 77 species from 41 families. Table 2 provides detailed list of species recorded from visual surveys in MCEs.

Corals

The hard bottom of the shelf margin was dominated by 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. Luck *et al.*[35] noted that the distribution of *Leptoseris papyracea* and *L. hawaiiensis* was restricted to deeper waters (more than 100 m) and habitats under shady conditions such as crevices, caves and overhangs[36–38].

Table 1. Details of scuba diving location

Station	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)
Hard coral		Dictyonellidae	*Acanthella acuta* Schmidt, 1862
Agariciidae	*Leptoseris explanata* Yabe & Sugiyama, 1941	Aplysinidae	*Aplysica cauliformis* (Carter, 1882)
		Pseudocerotidae	*Thysanozoon nigropapillosum* (Hyman, 1959)
	Pavona minuta Wells, 1954	Phyllidiidae	*Phyllidia ocellata* Cuvier, 1804
	Pavona maldivensis (Gardiner, 1905)	Gryphaeidae	*Hyotissa hyotis* (Linnaeus, 1758)
Dendrophylliidae	*Tubastraea micranthus* (Cairns and Zibrowius, 1997)		*Pteria penguin* (Roding, 1798)
		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)
Psammocoridae	*Psammocora haimeana* Milne Edwards & Haime, 1851		*Acanthurus xanthopterus* Valenciennes, 1835
		Caesionidae	*Pterocaesio chrysozona* (Cuvier, 1830)
Scleractinia incertae sedis	*Pachyseris speciosa* (Dana, 1846)	Balistidae	*Odonus niger* (Rüppell, 1836)
		Carangidae	*Caranx heberi* (Bennett, 1830)
Black coral		Chaetodontidae	*Chaetodon decussatus* Cuvier, 1829
Antipathidae	*Cirrhipathes spiralis* (Linnaeus, 1758)		*Heniochus acuminatus* (Linnaeus, 1758)
	Pseudocirrhipathes mapia Bo *et al*., 2009	Haemulidae	*Plectorhinchus vittatus* (Linnaeus, 1758)
	Antipathes dendrochristos Opresko, 2005	Holocentridae	*Myripristis kuntee* Valenciennes, 1831
	Antipathes grandis Verrill, 1928		*Myripristis botche* Cuvier, 1829
	Cupressopathes abies (Linnaeus, 1758)	Labridae	*Bodianus diana* (Lacepède, 1801)
			Bodianus neilli (Day, 1867)
Gorgonians			*Labroides dimidiatus* (Valenciennes, 1839)
Gorgoniidae	*Leptogorgia* sp.		*Thalassoma lunare* (Linnaeus, 1758)
	Eugorgia sp.	Lutjanidae	*Lutjanus bohar* (Forsskål, 1775)
Ellisellidae	*Ellisella* sp. 1		*Lutjanus russellii* (Bleeker, 1849)
	Ellisella sp. 2	Nemipteridae	*Scolopsis vosmeri* (Bloch, 1792)
	Ellisella sp. 3	Pomacanthidae	*Apolemichthys xanthotis* (Fraser-Brunner, 1950)
	Junceella sp.		*Pomacanthus semicirculatus* (Cuvier, 1831)
	Dichotella gemmacea		*Pomacanthus imperator* (Bloch, 1787)
	Viminella flagellum		*Chromis dimidiata* (Klunzinger, 1871)
Acanthogorgiidae	*Alackagorgia* sp.	Pomacentridae	*Chromis viridis* (Cuvier, 1830)
Acanthogorgiidae	*Muricella* sp.		*Chrysiptera rollandi* (Whitley, 1961)
	Acanthogorgia sp.		*Dascyllus aruanus* (Linnaeus, 1758)
Subergorgiidae	*Subergorgia* sp.		*Neopomacentrus cyanomos* (Bleeker, 1856)
Plexauridae	*Menella* sp.		*Neopomacentrus filamentosus* (Macleay, 1882)
	Muricea sp.	Serranidae	*Epinephelus malabaricus* (Bloch & Schneider, 1801)
	Echinogorgia sp.	Scorpaenidae	*Pterois volitans* (Linnaeus, 1758)
Melithaeidae	*Acabaria* sp.	Torpedinidae	*Torpedo marmorata* Risso, 1810

