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Reef-associated ichthyofauna from a marginal coral reef habitat along the west coast of India: Implication for management strategies

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Abstract: Coral reefs harbour remarkable high biodiversity. Reef fishes are among the most important communities in the coral reef ecosystem, significantly contributing to ecosystem functioning and reef resilience. However, under the continuous effect of climate change and human activities, corals and reef fishes are in peril. For the first time, we documented coral reef-associated ichthyofauna from Malvan marine sanctuary (MMS) on the central west coast of India, an understudied marginal patch coral reef habitat. Experiencing severe stress due to concurrent coral bleaching, fishing, sedimentation, intensifying tourism, and coastal development activities. We reported the occurrence of 47 species of reef fishes belonging to 35 genera and 26 families from the MMS, also a list of hard corals from in the MMS, thus highlighting the biodiversity of reef building corals and reef fishes in the MMS. The coral habitat in the MMS is experiencing severe stress due to concurrent thermal coral bleaching, fishing, sedimentation, intensifying tourism, and coastal development activities.. Therefore, urgent intervention with sustainable fishery management policies and long-term reef protection measures is a prerequisite for the persistence of the corals and the associated reef fishes in the MMS.

Résumé : *Ichtyofaune récifale provenant d'un habitat marginal de récifs coralliens le long de la côte ouest de l'Inde : implication pour les stratégies de gestion*. Les récifs coralliens abritent une biodiversité remarquable. Les poissons de récif font partie des communautés les plus importantes de l'écosystème des récifs coralliens, contribuant de manière significative au fonctionnement de l'écosystème et à la résilience des récifs. Cependant, sous l'effet continu du changement climatique et des activités humaines, les coraux et les poissons de récif sont en péril. Pour la première fois, nous avons documenté l'ichtyofaune associée aux récifs coralliens du sanctuaire marin de Malvan (MMS) sur la côte centre-ouest de l'Inde, un habitat de parcelles coralliennes marginales sous-étudié, subissant un stress sévère lié à la cooccurence du blanchissement des coraux, de la pêche, de la sédimentation, de l'intensification du tourisme et des activités de développement côtier. Nous signalons la présence de 47 espèces de poissons de récif appartenant à 35 genres et 26 familles du MMS, ainsi qu'une liste de coraux durs du MMS, mettant en évidence la biodiversité des coraux et des poissons dans le MMS. L'habitat corallien dans le MMS est gravement dégradé en raison de l'augmentation des activités humaines et des

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événements de blanchissement thermique des coraux induits par le changement climatique. Par conséquent, une intervention urgente avec des politiques de gestion durable de la pêche et des mesures de protection à long terme des récifs est une condition indispensable à la persistance des coraux et des poissons de récif associés dans le MMS.

Keywords: Coral; Reef fish ● Malvan Marine Sanctuary ● Marine Protected Area ● India

Introduction

Reef fishes are one of the most numerous, colorful, intriguing, and heterogeneous species that inhabit coral reefs, the most biodiverse ecosystem on Earth (Moberg & Folke, 1999). However, reef fishes are vulnerable to declines globally due to coral reef degradation (Graham et al., 2006; Graham, 2007; Wilson et al., 2008). The complex physical structures formed by reef-forming corals provide a protected environment from the surrounding open ocean, influencing the fish population by providing a conducive habitat and food resources (Ménard et al., 2012). Reef fishes are the conspicuous component of the healthy coral reef ecosystem and are recognized as a keystone group in the coral reef for their significant role in structuring coral communities and enhancing reef resilience (Graham et al., 2006; Green & Bellwood, 2009). Herbivores and grazers in the coral reef control macroalgal and turf algal growth and, reduce benthic space competition, therefore, aid coral larval settlement and contribute to the overall reef health and resilience (Heenan & Williams, 2013). Globally, the depletion of the herbivore fish community through intensive fishing and habitat loss has often resulted in a undesirable state of coral reefs, from coral dominated reef to algal dominated reef (Mumby et al., 2006). Additionally, studies reported that the diminution of herbivores may trigger to overgrow of macroalgae, which harbour coral pathogenic microbes, and eventually negatively impact the reef health by causing coraldiseases. (Sweet et al., 2013).

