Regional Studies in Marine Science 39 (2020) 101429

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Current biodiversity of Mandapam group of Islands in Gulf of Mannar Marine Biosphere Reserve, Southeast coast of Tamil Nadu, India

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ARTICLE INFO

Article history:
Received 22 November 2019
Received in revised form 12 August 2020
Accepted 23 August 2020
Available online 27 August 2020

Keywords:
Coral reefs
Macroalgae
Invertebrates
Reef fish
Gulf of Mannar

ABSTRACT

The global climate change is known to involve in the decline of biodiversity from different ecosystems, including coral reefs worldwide. The spatial distribution of reef associated flora and fauna in the Gulf of Mannar (GoM) Marine Biosphere Reserve (GOMMBR) are declined due to damage of coral reefs by three major global problems observed in coral reefs, pertaining to frequent bleaching events, sedimentation and overwhelming algal communities. The occurrence of rich biodiversity in reef areas indicates the healthy condition of an iconic reef ecosystem. In this study, to assess the health status of coral reefs in Mandapam group of Islands under GoM, the diversity and distribution patterns of species composition assembled in reefs at seven Islands were analyzed. In 2019, summer temperature range was exceeded between 32 to 36 °C than usual range 28 to 30 °C, which resulted again massive coral bleaching in GoM. Statistical analysis revealed the high diversity of macroalgae in all the reef sites at Mandapam group Islands. Considerably, dead reefs in Mandapam group Islands represent 90% of algal communities and very less to scarce faunal diversity. While, faunal diversity was well diversified in the live coral cover areas and reefs with less macroalgal assemblage. This assessment provides current reef biodiversity data for gaining further insights into complex spatial distribution patterns of reef biota in GoM, and this will support the authorities to plan conservation efforts and to support livelihood of local fisher folk community.

1. Introduction

Coral reefs are highly productive and biodiverse ecosystems on earth that provide an array of ecological services to nature and human (Moberg and Folke, 1999). Coral reefs provide seafood, seaweeds, medicinal sources, ornamental shells, and ornamental fish, act as spawning, nursery, breeding, feeding, and recreation grounds, supplies nutrients to pelagic food web, act as pollution and climate change indicators, fixes atmospheric nitrogen, regulates CO_2 and Ca levels, and protect coastal environments by buffering of waves and currents (Moberg and Folke, 1999). Coral reef ecosystems require an optimal range of temperature between 21.7 to 29.6 °C for the development, recruitment and resilience of coral reefs in tropical environments (Guan et al., 2015). In the current global warming scenario, the elevated temperatures around the globe are extirpating coral reef ecosystems worldwide (Burke et al., 2011; Camp et al., 2018). Damage of local and global reef ecosystems via frequent bleaching events, sedimentation, diseases, eutrophication, invasive algal species, sponges, gastropods, worms, crown-of-thorns starfish, mining activities, fishing, recreation and other detrimental impacts (e.g. increasing atmospheric CO_2 levels, El Niño, cyclones etc.) are appearing to cause severe negative impact on benthic and pelagic reef communities (Mohammed and Mohammed, 2005; Pratchett et al., 2011; Burke et al., 2011; Ponti et al., 2016; Renfro and Chadwick, 2017; Obura et al., 2017; Keith et al., 2018; Claar et al., 2018; Richards and Day, 2018; Ramesh et al., 2019).

To understand the current status on reef diversity worldwide, assessment on reef communities is conducted timely in different reef ecosystems around the world, including Australia, Britany, Jamaica, Red Sea, Caribbean, and Florida, and emphasized the decline and spatial shift of reef communities including corals, algae, invertebrates and fish (Vertino et al., 2014; de Bakker et al., 2017). Coral-algal phase shift dynamics have been well studied to understand the negative impact of algae on the survival of live coral cover and coral recruitment (Burke et al., 2011), and reef fish assemblage (Ainsworth and Mumby, 2015). Coral-algal phase shift dynamics are evidently altering the reef fish communities via reducing fishery production (Ainsworth and Mumby, 2015). Therefore many studies have raised the global alarm on reef conservation and reef restoration to maintain the healthy biodiversity.

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https://doi.org/10.1016/j.rsma.2020.101429

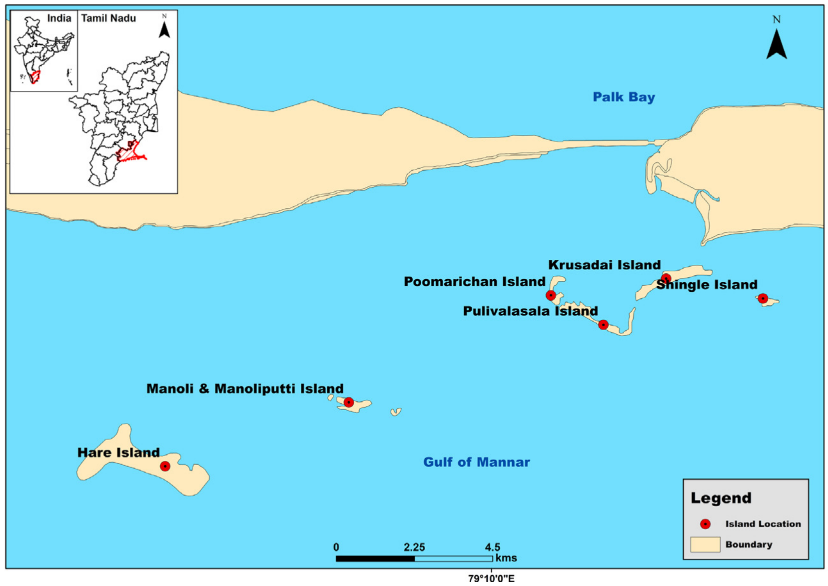

Fig. 1. Synoptic map delineating the study areas in seven Islands of Mandapam region, GoM.

