MARESSOL

Mannar Region Systemic Solutions

Abundance of abandoned fishing gear in coral reefs in the Gulf of Mannar, Tamil Nadu, India

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MARESSOL (Mannar Region Systemic Solutions) project, to study the fishery-related sources of marine litter, is partnered and implemented by SALT, Norway, IUCN (International Union for Conservation of Nature) Sri Lanka, SDMRI (Suganthi Devadason Marine Research Institute) India and LEF (Lanka Environment Fund) Sri Lanka and funded by Norwegian Retailers Environment Fund.

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i. Key findings

- The MARESSOL program funded by Norwegian Retailers Environment Fund focused on “Marine Litter from Fisheries in the Gulf of Mannar and Palk Strait”. In India, the study was conducted by SDMRI.

- This present survey assessed the abundance and types of Abandoned, Lost or otherwise Discarded Fishing Gear (ALDFG or “discarded nets”) litter on the coral reefs of Gulf of Mannar (GoM) southeast India.

- A combination of roving diver technique and belt transect method was applied to the assessment, which was conducted during the period between November 2022 and March 2023.

- A total of 1,242 items of marine litter were found in the surveyed 144 transects covering 14,400 m^2 of reef areas.

- Five types of marine litter were observed during the survey namely fishing nets 37.9%, ropes 23.7%, lines 17.6%, fishing traps 6.7% and other plastic debris 14.1%.

- The average density of marine litter in GoM islands was 8.5 no. of items/100m^2. Abandoned or derelict nets were the dominant contributors (85.7%) to the overall debris (14.39%).

- Fishing nets (38%) formed the most dominant type of lost gear, followed by ropes (24%), lines (17%), traps (7%) and other debris (14%).

- The maximum density of litter pollution was observed in the proximity of mainland (4.5 km) and in the developed urban centres, with Vaan Island reef having the highest densities of marine litter (11.50 no. of items/100 m^2); the minimum density was observed in Valai Island reef (6.0 no. of items/100m^2) due to its greater distance from the mainland (8 km).

- Added to the other threats, marine debris has emerged as a serious issue affecting the corals. Proper management and removal of debris are highly warranted to protect the fragile coral reef ecosystems, to conserve biodiversity and to secure the livelihood of the dependent fisher folk.

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1. Brief introduction

Marine debris is recognized as a component of marine ecosystem pollution increasing in magnitude. Among human activities, fishing may generate marine debris from the loss or disposal of fishing gear, otherwise known as abandoned, lost, or otherwise discarded fishing gear (ALDFG). Most of the ALDFG is made of non-biodegradable plastics that may sink to the sea floor or drift around in currents. It may remain unnoticed until it shows up on coral reefs, beaches and in other coastal habitats. This derelict fishing gear may represent one of the main causes of degradation of the marine benthic habitat. This study was initiated based on the program "Marine Litter from Fisheries in the Gulf of Mannar and Palk Strait" funded by Norwegian Retailers Environment Fund. The survey was conducted by SDMRI. In this baseline study, we document the abundance and types of ALDFG litter on the 21 coral reef islands in Gulf of Mannar (GoM) southeast India. A combination of roving diver technique and belt transect method was applied to the assessment, which was conducted during the period between November 2022 and March 2023. A total of 1,242 number of marine litterwere found in the surveyed 144 transects covering 14, 400m^2 areain the reef areas of the 21 GoM islands. Five types of marine litter were observed during the survey namely fishing nets 37.9%, ropes 23.7%, lines 17.6%, fishing traps 6.7% and other plastic debris 14.1%. The average density of marine litter was 8.5 no. of items/100m^2. Abandoned or derelict nets were the dominant contributors (85.7%) to the overall debris (14.39%).Fishing nets (38%) formed the most dominant type of lost gear, ropes (24%), lines (17%), traps (7%) and other debris (14%). Litter pollution increases in the proximity of the mainland (4.5 km) and the developed urban centres, with Vaan island reef having higher densities of marine litter (11.50 no. of items/100 m^2); and litter pollution decreases in the Valai island reef (6.0 no. of items/100m^2) due to the island being located far away from the mainland (8 km). According to Clean Coast Index (CCI), the coral reefs of GoM are categorized as clean and the observed CCI range was between 1.2 and 2.3. But the underwater visual observation during the survey revealed the reefs of GoM to be moderately affected by marine debris.

The present study provides baseline data on marine debris in the reef areas of GoM. Corals have fragile skeletons and soft tissues that can easily become damaged when they get in contact with lost fishing gear. Added to the other threats, marine debris has emerged as a serious issue affecting the corals in GoM. Coral reefs in GoM are the source of livelihood to thousands of fishermen and hence the conservation of corals is tantamount to the conservation of their livelihood. Even if nets serve as substrate for corals, it is recommended to remove them from reefs, where they form a major component of plastic pollution and cause damage to corals and other reef organisms. Hence, proper management

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and removal of debris are highly warranted to conserve the fragile coral reef ecosystems of GoM, to conserve biodiversity and to protect the livelihood of the dependent fisher folk. Proper recycling of the removed debris without damaging the environment should be developed. The fishermen should be suitably educated about the impact of marine debris on coral reef ecosystem and about the need to conserve corals for sustainable livelihood. Installation of proper solid waste management systems in coastal areas particularly in cities with tourist attractions is imperative to reduce the amount of other debris.The intensity and impact of marine debris on different coral genera and how it affects the coral health have to be studied in detail.

2. Background

Abandoned, lost or discarded fishing gear (ALDFG) represents a significant amount of the global plastic pollution in marine ecosystems, and is currently considered a major source of sea-based plastic pollution (Richardson et al., 2019, 2021a; GESAMP, 2021). The abundance and distribution of ALDFG in the world's oceans has risen significantly during the past decades, primarily due to the expansion of commercial fisheries worldwide and the transition towards cheaper and more durable synthetic materials (Kroodsma et al., 2018; Gilman et al., 2021). Due to its composition, ALDFG has the potential to persist in the marine environment for decades (Gilman et al., 2013; Wilcox et al., 2015; Nelms et al., 2021), with wide-reaching impacts beyond the environmental and socioeconomic effects caused by the accumulation in coastal areas (Gilman et al., 2021).

The immediate impacts of ALDFG on reef corals and associated biota are both direct and indirect. The direct impacts include physical damage, substrate covering and entanglement, and gut blockage if items are ingested (Sweet et al., 2019). Litter can also act as artificial substrate for the colonization of corals (Hoeksema and Hermanto, 2018), and when litter is transported over long distances it can facilitate the spread of invasive coral species (Mantelatto et al., 2020). In addition, large pieces of litter clearly damage the aesthetic value of coral reefs. The indirect impacts of plastics, in particular, include the introduction of pathogenic agents ‘hitch-hiking’ on the surface and increasing the appearance of diseases in corals (Lamb et al., 2018). In the long term, ALDFG decompose into micro- and nanoplastics that can be unintentionally ingested by corals. They may also become vectors of bacteria and chemicals that are toxic to corals (Allen et al., 2017). These toxic chemicals may enter and contaminate the marine food webs on which many people depend (Hicks et al., 2019). These adverse indirect effects are not exclusive to plastics, but most can be extended to a diverse variety of marine litter that also break down into micro- and nanoparticles and end up accumulating in reef ecosystems.

