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An assessment of reef fish abundance and evaluation of prevailing threats in a patch reef of the Gulf of Mannar, India

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ABSTRACT

Coral reefs are among the most dynamic marine ecosystems, harbouring thousands of commercially and ecologically important fish species. The reef fishery in India is an important source of income that supports the livelihood of fisherfolk living along the country's extensive coast. In the Gulf of Mannar, major coral reefs are distributed around the 21 uninhabited coral islands and this region is protected under a legal entity called the Gulf of Mannar Marine National Park (GOMMNP). There are reef patches outside the boundary of the GOMMNP, where commercial fishing is allowed. This study was conducted in one such reef patch, the mainland Punnakayal patch reef, where an underwater survey was conducted to assess the density and diversity of reef fishes. A total of 46 fish species belonging to 36 genera and 24 families were observed during the study with a total density of 117 250m^{-2}, the most abundant species among them being *Chaetodon octofasciatus* with 9.5 250m^{-2} followed by *Pempheris vanicolensis* and *Abudefduf saxatilis* with 7.8±2.3 250m^{-2} and 6±2.6 250m^{-2}, respectively. Among the 46 observed species, 20 are edible and saleable in the market for human consumption while the remaining 26 are mostly ornamental reef fishes. Among the observed species, carnivores were the most abundant, followed by omnivores, in terms of density and diversity. Several anthropogenic and climate-induced threats were observed at the patch reef causing damage to coral habitats and reef fishes. Conservation measures, including reducing threat intensity and restoring degraded habitats, are warranted to sustain the ecological and economic potential of the reef.

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1. Introduction

Coral reefs are among the most important marine ecosystems, providing food and shelter to a wide range of flora and fauna and offering other ecological services. They occupy only 0.1% of the ocean floor, but provide shelter to approximately 25% of all known marine species (Hoegh-Guldberg et al. 2017). The number of species associated with coral reefs has been estimated to be around 830,000 (Fisher et al. 2015). Among all the coral-associated organisms, reef fishes are ecologically and economically very important. Thousands of fish species with different shapes, sizes and colours live in the coral environment. More than 30% of the described marine fish species have been reported to inhabit coral reefs worldwide, where families such as Chaetodontidae, Labridae, and Acanthuridae are common (Hixon and Randall 2019). Burke et al. (2011) reported that 1 sq km of healthy coral reef can yield 5 to 10 tons of fish annually. The value of the global coral reef fishery is estimated at US$6.8 billion per year, supporting numerous local economies (Spalding et al. 2016).

The topographic complexity of coral reefs has been widely acknowledged as the primary reason for the abundance of fish in reef areas (Bell and Galzin 1984). Many studies have established links between live coral cover and species diversity, and between structural complexity and fish density (Syms and Jones, 2000; Messmer et al., 2011). Mere differences of less than 2-5% in live coral cover / structural complexity have been reported to produce significant differences in the density and diversity of reef fishes (Bell and Galzin, 1984). A meta-analysis of 17 studies by Wilson et al. (2006) revealed that a 62% decline in fish species occurred with a decline of less than 10% in live corals over three years. Fishes on a reef depend on corals primarily for food, shelter, living space, and the requisites for survival and reproduction (Wilson et al. 2006; Cole et al., 2008; Coker et al. 2014). Reef fishes, in general, can be categorized into major trophic groups such as herbivores, planktivores, omnivores, piscivores and benthic invertebrate feeders (Choat and Russell, 2008).

Due to the heavy dependence of reef fishes on corals, the decline of global coral reefs affects them instantly (Wilson et al. 2006). Global coral degradation is evident across reef regions worldwide due to various natural and human-induced factors. During the past few decades, climate change implications such as coral bleaching, ocean acidification, and ocean deoxygenation have become the primary threats to the survival of global coral reefs around the world (Hughes et al. 2018), apart from all the anthropogenic activities such as coral collection, over-exploitation, destructive fishing, tourism, coastal development and pollution (Hughes et al. 2017). The Intergovernmental Panel on Climate Change (IPCC) has warned that global coral reefs would decline by 70-90% with a 1.5 ° C increase in global temperature by 2100, and that almost all coral reefs will vanish if the rise is 2° C or higher (IPCC 2018). This projected decline in coral reefs will obviously affect the ecologically and economically important reef fishes and, consequently, the livelihoods and economies of coastal communities.