Information on distribution, biodiversity, and ecology of coral reef fishes have been reported from the major coral reef areas of India, in particular Andaman and Nicobar Islands, Gulf of Mannar Biosphere Reserve, Lakshadweep Islands, and Gulf of Kachchh. However, little is known on reef-dwelling fishes from the patch coral reefs along the West coast of India. Studies have documented reef fish diversity from Grande Island on Goa coast (36 reef-associated fish; Sreekanth et al., 2019), Angria bank coral reef off Maharashtra (18 reef-associated fishes; NIO, 2016), and Netrani Island on Karnataka coast (92 fish species; Zacharia et al., 2008). The present investigation aimed to document the reef-associated fishes in the understudied patch coral reefs of the Malvan Marine Sanctuary (MMS), a Marine Protected Area (MPA) on the West coast of India. Malvan is also one of the important fish landing centers of economic importance along the West coast of India, known for its high marine fish and shellfish diversity (Tike et al., 2009). Previous studies on fish diversity from the Malvan region were mostly focused on the fishes of commercial importance and caught by the fishing activities of local fishers (Parulekar, 1981; Barman et al., 2007; Tike et al., 2009). Despite the presence of fragile coral reefs with enormous ecological and socio-economic significance, very little information is known on the occurrence and diversity of reef-associated fishes from this Marine Protected Area. Considering the increasing environmental and anthropological pressure on corals at the MMS, and the complex functioning roles of reef fishes in the reef environment, documentation of the occurrence and distribution associated ichthyofauna is critically needed.

The present study provides baseline information on the occurrence and distribution of reef fishes at the MMS, based on systematic underwater surveys conducted around the major patch reefs. This study also shed light on the threats to MMS and emphasizes urgent management intervention to protect the vulnerable coral reef habitat.

Material and Methods

Study area

The Malvan Marine Sanctuary (MMS) is located along the central west coast of India and spread over a 29.122 km^2 area (ICMAM, 2001). Malvan Bay is protected by numerous rocky outcrops and the small

low fortified Sindhudurg Island. Patch reefs are distributed in shallow protected areas along with the MPA. Underwater surveys by SCUBA diving were conducted annually during the dry season at five patch reefs (T1 to T5) across the MMS from 2015 to 2019 (Table 1 & Fig. 1). Reef T1, T2, and T3 are located within the core zone of the MPA but are extensively used as commercial, recreational diving, and snorkeling sites by local tourism operators. Reefs T4 and T5 are fishing sites for local fishers. Recently, reef T5 has also become a recreational diving site. The Malvan Bay is well protected from wave action by Sindhudurg Island and a chain of submerged and exposed rocks. The patch reefs in the Malvan bay are primarily composed of a massive and encrusting form of *Porites* spp. and foliose form of *Turbinaria mesenterina* (De et al., 2015). Other abundant scleractinian species are *Goniopora* sp., *Goniastrea* sp., *Plesiastrea versipora*, *Leptastrea* sp., *Coscinaraea monile*, *Cyphastrea serailia* and *Pseudosiderastrea tayamai* (Table 2). High rainfall, rapidly changing land use, and terrigenous runoff cause relatively higher concentration of suspended particles and dissolved nutrients in the MMS (Hussain et al., 2016; De et al., 2021). Average water depth ranges between 2 and 10 meters along the study area.

Ichthyofaunal survey and data collection:

Underwater visual census was conducted by two SCUBA divers at each patch reef following the method described by Halford & Thompson (1994), one of the non-destructive approaches offered to assess coral reef fish communities. At each patch reef site, we conducted (20 m x 5 m) belt transect surveys in replicate (n = 3) by swimming along the center line of the transect tape and recorded all fish sighted within the area on either 2.5-m side of the transect tape. Transect tapes were laid at approximately 10 m interval along the depth contour of 2-10 m. GPS coordinates of the reef site and the start and endpoint of each transect were recorded using a hand-held GPS (Garmin GPSMAP 78S Marine GPS Navigator). The consecutive annual reef monitoring surveys were carried out following the same GPS coordinates. Underwater digital photographs were clicked using Nikon AW120 (14 megapixels, Japan) and GoPro Hero4 (12 megapixels, USA) underwater camera. Initial identification of the fishes was carried out