The Gulf of Mannar is an ecologically important critical habitat shared by India and Sri Lanka. GoM, situated in the Indian Ocean between south-eastern part of India and north-western region of Sri Lanka, is a highly productive marine ecosystem. It is bounded in the northeast by Rameswaram (an island), Adam's (Rama's) Bridge (a chain of shoals), and Mannar Island. The Indian part of the GoMisa Marine Biosphere Reserve (created in 1989), running down south from Rameswaram Island to Kanniyakumari in Tamil Nadu. A chain of 21 uninhabited coral islands occurs in GoM between Rameswaram and Tuticorin and these islands are known for coral reefs and associated biodiversity. There are over 100,000 fishermen living in hundreds of fishing villages and hamlets along the Indian coast of GoM, and they depend on the reef-associated fishery for their livelihood. The coastal population in GoM has increased a significant 34% during the period between 1989 and 2009 (GoMBRT, 2011), which has intensified the fishing pressure. Hence, leaving of unwanted fishing nets in the reef areas has become very common. The accidental laying of nets in the reef area and the movement of bottom laid nets during rough weather result in the entanglement of nets with live corals. Once a net is entangled with corals, it is difficult to recover it in good shape and hence it is abandoned by the fishermen. Domestic discharges and industrial pollution have been reported to cause significant damage to the coral health of GoM as they bring untreated sewage and solid wastes into the sea (Kumaraguru et al., 2006; Edward et al., 2012; Samuel et al., 2012). Moreover, pollution related to increased tourism is also a concern.

Though there are several works of research on corals of GoM, there is still only limited understanding the impacts of ALDFG and their quantities present on the seafloor, including coral reef areas. The aim of the present rapid survey was to collect preliminary data on the abundance of ALDFG on the coral reefs of Gulf of Mannar. We have also used the Clean Coast Index, previously utilized in the evaluation of other coastal ecosystems,mainly beaches and rocky shores, in the present assessment of ALDFG in reef area as suggested by Rangel-Buitrago et al. (2021). We hope that the outcomes will help highlight the growing and problematic nature of plastic pollution in the reefs of this region and will help the local managers and authorities to take action to conserve these unique and valuable habitats.

3. Methodology

Study area

The 21 uninhabited islands ofGoMlying in a 160-km long file almost parallel to the coast between Pamban and Tuticorin are surrounded by coral reefs (Fig. 1). The islands and the

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surrounding shallow coastal waters with reefs covering an area of 560 sq. km were declared as Gulf of Mannar Marine National Park (GoMMNP) in 1986 by the Government of Tamil Nadu for the protection and conservation of the biodiversity and associated environment. The Government of India in 1989 declared the entire Gulf of Mannar area covering 10,500 sq. km as Gulf of Mannar Marine Biosphere Reserve. The 21 islands are Shingle, Krusadai, Pullivasal, Poomarichan, Manoliputti, Manoli, Hare, Mulli, Valai, Thalaiyari, Appa, Poovarasanpatti, Valimunai, Anaipar, Nallathanni, Puluvinichalli, Upputhanni, Kariyachalli, Vilanguchalli, Koswari and Vaan (Fig. 1). The total number of floral and faunal species recorded in Gulf of Mannar is 4,223,which includes 132 coral species (Edward et al., 2023). The coral reefs in Gulf of Mannar provide direct and indirect livelihood benefits to thousands of small-scale and large-scale fisher folks. Here the small-scale fisheries constitute about 60% and the remaining 40% use large-scale fishing fleets like industrial trawlers (Radhakrishnan et al., 2021).Hence, any threat to coral reefs would directly affect the livelihood of the dependent people. Many crafts and gear are used for fishing in the Gulf of Mannar. The fisheries industry in the Gulf of Mannar has evolved significantly after the arrival of mechanization (Raj et al. 2017).

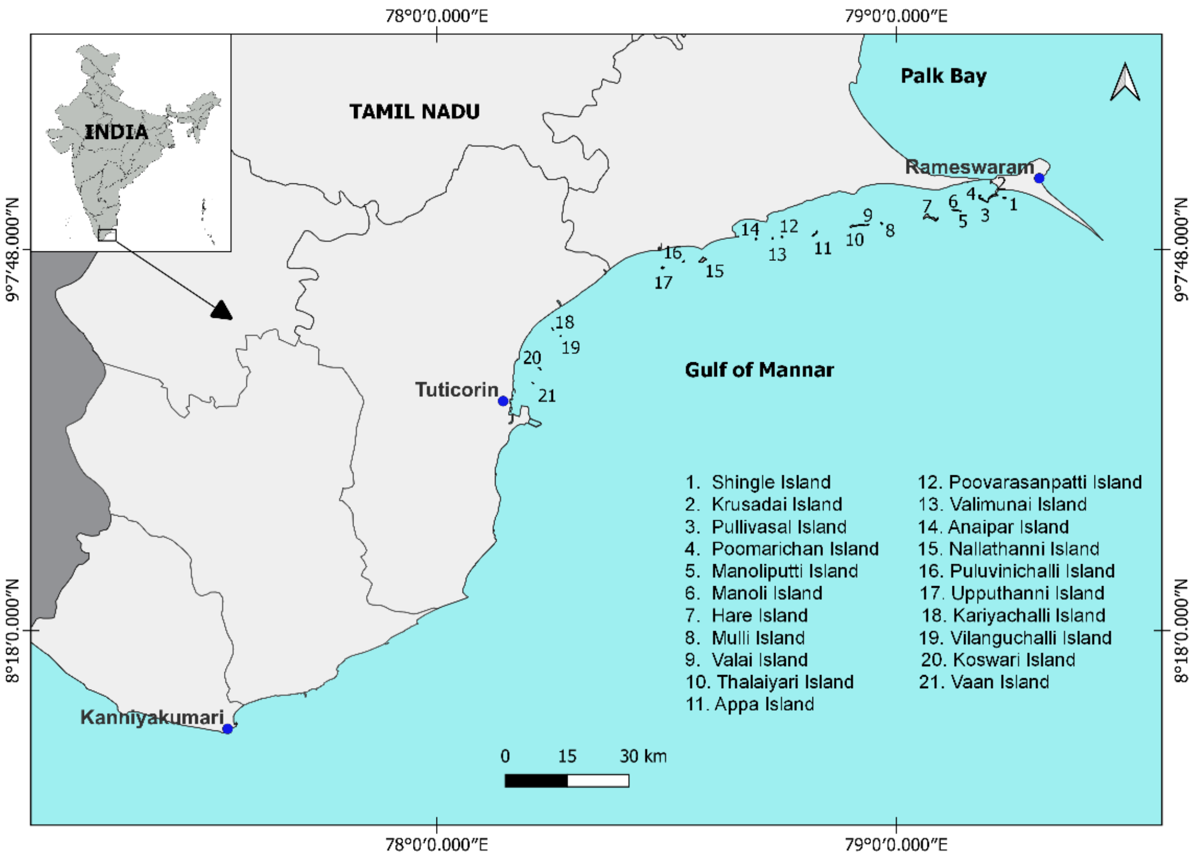

Fig. 1: Map showing the 21 islands in Gulf of Mannar.

