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Professional SCUBA divers as citizen scientists to document marine biodiversity of rocky reefs: A case study from Kovalam, Kerala, India

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ABSTRACT

Rocky reefs stand out as distinct coastal habitats characterized by exposed and submerged rock outcrops of varying relief. These formations create sheltered havens for a diverse array of organisms, particularly fish communities, and offer expansive surfaces for the colonization of algae and invertebrates. In this study, dive instructors, dive masters, and underwater photographers from Bond Ocean Safari, a professional scuba diving and water sports academy at Kovalam tourist beach, Thiruvananthapuram, Kerala, acted as citizen scientists. They meticulously documented biodiversity through video recordings spanning from 2015 to 2020. The analysis revealed the presence of 90 species within a single rocky reef ecosystem at Kovalam. Notable findings include four species each of Porifera and Cnidaria, five species of Mollusca, four species each of Arthropoda and Echinodermata (sea urchins and sea cucumbers), 67 species of fishes, and two species of turtles. Fish emerged as the predominant component of marine faunal diversity in the Kovalam rocky reef ecosystem, with 67 species representing 11 orders, 36 families, and 49 genera captured in the SCUBA divers' videos. The rocky reef area of Kovalam also provides a habitat for animals classified as rare, endangered, or protected under the Wildlife (Protection) Act of India. Noteworthy species such as the scleractinian hard coral *Favites pentagona*, acroporan coral *Montipora hispida*, sea cucumbers *Holothuria (Semperothuria) cinerascens* and *Holothuria (Mertensiothuria) leucospilota*, green sea turtle (*Chelonia mydas*), and hawksbill sea turtle (*Eretmochelys imbricata*) are included in Schedule I of the Wildlife (Protection) Act of India. A notable observation was the substantial decline in the abundance of mollusks, dominated by the brown mussel *Perna perna,* in 2019 and 2020. Overall, species abundance across all taxa was lower in these years, possibly due to the impact of Cyclone Ockhi, which removed floral and faunal encrustations from rocks in the region, along with increasing siltation. This paper highlights the threats facing the rocky reef ecosystem and recommends utilizing trained divers for precise and systematic documentation and monitoring of marine biodiversity in diving destinations.

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1. Introduction

The abundant diversity of marine life is crucial for maintaining ocean health and providing essential ecosystem services that support the social, economic, nutritional, recreational, and health needs of billions of people worldwide (Worm et al., 2006; McCauley et al., 2015; Canonico et al., 2019). However, human activities such as fishing, pollution, habitat destruction (Halpern et al., 2008, 2015), and climate change (Poloczanska et al., 2016) are increasing the pressure on marine biodiversity (IPBES, 2019), leading to significant losses in ecosystem services that directly affect society (Tadaki et al., 2017). The global extinction risk for marine biodiversity is high, with one-third of assessed species facing threats (O'Hara et al., 2018). Mitigating this pressure requires an understanding of distribution patterns and evolutionary interactions between species, which are fundamental to biology (Gaston, 2000).

Diversity is the cornerstone for ensuring ecosystem structure, function, and services. Consolidating knowledge about the spatial and temporal dynamics of ecosystems, as proposed by Gray (1997), is essential. The conservation and sustainable use of biodiversity, along with predicting current and future changes, necessitate comprehensive knowledge derived from continuous biodiversity observation and the development of appropriate models at global, regional, and local levels (Canonico et al., 2019).

Rocky reefs, characterized by exposed and submerged rock outcrops along coastlines, provide unique habitats that serve as refuges for various ocean organisms, especially fish communities. These reefs offer ample surface area for the colonization of algae and invertebrates (Raffaelli and Hawkins, 1996). Sub-tidal rocky reefs host a significant portion of faunal biomass in coastal areas, constituting complex natural systems (Sale, 1991). The habitat heterogeneity and trophic communities in rocky reefs influence the structure of fish assemblages (Holbrook et al., 1990; Curley et al., 2002). Despite their high levels of endemism and increased human activities, rocky reef fishes have received limited attention from planners and policymakers compared to coral reefs (Ebeling and Hixon, 1991; Turpie et al., 2000). These fishes and invertebrates play essential roles in ecosystems (Babcock et al., 1999; Shears and Babcock, 2002) and can act as indicators for defining Marine Protected Areas (MPAs) (Ward et al., 1999).

Rocky reefs also hold significant recreational and commercial importance, boasting a rich assemblage of fish and invertebrates (Taylor, 1998; Cowles et al., 2009; Piazzi et al., 2012). While macroecology projects often lack coverage of regional ecosystems and quantitative abundance information necessary for regional conservation and management, citizen science emerges as a viable approach. Recently, detailed marine biodiversity observations have explored the effective use of citizen science (Stuart-Smith et al., 2017; Pandya and Dibner, 2018; Seguigne et al., 2023; Chen et al., 2024). Research collaborations

involving volunteers in generating data, known as citizen science, have proven effective in terrestrial habitats and are increasingly applied in long-term reef monitoring (Hodgson, 2001; Loder et al., 2015).

Given the expensive and time-consuming nature of biodiversity field surveys, citizen science initiatives have emerged as valuable tools for systematically documenting and monitoring biodiversity sustainably, particularly in remote and under-surveyed regions globally (Gelcich et al., 2014; Edgar et al., 2016). While numerous successful citizen science models exist for biodiversity monitoring in terrestrial ecosystems (Smart et al., 2005), their application has expanded to include marine biodiversity monitoring and documentation across various taxa (Luksenburg and Parsons, 2014; Branchini et al., 2015a, b; Castilla et al., 2017).

The biodiversity of ecosystems, notably reef fish, plays a pivotal role in driving recreational and commercial ecotourism. Although various techniques are available for documenting biodiversity on rocky reefs (Kingsford and Battershill, 1998), many studies heavily rely on direct observation by divers or snorkelers (Harasti et al., 2015). In recent years, recreational scuba diving has gained global popularity, becoming an integral component of the tourism industry (Garrod, 2008). The public's enthusiasm to explore the marine world's natural wonders has fueled the growth of ecotourism associated with scuba diving (Cater and Cater, 2007; Musa and Dimmock, 2013). Scuba diving tourism has evolved into a low-impact recreational activity that provides significant socio-economic benefits while prioritizing environmental conservation (Cavallini et al., 2023). Technological advancements, improved training, and education have further facilitated the growth of the global Scuba Diving Tourism (SDT) industry and the development of dive tourism destinations and hotspots (Dimopoulos, 2019).

Trained recreational SCUBA divers, equipped with scientific survey techniques, voluntarily contribute their skills, expertise, and time to gather extensive data sets for marine biodiversity monitoring across the globe (Edgar and Stuart-Smith, 2014). Notably, programs like the Reef Life Survey (RLS) effectively utilize citizen-science, employing trained volunteer SCUBA divers to conduct comprehensive surveys on marine biodiversity in rocky and coral reef ecosystems (Stuart-Smith et al., 2017, 2018). These trained volunteers actively participate in research publications and serve as advocates for promoting community awareness and education on marine biodiversity and conservation (Done et al., 2017). Well-supervised and quality-controlled citizen science programs focusing on marine biodiversity documentation have proven successful in various regions (Stuart-Smith et al., 2018). Sekhsaria and Thayyil (2019) compiled information on 17 citizen science initiatives related to the ecology of India, with the majority centered on terrestrial ecosystems (Vattakaven et al., 2016; Sondhi and Kunte, 2020). Sneha Chandran et al. (2017) documented opisthobranch fauna in Kerala through a citizen science initiative.

In India, the subtidal rocky reefs and their associated biodiversity are inadequately documented, particularly in Kerala on the southwest coast where the rocky reef areas, rich in marine life, have recently become tourist attractions for scuba diving due to the absence of coral reefs in the region. This paper utilizes Scuba dive instructors and dive masters as citizen scientists to collect data on marine biodiversity in the rocky reef regions of the coastal tourism beach at Kovalam. The biodiversity of the region is carefully examined through an analysis of video recordings spanning from 2015 to 2020.