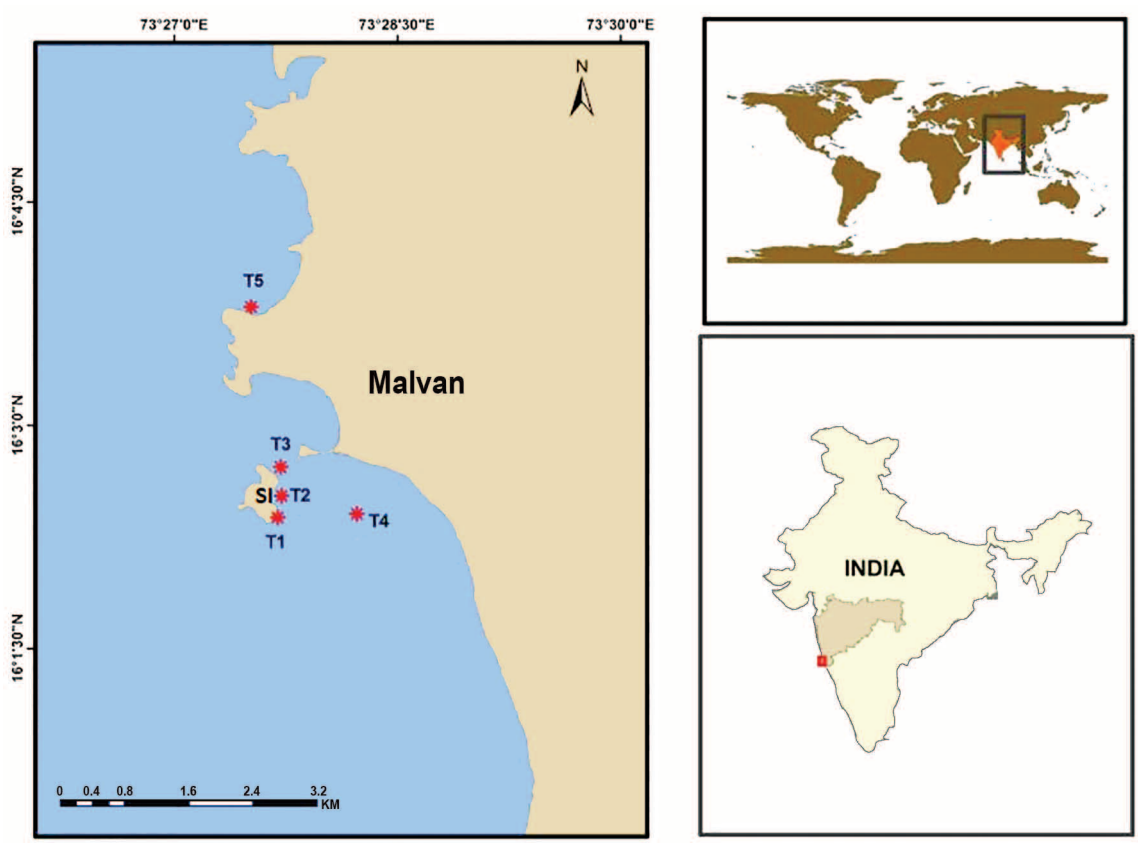

Figure 1. Map showing the location of the Malvan Marine Sanctuary and the study sites (T1 to T5).

Table 1. Location and characteristic of underwater survey sites in the MMS.

Site	Type of bottom substratum	Geographical positions		Water Depth (m)	Characteristic of human activity
		Latitude (N)	Longitude (E)		
T1	Rocky	16°02'22.8"N	73°27'41.9" E	2-3	Recreational diving site and fishing site
T2	Rocky	16° 2'31.50"N	73°27'43.40"E	2-3	Recreational diving site and fishing site
T3	Rocky	16° 2'47.15"N	73°27'42.58"E	2-5	Recreational diving site
T4	Rocky & sandy	16° 2'24.30"N	73°28'13.80"E	8-10	Fishing site
T5	Rocky & sandy	16° 3'54.48"N	73°27'27.18"E	7-9	Recreational diving site and fishing site

during underwater observation. Images were used for further confirmation at the best possible taxonomic resolution by using available identification keys (Talwar & Kacker, 1984; Randall et al., 1990; Allen, 2003; Murugan & Namboothri, 2012). Online database resources, such as FishBase ver. 02/2019 (www.fishbase.org), World Register of Marine Species: WoRMS (2015) (http://www.marinespecies.org/), (Froese & Pauly, 2019) the IUCN red list of threatened species (https://www.iucnredlist.org/), and bioSearch (http://www.biosearch.in) (Anonymous, 2015) were also used for identification keys, taxonomic validity, distribution range, and ecology. No collection of fish specimens or damage to coral reefs was done during the surveys.

Results

Patterns in species richness

During the present study, 47 species of reef fishes belonging to 35 genera and 26 families were encountered from the MMS coral reefs (Table 3). The most diverse family was Pomacentridae with four genera and seven species, followed by Chaetodontidae with two genera and six species (Fig. 2). We observed that the distribution of reef fishes varied between the studied sites. The highest species richness was observed at T2 (n = 21), followed by T1 (n = 17), and T3 (n = 16) around the Sindhudurg Island. Only, 15 and 14 species were

Table 2. Details of hard-coral species recorded during the study. Vulnerable: VU; Near threaten: NT; Data deficient: DD; Least concern: LC.