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Survey method

Rapid underwater surveys were conducted in the 21 coral reef islands of GoM for the assessment of marine debris during the period between November 2022 and March 2023.The Roving Diver Technique was used to determine ALDFG loads, and it followed the same protocol as Munro (2005), Hoeksema and Koh (2009) and Ballesteros et al. (2018). Two to three dives were made at each site. Divers surveyed at different directions from the boat to avoid overlapping, and maximum distance from the boat was given as 500 m. The items of debris were categorized as fishing nets, ropes, lines, fishing traps and 'other debris'. The category 'other debris' included plastic bottles, glass bottles, carry bags, toys, and other discarded plastic and metal objects used in boats and ships, etc. Transects were laid at different directions from the boat at each site and data were collected by following Melt Transect Method (English et al., 1997). Diving above the tape measurements, when a diver came across debris, the type and number of debris was noted. The presence of debris in the survey area was ascertained before the deployment of the transects. Area of each transect was 50 m × 2 m (1 m on either side of diver's line), leaving a minimum distance of 50 m between them. All debris found in the 100 m^2 (50 m × 2 m) corridor were counted and categorized along with the corals they were on and the ALDFG density was denoted as number per 100 m^2.

Clean coast Index (CCI)

Following the methodological framework developed for monitoring marine litter in coastal shoreline, we applied Clean Coast Index (CCI) developed by Alkalay et al. (2007) to determine the ALDFG on the reefs of GoM. The CCI was calculated using the formula:
CCI = (total litter on transect / total area of transect) x K

where: K (constant) = 20

CCI is defined as the number of litter items seen per square meter (density) multiplied by a constant K = 20 for better interpretation of the data and in order to make the picture clearer for the public.

The CCI classifies the marine litter coverage into five categories that range from "clean" to "fully covered by marine litter". CCI varies from "Very Clean" (0-2), "Clean" (2-5), "Moderately Dirty" (5-10), and "Dirty" (10-20) to "Extremely Dirty" (>20).

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CCI is based on the number of debris in a shoreline. The number of debris in a shore line is 100 times greater than on coral reefs (Santodomingo et al., 2021), but in reef environment the number of debris count would be low, while the debris covering area was higher. So the thresholds for cleanliness index might need to be standardized to properly reflect the health condition of polluted reefs. Hence, by following the CCI classification for shoreline area and also based on the underwater observation, the impact of ALDFG on coral reef areas has been categorized.

Statistical analysis

One-way ANOVA was performed for debris abundance among study sites. Statistical parameters were analyzed using SPSS software version16.0.

4. Results

Coral cover

The average live coral cover in GoM during 2021 was 27.3%. Fringing coral reefs occur around the 21 islands at depths from 0.5 to less than 5 m. The reef flat of the Gulf of Mannar has been reported to be extensive (Pillai, 1977). Totally 132 coral species from 40 genera have been reported from the Gulf of Mannar, of which Porites, Acropora, Montipora, Dipsastraea, and Favites are the most common (Edward et al., 2023).

Total abundance of marine debris in GoM islands

A total of 1,242 number of marine litter were found in the surveyed 144 transects covering 14, 400m^2 areain the reef areas of the 21 GoM islands. The litter fall in five types (Fig.2a) namely fishing nets (37.9%), ropes (23.7%), lines (17.6%), fishing traps (6.7%) and other plastic debris (14.1%). Abandoned or derelict nets were the dominant contributors (85.7%) to the overall debris (14.39%) (Fig.2b). The quantities of marine debris were found to be higher in Vaan Island (11.5 no. of items /100 m^2), where the density of coastal population is the highest in GoM. The lowest quantity of marine debris was observed in Valai Island with 6.0 no. of items /100m^2 (Fig.3). The results of one way ANOVA showed the absence of any significant variation among the islands in the values for debris abundance(DF = 20; F = 1.302; P = 0.190; $p>0.05$).

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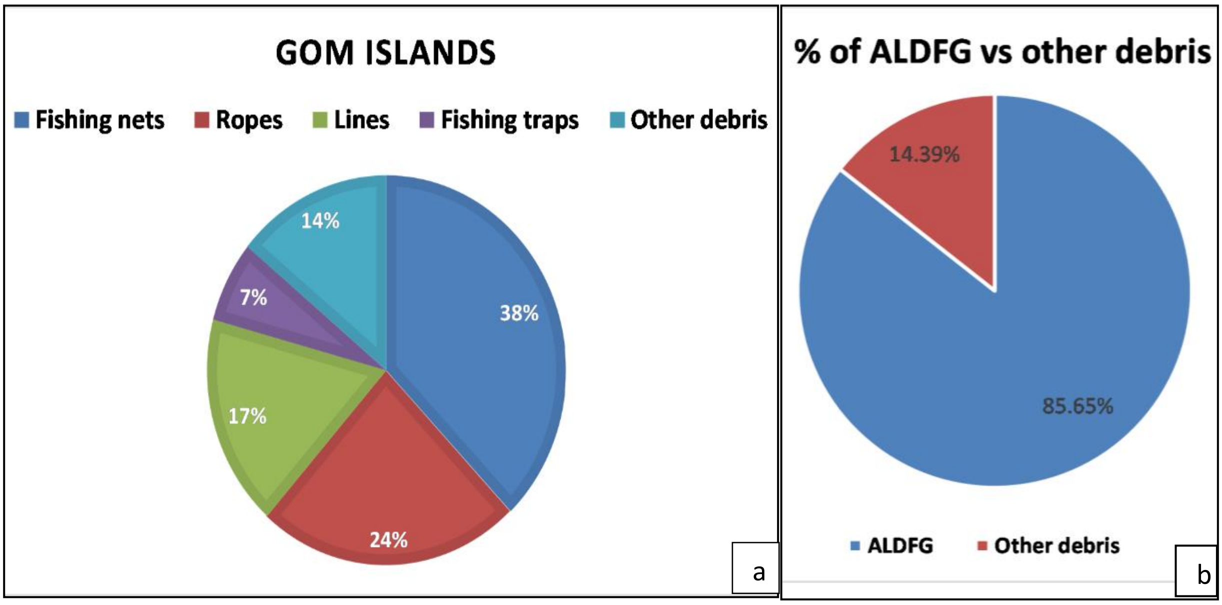

Fig.2: (a) Overall percentage of marine debris in the 21 islands of GoM; (b) Percentage of ALDFG vsother debris