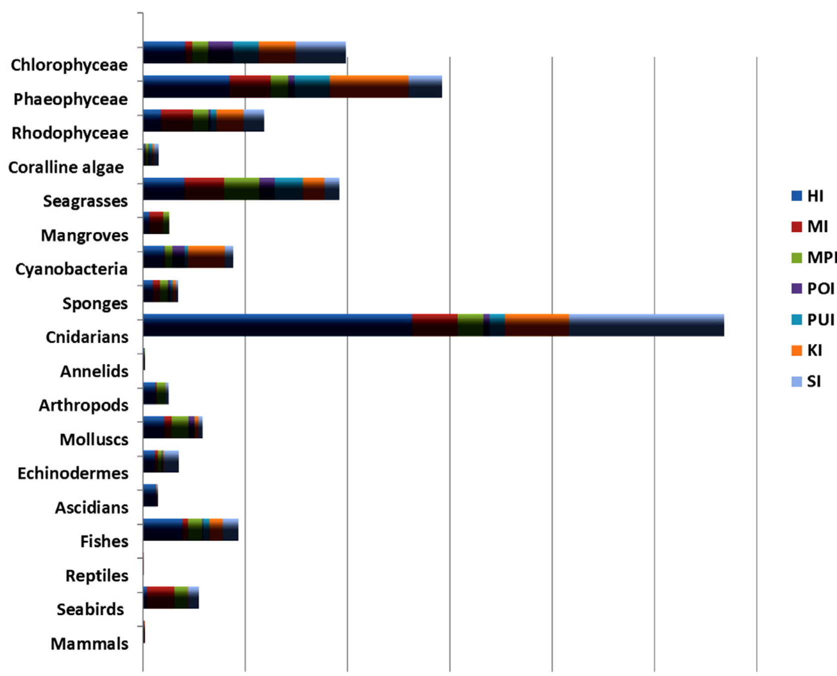

Fig. 2. Overall diversified group's abundances in seven study areas (square root transformed data).

Considerably, reefs around the tropical coastal areas are potentially at risk due to anthropogenic activities such as fishing for fish protein (Burke et al., 2011). Various environmental factors such as high temperature, direct exposure to intense solar radiation during neap tide, sedimentation, and profuse algae are known to alter the reef assemblages (Mohammed and Mohammed, 2005). Ocean acidification is appear to be a less influential factor that damaging corals; whereas global warming and raising atmospheric CO_2 concentrations are considered as potential global threats to coral reefs ecosystems distributed in both tropical and temperate regions (Couce et al., 2013). These natural and anthropogenic disturbances cause changes in diversity and abundance of reef biota, which subsequently leads to collapsed habitat structure.

Along the GoM coast, several studies have investigated the different aspects of coral reefs, including reef community structure, reef fishes, reef algae, reef ornamental fishery, biomedical resources, reef restoration, coral bleaching, ocean acidification, and coral recruitment etc. Kumaraguru et al. (2006), Sukumaran et al. (2007), Sukumaran and George (2010) and Marimuthu et al. (2018). The existing knowledge about reef diversity and distribution is mostly based on the assessments carried out at single site or selected sites. Studies on coral reefs of the GoM revealed potential threats such as diseases, sedimentation, frequent bleaching events, bleaching patterns, invasive alga and fauna which appear to cause damage to reef ecosystems (Thangaradjou et al., 2016; Edward et al., 2017; Manikandan and Ravindran, 2017; Krishnan et al., 2018; Ramesh et al., 2019). However, so far no study has conducted the detailed reef diversity assessment

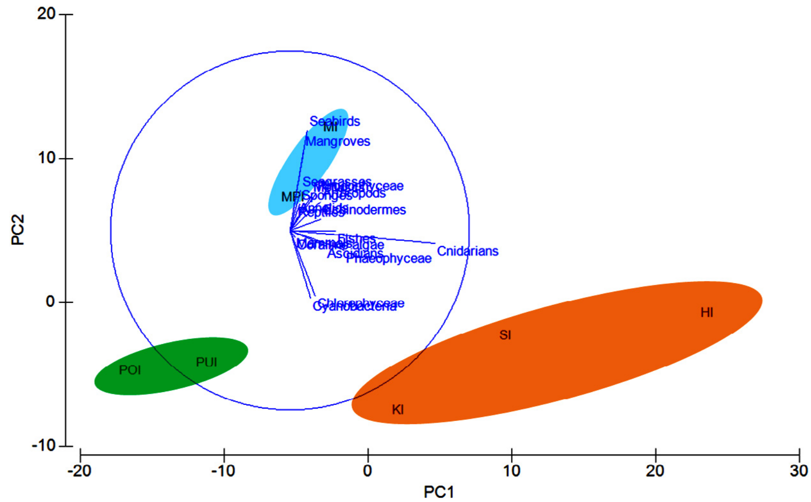

Fig. 3. PCA plot shows multivariate similarity patterns of plant and animal components (variables) assemblages among seven study sites (samples). Cluster 1 (HI, SI, and KI) indicate rich abundance of mixed flora and faunal components; Cluster 2 (MI and MPI) represents abundance of mangroves and seabirds; Cluster 3 (PUI and POI) shows damaged reef with less species diversity.

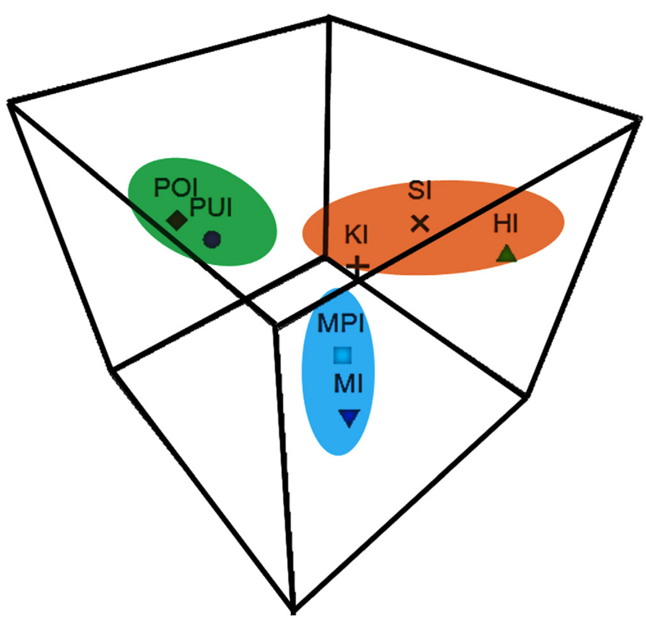

Fig. 4. NMDS 3D plot based on Bray–Curtis similarity shows the overall abundance of plant and animal components in cluster 1 (HI, SI, and KI). Stations MPI and MI indicate the abundance of seagrass and seabirds diversity in cluster 2. While, the third cluster, PUI and POI indicate destroyed reef or least abundance of flora and faunal components.

on spatial distribution of marine flora and fauna in GoM with relations to multifactorial environmental variables. Understanding the reef biodiversity status in the current context of climate change and reef degradation in connection to environmental and biological variables is a primary research concern for conservation and management of reef ecosystems.