Species	Observed site	IUCN red list status
Turbinaria mesenterina (Lamarck, 1816)	All reef sites	VU
Siderastrea savignyana Milne Edwards & Haime, 1849	T2, T3	LC
Pseudosiderastrea tayamai Yabe & Sugiyama, 1935	Intertidal rock pools, and T2, T3	NT
Coscinaraea monile (Forskål, 1775)	T2, T3, T4	LC
Favites melicerum (Ehrenberg, 1834)	T1, T2, T4, T5	NT
Favites halicora (Ehrenberg, 1834)	T1, T2, T4	NT
Goniastrea sp.	T1, T2, T3	-
Pavona sp.	T1, T4	-
Cyphastrea serailia (Forskål, 1775)	All reef sites	LC
Plesiastrea versipora (Lamarck, 1816)	T3, T4, T5	LC
Porites lichen (Dana, 1846)	T1, T2, T3, T5	LC
Porites lutea Milne Edwards & Haime, 1851	All reef sites	LC
Porites compressa Dana, 1846	T1, T2, T3	LC
Goniopora stokesi Milne Edwards & Haime, 1851	T4, T5	NT
Goniopora pedunculata Quoy & Gaimard, 1833	T4	NT
Bernardpora stutchburyi (Wells, 1955)	T4	LC
Tubastrea cocinea Lesson, 1830	T4, T5	LC

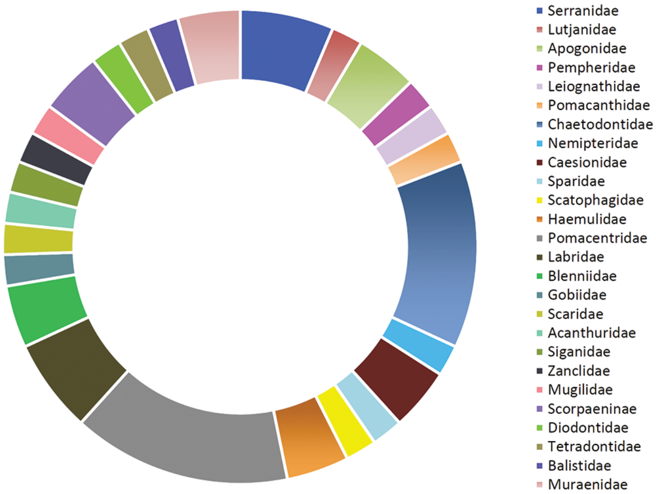

Figure 2. Prominent families of fishes contributing to the reef fish diversity (%) at the MMS (SI: Sindhudurg Island).

reported at reef stations T4 and T5, respectively. Highest density of reef fishes was observed at patch reef location T1, T2, and T3. From our *in-situ* visual survey, it was found that *Neopomacentrus violascens* (Bleeker, 1848), *Neopomacentrus cyanomos* (Bleeker, 1856), *Abudefduf bengalensis* (Bloch, 1787), *A. sordidus* (Forsskål, 1775), and *Cheiloprion labiatus* (Day, 1877) formed large schools in the reef sites. We also noticed large schools formation of juvenile fishes composed of mixed species, mainly *Neopomacentrus* spp., *Abudefduf* spp., and *Cheiloprion* sp. Ten fish species were observed to be common in all the study sites, namely, *Halichoeres leucurus* (Walbaum, 1792), *C. labiatus* (Day, 1877), *N. violascens* (Bleeker, 1848), *N. cyanomos* (Bleeker, 1856), *Cryptocentrus caeruleopunctatus* (Rüppell, 1830), *Scatophagus argus* (Linnaeus, 1766), *Cephalopholis formosa* (Shaw, 1812), *Blenniella periophthalmus* (Valenciennes, 1836), *Salarias faciatus* (Bloch, 1786), and *Chaetodon collare* Bloch, 1787 (Fig. 3).

The site T5, showed the most unique species assemblage with eight unique species including *Cephalopholis sonnerati* (Valenciennes, 1828), *Karalla daura* (Cuvier, 1829), *Zanclus cornutus* (Linnaeus, 1758), *Chilomycterus reticulatus* (Linnaeus, 1758), *Caesio teres* Seale, 1906, *Plectorhinchus chubbi* (Regan, 1919), *Gymnothorax griseus* (Lacepède, 1803), *Gymnothorax favagineus* Bloch & Schneider, 1801. Four unique species were reported only at the site T4: *Scolopsis vosmeri* (Bloch, 1792), *Pomacanthus annularis* (Bloch, 1787), *Lutjanus argentimaculatus* (Forsskål, 1775), *Scorpaenopsis venosa* (Cuvier, 1829). The site T1 was also characterized by four unique species: *Heniochus monoceros* Cuvier, 1831, *Pomadasys guoraca* (Cuvier, 1829), *Odonus niger* (Rüppell, 1836), *Epinephelus malabaricus* (Bloch & Schneider, 1801). Patch reef site T2 was represented by three unique species, which were *Labroides dimidiatus* (Valenciennes, 1839), *Caesio xanthonota* Bleeker, 1853, *Chaetodon lineolatus* Cuvier, 1831. *Taeniamia fucata* (Cantor, 1849), and *Scarus ghobban* Forsskål, 1775, were only found at the T3 location (Fig. 3).