2. Materials and Methods

2.1. SCUBA tourism site

Bond Ocean Safari Kovalam (https://www.bondsafarikovalam.com/) is a SCUBA and water sports centre located at Kovalam, Thiruvananthapuram, Kerala. Unlike other popular SCUBA tourism initiatives in coral reef areas, the ocean tourism activities of Bond Ocean Safari Kovalam is seasonal, and the SCUBA dives for tourists are done between October and May every year when the sea is relatively calm and clear. Before each dive, the tourists are briefed about the ecosystem conditions and sea safety and provide in-water skill training to use the SCUBA equipment and gadgets. After filling medical forms, the tourists and PADI certified dive instructors would go to the beach. The instructors help the customers to kit up and repeat the skills in the shallow, calm water of the site area to ensure that they are comfortable. Then we swim out to a comfortable depth and descend for the dive. A divemaster will accompany each customer in a 1:1 ratio under the strict supervision of a PADI certified instructor (Fig. 2 A-D). During each dive, the skilled instructors (SCUBA divers) cover a distance of

Fig. 1. Map of Kovalam beach, Thiruvananthapuram, showing the SCUBA diving destination in rocky reefs

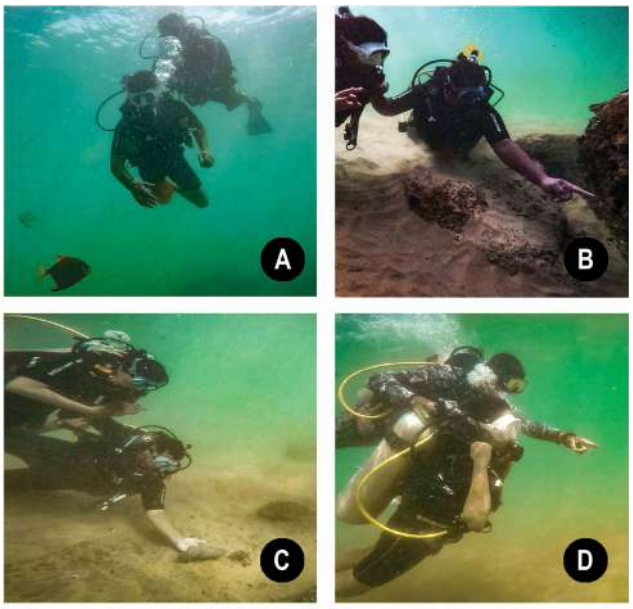

Fig. 2 A-D. SCUBA tourism by Bond Ocean Safari Kovalam, tourist and SCUBA diver in the rocky reef area

about 500 meters in a specific rocky reef area and video record the event with GoPro camera.

2.2. Biodiversity documentation

In this study biodiversity of rocky reef ecosystem in Kovalam was analysed based on the video recordings of professional SCUBA divers of Bond Ocean Safari Kovalam who used to take tourists for SCUBA diving to a defined sub-tidal rocky reef area (8.3953007 N, 76.9719536 E) near Kovalam beach, Thiruvananthapuram (Fig. 1). This subtidal rocky reef ecosystem is a habitat dominated by mussels, barnacles and sponges occurring at depths of 5-10 m (Fig. 3 A-F).

The underwater visual census (UVC) methodology is the commonly followed method for the scientific documentation of marine biodiversity of rocky reefs (Edgar and Barrett, 1997; Edgar et al., 1997). In this study, the 30-minute video recordings representing dive to a specific location in the rocky reef region of Kovalam were collected for analyses from the year 2015 to 2020. In place of line transect, the 500-meter distance covered by the diver each time and the biodiversity recorded in the video was analysed. Five video recordings of uniform effort for each year were analysed for documenting the biodiversity. Each video with biodiversity elements representing macroinvertebrates, fish and turtle were converted into separate photo frames, edited analysed.

The photos prepared from the videos were analysed for identifying the major taxa such as sponges (Porifera), Cnidaria, Mollusca, Arthropoda, Echinodermata, Pisces and turtles. The following textbooks were referred for identification.

Invertebrates: Colin and Arneson, 1995; Vine, 1986; Naderloo, 2017; Norman, 2000; Raghunathan et al., 2016; Venkataraman et al., 2003; Apte, 2012.

Pisces: Fischer & Bianchi 1984; De Bruin et al. 1994; Rao et al. 2000; Allen et al. 2003

Turtles: Marine Turtle Identification Cards, Indian Ocean

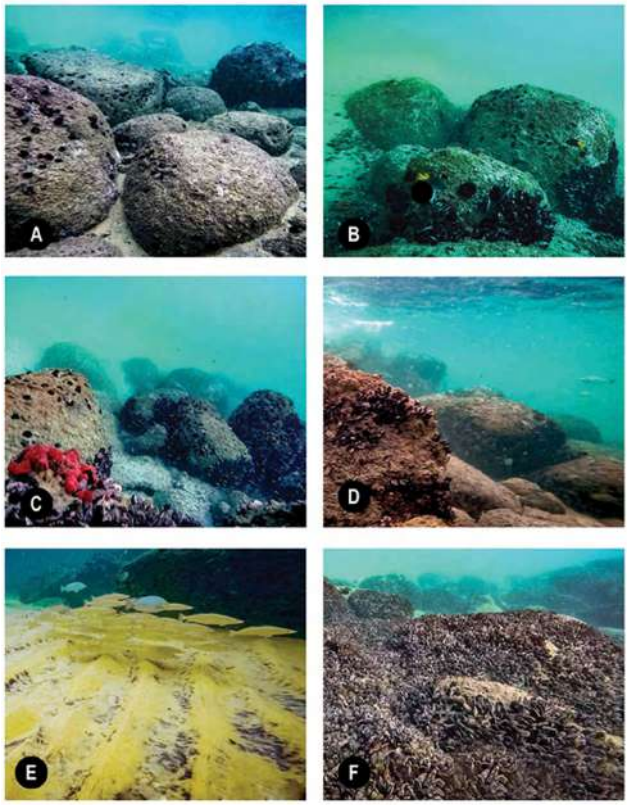

Fig. 2 A-F. Habitat diversity in the subtidal ecosystem at Kovalam

Fisheries, FAO (http://www.fao.org/3/i8916en/I8916EN.pdf)

3. Results

3.1. Diversity

The analysis of video recordings of professional SCUBA divers of Bond Ocean Safari Kovalam revealed the presence of 90 species in a single rocky reef ecosystem at Kovalam (Table 1). The diversity is represented by four species each of Porifera (sponges) and Cnidaria (scleractinian corals, acroporan corals, sea anemone and jellyfish), five species of Mollusca (bivalves and cuttlefish), four species each of Arthropoda (barnacle, lobster and crabs) and Echinodermata (sea urchins and sea cucumbers), 67 species of fishes and two species of turtles (Figs. 4 to 93).

Porifera: The four species of sponges recorded from the area include two species each from the genera *Callyspongia* and *Tedania*, which are common inhabitants of sub-tidal rocky reefs in tropics. The sponge species *Callyspongia diffusa* and *Tedania anhelans* are the most common species encountered. The number may be underrepresented, as it is challenging to identify sponge diversity through visual surveys and from video recordings.

Cnidaria: One interesting observation in the area is the presence of scleractinian hard coral *Favites pentagona* (family Merulinidae) and acroporan coral *Montipora hispida* (family Acroporidae), both included in the Schedule I of the Wildlife (Protection) Act of India. The most abundant species of cnidarian in the ecosystem is the Burgundy anemone *Bunodosoma goanense.* The large lion's mane jellyfish *Cyanea nozakii* was recorded

Table 1. Faunal diversity recorded from the rocky reef areas of Kovalam from the video footage of scuba divers

No.	Taxa/Species	Common name	Abundance	Fig. No.
PHYLUM: PORIFERA				
	Order: Haplosclerida			
	Family: Callyspongiidae			
1	*Callyspongia diffusa* (Ridley, 1884)		2	4
2	*Callyspongia sp.*		1	5
	Order: Poecilosclerida			
	Family: Tedaniidae			
3	*Tedania anhelans* (Vio in Olivi, 1792)		1	6
4	*Tedania* sp.		2	7
PHYLUM: CNIDARIA				
	Order: Scleractinia			
	Family: Merulinidae			
5	*Favites pentagona* (Esper, 1795)	Larger star coral	4	8
	Family: Acroporidae			
6	*Montipora hispida* (Dana, 1846)	Pore coral	6	9
	Order: Actiniaria			
	Family: Actiniidae			
7	*Bunodosoma goanense* den Hartog & Vennam, 1993	Burgundy anemone	51	10
	Order: Semaeostomeae			
	Family: Cyaneidae			
8	*Cyanea nozakii* Kishinouye, 1891	lion's mane jellyfish	1	11
PHYLUM: MOLLUSCA				
	Order: Littorinimorpha			
	Family: Rostellariidae			
9	*Tibia curta* (G. B. Sowerby II, 1842)	Indian tibia	1	12
	Order: Mytilida			
	Family: Mytilidae			
10	*Perna perna* (Linnaeus, 1758)	Brown Mussel	352	13
	Order: Ostreida			
	Family: Gryphaeidae			
11	*Hyotissa hyotis* (Linnaeus, 1758)	Foam oysters	1	14
	Order: Sepiida			
	Family: Sepiidae			
12	*Sepia ramani* Neethiselvan, 2001		1	15
13	*Sepia pharaonis Ehrenberg, 1831*	Pharaoh cuttlefish	1	16
PHYLUM: ARTHROPODA				
	Order: Decapoda			
	Family: Palinuridae			
14	*Panulirus homarus* (Linnaeus, 1758)	Green spiny lobster	2	17
	Family: Portunidae			
15	*Portunus sanguinolentus* (Herbst, 1783)	Three spot swimming crab	2	18
16	*Charybdis* sp.		1	19
	Order: Sessilia			
	Family: Balanidae			
17	*Megabalanus tintinnabulum* (Linnaeus, 1758)	Barnacle	69	20
PHYLUM: ECHINODERMATA				
	Order: Camarodonta			
	Family: Toxopneustidae			
18	*Tripneustes gratilla* (Linnaeus, 1758)		3	21
	Order:Stomopneustoida			
	Family:Stomopneustidae			
19	*Stomopneustes variolaris* (Lamarck, 1816)		19	22
	Order: Holothuriida			
	Family: Holothuriidae			
20	*Holothuria (Semperothuria) cinerascens* (Brandt, 1835)		1	23
21	*Holothuria (Mertensiothuria) leucospilota* (Brandt, 1835)		1	24