Assessment on the reef diversity provides a detailed information about species diversity and distribution, abundance, threats status, and potential links with anthropogenic activities and climate change. Investigations on reef diversity would unveil potential causes involved in decline of reef population and to better understand the reef biodiversity dynamics over the time. After several bleaching events that occurred in the past two decades, the present study investigated the reef biodiversity of seven islands distributed along GoM coast. The discussion presented in this paper also provides timely information on how physical, environmental and biological factors, such as sea surface temperature, sedimentation, bottom topography, and algal dynamics contributed to spatial shift of reef diversity in GoM. We also aimed to provide the current data on spatial variability in consortium of reef flora and fauna, which will be useful to make conservation of reefs for achieving recovery of corals and coral reef associated communities.

2. Materials and methods

2.1. Study area

The study was conducted on fringing coral reefs situated around seven Islands under Mandapam group in the GoM, Southeast coast of Tamil Nadu, India (Fig. 1). The GoM coast is influenced by two main current patterns: East India Coastal Current (EICC) and West India Coastal Current (WICC) (Jagadeesan et al., 2013). These currents flows between the Bay of Bengal, Laccadive Sea, and Arabian Sea, and mixes shallow water of Palk Bay and deep waters of GoM (Jagadeesan et al., 2013). The fringing reefs in Mandapam region are distributed at bathymetric range of 30 cm to 8 m. These reefs are very close to the islands; the reef crest is 50 to 150 m away from shore and the reef slope and terrace extends up to a distance of 500 m ± 1.0 km from shore. An average depth of 1 to 5 m was observed at all reef flats in seven islands. During early 1990's, the fringing reefs in GoM were called as Marine Biologists Paradise. However, several bleaching events frequently occurring since 1998 to till and damaged the reefs greatly, thus these reefs are now being called as ghost islands (George and Jasmine, 2015). Presently, frequent bleaching events, algal dynamics, heavy siltation and fishing activities in GoM are altering coral reefs and reef biodiversity.

2.2. Ethics statement

The present study conducted in the Gulf of Mannar Marine Biosphere Reserve was officially permitted by the local government, Gulf of Mannar Forest Reserve Trust, Ramanthapuram, Tamil Nadu. This study has been approved by the Chief Wildlife Warden, Department of Environment and Forest, Government of Tamil Nadu under Ref. No. WL 5(A)/18855/2017- Permit No. 736/2017.

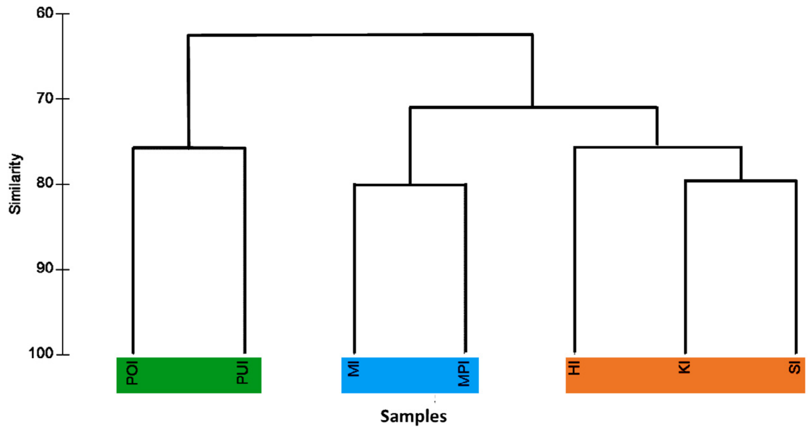

Fig. 5. Dendrogram from cluster analysis on diversity similarities between sample sites. The x axis shows the study sites and y-axis shows the Bray Curtis % similarity coefficient. Cluster 1 (HI. SI, & KI) show maximum diversity of flora and fauna; Cluster 2 (MI & MPI) indicates abundance of mangroves, seagrass and seabirds; Cluster 3 (PUI & POI) shows damaged reef condition and less abundance of flora and faunal communities.

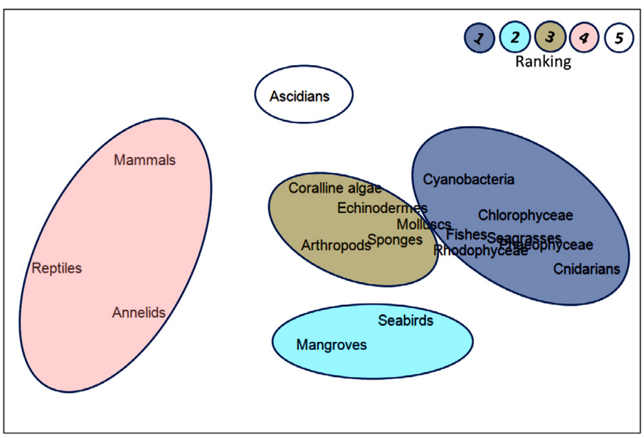

Fig. 6. NMDS 2D plot based on Bray–Curtis similarity showing the overall abundance of variables in the Mandapam group of islands. Cluster 1 dominated by cnidarians and algal communities; Cluster 2 abundant in mangroves and seabirds; Cluster 3 comprises sponges, arthropods, molluscans, and echinoderms; Cluster 4 reveals annelids, reptiles, and mammals; Cluster 5 contain low abundance of Ascidians. Ranking of variables forming different clusters were indicated in circles on top right.