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, commonly known as the black sun coral, lack 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 with dense populations were observed in the study area (Figure 3). Roark *et al*.[39] observed that the black corals are sessile benthic suspension feeders, slow-growing species, potentially indicating the oldest living animals on earth, with colonies dated to over 4000 years old. They are important components of the mesophotic benthic communities, and 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 two sub-orders and seven 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. In this study we observed limited number of species, with four distinct taxa, viz. Bob Marley sponge *Pipestela candelabra* Alvarez, Hooper & van Soest, 2008; *Axinella corrugate* (George & Wilson, 1919); orange lumpy sponge *Acanthella acuta* Schmidt, 1862, and 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), also known as red-toothed triggerfish (Figure 3), and the cleaner wrasse *Labroides dimidiatus* (Valenciennes, 1839). These fish species play key ecological

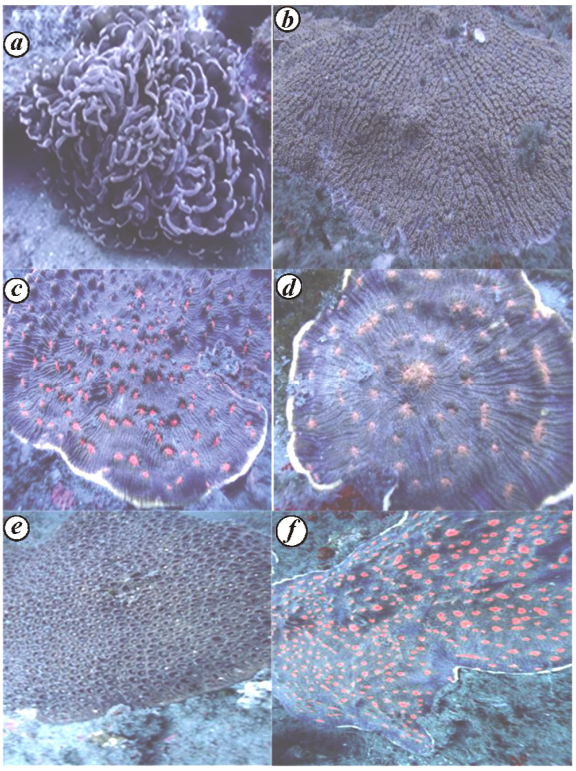

Figure 2. Coral species in the study area: ***a***, *Euphyllia ancora*; ***b***, *Psammocora haimiana*; ***c***, ***d***, *Leptoseris explanata*; ***e***, *Dipsastraea favus*; ***f***, *Montipora* sp.