The Gulf of Mannar on the southeast coast of India is one of the biodiversity hotspots, with legal statuses such as a biosphere reserve, a marine national park, and a Ramsar site. The Gulf occurs between Rameswaram and Kanniyakumari in the state of Tamil Nadu. There are 21 uninhabited coral islands in the Gulf of Mannar between Rameswaram and Tuticorin around which fringing type of coral reefs have developed. In order to protect the coral reefs and the rich biodiversity around the 21 islands, the Government of Tamil Nadu created in 1986 the Gulf of Mannar Marine National Park (GOMMNP) encompassing all islands and surrounding shallow waters. A total of 132 species of corals have been reported from the Gulf of Mannar (Edward et al. 2023a) where thousands of coastal fishermen depend on these reefs for their livelihood. Corals in the Gulf of Mannar have been reported to face several climatic and non-climatic threats and, as a result, have degraded significantly during the past two decades (Edward et al. 2023a). A total of 228 reef-associated fish species belonging to 48 families have been reported from the reef areas of the Gulf of Mannar (Laju, 2019). Despite several studies on coral reefs and associated organisms in the Gulf of Mannar, reef fishes have been studied only briefly.

Almost all studies on coral reefs have concentrated within the boundaries of the GOMMNP, while other patch reefs throughout the Gulf of Mannar have good coral cover and associated reef fish species (Edward et al. 2023b). These patch reefs, which often occur outside GOMMNP jurisdiction, are unprotected where commercial fishing is allowed. The objective of the present study was to assess the density and diversity of reef fishes on one such patch reef, evaluate the threats they face, and suggest management actions to protect coral reefs, reef fishes, and the livelihoods of dependent people.

2. Materials and Methods

Mainland Punnakayal patch reef (Fig. 1) occurs in the Tuticorin region of the Gulf of Mannar that falls roughly 15 km outside the boundary of the GOMMNP. The reef starts from the Tuticorin harbour area and runs parallel to the mainland, extending beyond Punnakayal fishing village, where most of the corals occur at depths of 5-6 m. Active fishing is happening on this reef as this area is not legally protected. A significant coral cover of over 62% with *Turbinaria* as the dominant genus has been reported on this reef (Raj et al. 2023). This underwater study was carried out at the following coordinates: latitude 8°42'23.52"N and longitude 78° 9'51.39"E.

Fish assessment was carried out in December 2023 using the belt transect (50 x 5 m) method, following English et al. (1997). As fishes are highly mobile and a single measurement may miss several species, the assessment was carried out twice throughout the month, and the data were averaged. On each day, a total of 5 transects were laid perpendicular to the mainland and a minimum distance of 25 m was given between transects. Along each transect, fishes were counted using a visual census technique. The census area of each transect covered 250 $m^{2,}$ extending 2.5 m to the right and left sides of a 50-m transect line. All fish spotted were identified and counted underwater and details were written on underwater slates. Underwater photographs and videos were also taken to confirm fish identification. Morphometric characters were used to confirm species following Laju (2019), and nomenclature was confirmed with the World Register of Marine Species (WORMS; https://www.marinespecies.org/). Observed fish species were categorized according to their trophic group as herbivores, planktivores, omnivores, piscivores and benthic invertebrate feeders (Choat and Russell, 2008). Among the



Fig. 1. Map showing the study site

observed fish species, edible and commercially important fish were identified based on landing center observations. Thus, fish were also categorised into edible and non-edible species. Prevailing threats to the reef fishes of the mainland patch reef were identified from field observations during the study period and also from observations from the published literature.

3. Results

3.1 Reef fish density and diversity

At the mainland Punnakayal patch reef, a total of 46 fish species belonging to 36 genera and 24 families were observed during the study with a total density of 117 250m^{-2}. Among the 46 species, the most abundant ones were *Chaetodon octofasciatus* with 9.5 250m^{-2}, followed by *Pempheris vanicolensis* and *Abudefduf saxatilis* with 7.8±2.3 250m^{-2} and 6.0±2.6 250m^{-2} respectively. *Caesio cuning, Chaetodon plebeius, Lethrinus lentjan, Nemipterus zysron,* and *Abudefduf vaigiensis* were among the other dominant fish species at the study site (Table 1).

Of the 46 observed species, 20 were edible and saleable in the market for human consumption while the remaining 26 were mostly ornamental reef fishes. Some of the commercially important species included *Scarus ghobban, Lethrinus* spp., *Lutjanus* spp., *Epinephelus* spp. and *Parupeneus indicus*. Ornamental reef fishes included *Chaetodon* spp., *Amphiprion sebae*, *Chromis viridis* and *Dascyllus* sp. The total density of observed edible fishes was 52.7 250m^{-2} while the density of other reef fishes was 64.33 250m^{-2}.