2.3. Field surveys and data collection

Field surveys were conducted on dead and live coral reef sites distributed around seven islands under Mandapam region such as Hare Island (HI), Manoli Island (MI), Manoliputti Island (MPI), Poomarichan Island (POI), Pullivasal Island (PUI), Krusadai Island (KI), and Shingle Island (SI). Based on the field observations from seven Islands, three different reefs are classified: (1) Healthy reefs (reefs with live corals and mixed biodiversity), (2) sedimented reefs (reefs damaged by sedimentation), and (3) Dead reefs (reefs damaged by bleaching or algal invasion). The present study data is collected only from healthy reefs to assess the current status on biodiversity.

At each study site, a line transect of 10 m length was laid and Line Intercept Transect (LIT) method and quadrat sampling methods (English et al., 1997; Freiwald et al., 2015) were employed to estimate the diversity and abundance of reef biota in seven Islands of Mandapam region. Benthic forms observed along the line transects were recorded using 1 m^2 quadrates (English et al., 1997). Fish diversity was assessed by visual and video based fish community assessment method as described in previous studies (Holmes et al., 2013; Tessier et al., 2013). The total number of each fish species observed along the each line transects were converted to mean values. In addition to reef associated diversity, data of mean number (species) seagrasses, mangroves, and birds

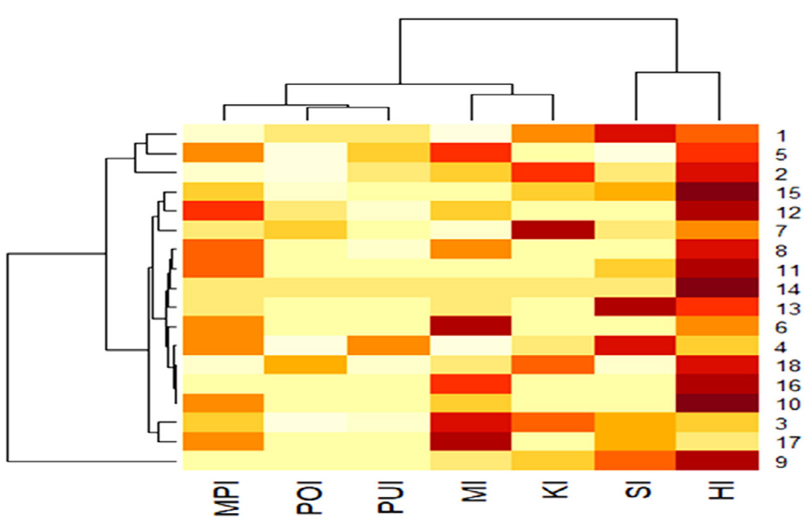

Fig. 7. Heat map showing maximum diversity and distribution patterns in Mandapam group of islands.

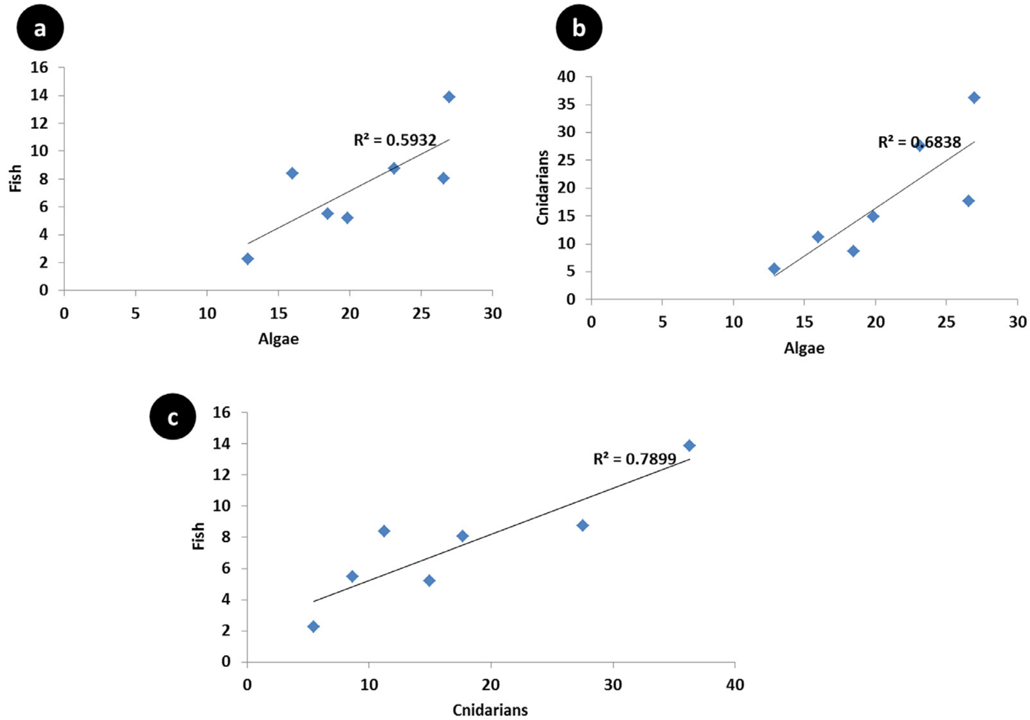

Fig. 8. Generalized linear models conducted for variables algae, fish and cnidarians.

observed from each island were also included for statistical data to analyze the overall biodiversity in each island. The mean percentage of other live benthic forms (from quadrants) and mean numbers of fish obtained from line transects were subjected to statistical analysis. To state the overall biodiversity status of each island, all flora and faunal components were included for diversity (i.e. H', J', etc.) analysis in PRIMER 6 software. Study period was from August 2018 to June 2019. Using underwater camera and by scuba diving, reef flora and faunal species were recorded along the line transects. Locations of the study sites were marked with handheld Garmin GPS, and latitude and longitude of GPS coordinates were entered in ArcGIS and mapped (Fig. 1). Environmental parameters including depth, temperature, salinity, pH, HDO and were analyzed using Manta+ Water Quality Sonde.