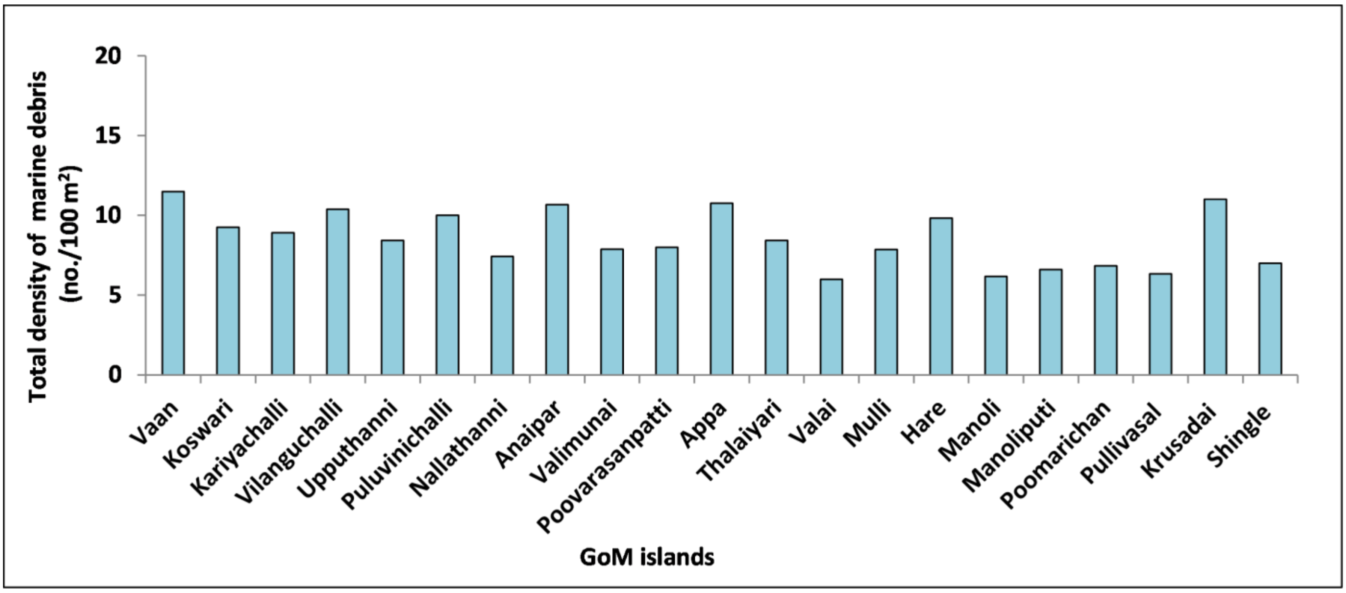

Fig.3: Total density of marine debris in GoM islands

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Island-wise differences in occurrence and types of debris

The 21 uninhabited low-lying coral islands of GoM are placed under three groups: the Tuticorin group (with seven islands namely Vaan, Koswari, Vilanguchalli, Kariyachalli, Upputhanni, Puluvinichalli, Nallathanni), the Keelakarai group (with seven islands namely Anaipar, Valimunai, Poovarasanpatti, Appa, Thalaiyari, Valai, Mulli), and the Mandapam group (with seven islands namely Hare, Manoli, Manoliputti, Poomarichan, Pullivasal, Krusadai, Shingle).Quantification of marine debris in each of the 21 islands is given below (Fig.4).

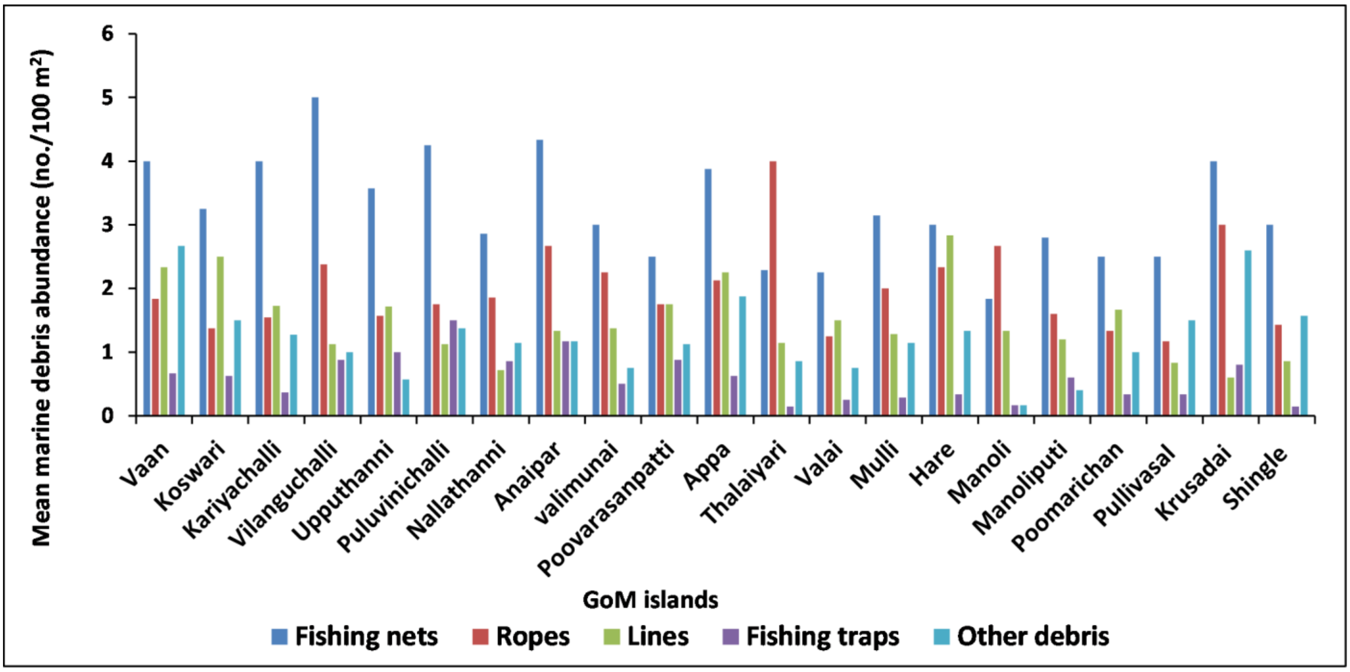

Fig.4: Mean density of marine debris in the 21 islands of GoM

In Tuticorin group, the mean density of marine litter in Vaan Island was 11.50 ± 1.75 no. of items /100 m^2 in the surveyed 6 transects in reef sites. Fishnet contributed the major portion of ALDFG with 4.00no., followed by lines with 2.33, ropes with 1.83, fishing traps with 0.67 and other debris with 2.67 no. of items / 100 m^2. The mean density of marine litter in Koswari Island was 9.25 ± 1.91 no. of items/100 m^2 in the surveyed 8 transects in reef sites. Fishnet contributed the major portion of ALDFG with 3.25 no., followed by lines with 2.50, ropes with 1.38, fishing traps with 0.63 and other debris with 1.50 no.of items / 100 m^2. The mean density of marine litter in Kariyachalli Island was 8.91 ± 0.77 no. of

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items/100 m^2 in the surveyed 11 transects in reef sites. Fishnet contributed the major portion of ALDFG with 4 no., followed by lines with 1.73, ropes with 1.55, fishing traps with 0.36 and other debris with 1.27 no.of items / 100 m^2. The mean density of marine litter in Vilanguchalli Island was 10.38 ± 0.77 no.of items /100 m^2 in the surveyed 8 transects in reef sites. Fishnet contributed the major portion of ALDFG with 5.00 no., followed by ropes with 2.38, lines with 1.13, fishing traps with 0.88 and other debris with 1.00 no.of items / 100 m^2.

The mean density of marine litter in Upputhanni Island was 8.43 ± 1.13 no. of items/ 100 m^2 in the surveyed 7 transects in reef sites.Fishnet contributed the major portion of ALDFG with 3.57 no., followed by ropes with 1.57, lines with 1.71, fishing traps with 1.00 and other debris with 0.57 no. of items / 100 m^2. The mean density of marine litter in Puluvinichalli Island was 10.00 ± 2.38 no.of items /100 m^2 in the surveyed 8 transects in reef sites. Fishnet contributed the major portion of ALDFG with 4.25 no., followed by lines with 1.75, ropes with 1.13, fishing traps with 1.50 and other debris with 1.38 no.of items / 100 m^2. The mean density of marine litter in Nallathanni Island was 7.43 ± 1.46 no.of items/100 m^2 in the surveyed 7 transects in reef sites. Fishnet contributed the major portion of ALDFG with 2.86 no., followed by ropes with 1.86, lines with 0.71, fishing traps with 0.86 and other debris with 1.14 no.of items / 100 m^2.