PHYLUM: CHORDATA				
SUPERCLASS: PISCES				
	Class: Chondrichthys			
	Subclass: Elasmobranchii			
	Super order: Squalomorphi			
	Division: Batomorphi			
	Order: Torpediniformes			
	Family: Torpedinidae			
22	*Torpedo sinuspersici* (Olfers, 1831)	Variable torpedo ray	1	25
	Order: Myliobatiformes			
	Family: Dasyatidae			
23	*Brevitrygon imbricata* (Bloch & Schneider, 1801)	Bengal whipray	1	26
	Class: Actinopterygii			
	Order: Anguilliformes			
	Family: Muraenidae			
24	*Gymnothorax favagineus* (Bloch & Schneider, 1801)	Laced moray	3	27
25	*Gymnothorax punctatus* Bloch & Schneider, 1801	Red Sea whitespotted moray	1	28
	Order: Clupeiformes			
	Family: Clupeidae			
26	*Sardinella longiceps* (Valenciennes, 1847)	Indian oil sardine	1121	29
	Order: Mugiliformes			
	Family: Mugilidae			
27	*Mugil cephalus* (Linnaeus, 1758)	Flathead grey mullet	7	30
	Order: Atheriniformes			
	Family: Atherinidae			
28	*Atherinomorus lacunosus* (Forster, 1801)	Wide-banded hardyhead silverside	22	31
	Order: Perciformes			
	Family: Acanthuridae			
29	*Acanthurus nigricans* (Linnaeus, 1758)	Whitecheek surgeonfish	1	32
30	*Acanthurus nigricauda* (Duncker & Mohr, 1929)	Epaulette surgeonfish	2	33
31	*Acanthurus nigrofuscus* (Forsskål, 1775)	Brown surgeonfish	6	34
32	*Acanthurus thompsoni* (Fowler, 1923)	Thompson's surgeonfish	2	35
33	*Naso* sp.		12	36
34	*Zebrasoma desjardinii* (Bennett, 1836)	Indian sail-fin surgeonfish	2	37
	Family: Apogonidae			
35	*Ostorhinchus cookii* (Macleay, 1881)	Cook's cardinalfish	14	38
	Family: Blenniidae			
36	*Alticus kirkii* (Günther, 1868)	Kirk's blenny	1	39
37	*Entomacrodus epalzeocheilos* (Bleeker, 1859)	Fringelip rockskipper	1	40
	Family: Caesionidae			
38	*Caesio xanthonota* (Bleeker, 1853)	Yellowback fusilier	23	41
	Family: Carangidae			
39	*Caranx sexfasciatus* (Quoy & Gaimard, 1825)	Bigeye trevally	21	42
40	*Selar boops* (Cuvier, 1833)	Oxeye scad	5	43
41	*Trachinotus baillonii* (Lacepède, 1801)	Small spotted dart	13	44
42	*Gnathodon speciosus*(Forsskål, 1775)	Golden trevally	1	45
	Family: Chaetodontidae			
43	*Chaetodon collare* (Bloch, 1787)	Redtail butterflyfish	5	46
44	*Chaetodon decussatus* (Cuvier, 1829)	Indian vagabond butterflyfish	1	47
45	*Heniochus diphreutes* D. S. Jordan, 1903	False moorish idol	8	48
	Family: Cirrhitidae			
46	*Cirrhitichthys bleekeri* (Day, 1874)		2	49
	Family: Ephippidae			
47	*Platax teira* (Forsskål, 1775)	*Longfin batfish*	*1*	*50*
	Family: Gerreidae			
48	*Gerres erythrourus* (Bloch, 1791)	Deep-bodied mojarra	1	51
	Family: Haemulidae			
49	*Plectorhinchus diagrammus* (Linnaeus, 1758)	Striped sweetlips	1	52
50	*Plectorhinchus vittatus* (Linnaeus, 1758)	Indian Ocean oriental sweetlips	1	53
51	*Plectorhinchus* sp		2	54
52	*Pomadasys guoraca* (Cuvier, 1829)		7	55
	Family: Labridae			
53	*Labroides dimidatus* (Valenciennes, 1839)	Bluestreak cleaner wrasse	3	56
54	*Halichoeres nigrescens* (Bloch & Schneider, 1801)	Bubblefin wrasse	1	57
55	*Halichoeres zeylonicus* (Bennett, 1833)	Goldstripe wrasse	3	58

	Family: Leiognathidae			
56	*Karalla daura* (Cuvier, 1829)	Goldstripe ponyfish	13	59
	Family: Lutjanidae			
57	*Lutjanus bengalensis* (Bloch, 1790)	Bengal snapper	1	60
58	*Lutjanus fluviflamma*(Forsskål, 1775)	Dory snapper	13	61
59	*Lutjanus lunulatus* (Park, 1797)	Lunartail snapper	1	62
60	*Lutjanus quinquelinaeatus*(Bloch, 1790)	Five-lined snapper	1	63
61	*Paracaesio xanthura* (Bleeker, 1869)	Yellowtail blue snapper	9	64
	Family: Monodactylidae			
62	*Monodactylus argenteus* (Linnaeus, 1758)	Silver moony	36	65
	Family: Mullidae			
63	*Parupeneus indicus* (Shaw, 1803)	Indian goatfish	4	66
64	*Upeneus tragula* (Richardson, 1846)	Freckled goatfish	2	67
	Family: Nemipteridae			
65	*Scolopsis bimaculata* (Rüppell, 1828)	Thumbprint monocle bream	2	68
66	*Scolopsis vosmeri* (Bloch, 1792)	Whitecheek monocle bream	1	69
	Family: Pempheridae			
67	*Pempheris malabarica* Cuvier, 1831		25	70
	Family: Pomacentridae			
68	*Abudefduf septemfasciatus* (Cuvier, 1830)	Banded sergeant	5	71
69	*Abudefduf vaigiensis* (Quoy & Gaimard, 1825)	Indo-Pacific sergeant	51	72
70	*Pomacentrus caeruleus* (Quoy & Gaimard,1825)	Caerulean damsel	4	73
	Family: Scatophagidae			
71	*Scatophagus argus* (Linnaeus, 1766)	Spotted scat	1	74
	Family: Serranidae			
72	*Cephalopholis boenak* (Bloch, 1790)	Chocolate hind	1	75
73	*Epinephelus malabaricus* (Bloch & Schneider, 1801)	Malabar grouper	1	76
74	*Epinephelus merra* (Bloch, 1793)	Honeycomb grouper	2	77
75	*Epinephelus tauvina* (Forsskål, 1775)	Greasy grouper	2	78
76	*Epinephelus radiatus* (Day,1868)		1	79
	Family: Siganidae			
77	*Siganus javus* (Linnaeus, 1766)	Streaked spinefoot	1	80
78	*Siganus lineatus* (Valenciennes, 1835)	Golden-lined spinefoot	3	81
	Family: Sillaginidae			
79	*Sillago sihama* (Forsskål, 1775)	Silver sillago	11	82
	Order: Lophiiformes			
	Family: Antennariidae			
80	*Antennarius striatus* (Shaw, 1794)	Striated frogfish	1	83
	Order: Tetraodontiformes			
	Family: Diodontidae			
81	*Diodon holocanthus* (Linnaeus, 1758)	Longspined porcupinefish	5	84
82	Arothron immaculatus (Bloch & Schneider, 1801)	Immaculate puffer	2	86
	Family: Tetraodontidae			
83	*Diodon hystrix* (Linnaeus, 1758)	Spotted porcupine fish	9	85
	Family: Ostraciidae			
84	*Ostracion cubicus* (Linnaeus, 1758)	Yellow boxfish	1	87
	Family: Balistidae			
85	*Balistoides viridescens* (Bloch & Schneider, 1801)	Titan triggerfish	1	88
	Order: Syngnathiformes			
	Family: Fistulariidae			
86	*Fistularia commersonii* (Rüppell, 1838)	Bluespotted cornetfish	4	89
	Order: Scorpaeniformes			
	Family: Dactylopteridae			
87	*Dactyloptena orientalis* (Cuvier, 1829)	Oriental flying gurnard	1	90
	Family: Platycephalidae			
88	*Grammoplites suppositus* (Troschel, 1840)	Spotfin flathead	1	91
	Class: Reptilia			
	Order: Testudines			
	Family: Cheloniidae			
89	*Chelonia mydas* (Linnaeus, 1758)	Green sea turtle	1	92
90	*Eretmochelys imbricata* (Linnaeus, 1766)	Hawksbill sea turtle	1	93