We evaluated a total of 260 line transects (covering a total area of 2600 m^2) laid on reef sites in different islands, of which 40 from Shingle Island, 60 from Krusadai Island, 20 from Pullivasal Island, 15 from Poomarichan Island, 15 from Manoliputti Island, 40 from Manoli Island , and 70 from Hare Island. The number of transects evaluated in respective island were depended on the availability of coral reefs. Only live reef sites were surveyed to generate reliable data on reef diversity. Although surveys were conducted on completely dead coral reefs, data were not analyzed in order to avoid the misinterpreting data caused by algal assemblage. The number of species observed on each transect were recorded as scattered to high density and performed the statistical analysis.

2.4. Statistical analyses

The spatial variability of reef diversity in Mandapam group of Islands was evaluated by performing an analysis of similarities (ANOSIM) of square-root transformed Bray–Curtis dissimilarities in Primer 6 software. Taxonomic diversity indices such as richness (d), evenness (J'), Shannon diversity (H'($\log^2$)), and Simpson diversity (1-Lambda') were analyzed for the transformed data. The significant spatial variability changes in species composition of Mandapam group of Islands were also evaluated using vegan's 'simper' function in the SIMPER analysis. The degree of relative similarity between (within and among) the assemblage of reef associated fauna and flora have been plotted using non-metric multi-dimensional scaling (nMDS) 3D plot based on Bray–Curtis similarity matrix calculated from log transformation (square-root transformed) data. Generalized linear models (GLM) were performed to test whether there were any significant differences among selected variables (i.e. fish, algae and cnidarians) using Poisson distribution using log link function. Statistical analyzes were conducted in the PRIMER 6, PAST, and in R (The R Foundation for Statistical Computing, Viennna, Austria, v.3.1.3) programming with "vegan" community ecology package which includes MASS, cluster, and mgcv packages.

3. Results and discussion

Field investigations revealed the rich diversity of green algal communities, followed by sponges and some reef fishes on reef flats of Mandapam group of Islands. Significantly, reef associated flora and faunal community structure differed among sites and displayed a heterogeneous distribution in the study areas (Table 1). Differences in the species composition between seven islands were significantly related to the presence of live coral cover merely. Species composition analysis, PCA analysis, nMDS, and cluster analysis have clearly separated these seven islands into three distinct groups (Figs. 2, 3, 4 & 5). Mostly, algae, invertebrates and fish were confined to healthy reef sites, while mixed invasive algal assemblage is profound in sedimented reefs and dead reefs. Based on the Bray Curtis similarity cluster analysis, the maximum density of reef fish was found at Hare Island, Manoli & Pullivasal Islands, followed by Shingle, Manoliputti, and Krusadai Islands. The overall highest species diversity was found at Hare (Shannon–Wiener diversity index (H'e), H' = 3.776), Manoli & Manoliputti (H' = 3.659 & 3.792), Shingle (3.506) and Krusadai (3.441) Islands (Table 2). Manoli and Manoliputti Islands represented high H' value due to two principle components Mangroves and seabirds which are not abundantly seen in other islands.

Table 1
List of marine flora and fauna found along the Mandapam group of Islands, Gulf of Mannar.

Type	Species	Island						
		HI	MI	MPI	POI	PUI	KI	SI
Chlorophyceae	*Avrainvillea erecta*	−	−	−	+	−	−	−
	Boergesenia forbesii	+	−	+	+	−	+	−
	Bryopsis pennata	−	+	−	−	−	−	−
	Bryopsis plumosa	+	+	+	−	−	+	+
	Caulerpa fastigiata	+	−	−	−	−	−	−
	Caulerpa fergusonii	−	−	+	−	−	−	+
	Caulerpa lentillifera	+	−	−	−	−	−	−
	Caulerpa mexicana var. pluriseriata	+	−	−	−	−	−	−
	Caulerpa microphysa	+	−	−	+	+	+	+
	Caulerpa peltata	+	+	+	+	+	+	+
	Caulerpa racemosa	+	+	+	+	+	+	+
	Caulerpa racemosav. occidentalis	+	+	−	+	−	+	+
	Caulerpa racemosa var. turbinata	+	−	−	+	−	+	+
	Caulerpa scalpelliformis	+	+	−	−	−	+	−
	Caulerpa serrata	+	−	−	−	−	−	−
	Caulerpa serrulata	+	−	+	−	−	−	−
	Caulerpa sertularioides	+	+	+	+	+	+	+
	Caulerpa taxifolia	+	+	+	−	−	−	−
	Caulerpa verticillata	+	−	−	+	+	+	+
	Chaetomorpha antennina	−	−	−	+	−	−	−
	Chaetomorpha crassa	+	−	−	+	+	+	−
	Cladophora glomerata	−	−	+	−	−	−	−
	Cladophora vagabunda	+	−	−	−	−	−	−
	Cladophoropsis javanica	−	+	+	−	−	+	−
	Codium arabicum	+	−	−	−	−	−	−
	Codium decorticatum	−	−	+	−	−	+	−
	Codium dwarkense	−	−	−	−	−	+	−
	Codium edule	+	−	−	−	−	−	−
	Codium fragile	+	−	−	−	−	−	−
	Colpomenia sinuosa	+	−	+	+	+	+	+
	Dictyosphaeria cavernosa	+	−	+	−	−	−	+
	Enteromorpha compressa	+	+	+	−	−	−	−
	Enteromorpha flexuosa	+	+	−	−	−	−	−
	Halimeda tuna	+	−	+	−	−	−	−
	Halimeda capiosa	+	−	−	−	−	−	−
	Halimeda macroloba	+	−	−	−	−	−	+
	Halimeda opuntia	+	−	−	−	−	−	−
	Neomeris annulata	+	−	−	+	−	−	−
	Ulva lactuca	+	−	−	−	−	−	−
	Ulva reticulata	+	−	+	+	+	+	+
	Ulva rigida	+	−	−	+	−	+	−
	Valonia utricularis	−	−	+	−	−	+	+
Phaeophyceae	*Colpomenia sinuosa*	+	−	+	+	+	+	+
	Cystoseira indica	−	+	−	−	−	−	−
	Dictyota dichotoma	+	−	−	−	−	+	−
	Dictyota pinnatifida	−	+	+	−	−	+	+
	Dictyopteris acrostichoides	+	+	−	−	+	+	+
	Ectocarpus	+	−	−	−	−	−	−
	Hincksia mitchelliae	+	+	+	−	−	−	−
	Hydroclathrus clathratus	+	+	+	+	−	+	+
	Laurencia papillosa	+	+	+	+	+	+	+
	Lobophora variegata	+	+	+	−	+	+	+
	Nitophyllum marginatum	−	−	−	−	−	+	−
	Padina boergesenii	+	+	+	+	+	+	+
	Padina gymnospora	+	+	+	−	−	+	+
	Padina tetrastromatica	−	−	+	−	−	−	+
	Sargassum ilicifolium	+	+	+	+	+	+	+
	Sargassum johnstonii	−	+	−	−	−	−	−
	Sargassum swartzii	+	+	+	+	+	+	+
	Sargassum tenerimum	+	+	−	+	−	+	−
	Sargassum wightii	+	+	+	+	+	+	+
	Sphacelaria sp.	+	−	−	−	−	−	−
	Stoechospermum marginatum	+	+	−	+	+	+	+
	Turbinaria conoides	+	+	+	+	+	+	+
	Turbinaria crenata	+	−	−	−	−	−	−
	Turbinaria decurrens	+	+	+	+	+	+	+
	Turbinaria ornata	+	+	+	+	+	+	+
	Turbinaria triquetra	+	+	+	−	−	+	+
Rhodophyceae	*Acanthophora spicifera*	−	+	−	−	−	+	−
	Ahnfeltia plicata	+	+	+	−	−	+	+
	Amphiroa fragilissima	−	−	+	+	−	−	+
	Amphiroa anceps	−	−	−	−	−	+	−
	Asparagopsis taxiformis	−	+	−	−	+	−	−