In Keelakarai group, the mean density of marine litter in Anaipar Island was 10.67 ± 1.71 no. of items/ 100 m^2 in the surveyed 6 transects in reef sites. Fishnet contributed the major portion of ALDFG with 4.33 no., followed by ropes with 2.67, lines with 1.33, fishing traps with 1.17 and other debris with 1.17 no.of items / 100 m^2. The mean density of marine litter in Valimunai Island was 7.88 ± 1.54 no. of items/ 100 m^2 in the surveyed 8 transects in reef sites. Fishnet contributed the major portion an ALDFG with 3 no., followed by ropes with 2.25, lines with 1.38, fishing traps with 0.50 and other debris with 0.75 no.of items / 100 m^2. The mean density of marine litter in Poovarasanpatti Island was 8 ± 0.96 no. of items /100 m^2 in the surveyed 8 transects in reef sites. Fishnet contributed the major portion of ALDFG with 2.50 no., followed by ropes with 1.75, lines with 1.75, fishing traps with 0.88 and other debris with 1.13 no.of items / 100 m^2. The mean density of marine litter in Appa Island was 10.75 ± 0.96 no. per 100 m^2 in the surveyed 8 transects in reef sites. Fishnet contributed the major portion of ALDFG with 3.88 no., followed by ropes with 2.13, lines with 2.25, fishing traps with 0.63 and other debris with 1.88 no.of items/ 100 m^2. The mean density of marine litter in Thalaiyari Island was 8.43 ± 1.67 no. of items/100 m^2 in the surveyed 7 transects in reef sites. Ropes contributed the major portion of ALDFG with 4 no., followed by fishing nets with 2.29, lines with 1.14, fishing traps with 0.14 and other debris with 0.86 no.of items/100 m^2. The mean density of marine litter in Valai Island was 6 ± 0.82 no. of items/100 m^2 in the

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surveyed 4 transects in reef sites. Fishing nets contributed the major portion of ALDFG with 2.25 nos., followed by lines with 1.50, ropes with 1.25, fishing traps with 0.25 and other debris with 0.75 no.of items / 100 m^2. The mean density of marine litter in Mulli Island was 7.86 ± 0.82 no. of items/ 100 m^2 in the surveyed 7 transects in reef sites. Fishing nets contributed the major portion of ALDFG with 3.14 no., followed by ropes with 2.00, lines with 1.29, fishing traps with 0.29 and other debris with 1.14 no.of items / 100 m^2.

In Mandapam group, the mean density of marine litter in Hare Island was 9.83 ± 1.25 no. of items/ 100 m^2 in the surveyed 6 transects in reef sites. Fishing nets contributed the portion of major ALDFG with 3.00 no., followed by lines with 2.83, ropes with 2.33, fishing traps with 0.33 and other debris with 1.33 no. of items / 100 m^2. The mean density of marine litter in Manoli Island was 6.17 ± 0.91 no. of items/ 100 m^2 in the surveyed 6 transects in reef sites. Ropes contributed the major portion of ALDFG with 2.67 no., followed by fishing nets with 1.83, lines with 1.33, fishing traps with 0.17 and other debris with 0.17 no.of items / 100 m^2. The mean density of marine litter in Manoliputti Island was 6.60 ± 1.21 no. of items/ 100 m^2 in the surveyed 5 transects in reef sites. Fishing nets contributed the major portion of ALDFG with 2.80 no., followed by ropes with 1.60, lines with 1.20, fishing traps with 0.60 and other debris with 0.40 no.of items/100 m^2. The mean density of marine litter in Poomarichan Island was 6.83 ± 1.82 no. of items/100 m^2 in the surveyed 6 transects in reef sites. Fishing nets contributed the major portion of ALDFG with 2.50 no., followed by lines with 1.67, ropes with 1.33, fishing traps with 0.33 and other debris with 1.00 no.of items/100 m^2. The mean density of marine litter in Pullivasal Island was 6.33 ± 1.82 no.of items/100 m^2 in the surveyed 6 transects in reef sites. Fishing nets contributed the major portion of ALDFG with 2.50 no., followed by ropes with 1.17, lines with 0.83, fishing traps with 0.33 and other debris with 1.50 no. of items /100 m^2. The mean density of marine litter in Krusadai Island was 11 ± 1.41 no. of items/100 m^2 in the surveyed 5 transects in reef sites. Fishing nets contributed the major portion of ALDFG with 4 no., followed by ropes with 3.00, lines with 0.60, fishing traps with 0.80 and other debris with 2.60 no.of items/100 m^2. The mean density of marine litter in Shingle Island was 7 ± 1.23 no. of items/100 m^2 in the surveyed 7 transects in reef sites. Fishing nets contributed the major portion of ALDFG with 3.00 no., followed by ropes with 1.43, lines with 0.86, fishing traps with 0.14 and other debris with 1.57 no.of items/100 m^2.

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Overall percentage of marine litters in 21 islands of GoM

Table1: Percentage composition of marine debris in GoM islands

Islands	Fishing nets (%)	Ropes (%)	Lines (%)	Fishing traps (%)	Other debris (%)
Vaan	34.78	15.94	20.29	5.80	23.19
Koswari	35.14	14.86	27.03	6.76	16.22
Kariyachalli	44.90	17.35	19.39	4.08	14.29
Vilanguchalli	48.19	22.89	10.84	8.43	9.64
Upputhanni	42.37	18.64	20.34	11.86	6.78
Puluvinichalli	42.50	17.50	11.25	15.00	13.75
Nallathanni	38.46	25.00	9.62	11.54	15.38
Anaipar	40.63	25.00	12.50	10.94	10.94
Valimunai	38.10	28.57	17.46	6.35	9.52
Poovarasanpatti	31.25	21.88	21.88	10.94	14.06
Appa	36.05	19.77	20.93	5.81	17.44
Thalaiyari	27.12	47.46	13.56	1.69	10.17
Valai	37.50	20.83	25.00	4.17	12.50
Mulli	40.00	25.45	16.36	3.64	14.55
Hare	30.51	23.73	28.81	3.39	13.56
Manoli	29.73	43.24	21.62	2.70	2.70
Manoliputti	42.42	24.24	18.18	9.09	6.06
Poomarichan	36.59	19.51	24.39	4.88	14.63
Pullivasal	39.47	18.42	13.16	5.26	23.68
Krusadai	36.36	27.27	5.45	7.27	23.64
Shingle	42.86	20.41	12.24	2.04	22.45

Overall, fishing nets were dominant with the abundance ranging from 27.1 % - 48.2%, followed by ropes (14.9-47.5%), lines (5.5- 28.8%), fishing traps (1.7-15%) and other debris (2.7-23.7%).

Clean coast index (CCI)

Clean Coast Index (CCI) assesses the cleanliness of a shoreline. Thisindex can be used as direct indicator of the aesthetic value of a shoreline but it might also give the first sign of the

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health status when applied to a coral reef. According to CCI, the coral reefs of GoM are categorized as ‘clean’ and the observed range is between 1.2 and 2.3.

But according to the underwater visual observation during the survey we noted the reefs of GoM were moderately affected by marine debris. CCI is based on the number of debris in a shoreline. The number of debris in a shoreline is 100 times greater than in coral reefs (Santodomingo et al., 2021), but in the reef environment though the number of debris count was low, the debris covering area was higher. So the thresholds for cleanliness index might need to be standardized to properly reflect the health condition of polluted reefs.