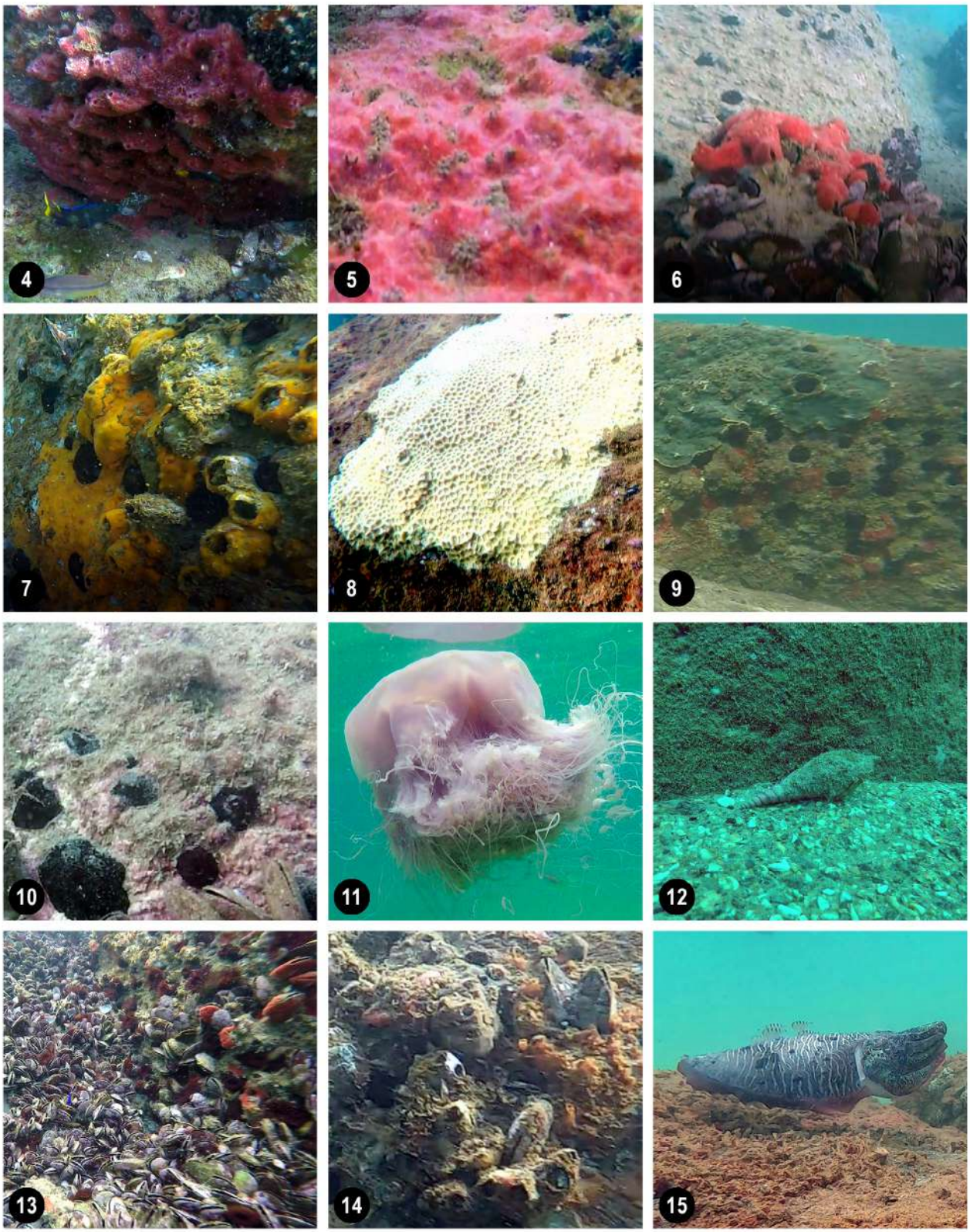

Fig. 4-15

once from the rocky reef area. The diversity of cnidarian fauna recorded in the study also may not represent the true diversity, as a detailed microscopic examination is needed to identify the species precisely.

Mollusca: The molluscan fauna in the region is dominated by the beds of brown mussel *Perna perna,* which also support the local fishery in the area. The gastropod Indian tibia (*Tibia curta*), the foam oyster *Hyotissa hyotis*, and two species of cuttlefish *Sepia ramani* and *S. pharaonis* were also encountered by the SCUBA divers in the rocky reef. Both the mussel beds and the cuttlefish form major attractions to the tourists undertaking SCUBA diving in the area.

Arthropoda: The larger arthropods only could be identified from the video recordings, which include the green spiny lobster *Panulirus homarus,* the crabs *Portunus*

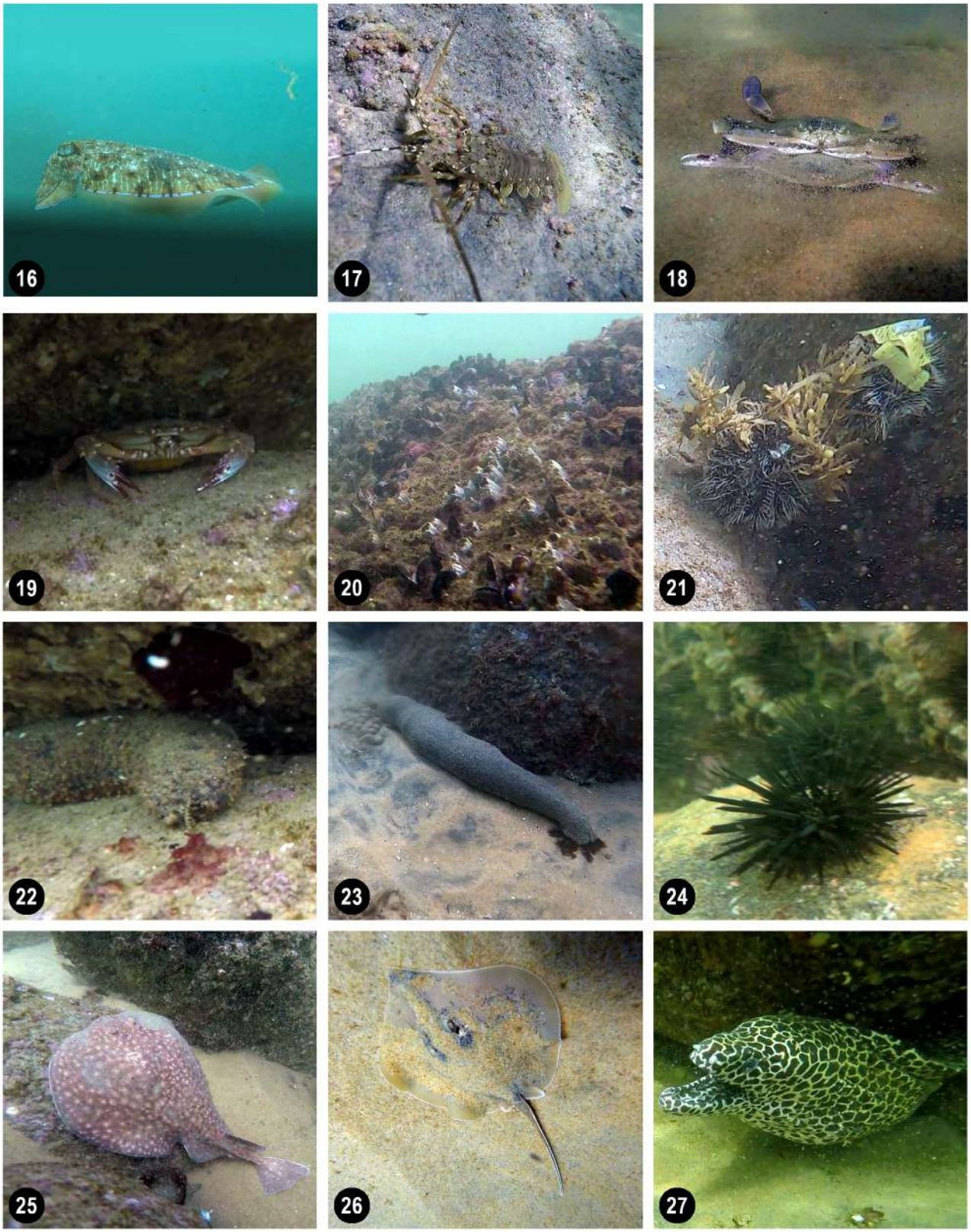

Fig. 16-27

sanguinolentus and *Charybdis* sp. and the barnacle *Megabalanus tintinnabulum,* which represents the most abundant arthropod in the region.