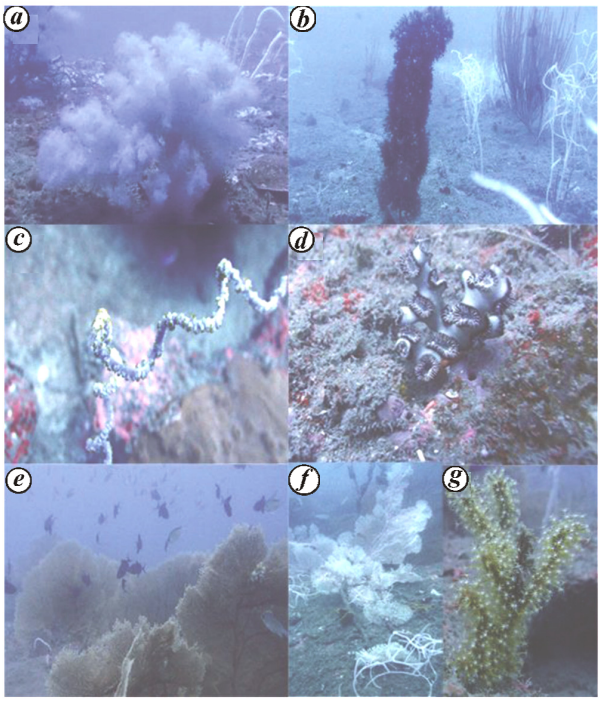

Figure 3. Black coral and gorgonian species in the study area: ***a***, *Cirripathas spiralis*; ***b***, *Cupressopathes abies*; ***c***, *Antipathes dendrochristos*; ***d***, *Tubastraea micranthus*; ***e***, School of fish in the gorgonian forest; ***f***, *Eugorgia* sp.; ***g***, *Ellisella* sp.

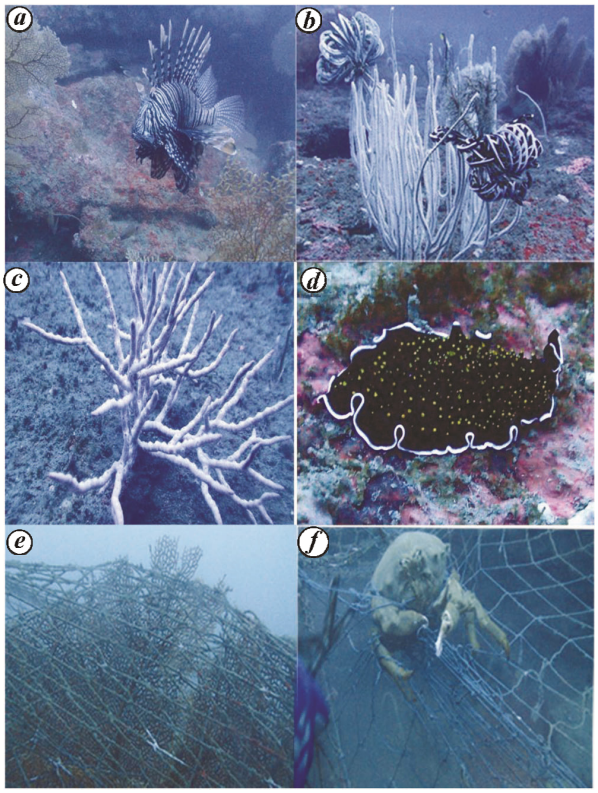

Figure 4. ***a***, *Pterois volitans*; ***b***, feather star *Cenometra bella* on *Eugorgia* sp.; ***c***, row pore rope sponge *Aplysica cauliformis*; ***d***, *Thysanozoon nigropapillosum*; ***e***, a discarded fishing net was smothering the gorgonids species; ***f***, sponge crab *Dromia dromia* on the fishing net.

roles, and show high species diversity within MCEs[6,42–44]. The lionfish *Pterois volitans* (Linnaeus, 1758) originally native to the Indian and Pacific Oceans and the Red Sea, was also recorded. They have rapidly spread over the past decade from their few initial sightings to colonizing the 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 has 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 Ocean, 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). Another crab *Dromia dromia* (Linnaeus, 1763) was found associated with the sponges and 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 deeper reef habitats. The Arabian Gulf sea snake *Hydrophis lapemoides* (Gray, 1849) was identified by its striking patterning, comprising 33–35 dark bands along its body length. It is well-adapted for an entire life cycle in the marine environment. It feeds 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 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 MCEs off Puducherry are not an exemption, as we observed a discarded fishing net smothering the gorgonids (Figure 4 *e*). Fishing boats operating trawl nets were observed in the study area and such trawl operations will undoubtedly cause severe destruction to the MCEs. 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 MCEs off Puducherry. The high species diversity in the MCEs might play an important role in replenishing the biodiversity of shallow-water reef ecosystems and therefore they 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 the hard bottom of the east coast of India. The present study has documented the species diversity of MCEs within this offshore hard-bottom and provides important data for further studies on fish assemblages of MCE habitats.

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