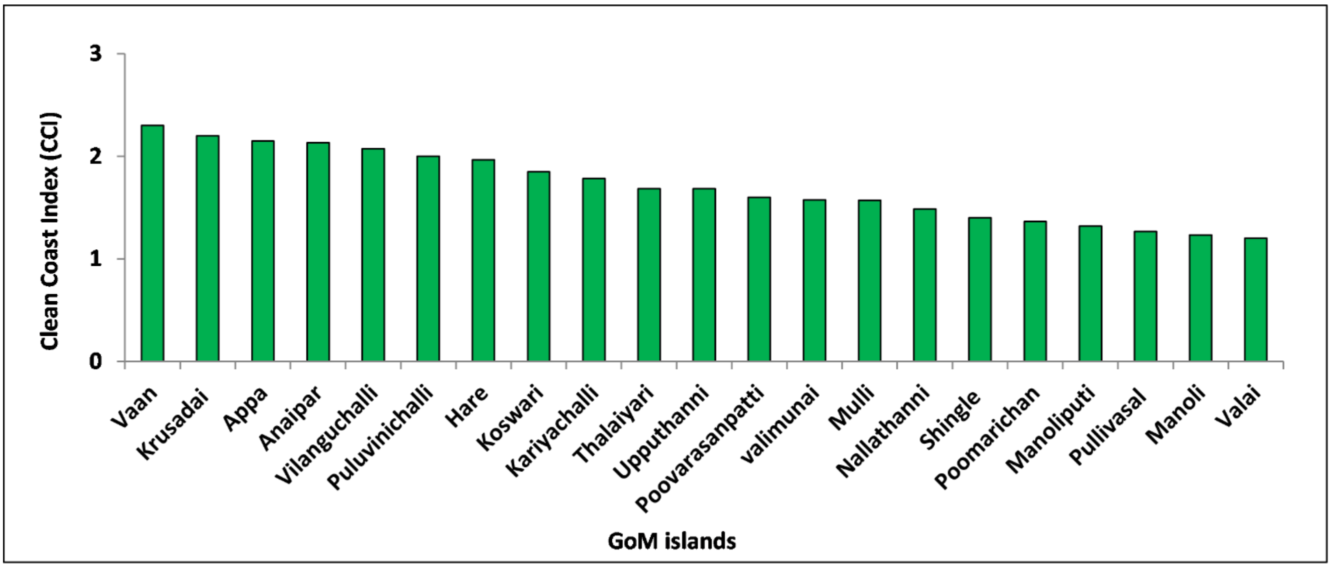

Fig.5: Clean-Coast Index in GoM Island

5. Discussion

The growing coastal population around the GoM has most likely increased the presence of marine debris. The mean densities per sampled location of marine debris in coral reefs range between 6.0 - 11.5 no. of items/100 m^2. As a comparison, mean densities of marine litter items in other studied regions fall within the range of 3.0 to 9.6 no. of items/100 m^2 in coral reefs of Darvel Bay (East Sabah, Malaysia) as reported by Santodomingo et al. (2021) and 2.0 to 10.9 no. of items/100 m^2 from 159 reefs in the Asia-Pacific regionas reported by Lamb et al. (2018).And maximum density was observed at 25.6 no.of items/100 m^2 in the reefs of Indonesia, and the value in Sakar Island of Malaysia was 47.0 ± 4.0 no. of items/100 m^2. However, the density is much lower when compared with touristic areas in the Gulf of

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Aqaba where densities were as high as 280 no. of items/100 m^2 (max. 600 no. of items/100 m^2) (Abu-Hilal and Al-Najjar, 2009).

Abandoned fishing nets were found in the largest quantities in Vaan Island. The islands occurring near Tuticorin city, where the density of coastal population is the highest, are the most affected. Fishing pressure, solid waste disposal and ship traffic are also significantly higher in Tuticorin region of GoM (Raj et al., 2015, 2017). The lowest density was observed in Valai island of GoM due to the nearby villages being less populated and to the remoteness of the reef site; and similar results were observed in the remote reefs from Mayote with 0.8 ± 0.3 no. of items100 m^2 (Mulochau et al., 2020). Also, the distance from the islands of Vaan and Valai to the mainland is 4.5 and 8 km from the coast, respectively. This reflectsthat the proximity of the island to the mainland may play a role in marine litter distribution. This finding is consistent with observations reported by previous studies, including a study by Pedrotti et al. (2016), which reported higher concentrations of plastic debris in waters 1 km from the coast of Mediterranean Sea than in waters 10 km from the coast.

ALDFG are the dominant contributors to marine litter on the studied coral reef in the GoM, making up 85.7% of total observed litter items, which clearly shows the intensity of fishing in the reef areas. Macfadyen et al. (2009), Lebreton et al. (2017), and Sweet et al. (2019) reported that abandoned fishing gears contributed between 10 and 46% of the marine debris. The increase in coastal population has caused a corresponding increase in the fishing pressure on coastal habitats of GoM. According to a report the coastal population in GoM has increased about 34% during the period between 1989 and 2009 (GoMBRT, 2011). The increasing population size, crowded fishing grounds, competition for the available fishery resources, rising demand for fishery products and declining catches have made the fishermen even to opt for destructive fishing activities. The bottom laid gill nets in the periphery of reef areas is a common practice in GoM. These nets are sometimes misplaced by the fishermen on the reef areas. If nets are trapped on live coral colonies, they are damaged severely and cannot be recovered. Hence fishermen give them up, which later become 'ghost nets' and end up being permanent debris. In other cases nets are washed into the reef areas by strong winds and currents during the rough weather season especially between April and September. Abandoned fish-traps are other major contributors in GoM as the intensity of trap fishing has increased significantly (Edward et al., 2012). Lines, ropes and other debris such as plastic bottles and carry bags were also found on reef areas of GoM. Overall, the intensive fishing activities driven by the escalated demand for fishery resources, shore-side disposal of unwanted gear, bad weather, illegal fishing are the reasons

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for receiving more abandoned nets than other debris. Similarly, Duncan et al. (2023) report that, historically, overfished areas exhibit a higher and more prolonged legacy of pollution, as well as being identified as potential hotspots for ALDFG.There are numerous fishing villages along the coast of GoM, where solid wastes, including discarded fishing gear, are dumped into the sea or on the shoreline (Patterson Edward, 2020). As GoM enjoys historical and archaeological importance it attracts thousands of tourists every day (Kumaraguru et al., 2006). There are places of interest for the pilgrims along the coast and as a consequence solid wastes are generated in huge quantities. Even though the 21 islands are protected from tourism activities, illegal visits take place in some of them. Thus, increasing coastal population and increasing intensity of tourism can escalate the levels of marine debris in GoM in the future.

Many international studies point out the fact that a significant share of plastic litter on the sea floor is related to fishing or aquaculture (Eriksen et al., 2014; Law, 2017; Ballesteros et al., 2018). In this specific survey of the GoM, fishing nets contributed the major fraction (38%), followed by ropes (23%), lines (17%), and fishing trap (7%). Fishing nets, traps, lines and ropes are the commonly reported seafloor marine debrisfrom many regions in recent times (Wilcox et al., 2013; Oliveira et al., 2015; Farias et al., 2018; Ballesteros et al., 2018). A large quantity of fishing net materials was reported by Krishnakumar et al. (2018) in Nallathanni Island of GoM. The results of the present rapid survey align with the findings of the above studies from different areas as fishing-related debris contributes primarily to the marine debris in GoM.