Echinodermata: The echinoderm fauna, a common inhabitant of the rocky reefs, is represented by two species of sea urchins *Tripneustes gratilla* and *Stomopneustes variolaris* (most abundant echinoderm in the region) and two species of sea cucumbers *Holothuria (Semperothuria) cinerascens* and *Holothuria (Mertensiothuria) leucospilota.* All the sea cucumbers are included in the Schedule I of the Wildlife (Protection) Act of India.

Fishes: Fish form the most common component of marine

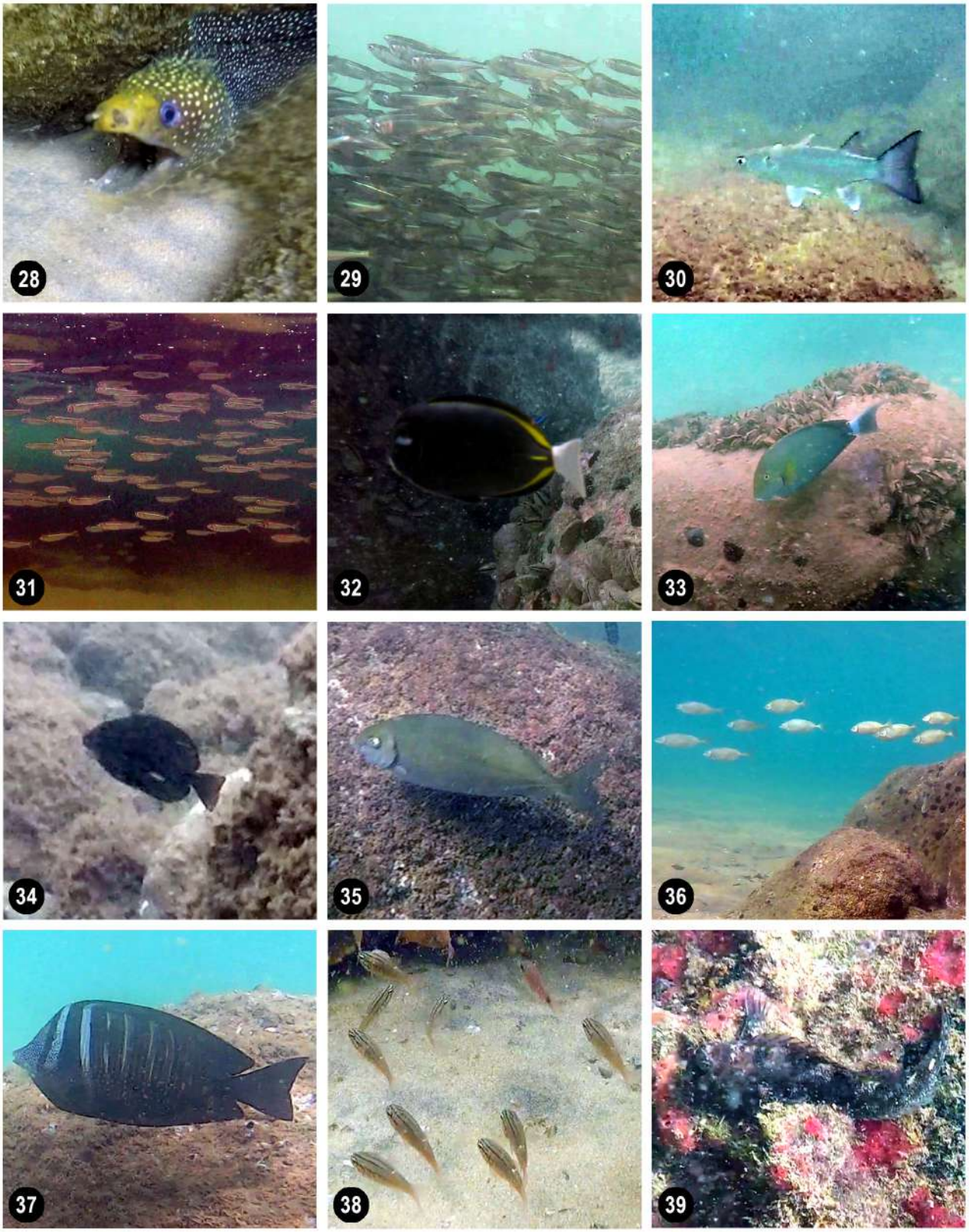

Fig. 28-39

faunal diversity in the rocky reef ecosystem of Kovalam. A total of 67 species of fish representing 11 orders, 36 families and 49 genera are represented in the videos of SCUBA divers in the region.

The fish families encountered in the region include Torpedinidae, Dasyatidae, Muraenidae, Clupeidae, Mugilidae, Atherinidae, Acanthuridae, Apogonidae, Blenniidae, Caesionidae, Carangidae, Chaetodontidae, Cirrhitidae, Ephippidae, Gerreidae, Haemulidae, Labridae, Leiognathidae, Lutjanidae, Monodactylidae, Mullidae, Nemipteridae, Pempheridae, Pomacentridae, Scatophagidae, Serranidae, Siganidae, Sillaginidae, Antennariidae, Diodontidae, Tetraodontidae, Ostraciidae, Balistidae, Fistulariidae, Dactylopteridae, and

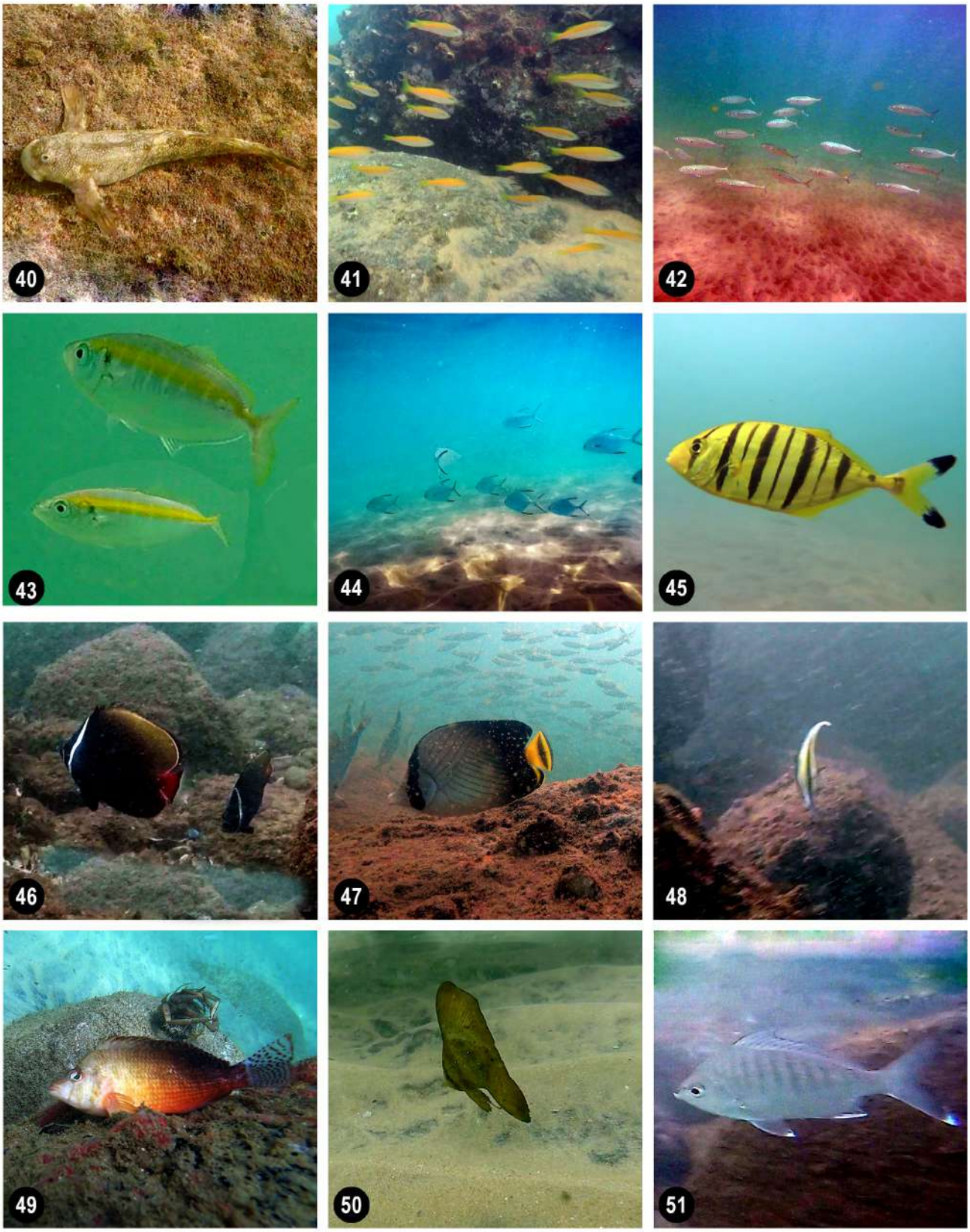

Fig. 40-51

Platycephalidae. Acanthuridae (six species), Lutjanidae (five species) and Serranide (five species) represent the species-rich families in the rocky reef of Kovalam (Fig. 94).