3.2 Reef fish trophic groups

Among the 46 observed fish species, carnivores were the most dominant with representation from 18 species,

Table 1. Densities of observed fish species at mainland Punnakayal patch reef

S. No.	Species	Family	Edible/Other reef fish	Density (no. 250m^{-2})
1	*Acanthurus lineatus*	Acanthuridae	Other reef fish	3.83
2	*Acanthurus mata*	Acanthuridae	Other reef fish	2.00
3	*Zebrasoma veliferum*	Acanthuridae	Other reef fish	1.00
4	*Balistoides viridescens*	Balistidae	Other reef fish	0.67
5	*Odonus niger*	Balistidae	Other reef fish	0.67
6	*Caesio cuning*	Caesionidae	Edible	5.67
7	*Gnathanodon speciosus*	Carangidae	Edible	0.67
8	*Chaetodon octofasciatus*	Chaetodontidae	Other reef fish	9.50
9	*Chaetodon plebeius*	Chaetodontidae	Other reef fish	4.50
10	*Chaetodon decussatus*	Chaetodontidae	Other reef fish	2.00
11	*Chaetodon collare*	Chaetodontidae	Other reef fish	3.33
12	*Heniochus acuminatus*	Chaetodontidae	Other reef fish	1.33
13	*Bryaninops yongei*	Eleotridae	Other reef fish	0.17
14	*Plectorhinchus orientalis*	Haemulidae	Edible	1.83
15	*Sargocentron rubrum*	Holocentridae	Edible	2.33
16	*Bathygobius laddi*	Gobiidae	Other reef fish	2.50
17	*Thalassoma lunare*	Labridae	Other reef fish	2.83
18	*Coris formosa*	Labridae	Other reef fish	2.67
19	*Lethrinus lentjan*	Lethrinidae	Edible	4.83
20	*Lethrinus mahsena*	Lethrinidae	Edible	2.17
21	*Lutjanus decussatus*	Lutjanidae	Edible	3.67
22	*Lutjanus lutjanus*	Lutjanidae	Edible	3.33
23	*Leiognathus sp.*	Leiognathidae	Edible	2.83
24	*Parupeneus indicus*	Mullidae	Edible	3.83
25	*Upeneus vittatus*	Mullidae	Edible	1.83
26	*Gymnothorax favagineus*	Muraenidae	Other reef fish	1.00
27	*Nemipterus zysron*	Nemipteridae	Edible	4.83
28	*Scolopsis vosmeri*	Nemipteridae	Edible	1.17
29	*Pempheris vanicolensis*	Pempheridae	Other reef fish	7.83
30	*Pomacanthus semicirculatus*	Pomacanthidae	Other reef fish	0.67
31	*Pomacanthus imperator*	Pomacanthidae	Other reef fish	1.00
32	*Amphiprion sebae*	Pomacentridae	Other reef fish	0.33
33	*Chromis viridis*	Pomacentridae	Other reef fish	2.00
34	*Dascyllus sp.*	Pomacentridae	Other reef fish	1.17
35	*Abudefduf saxatilis*	Pomacentridae	Other reef fish	6.00
36	*Abudefduf vaigiensis*	Pomacentridae	Other reef fish	5.17
37	*Scarus ghobban*	Scaridae	Edible	3.50
38	*Epinephelus malabaricus*	Serranidae	Edible	1.83
39	*Epinephelus merra*	Serranidae	Edible	1.33
40	*Cephapholis formosa*	Serranidae	Edible	1.50
41	*Pterois russellii*	Scorpaenidae	Other reef fish	0.67
42	*Siganus lineatus*	Siganidae	Edible	2.33
43	*Siganus javus*	Siganidae	Edible	1.83
44	*Terapon theraps*	Terapontidae	Edible	1.33
45	*Canthigaster solandri*	Tetraodontidae	Other reef fish	0.50
46	*Zanclus cornutus*	Zanclidae	Other reef fish	1.00