But according to the underwater visual observation during the survey we noted the reefs of GoM are moderately affected by marine debris. The clean-coast index (CCI) which was developed as a tool for evaluation of the actual coast cleanliness in shorelines has been appropriately modified to evaluate the cleanliness in coral reef areas of GOM. The abundance of marine litter can be 100 times higher on shorelines than on coral reefs, so the thresholds for cleanliness status might need to be adjusted to properly reflect the health condition of affected reefs. In order not to give the false impression that reefs are impacted by relatively low densities of litter when compared with the higher values found on beaches, we could also explore the use of different scaling factors when estimating the CCI index.

As per the Coastal Clean Index analysis for shoreline, the observed range of values between 1.2 and 2.3 shows that the coral reefs of GoM are categorized as “clean”. But the underwater visual observation reveals that the reefs of GoM are moderately affected by

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marine debris, based on the extent of cover by the debris which needs to be studied in detail.

6. Conclusion

The present study provides baseline data on marine debris abundance in the reef areas of GoM. A total of 1,242 number of marine litterwere found in the surveyed 144 transects covering 14, 400m^2 areain the reef areas of the 21 GoM islands. Five types of marine litter were observed during the survey, namely fishing nets 37.9%, ropes 23.7%, lines 17.6%, fishing traps 6.7% and other plastic debris 14.1%. Abandoned or derelict nets were the dominant contributors with (85.7%) to the overall debris (14.39%). The quantities of marine debris were found to be higher in Vaan Island (11.5 no. of items/100 m^2) and lower debris was observed in Valai Island with 6.0 no. of items/100m^2. Such baseline data is essential for the proper management and removal of debris,which actions are highly warranted to conserve the fragile coral reef ecosystems of GoM, to conserve biodiversity and to protect the livelihood of the dependent fisher folk.The damage caused by lost gear may contribute to coral disease and mortality, but no quantitative information has been collected on such parameters. Once nets and ropes settle, they may become substrate for benthic organisms and act as sediment traps. Tissue damage in corals caused by plastics may cause infections by microbes which might develop into diseases. Removal of stabilized gear from entangled corals may easily cause damage to corals and their environment. Therefore, detailed studiesneed to be conducted on the extent of cover of lost gears on reefs and their impact, extent of entanglement of marine debris in marine wildlife and plastic ingestion by marine wildlife. It is recommended to remove newly arrived nets from the reefs as soon as possible in order to prevent ghost fishing and coral damage.

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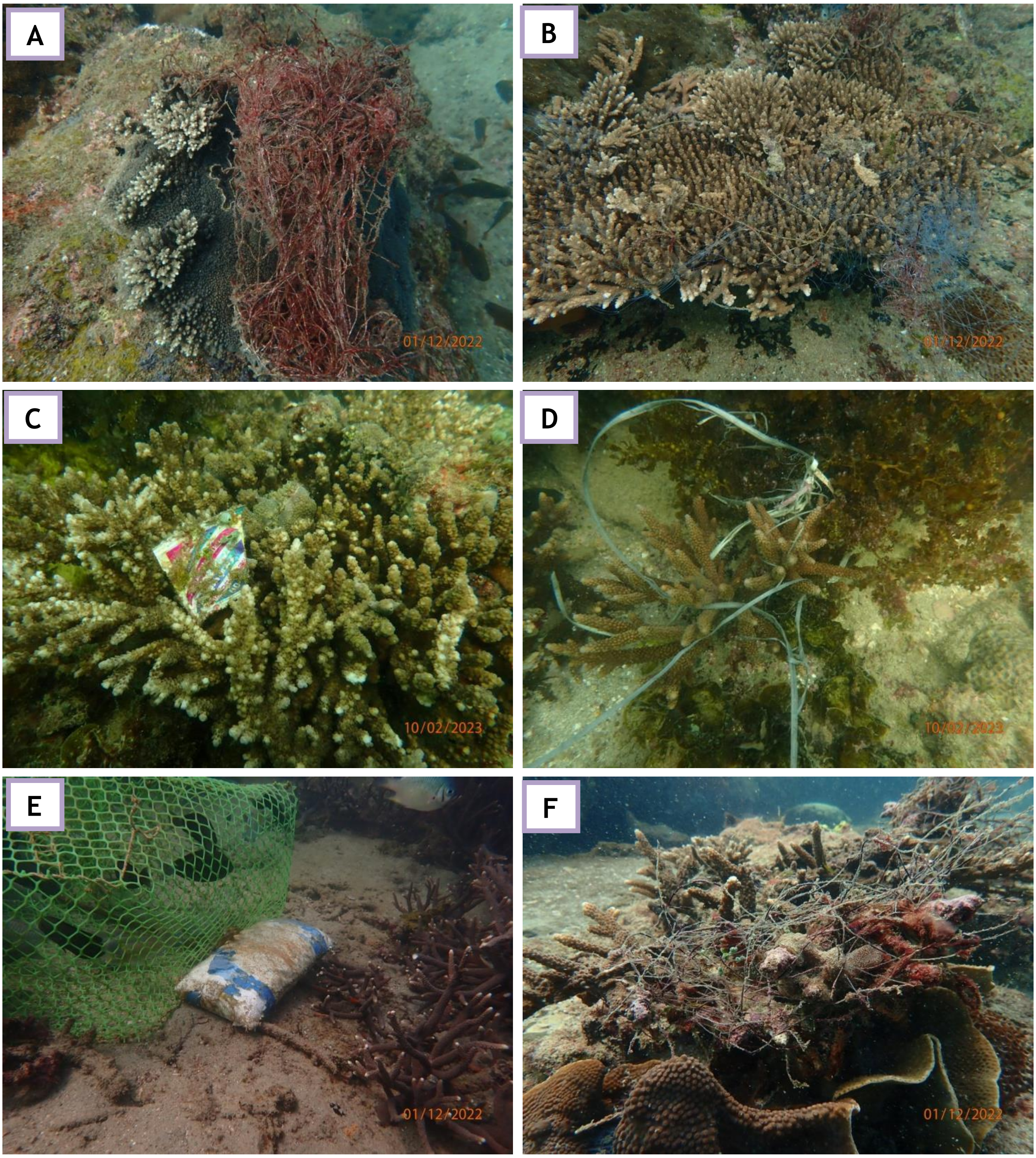
Marine debris in coral reef areas in Gulf of Mannar



(A) Abandoned fishing net – ***Acropora cytherea*** (B) Fishing net entanglement – ***Acropora cytherea*** (C) Plastic cover – ***Acropora* sp.** (D) Rope entanglement – ***Acropora muricata*** (E) Fishing trap – ***Acropora* sp.**(F) Rope entanglement – ***Turbinaria mesenterina***