The most abundant fish species in the rocky reef, represented in shoals are *Sardinella longiceps*, *Atherinomorus lacunosus, Caesio xanthonota, Caranx sexfasciatus,* and *Pempheris malabarica*. The large shoal of Indian Oil Sardine *Sardinella longiceps* represented by 1121 number of individuals was observed only in once during 2016. The most frequently encountered fish species the rocky reef area is the Indo-Pacific sergeant *Abudefduf vaigiensis* (51)

Fig. 52-63

and the Siver moony *Monodactylus argenteus* (36), which were present in all the years under study.

Turtles: The SCUBA divers encountered two species of turtles, the Green sea turtle (*Chelonia mydas*) and the Hawksbill sea turtle (*Eretmochelys imbricata*) from the rocky reef of Kovalam. Both the species are included in the Schedule I of the Wildlife (Protection) Act of India. *C. mydas* is listed as endangered by the IUCN in the red list and protected under CITES, while *E. imbricata* is a critically endangered sea turtle offered protection globally.

3.2 Temporal variation of diversity

The variation in species diversity encountered in various

Fig. 64-75

taxa from 2015 to 2020 in the rocky reef area of Kovalam is given in Table 2 and Fig. 95.

In all the years, the faunal diversity was well dominated by fishes, and the diversity was maximum in the year 2018 (31 species) and minimum in 2016 and 2017 (10 species each). Porifera and turtles were recorded only in two years, and except fishes, the diversity recorded using video recordings were less, with most cases singletons. In general, total species diversity was maximum in 2018 (40 species) and minimum in 2017 (11species).

In the rocky reef region, the most abundant taxa in all the years under study was Pisces, followed by Mollusca and

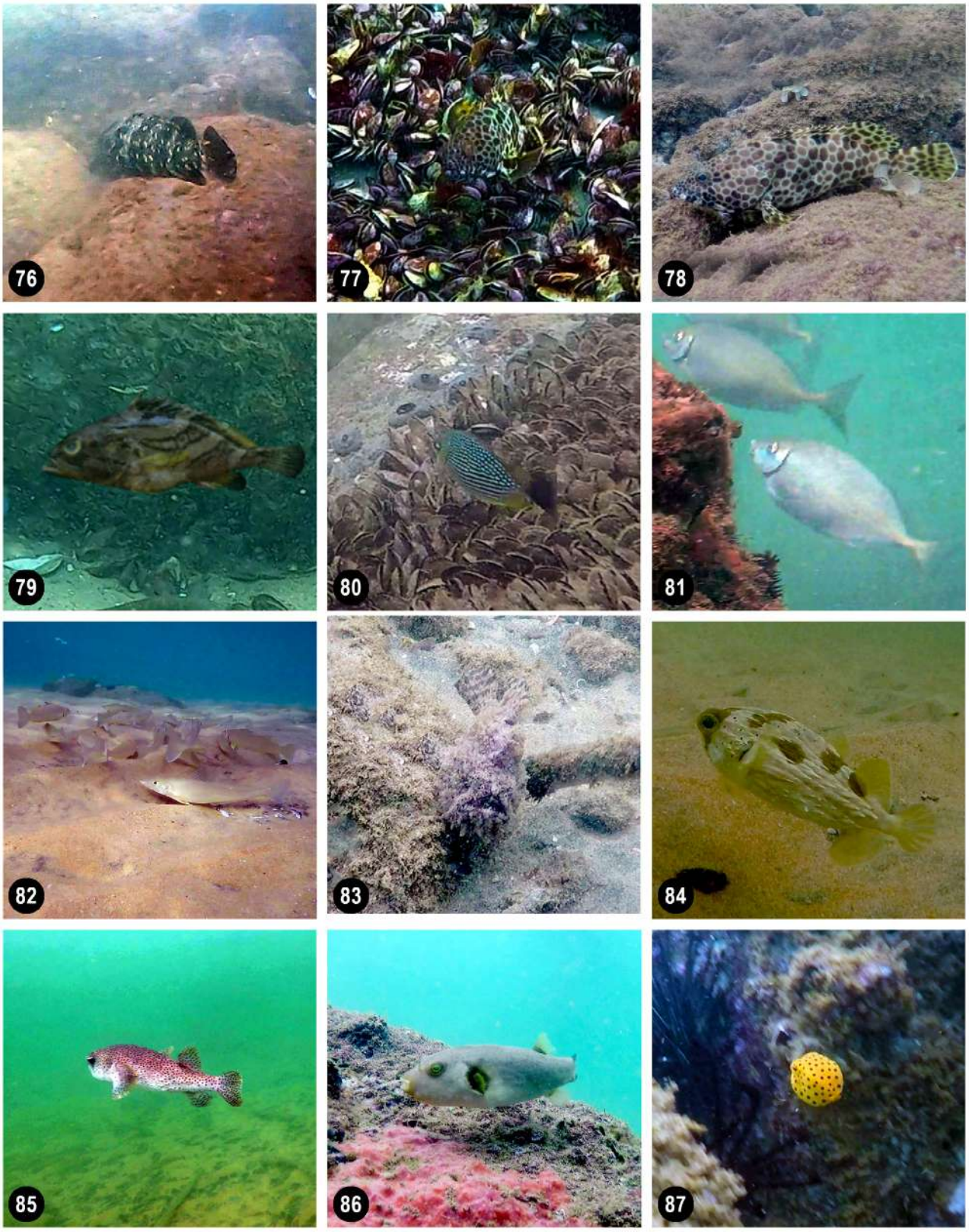

Fig. 76-87

Arthropoda (Fig. 96). In terms of total abundance of all taxa in different years, maximum abundance (1298) was observed in the year 2016 and minimum (83) in 2019. One noticeable feature was the considerable decline in the abundance of molluscs (dominated by the brown mussel *Perna perna*) in the years 2019 and 2020. In general, the abundance of species all the taxa were less in the years 2019 and 2020.

3.3 Threats to the rocky reefs

As the location of the rocky reef is close to Kovalam beach, a famous tourism destination in Kerala, the coastal ocean is contaminated with marine debris, which includes clothes,

Fig. 88-93

Table 2. Variation in species diversity encountered in various taxa from 2015 to 2020 in the rocky reef area of Kovalam

TAXA	2015	2016	2017	2018	2019	2020
Porifera	2	0	0	0	0	3
Cnidaria	1	1	0	3	0	0
Arthropoda	2	1	0	2	0	1
Mollusca	1	1	1	1	2	2
Echinodermata	0	1	0	2	3	2
Pisces	16	10	10	31	17	19
Turtles	0	0	0	1	0	1

tyres, plastic wastes, and discarded (ghost) nets (Fig. 97 A-F). In 2018, after the Ockhi cyclone that hit Kerala coast on November 29, 2017, the rocks lost the encrustations with sponges, mussels and barnacles, and the sedimentation also has increased in the locality due to the dredging activity (Fig. 97 E). The distribution of marine debris was noticed in the whole area of the reef and entangling of fish in the discarded fishing net was also observed.

4. Discussion

Rocky reef habitats serve as crucial ecosystems, fostering rich biodiversity and often attracting recreational tourism worldwide (Sale, 1991; Taylor, 1998; Cowles et al., 2009). In India, these habitats support seaweed growth and a biodiversity profile akin to coral reefs (Singarayan and Rethnaraj, 2016). Rocky shores, characterized by their biodiversity richness, contribute significantly to marine life (Ravinesh and Biju Kumar, 2013). Sub-tidal rocky reefs, in particular, host diverse fish assemblages (Sale, 1991) and mobile invertebrates (Cowles et al., 2009).