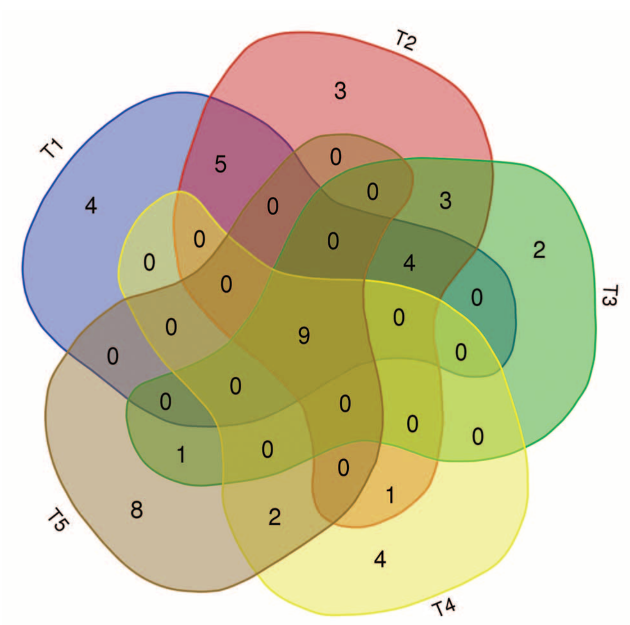

Figure 3. Venn diagram representing the differences in reef fish assemblages at different patch reef sites at the MMS.

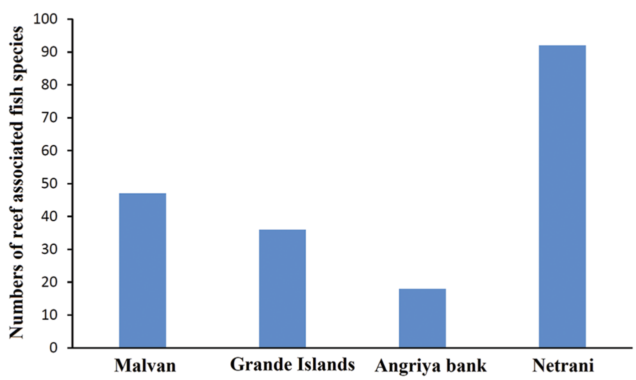

Figure 4. Reef associated fish species richness in different coral reef habitats along the central west coast of India (data source Sreekanth et al., 2019; NIO, 2016; Zacharia et al., 2008, present study).

Table 3. Coral reef-associated ichthyofauna reported from MMS during the present study along with their occurrence, relative abundance feeding habits, and IUCN red list status. Not evaluated: NE, Data deficient: DD, Least concern: LC, Vulnerable: VU.