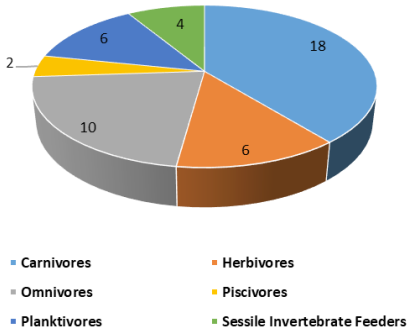


Fig. 2. Representative fish species for each trophic group at the study site

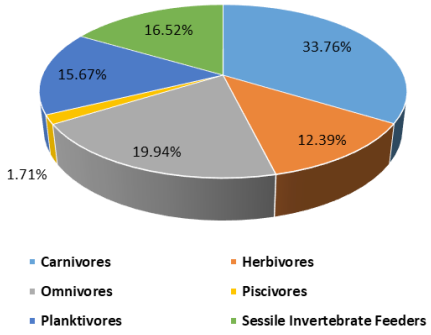


Fig. 3. Proportion of each trophic group at the study site

followed by omnivores with 10. Herbivores, planktivores, sessile invertebrate feeders, and piscivores were represented by 6, 6, 4, and 2 species, respectively (Fig. 2). In terms of density, carnivores were the dominant group, with 39.5 250m^{-2} contributing 33.8% of the total, followed by omnivores with 23.3 250m^{-2} contributing 19.9%. The respective densities of herbivores, planktivores, sessile invertebrate feeders and piscivores were 14.5, 18.3, 19.3 and 2.0 250m^{-2} contributing 12.4, 15.7, 16.5 and 1.7% respectively (Fig. 3).

3.3 Threats to reef fishes

Due to its position outside the boundary of the GOMMNP, commercial fishing activities are allowed here where destructive fishing practices also take place. Several types of destructive fishing activities were observed during the study period, which included surface-supplied diving, purse seine, trap fishing, and bottom-settling gillnetting. Most of the fishes caught here were reef fishes. These activities not only cause overexploitation of reef fishes but also damage corals, leading to habitat loss. Using surface-supplied diving, fishermen from the Thirespuram area carry out shell collection, spearfishing, and purse seine operations, thereby damaging corals and overexploiting fish resources. Collection of ornamental reef fishes also occurs on this reef, using surface-supplied diving. Trap fishing is one of the most widespread activities on this reef, removing ecologically important herbivorous fishes such as parrotfish and rabbitfish. Crab nets, lobster nets and other bottom-settling gillnets are also commonly used on this reef that mechanically damage corals. The mainland Punnakayal area is an industrial corridor located near the Tuticorin port.



Fig. 4. Underwater images of reef fishes in the mainland Punnakayal patch reef;
a) *Caesio cuning*; b) *Nemipterus azysron*; c) *Cephalopholis Formosa*; d) *Lutjanus fulvus*

Several thermal power plants and other chemical industries are situated along the coast. A major recreational beach also occurs on the coast. Climate change impacts such as coral bleaching and space competition have been reported on this patch reef causing habitat loss. During the study, several coral colonies were completely dead, many were partially dead, and some were overgrown by other organisms, such as macroalgae, sponges, and octocorals. Commercial cultivation of the invasive seaweed *Kappaphycus alvarezii* is also practised along the mainland coast of the Punnakayal patch reef, which puts the corals at risk, though invasion has not been reported so far. Figure 4 shows underwater images of reef fishes in the mainland Punnakayal patch reef.

4. Discussion

Maintaining healthy populations of reef fishes is very important for sustainable utilisation and overall reef function. Reef fishes contribute significantly to the commercial fishery and provide livelihood to millions of people around the world (Muallil et al. 2015). They provide food security to coastal communities and also offer cultural, recreational and aesthetic services (Hicks et al. 2019; Woodhead et al., 2019). This study from an unstudied patch reef of the Gulf of Mannar revealed the presence of 46 fish species with a density of 117 250m^{-2}, which included commercially and ecologically important reef fishes. Despite the regular fishing, the density and diversity of reef fishes in this short-term study on this patch reef can be considered fair. Almost half of the observed fish species at the study site were edible and were either exported or locally consumed. Commercially important edible fish genera on the study site, such as *Scarus, Lethrinus, Lutjanus, Epinephelus,* and *Parupeneus,* provide livelihoods to dependent coastal communities. Apart from these commercially exploited edible fishes, the trade of ornamental fishes is a big global industry which involves more than 1,400 species of marine fishes (Bruckner 2005). The study site also hosts several species of interest to the aquaculture trade, such as damselfishes and butterflyfishes. The mainland Punnakayal patch reef thus holds great economic importance.