(*continued on next page*)

Table 1 (*continued*).

Type	Species	Island						
		HI	MI	MPI	POI	PUI	KI	SI
	Cryptonemia undulata	+	−	−	−	−	−	−
	Galaxaura sp.	+	−	−	−	−	−	−
	Gelidium micropterum	−	+	−	−	−	−	−
	Gelidiella acerosa	+	−	−	−	−	+	+
	Gracilaria crassa	+	−	−	−	−	−	−
	Gracilaria debilis	+	−	−	+	−	−	+
	Gracilaria dura	+	+	+	−	−	+	+
	Gracilaria edulis	+	−	−	−	−	−	−
	Gracilaria salicornia	−	−	+	−	−	−	−
	Gracilaria textorii	−	−	−	−	−	−	+
	Grateloupia indica	−	−	+	−	−	−	−
	Halymenia floresii	+	−	−	−	−	−	−
	Halymenia venusta	+	+	+	−	−	−	+
	Hypnea pannosa	−	+	+	−	−	+	−
	Hypnea valentiae	−	+	−	−	−	−	+
	Jania rubens	+	+	+	−	−	+	−
	Laurencia obtusa	−	−	−	−	−	−	−
	Liagora ceranoides	+	−	−	−	−	+	−
	Liagora viscida	+	−	−	−	−	−	−
	Peyssonnelia obscura	+	+	+	−	−	+	+
	Platysiphonia delicata	+	+	+	−	−	−	−
	Polysiphonia sp.	−	−	−	−	−	−	+
	Porphyra vietnamensis	+	−	−	−	−	−	−
	Portieria hornemannii	+	+	+	+	+	+	+
Coralline algae	*Lithophyllum* sp.	+	−	−	−	+	−	+
	Lithothamnion sp.	+	+	−	−	−	+	−
	Lobophora sp.	+	−	+	+	−	−	+
	Hydrolithon sp.	+	−	+	−	+	+	+
	Mesophyllum sp.	+	+	−	+	−	−	+
	Neogoniolithon sp.	+	−	+	−	+	+	−
	Palmophyllum sp.	+	−	+	−	+	−	+
	Peyssonnelia obscura	+	+	−	−	−	+	−
	Porolithon sp.	+	−	−	+	−	+	+
	Sporolithon sp.	+	−	+	−	+	−	+
Seagrasses	*Cymodocea rotundata*	+	+	+	−	+	+	+
	Cymodocea serrulata	+	+	+	−	+	+	+
	Enhalus acoroides	+	+	+	+	+	+	+
	Halophila decipiens	−	−	+	−	−	−	−
	Halophila minor	−	−	+	−	−	−	−
	Halophila ovalis	+	+	+	+	+	+	+
	Halophila ovata	+	+	+	+	+	+	+
	Halodule pinifolia	−	+	+	−	−	−	−
	Halodule uninervis	+	+	+	+	+	+	+
	Syringodium isoetifolium	+	+	+	+	+	+	+
	Thalassia hemprichii	+	+	+	−	+	+	+
	Thalassia testudinum	+	+	+	−	−	−	+
Mangroves	*Avecinnia marina*	+	+	+	−	−	−	−
	Bruguiera gymnorhiza	−	+	−	−	−	−	−
	Ceriops tagal	+	+	−	−	−	−	−
	Exocoecaria indica	−	+	−	−	−	−	−
	Luminitzera racemosa	+	−	−	−	−	−	−
	Rhizophora mucronata	−	+	−	−	−	−	−
Cyanobacteria	*Lyngbya majuscula*	+	−	−	+	+	+	−
	Symploca hydnoides	+	+	+	−	−	−	−
	Synechococcus sp.	−	−	−	−	−	−	+
	Trichodesmium erythraeum	+	+	+	+	+	+	+
Sponges	*Axinella cannabina*	−	−	+	−	−	−	−
	Clathria gorgonoides	+	−	+	−	−	−	−
	Oceanapia saggitaria	+	−	+	−	−	−	−
	Neopetrosia sp.	+	−	−	−	−	−	−
	Stylissa massa	+	−	+	−	−	−	−
	Terpios hoshinota	+	+	−	−	−	−	−
	Verongula rigida	−	+	−	−	−	−	−
	Cliona viridis	+	+	+	−	−	−	−
	Haliclona sp.	+	+	+	+	+	+	+
	Thalysia sp.	−	−	+	−	−	−	−
	Siphonodictyum	+	+	+	−	−	−	−
	Holopsamma sp.	+	+	+	−	+	−	+
	Polymastia sp.	−	−	−	−	−	−	+
	Spheciospongia sp.	+	+	+	+	+	+	+

(*continued on next page*)

Table 1 (*continued*).