Sr. No.	Species Name	Common name	Occurrence site	Relative abundance	Feeding guild	Food/diet	IUCN status
1	*Gymnothorax griseus* (Lacepède, 1803)	Geometric moray eel	5	Rare	Carnivore	crustaceans, small fish	LC
2	*Gymnothorax favagineus* Bloch & Schneider, 1801	Honeycomb moray	5	Rare	Carnivore	crustaceans, small fish	LC
3	*Cephalopholis formosa* (Shaw, 1812)	Blue lined grouper	All sites	Rare	Carnivore	small fish, mollusk, crustacean	LC
4	*Cephalopholis sonnerati* (Valenciennes, 1828)	Tomato Hind	5	Rare	Carnivore	small fish, mollusk, crustacean	LC
5	*Epinephelus malabaricus* (Bloch & Schneider 1801)	Malabar grouper	1	Rare	Carnivore	small fish, molluscs, crustaceans	LC
6	*Taeniamia fucata* (Cantor, 1849)	Orangetailed cardinal fish	3	Common	Carnivore	crustaceans, invertebrate	NE
7	*Ostorhinchus fasciatus* (White, 1790)	Broad-banded cardinalfish	2, 3	Common	Invertivore	zooplankton, crustaceans, invertebrates	NE
8	*Pempheris vanicolensis* (Cuvier, 1831)	Vanikoro sweeper	3.5	Common	Planktivore	zooplankton, crustaceans	NE
9	*Karalla daura* (Cuvier, 1829)	Goldstripe ponyfish	5	Rare	Omnivore	crustaceans, worms, molluscs, invertebrates	NE
10	*Pomacanthus annularis* (Bloch, 1787)	Blue-ringed angelfish	4	Rare	Omnivore	algae, zooplankton, sponges, tunicates, coral polyps, small fishes	LC
11	*Chaetodon collare* (Bloch, 1787)	White collared butterfly fish	All sites	Common	Omnivore	algae, coral polyps, crustaceans, invertebrate	LC
12	*Chaetodon decussatus* Cuvier, 1829	Indian vagabond butterflyfish	1.2	Rare	Invertivore	benthic invertebrates, crustaceans	LC
13	*Chaetodon dolosus* Ahl, 1923	African butterfly fish	1, 2	Rare	Invertivore	crustaceans, invertebrate	LC
14	*Chaetodon lineolatus* Cuvier, 1831	Lined butterflyfish	2	Rare	Carnivore	coral polyps, anemones, algae, benthic invertebrate	LC
15	*Heniochus acuminatus* (Linnaeus, 1758)	Bannerfish/ Pennant coral fish	2, 3	Rare	Carnivore	coral polyp, crustaceans, benthic invertebrates,	LC
16	*Heniochus monoceros* Cuvier, 1831	Masked bannerfish	1	Rare	Carnivore	benthic invertebrates	LC
17	*Lutjanus argentimaculatus* (Forsskål, 1775)	Mangrove red snapper	4	Rare	Carnivore	small fish, crustaceans	LC
18	*Scolopsis vosmeri* (Bloch, 1792)	Whitecheek monocle bream	4	Rare	Invertivore	crustaceans, benthic invertebrate	NE
19	*Caesio xanthonota* (Bleeker, 1853)	Yellowback fusilier	2	Rare	Invertivore	zooplankton, crustaceans, invertebrate	LC
20	*Caesio teres* Seale, 1906	Yellow and blueback fusilier	5	Rare	Invertivore	zooplankton, crustaceans, invertebrate	NE
21	*Acanthopagrus berda* (Forsskål, 1775)	Goldsilk seabream	2	Rare	Carnivore	small fish, echinoderms, worms, crustaceans, molluscs	LC
22	*Scatophagus argus* (Linnaeus, 1766)	Spotted Scat	All sites	Common	Omnivore	algae, zooplankton, crustaceans, invertebrates	LC
23	*Pomadasys guoraca* (Cuvier, 1829)	Guoraca Grunter	1	Rare	Carnivore	crustaceans, molluscs, invertebrates	LC
24	*Plectorhinchus chubbi* (Regan, 1919)	Dusky Sweetlips	5	Rare	Invertivore	benthic invertebrates, crustaceans, worms	LC
25	*Abudefduf sordidus* (Forsskål, 1775)	Black spot sergeant	1,2,3	Common	Omnivore	algae, crustaceans, small invertebrates	LC

Table 3. continued

26	*Abudefduf bengalensis* (Bloch, 1787)	Bengal sergeant	1,2,3	Common	Omnivore	algae, crustaceans, small invertebrates	LC
27	*Abudefduf vaigiensis* (Quoy & Gaimard, 1825)	Indo-Pacific sergeant	1,2,3	Common	Omnivore	algae, crustaceans, invertebrates	LC
28	*Cheiloprion labiatus* (Day, 1877)	Big lip damsel	All sites	Common	Omnivore	algae, coral polyps, invertebrates	NE
29	*Chrysiptera unimaculata* (Cuvier, 1830)	One spot damsel	1,2,3	Rare	Omnivore	algae, crustaceans, small invertebrates	LC
30	*Neopomacentrus cyanomos* (Bleeker, 1856)	Regal Demoiselle	All sites	Common	Omnivore	algae, zooplankton, crustaceans, small invertebrates	VU
31	*Neopomacentrus violascens* (Bleeker, 1848)	Violet demoiselle	All sites	Common	Omnivore	algae, zooplankton, crustaceans, small invertebrates	NE
32	*Halichoeres leucurus* (Walbaum, 1792)	Chain lined wrasse	All sites	Common	Invertivore	crustaceans, small invertebrates	LC
33	*Thalassoma lunare* (Linnaeus, 1758)	Moon Wrasse	2.3	Rare	Carnivore	benthic invertebrates, worms, fish egg	LC
34	*Labroides dimidiatus* (Valenciennes, 1839)	Bluestreak cleaner wrasse	2	Common	Ectoparasite feeder	parasitic copepods, invertebrates	LC
35	*Scarus ghobban* Forsskål, 1775	Blue-barred parrotfish	3	Rare	Herbivore	benthic algae/weeds	LC
36	*Acanthurus gahhm* (Forsskål, 1775)	Black Surgeon	4.5	Rare	Omnivore	zooplankton, benthic algae, detritus, invertebrates	LC
37	*Siganus vermiculatus* (Valenciennes, 1835)	Rabbit fish/ Vermiculated Spinefoot	1, 2	Common	Herbivore	algae, seaweed	LC
38	*Zanclus cornutus* (Linnaeus, 1758)	Moorish idol	5	Rare	Invertivore	sponges, invertebrates	LC
39	*Mugil cephalus* Linnaeus, 1758	Flathead grey mullet	1.2	Common	Omnivore	diatoms, algae, copepods, decayed organic matter	LC
40	*Scorpaenopsis venosa* (Cuvier, 1829)	Raggi scorpion fish	4	Rare	Carnivore	small fish, crustacean	LC
41	*Pterois volitans* (Linnaeus, 1758)	Red lion fish	4, 2	Rare	Carnivore	small fish, crustaceans, benthic invertebrates	LC
42	*Istigobius ornatus* (Rüppell, 1830)	Ornate goby	1,2,3	Common	Invertivore	benthic invertebrates	LC
43	*Blenniella periophthalmus* (Valenciennes, 1836)	Blue-dashed rockskipper, Bullethead rockskipper	All sites	Common	Omnivore	algae, benthic invertebrates	LC
44	*Salarias fasciatus* (Bloch, 1786)	Jewelled blenny	All sites	Common	Omnivore	benthic algae, weeds, crustaceans, detritus	LC
45	*Odonus niger* (Rüppell, 1836)	Redtoothed trigger fish	1	Rare	Carnivore	benthic invertebrates, small fish, molluscs, crustaceans, worms	NE
46	*Chilomycterus reticulatus* (Linnaeus, 1758)	Spotted burrfish	5	Rare	Carnivore	molluscs, sea urchins, crustaceans	LC
47	*Arothron immaculatus* (Bloch & Schneider, 1801)	Immaculate Puffer	4, 5	Rare	Carnivore	crustaceans, molluscs	LC