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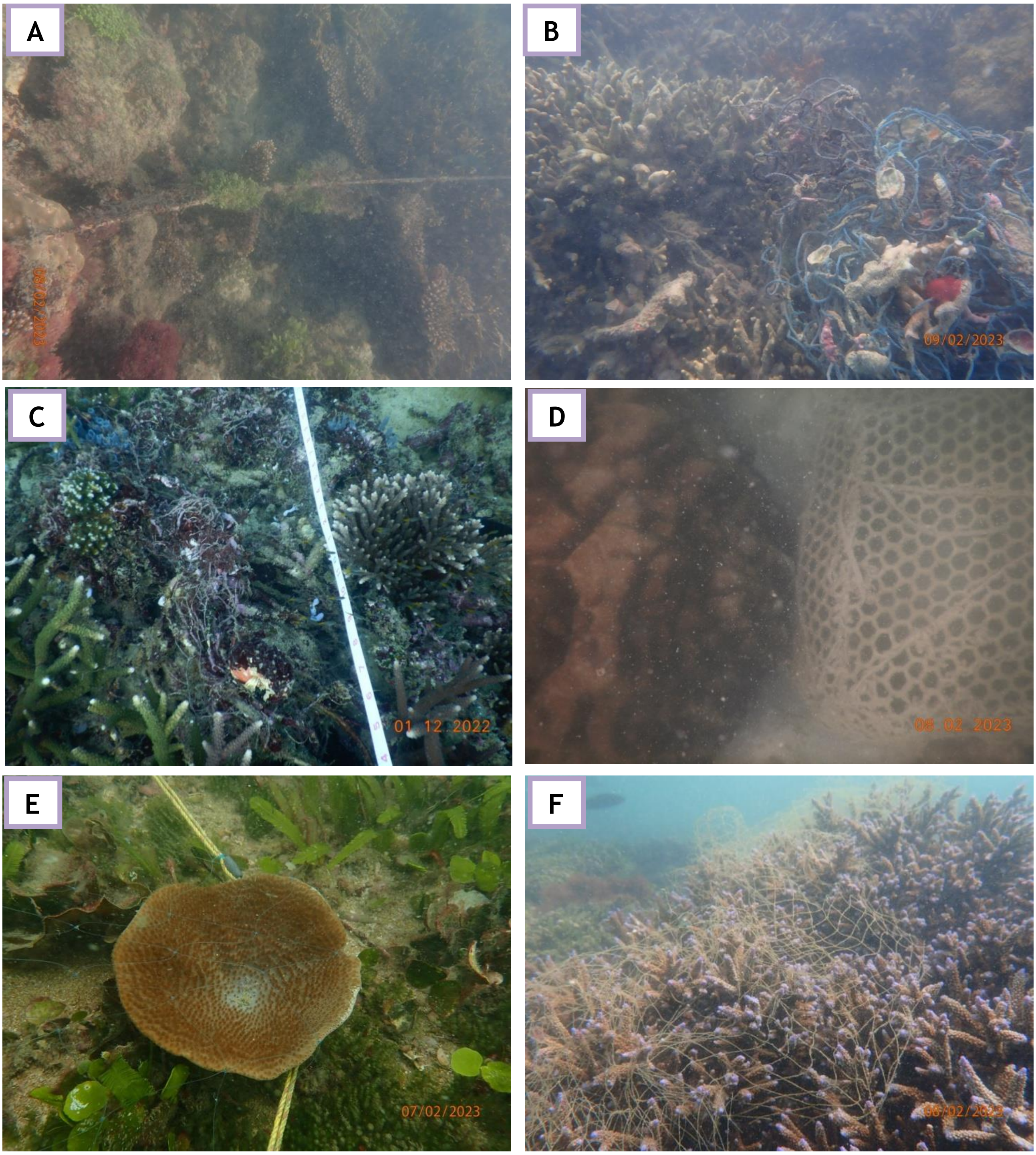

(A) Fishing lines- ***Acropora* sp.**(B)Fishing net entanglement –***Montipora digitata***(C) Degraded fishing nets – ***Acropora* spp.**(D) Fishing trap – ***Goniastrea* sp.** (E) Rope – ***Turbinaria* sp.**(F) Fishing net entanglement – ***Acroporaro busta***

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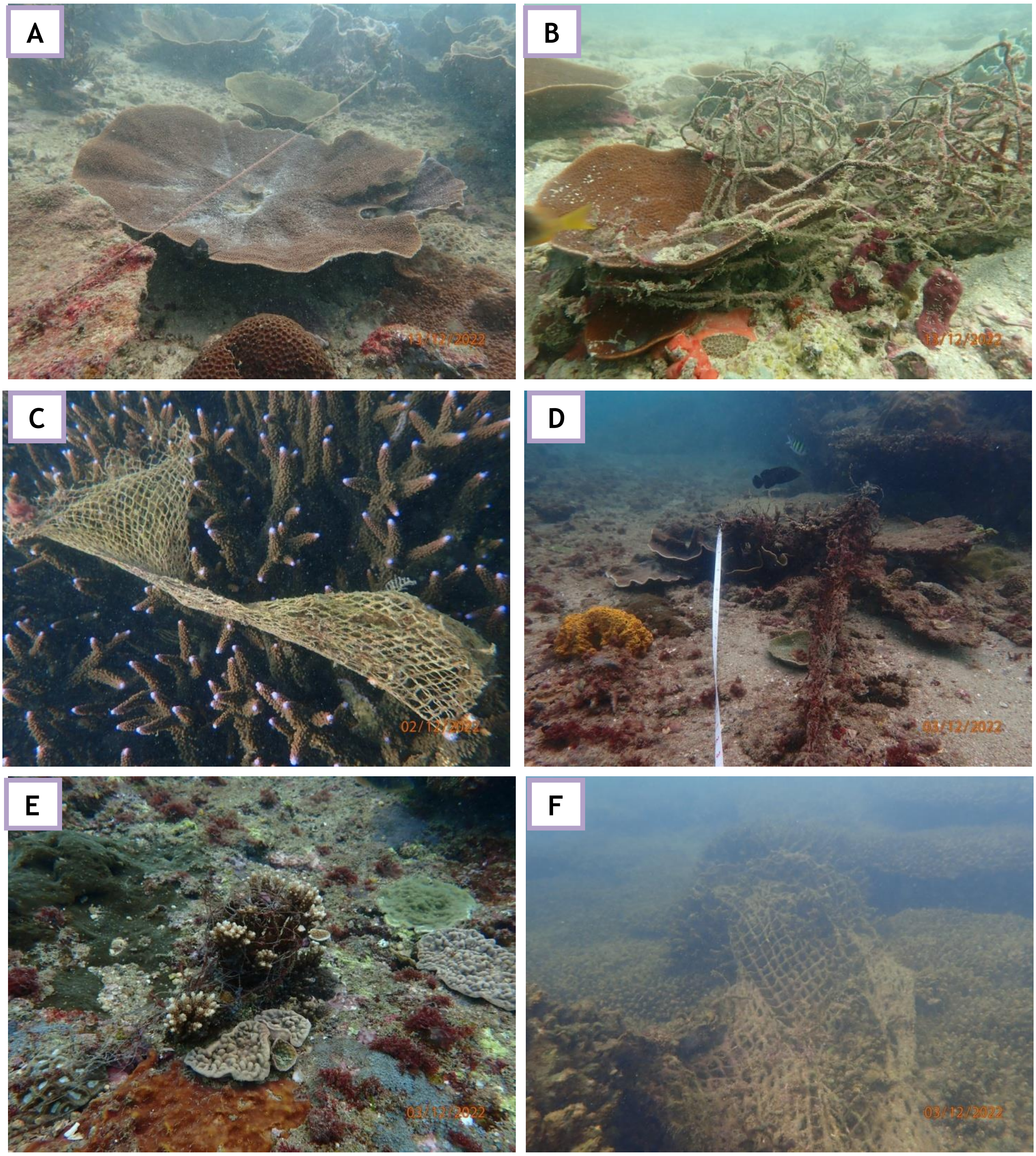

A) Fishing lines- ***Turbinaria* sp.**(B)Fishing net entanglement –***Turbinaria mesenterina***(C) Fishing net – ***Acropora robusta***(D) Degraded fishing net – ***Turbinaria* sp.** (E) Fishing net entanglement – ***Acropora* sp.**(F) Fishing net entanglement – ***Acropora cytherea***

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