Type	Species	Island						
		HI	MI	MPI	POI	PUI	KI	SI
Cnidarians	*Aurelia aurita*	+	−	−	−	−	−	−
	Beroe sp.	−	−	+	−	−	−	+
	Carybdea sp.	+	−	−	−	−	−	−
	Cassiopea cf. *andromeda*	+	−	+	−	−	+	−
	Chiropsalmus	−	−	−	−	−	−	−
	Chrysaora caliparea	+	+	+	+	+	+	+
	Crambionella stuhlmanni	+	−	−	−	−	−	−
	Lychnorhiza malayensis	+	−	−	−	−	−	−
	Mastigias cf. *papua*	+	−	−	−	−	+	−
	Phyllorhiza punctata	+	−	+	−	−	+	+
	Rhizostoma	+	−	−	−	−	−	−
	Rhopilema cf. *hispidum*	+	−	−	−	−	−	−
	Pelagia noctiluca	+	+	+	−	−	−	−
	Physalia utriculus	−	−	−	−	−	+	−
	Obelia sp.	+	+	+	+	+	+	+
	Halocardyle sp.	+	+	−	+	+	+	+
	Stichodactyla haddoni	+	+	+	−	+	+	+
	Stichodactyla sp.	+	+	−	−	−	+	−
	Stichodactyla sp.	+	−	−	−	−	−	−
	Stichodactyla sp.	+	−	−	−	−	−	+
	Pachycerianthus sp.	−	−	+	−	−	−	−
	Protopalythoa sp.	−	−	−	−	−	−	+
	Palythoa tuberculosa	−	+	−	−	−	−	+
Corals	*Sarcophyton* sp.	+	+	+	+	−	+	+
	Lobophytan sp.	+	+	−	−	+	+	−
	Gorgonian	+	−	+	−	−	−	+
	Sinularia sp.	+	+	−	−	−	+	+
	Subergorgia suberosa	+	+	−	−	−	−	−
	Acropora cytherea	+	−	−	−	−	−	−
	Acropora digitifera	+	+	−	−	−	+	+
	Acropora formosa	+	+	+	+	+	+	+
	Acropora gemmifera	+	+	−	−	−	+	+
	Acropora humilis	+	+	−	−	−	+	+
	Acropora hyacinthus	+	+	−	−	+	+	+
	Acropora millepora	+	−	+	−	−	+	+
	Acropora nobilis	+	−	−	−	−	−	−
	Acropora valenciennesi	+	−	−	−	−	−	−
	Montipora aequituberculata	−	+	−	−	−	−	+
	Montipora digitata	+	+	+	+	+	+	+
	Montipora foliosa	+	+	+	−	−	+	+
	Pavona decussata	−	+	−	−	−	−	−
	Pavona explanulata	−	−	−	−	−	+	−
	Turbinaria mesenterina	+	+	+	+	+	+	+
	Dipsastraea favus	+	+	+	−	+	+	+
	Favia pallida	+	+	+	−	−	+	+
	Dipsastraea speciosa	+	+	+	+	+	+	+
	Echinopora lamellosa	−	+	+	−	−	+	+
	Favites abdita	+	+	+	−	−	+	+
	Favites complanata	+	+	−	−	−	+	−
	Favites halicora	+	−	+	−	−	+	+
	Favites pentagona	+	−	−	−	−	−	−
	Favites spinosa	−	+	−	−	−	+	+
	Goniastrea pectinata	+	−	−	−	−	−	−
	Goniastrea retiformis	+	+	+	+	+	+	+
	Hydnophora exesa	+	+	−	−	−	+	+
	Hydnophora microconos	+	+	−	−	−	+	+
	Leptoria phrygia	+	−	−	−	−	+	−
	Platygyra daedalea	+	−	−	−	−	−	−
	Platygyra lamellina	+	+	−	−	−	+	−
	Merulina ampliata	+	−	−	−	−	+	+
	Symphyllia radians	−	−	−	−	−	−	+
	Siderastrea sp.	+	+	−	−	+	+	+
	Galaxea fascicularis	+	+	+	−	−	+	+
	Pocillopora damicornis	+	+	+	−	−	+	+
	Stylophora pistillata	+	+	+	−	−	+	+
	Goniopora planulata	+	+	+	−	−	+	+
	Porites compressa	+	+	+	+	+	+	+
	Porites cylindrica	+	+	−	−	−	+	+
	Porites lichen	+	+	+	+	−	+	+
	Porites lutea	+	+	+	+	+	+	+
	Porites solida	+	+	+	+	+	+	+
	Psammocora contigua	−	−	+	−	−	+	−
	Siderastrea savignyana	+	−	−	−	−	−	−

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Table 1 (*continued*).