A comprehensive study based on video recordings by professional SCUBA divers from Bond Ocean Safari Kovalam unveiled the presence of 90 species in a single rocky reef ecosystem at Kovalam. This includes four species each of Porifera, Cnidaria, Arthropoda, and Echinodermata, five species of Mollusca, 67 species of Pisces, and two species of turtles. The findings underscore the significance of rocky reefs as vital sub-tidal habitats for coastal marine biodiversity, primarily dominated by fish. These results align with global observations, positioning rocky reefs as central hubs for coastal fish assemblages (Piazzi et al., 2012). The complex living organisms, including seaweeds and sessile invertebrates, find favorable conditions for settlement and establishment in these rocky bottoms, supporting a richer biodiversity than adjacent zones (Guidetti and Bussotti 2000; Guidetti and Boero, 2004). Additionally, these areas function as feeding and nursery grounds, offering refuge to numerous juvenile and adult organisms (Guidetti, 2000).

The rocky reef area in Kovalam plays a crucial role in supporting rare, endangered, or protected species under the Wildlife (Protection) Act of India. Species such as

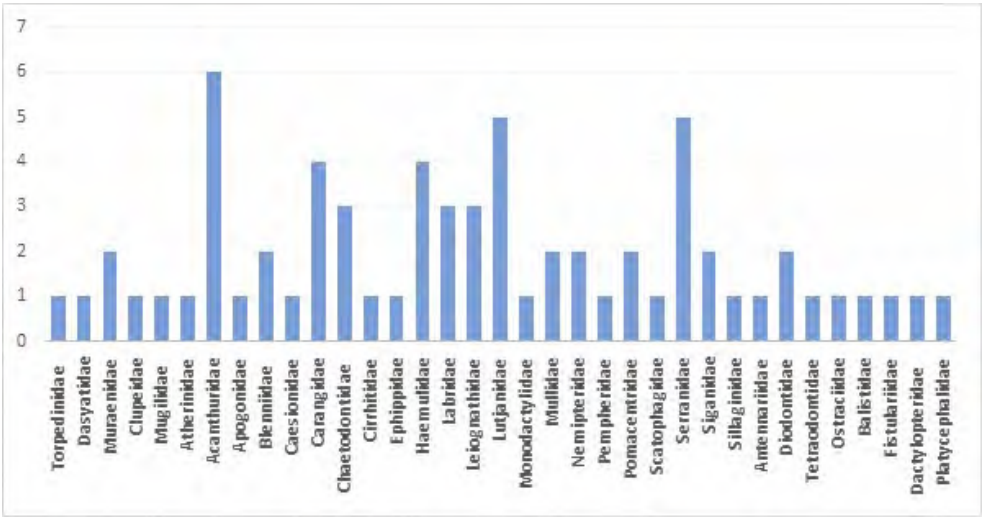

Fig. 94. Species diversity in various families inhabiting rocky reef of Kovalam

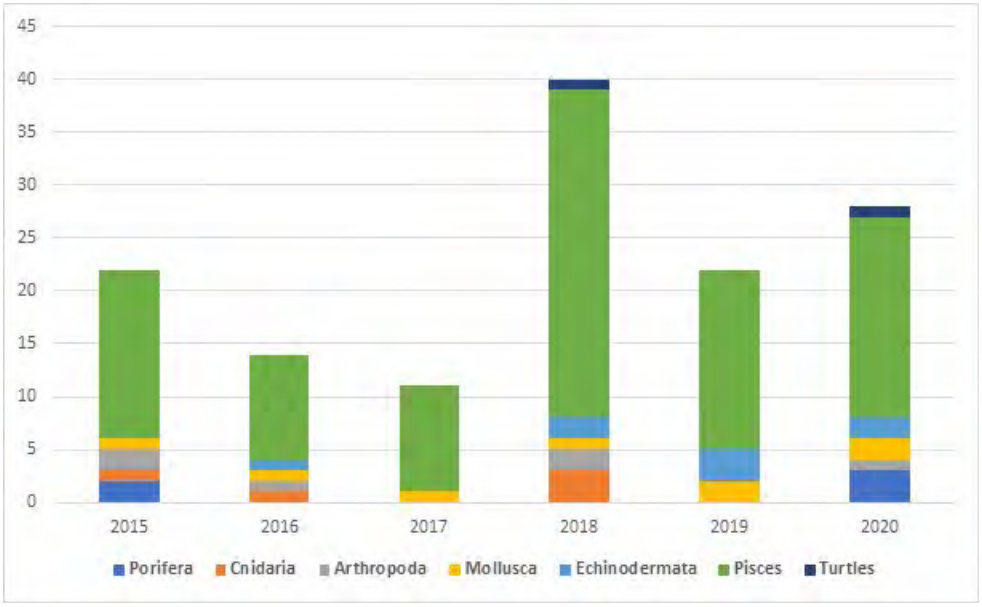

Fig. 95. Diversity various taxa in the rocky reef area of Kovalam from 2015 to 2020

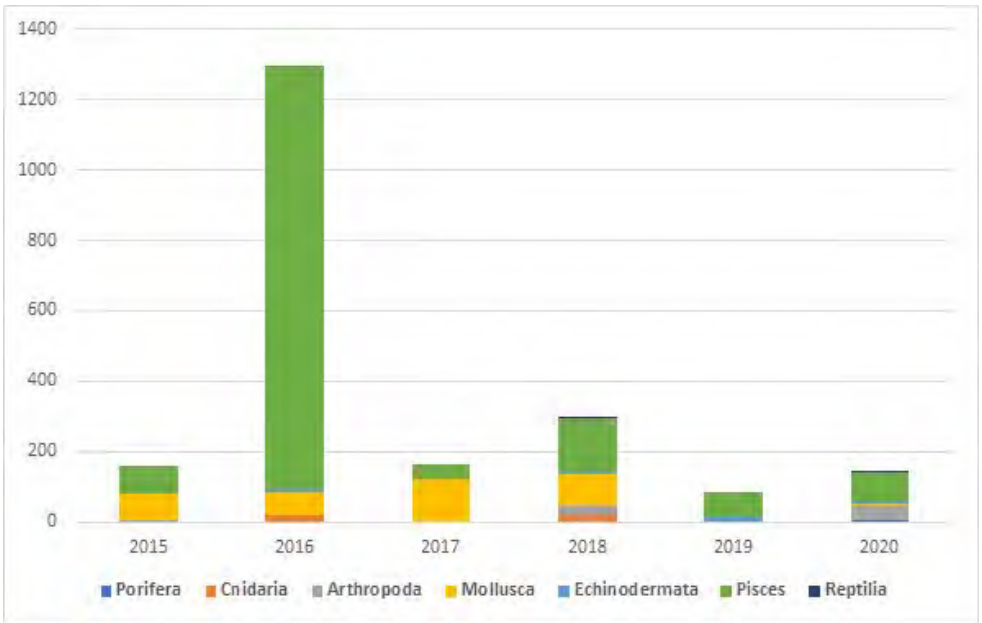

Fig. 96. Diversity various taxa in the rocky reef area of Kovalam from 2015 to 2020