Feeding guild analysis of the observed fish species indicates that most of the reef fishes in the MMS were belonging to carnivore (18 species) and omnivore (15 species) categories (Table 3). Only two species (*Siganus vermiculatus, Scarus ghobban*) were found to be exclusively herbivores. Among the reported fish species, only *N. cyanomos* belong to the Vulnerable category of IUCN Red List, whereas 28 fishes belong to Least Concern (LC) category and six have not been evaluated.

Discussion

Documentation and monitoring of fish assemblages in the coral reef is crucial to assess the health and resilience of the coral reef and also to achieve conservation and management goals. The Malvan Marine Sanctuary was designated in 1987; however, little is known about the diversity and distribution of reef-associated fishes from the patch coral reefs across the MMS. During the present study, 47 species of reef-associated fishes were documented from the MMS. These reef fishes depend upon coral reefs for food, shelter, and breeding grounds. We observed that the presence of shallow water patch coral reefs provides ideal nurseries to the fishes by offering shelter for juvenile fishes and buffers the wave action, which is easier for the fish juveniles to locomotion, feeding, and predators identification (Ménard et al., 2012).

The reef fish diversity in the MMS is comparatively lower when compared with the major well developed coral reef ecosystems along the west coast of India, particularly, the Lakshadweep Islands, where 177 species of reef fishes belonging to 30 families were recorded (Ajith Kumar et al., 2012). This low species richness is due to the relative small coral cover of the near shore patch reefs and high intensity of chronic local anthropogenic stressors, including artisanal and recreational fishing in the reef area, high number of diving tourists, and heavy tourist boat traffic on a relatively small reef area (De et al., 2020a). In addition to these human disturbances, these patch coral reefs are also exposed to extreme range of seawater temperature variation, sedimentation pulses and high turbidity due to terrigenous discharge, and monsoonal freshwater influx causing low salinity stress (Parulekar, 1981; Qasim & Wafar, 1979; De et al., 2021). Recent study revealed that the reef building corals in the MMS were subject to thermal stress-drivenrecurrent coral bleaching episodes from 2014 to 2019, which has significantly declined live coral cover in these patch coral reefs due to mass coral mortality, and caused possible phase shift from coral dominated state to macroalgae dominated state (De et al., 2021). The coral health degradation by back-to-back thermal stress, suboptimal environment for coral growth and fishing in the reef area could negatively influence the reef-associated fish assemblage and led in low fish diversity (Jones et al., 2004). However, the extent of diversity is consistent with observation in other near shore patch coral reef habitats along the west coast of India where the coral reefs experiencing similar anthropogenic disturbance regime, including Grande Island in Goa coast, where 36 reef-associated fish species were reported (Sreekanth et al., 2019), and Gulf of Kachchh with 41 species belonging to 35 genera and 27 families (Parmar et al., 2015). Preliminary observation from the Angria bank coral reef off Maharashtra coast have made possible to identify 18 species of reef-associated fishes (NIO, 2016). On the other hand, a relatively higher number of fish species was recorded from the patch reefs around Netrani Island on Karnataka coast with 92 fish species belonging to 35 families and 58 genera (Zacharia et al., 2008). This higher reef fish diversity in Netrani may be due to relatively better reef health and low human pressure like land-based pollution, and fishing (Zacharia et al., 2008). Therefore, diversity and distribution of reef-associated fishes along the different disturbance gradient in the Indian coral reefs need to be explored.