Apart from their economic importance, reef fishes play significant ecological roles; by grazing and predation, they shape the community composition of the reef (Bellwood et al., 2019; Perry et al., 2022). They are part of several food webs within the reef ecosystem and a decline in key species may consequently disrupt the entire reef. Among the reef fishes, herbivores control the proliferation of space-competing macroalgae on the reef while large predators exert top-down control on fishes that prey on herbivores (Bradley et al. 2020). Among the observed reef fishes at the study site, carnivores followed by omnivores were the dominant ones and this trend is consistent with that of many other reefs (Valentine and Heck, 2005; Kang et al. 2024). However, the density and diversity of herbivorous fishes were comparatively very low at the study site due to the targeted catch, which is not a good sign for a healthy reef. Corals in the Gulf of Mannar have suffered massive bleaching events and thus experienced subsequent space competition from macroalgae (Raj et al. 2021a; Edward et al. 2023a). Hence, the conservation of herbivorous fishes, especially from the families Scaridae and Labridae, is very important for the reef's harmony. Other trophic levels are also important as they play smaller but important ecological roles to maintain the reef's functioning. For instance, sessile invertebrate feeders such as spongivores and corallivores have been found to play roles that affect the entire reef ecosystem (Raj et al. 2016; Emmett et al. 2021). Spongivorous fishes have been reported to control sponge proliferation (Emmett et al. 2021), while butterfly fishes have been suspected of vectoring coral diseases (Raj et al. 2016) in the Gulf of Mannar.

The mainland Punnakayal patch reef faces climatic and non-climatic threats that affect reef fishes and their habitats. The declaration of the Marine National Park has helped reefs around the islands in the Gulf of Mannar fare better in terms of anthropogenic impacts. As the mainland Punnakayal patch reef lies outside the GOMMNP, the anthropogenic threat level here is much higher. The study site lies closer to various industries, but there is no regular monitoring of environmental parameters in the marine environment in place to identify and mitigate pollution issues. Further, the destructive invasive red alga *Kappaphycus alvarezii* is cultivated along the shore proximate to the reef areas. The alga has been shown to pose a significant threat to corals in the Gulf of Mannar (Arasamuthu et al. 2023) and is an imminent danger to corals and reef fishes.

More importantly, destructive fishing practices are significantly affecting the integrity of the reef. Targeted fishing of herbivores such as *Scarus ghobban* using trap fishing causes ecological disruptions (Emmett et al. 2021). Bottom-settling gillnets cause mechanical damage to corals as they fragment or uproot corals (Edward et al. 2023a). Shore seine is another activity that affects near-shore benthic organisms, including corals (Raj et al. 2017). Moreover, hundreds of mechanised trawlers are operating near this patch reef, affecting bottom stability (Edward et al. 2023a). Surface-supplied diving is also used at the study site for shell collection, purse seine operations, spearfishing, and the collection of marketable benthic organisms (Raj et al., 2015, 2021b; Edward et al., 2023a). In the process, surface-supplied divers cause mechanical damage and disruptions in food webs. Heaps of uprooted or fragmented corals found near the landing centres indicate the damage to corals, which are the foundation species. It is important here to note that corals in India are protected under the Wildlife Protection Act, 1978, Govt. of India.

Climate change has become the biggest threat to all living beings on Earth, and coral reefs around the world have suffered from its impacts, primarily coral bleaching. There has been a significant decline in coral cover in the GOMMNP during the past two decades driven by multiple mass bleaching events (Raj et al. 2021a; Edward et al. 2023a). Although there is no long-term data to substantiate the impact, it is understood that corals in the mainland patch reef also suffer from mass bleaching events. A recent report from this patch reef reveals the impact of a coral-killing marine sponge (Raj et al. 2023). Thus, coral bleaching events, benthic space competition, and unprecedented

human impacts may lead to further deterioration of coral habitats and, consequently, reef fishes. While predictions for the future reveal that corals of the Gulf of Mannar will undergo annual severe bleaching before 2070 (Raj et al. 2021a), an increasing coastal population would add more pressure on coral habitats. Loss of corals would directly affect reef fishes and ultimately jeopardize the livelihood of the dependent coastal communities.

Considering the ecological and economic importance of the mainland Punnakayal patch reef, as borne out by the present assessment of reef fish abundance, concrete conservation measures are warranted. Within the GOMMNP, several initiatives, including reducing threat intensity and restoring lost habitats, are underway and need to be extended to the mainland Punnakayal patch reef. As fishermen are the primary stakeholders, community-mediated conservation measures should be developed. Community-led initiatives in Wakatobi National Park, Indonesia, in collaboration with park authorities stopped fishing activities in fish-aggregating areas resulting in the reversal of decline of reef fishes (Burke et al. 2011). Such initiatives can help control destructive fishing activities in the mainland Punnakayal patch reef. Detailed surveys, mapping, and demarcation should be conducted to develop legal protection measures to conserve these currently unprotected reefs. Permanent monitoring should be in place to respond immediately in times of crisis such as bleaching events, disease outbreaks and algal blooms. The conservation of mainland Punnakayal patch reef and similar other patch reefs found throughout the Gulf of Mannar will not only protect corals and reef fishes but also sustain the livelihood of thousands of dependent coastal communities.

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