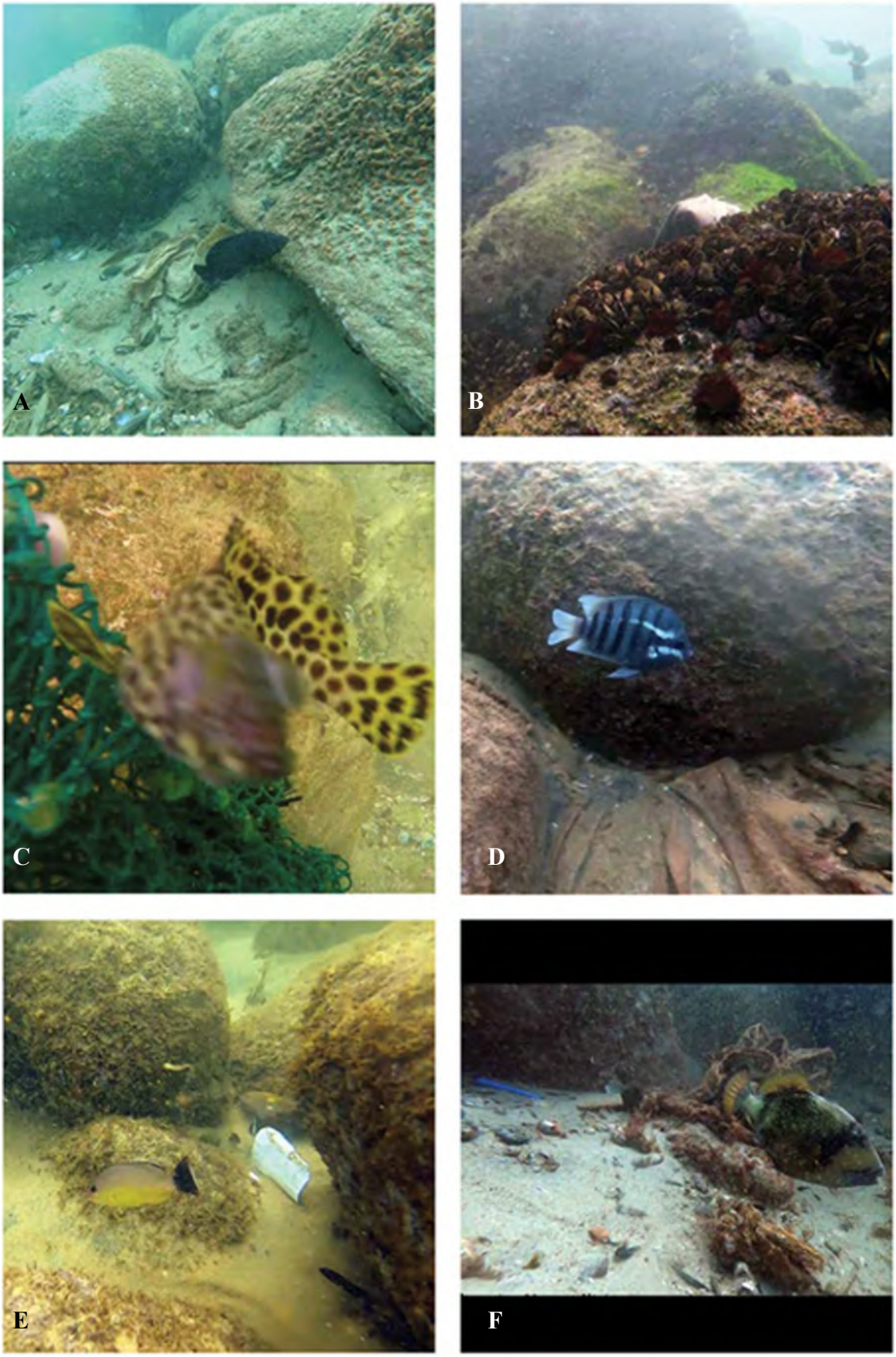

Fig. 97. Major threats recorded in the rocky reefs of Kovalam. A, D: Denuded rocks after Ockhi cyclone in 2017; B, C, E, F: Plastic pollution; C. Grouper entangled in ghost net; A, D, F: Marine debris settled at the sandy bottom

the scleractinian hard coral *Favites pentagona* (family Merulinidae), acroporan coral *Montipora hispida* (family Acroporidae), sea cucumbers *Holothuria (Semperothuria) cinerascens and Holothuria (Mertensiothuria) leucospilota*, and the green sea turtle (*Chelonia mydas*) and Hawksbill sea turtle (*Eretmochelys imbricata*) fall under Schedule I of the Wildlife (Protection) Act of India. The hawksbill sea turtle is critically endangered, while the green sea turtle is classified as endangered by the IUCN in the red list, and both species are protected under CITES.

In the rocky reef of Kovalam, fish constitute a species-rich and abundant faunal group, with a diversity of 67 species categorized under 11 orders and 36 families. Although most species are recorded in smaller numbers, SCUBA divers sporadically documented larger shoals of fish, including species like *Sardinella longiceps, Atherinomorus lacunosus, Caesio xanthonota, Caranx sexfasciatus,* and *Pempheris malabarica.* Fishes play a functionally significant role in the trophic dynamics of rocky reef ecosystems (Babcock et al., 1999; Shears and Babcock, 2002), and understanding their spatial and temporal distribution aids in the selection and design of Marine Protected Areas (MPAs) (Holbrook et al., 1990; Ward et al., 1999; Curley et al., 2002).

The vibrant biodiversity supported by reef ecosystems, particularly the diverse fish fauna, plays a pivotal role in driving marine tourism activities like SCUBA diving and snorkeling. This study highlights the potential of data generated by professional SCUBA divers involved in marine tourism initiatives to serve as valuable contributors to marine biodiversity documentation, given their frequent visits to tourist sites. With appropriate training in biodiversity sampling techniques, these divers can play a crucial role in long-term biodiversity monitoring and documentation, as direct visual observation remains one of the most effective methods for documenting biodiversity in reef ecosystems (Harasti et al., 2015).

Limited research has been conducted on the fish fauna diversity of the rocky reef ecosystems along the southwest coast of India, with existing results presented mainly in the form of checklists (Sulka, 2013; Sirajudheen and Biju Kumar, 2014; Baiju et al., 2016, 2019). Sulka (2013) documented 184 species from 41 families in the rocky reef and coastal ecosystems of Kerala and Tamil Nadu, with Serranidae (20 species), Acanthuridae (18 species), Labridae (18 species), and Pomacentridae (16 species) dominating. Sirajudheen and Biju Kumar (2014) focused on ornamental fish diversity associated with rocky habitats in Thiruvananthapuram, recording 101 species, with Pomacentridae (10 species), Labridae (9 species), Serranidae (8 species), Chaetodontidae (7 species), and Lutjanidae (species) as the dominant families. Baiju et al. (2016, 2019) documented 228 fish species in 60 families from Thiruvananthapuram coast, with Pomacentridae (20 species), Labridae (17 species), Lutjanidae (15 species), Chaetodontidae (11 species), Acanthuridae (10 species), Apogonidae (10 species), Serranidae (9 species), and Muraenidae (9 species) being notable. In this study, 67 fish species were recorded from a single site, potentially explaining the lower diversity.

Compared to earlier periods when higher fish diversity was recorded, the rocky reef system in the Kovalam region is currently facing increased anthropogenic interventions, including rising marine debris and wastewater discharge from nearby urban settlements and tourism establishments, along with elevated siltation due to construction activities in the coastal belt. These factors are likely impacting the biodiversity of the region significantly. Field observations by SCUBA divers also noted a substantial loss of floral and faunal encrustations on rocks during Cyclone Ockhi in November 2017. The cyclone had devastating effects on parts of Sri Lanka and India, with a particularly strong impact on benthic coral reef assemblages in Kavaratti Island, Lakshadweep (Riyas et al., 2019). The observed decrease in sessile macroinvertebrates' abundance in the rocky reef of Kovalam from 2018 to 2020 may be attributed to these events.

Fish encounters in a reef ecosystem are influenced by various factors, with ecosystem health playing a crucial role. The variations in species diversity observed in the rocky reef of Kovalam from 2015 to 2020 are not significant, despite a lower frequency of regularly observed species. The absence of notable differences among years is an intriguing finding, suggesting that fish abundance may fluctuate due to factors such as fishing pressure, food availability, behavioral changes, and migrations (Francour, 1994; Dufour et al., 1995; Pelaprat, 1999). Conducting in-depth studies on fish assemblages in rocky reefs is recommended, as this can provide valuable information for using them as bioindicators, especially considering that only a few fish species in the area are regular inhabitants. Pelagic species like *Sardinella longiceps, Atherinomorus lacunosus, Caesio xanthonota, Caranx sexfasciatus,* and *Pempheris malabarica*, observed in shoals, may be seasonal, and their abundance may not accurately reflect the true biodiversity of the region. Temporal variations in pelagic species, according to D'Anna et al. (1999), may be more linked to the seasonal presence of pelagic species in coastal waters than changes in the abundance of resident fishes. However, as the video recording was not specifically conducted for recording biodiversity, generalizations about temporal variations are not feasible. Professional SCUBA divers can undergo training to enhance their effectiveness in biodiversity documentation in similar sites across different locations, providing insights into diversity patterns and aiding in the formulation of management strategies (Piazzi et al., 2012).

A clean and healthy ocean is essential for promoting marine tourism in reef ecosystems. SCUBA divers prioritize the quality of coral reefs, including coral and fish diversity, water visibility, and pollution-free habitats when selecting dive destinations worldwide (Dimmock, 2003). Reefs in urbanized embayment with higher pollutant levels consistently exhibit characteristics such as smaller, faster-growing species, reduced fish biomass and richness, and diminished mobile invertebrate abundance and richness (Stuart-Smith et al., 2015). Maintaining a balance of pollutants is crucial for preserving species distribution.

The study highlights limitations in using video recording

for species diversity assessment, as benthic and cryptic species may not be well differentiated through videos alone, and many smaller invertebrates may remain unidentified through visual observations. While citizen science has its limitations, generating less reliable datasets than traditional scientific methods (Mengersen et al., 2017; Lucerzi et al., 2018), professional SCUBA divers can overcome these limitations with advanced training for underwater surveys and documenting the diversity of rocky and coral reef ecosystems. Well-supervised and quality-controlled citizen science programs focusing on marine biodiversity have proven successful (Stuart-Smith et al., 2018).

The study underscores the potential of citizen science, defined as "research collaboration that involves volunteers in producing authentic scientific research" (Wiggins and Crowston, 2014), for effectively monitoring reef areas, as demonstrated in coral reef and rocky reef areas globally (Hodgson, 2001; Loder et al., 2015; Stuart-Smith et al., 2017; Pandya and Dibner, 2018). There is a significant opportunity to develop citizen science programs specifically for marine biodiversity documentation and monitoring, particularly in regionally important ecosystems such as rocky reefs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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