The presence of the lionfish *Pterois volitans* is of particular concern for reef health, as this predatory species preys on native herbivore reef fishes and invertebrates, posing a threat to herbivore abundance in the reef and impacting negatively the reef ecosystem (Green et al., 2012). Fish families like Caesionidae, Serranidae, and Lutjanidae contributed to the abundance of commercial food fish species. In contrast, Pomacentridae, Chaetodontidae, Pomacanthidae, and Tetraodontidae contribute to the ornamental species assemblage (Sreekanth et al., 2019).

Corals in the MMS have been undergoing severe bleaching events and associated coral mortality in recent years because of elevated sea surface temperature triggered by global climate change. During 2014, ~15% of coral colonies were affected by bleaching (De et al., 2015) and the prevalence of coral bleaching increased drastically to 54.20% in May 2015 (De et al., 2021) and 70.93% in December 2015, with an 8.38% coral mortality rate (Raj et al., 2018). Subsequently, thermal stress inducing coral bleaching events were recorded in May 2016 (46.76% of colonies affected by bleaching), in May 2017 (20.22%), in October 2018 (5.07%), and in April 2019 (8.37%) (De et

al., 2021). Additionally, coral diseases like white syndrome and the coral tumor or growth anomalies were observed across the reefs in the MMS (Hussain et al., 2016). The occurrence of recurrent bleaching events and coral mortality, and the occurrence of coral diseases, indicated that corals in the MMS were under severe stress (De et al., 2021). Our recent study based on consistent annual surveys from 2014-2019 unveiled gradual decline in the live coral cover (53.54% relative decrease in live coral cover) combined with steady rise of fleshy macroalgae and algal turf, and decline in coral recruitment (De et al., 2021).

Moreover, we observed artisanal fishing activity in the reef area with gill net and cast net during our surveys. Fishing activities inside the core protected area could lead in a decrease of critical functional groups of reef species including herbivores which control algal population in the reef environment (Chung et al., 2019). It may result in a cascading impact on reef-associated species and may further disrupt the reef resilience to multiple stressors (Mumby et al., 2007). The accordance of sanctuary status (MPA) to this region has always been opposed by the local fishermen because of their apprehension that they would be denied access to their traditional fishing grounds (Rajagopalan, 2008). Concurrently, in the absence of stringent management practice, destructive tourism practices, fishing, and poaching activity continue to date (De et al., 2020a). Effective management of no-take region in coral reef areas where fishing is prohibited has proven to improve the reef health and resilience capacity. Therefore, it is crucial to devise a local fishery management policy and reef protection framework from local stressors in order to maintain reef resilience in the face of global climate change and intensifying human influence (Weijerman et al., 2018).

Coral reefs and associated stunning colored reef fishes attract thousands of recreational tourists around the year and serve as critical sources of livelihood to the local population in Malvan. In recent years, MMS has witnessed a dramatic increase in low-cost SCUBA tourism in the coral reef. Although it has improved the local economy, a large number of tourists (mostly untrained, and first-timer) on a relatively small coral reef has resulted in mass mechanical coral damage and detachment of fragile corals due to trampling and boat anchoring on the reefs, already exposed to severe stress due to catastrophic coral bleaching (De et al., 2017, 2020a & 2021). Additionally, artificial feeding of the reef fishes by SCUBA diving operators was observed during the study period to attract fish aggregation around the diving tourists for photographs (De et al., 2020a). High abundance and unnatural aggregation of fish in big schools were observed at all the diving sites T1, T2, and T3. These schools were mainly composed of *A. bengalensis*, *A. sordidus*, *N. cyanomos, C. labiatus*, and *A. berda*, suggesting that these species showed affinity for the tourist recreational feeding. Feeding of reef fishes was reported to be detrimental to reef health through trophic alteration, malnutrition, and to catalyze reef degradation (Brookhouse et al., 2013; de Paula et al., 2018). A higher abundance of omnivorous generalists or opportunistic species leads to low species heterogeneity of the community (reviewed in de Mattos & Yeemin, 2018). Therefore, unsustainable tourism and fishing practices in the protected coral reefs in the MMS pose serious threats to already stressed corals by recent mass bleaching events and hinder the recovery process and resilience to the disturbances.

Coral reefs in India are suffering from acute stress events like thermal stress mass coral bleaching and chronic coastal development activities, which has led some coral species on the verge of local extinction (Nanajkar et al., 2019; De et al. 2020b). Despite being a hotspot of ecological and economic importance, scientific documentation of the coral reef biodiversity and mapping of the threats to marine life yet to be complete in the MMS reefs, which could assist in regulatory interventions from the conservation point of view. Hence, habitat restoration and management practices should be focused on improving the reef fish populations, with limiting reef resource extraction and consequently improve the reef resiliency to local and climate-induced stressors.

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