Type	Species	Island						
		HI	MI	MPI	POI	PUI	KI	SI
Annelids	*Odontosyllis* sp.	−	−	+	−	−	−	−
	Sabellastarte indica	−	+	−	−	−	−	−
	Pseudoceros concinnus	+	−	+	−	−	−	−
	Chloeia flava	+	−	−	−	−	−	−
	Spirobrancho sp.	+	−	−	−	−	−	−
	Terebella sp.	−	−	+	−	−	−	−
Arthropods	*Atergatis* sp.	+	−	−	−	−	−	−
	Dardanus megistos	−	−	−	−	−	−	+
	Dotilla myctiroides	+	−	−	−	−	−	−
	Grapsus sp.	−	+	−	−	−	−	−
	Portunus pelagicus	+	−	+	−	−	+	+
	Portunus sanguinolentus	+	+	+	−	−	−	−
	Xanthid crab	−	+	−	−	−	−	−
	Balanus	+	−	+	−	−	−	−
	soldier carb	−	−	−	−	−	−	+
	Huenia heraldica	−	−	−	−	−	+	−
	Periclimenes brevicarpalis	+	+	−	−	−	−	−
	Pseudosquilla ciliata	+	−	−	−	−	−	−
	Panulirus versicolor	−	−	−	−	−	−	+
Molluscs	*Malleus malleus*	+	+	−	−	−	+	+
	Pinna sp.	+	−	+	−	−	−	−
	Chiton	+	−	−	−	−	−	−
	Plachobranchus ocellatus	−	−	+	−	−	−	−
	Pseudoceros gamblei	+	−	−	−	−	−	−
	Clypeomorus sp.	−	−	+	−	−	−	−
	Dendropoma sp.	+	−	−	−	−	−	−
	Lambis lambis	+	−	−	−	−	−	−
	Balanus reticulatus	+	+	+	+	+	+	+
	Lepas sp.	+	−	−	−	−	−	+
	Chthamalus stellatus	−	+	−	−	−	−	−
	Chelonibia testudina	+	−	−	−	−	−	−
	Drupella cornus	+	−	+	−	−	−	−
	Trochus maculatus	+	+	+	−	−	−	−
	Lambis lambis	+	+	−	−	−	−	−
	Stombus canerium	+	−	−	−	−	−	−
	Cyprea tigris	+	−	−	−	−	−	−
	Pinna bicolor	+	−	−	+	−	−	−
	Pinctada margaritifera	+	−	−	−	−	−	−
	Pteria penguin	+	−	−	−	−	−	−
	Crassostrea madrasensis	+	−	−	+	−	−	−
	Turbo radiatus	+	+	+	−	+	+	+
	Xancus pyrum	+	+	−	+	−	−	−
	Sepia pharaonis	+	−	−	−	−	+	+
	Octopus sp.	−	−	−	−	−	+	−
	Discodoris boholiensis	−	−	−	−	−	+	−
	Elysia grandifolia	+	−	−	−	−	−	−
	Haminoea ovalis	+	−	−	−	−	−	−
	Jorunna funebris	+	−	−	−	−	−	−
	Onchidium sp.	−	+	−	−	−	−	−
	Plakobranchus ocellatus	+	−	+	−	−	−	−
	Aplysia dactylomela	−	+	−	−	−	−	−
Echinoderms	*Diadema setosum*	−	−	+	−	−	−	−
	Echinothrix diadema	+	−	−	−	−	−	−
	Echinothrix calamaris	−	−	+	−	−	−	−
	Salmacis virgulata	+	−	−	−	−	−	−
	Stomopneustes variolaris	+	+	+	+	+	+	+
	Temnopleurus toreumaticus	+	−	−	+	−	−	−
	Protoreaster lincki	−	+	−	−	−	−	−
	Pentaceraster mammillatus	+	+	−	−	−	−	−
	Ophiocoma brevipes	+	−	−	−	−	−	+
	Ophiactis savignyi	+	−	−	−	−	−	−
	Oligometra serripinna	−	+	−	−	−	−	−
	Bohadschia marmortrata	−	+	−	−	−	−	−
	Holothuria artra	+	+	+	−	−	−	−
	Holothuria scabra	+	+	+	−	−	−	−
Ascidians	*Cystodytes* sp.	+	−	−	−	−	−	−
	Didemnum molle	−	−	−	−	−	−	+
	Didemnum sp.	−	−	−	−	−	+	−
	Distaplia nathensis	+	−	−	−	−	−	−
	Diplosoma sp.	+	−	−	−	−	+	+

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Table 1 (*continued*).

Type	Species	Island						
		HI	MI	MPI	POI	PUI	KI	SI
Fishes	*Hippocampus fuscus*	+	+	−	−	−	−	−
	Syngnathoides biaculeatus	+	−	−	−	−	−	−
	Acanthurus nigricauda	+	−	−	−	−	−	−
	Acanthurus auranticavus	+	−	−	−	−	−	−
	Acanthurus grammoptilus	+	−	−	−	−	+	−
	Acanthurus sp.	+	−	−	−	−	−	−
	Apogon angustatus	+	−	+	−	−	−	−
	Abudefduf bengalensis	+	−	−	−	−	+	+
	Abudefduf notatus	+	+	+	−	−	−	−
	Abudefduf saxitalis	+	+	+	−	−	−	−
	Abudefduf sorbidus	+	−	−	−	−	+	+
	Archamia fucata	−	−	−	−	−	+	+
	Sphyraena sp.	+	+	+	−	−	−	−
	Coris dorsomacula	+	−	−	−	−	−	−
	Chlorurus bleekeri	+	−	+	−	−	−	−
	Cetoscarus bicolor	+	−	−	−	−	−	−
	Chrysiptera	+	−	−	−	−	−	−
	Cymbacephalus sp.	−	−	−	−	−	−	+
	Diodon liturosus	+	−	−	−	−	−	−
	Lactoria cornuta	+	−	−	−	−	−	−
	Arothron hispidus	−	−	+	−	+	−	−
	Monodactylus argenteus	+	−	−	−	−	−	−
	Melichthys niger	+	+	+	−	+	+	+
	Gymnomuraena zebra	+	−	−	−	−	−	+
	Gymnothorax favagineus	+	−	−	−	−	−	−
	Gnathanodon speciosus	+	−	−	−	−	−	−
	Gnathodentex aureolineatus	+	−	−	−	−	−	−
	Holocentrus rufus	+	−	−	−	−	−	−
	Hologymnosus annulatus	+	−	−	−	+	+	+
	Echidna sp.	−	−	−	−	+	−	+
	Epinephelus bleekeri	+	−	−	−	−	−	−
	Epinephelus merra	+	−	+	−	−	+	+
	Epinephelus tauvina	−	−	+	−	−	−	−
	Cheilodipterus macrodon	+	+	+	−	−	−	−
	Cheiiodipterus quinquelineatus	+	+	−	−	−	−	−
	Halichoeres nigrescens	+	−	−	−	−	−	−
	Halichoeres centriquadrus	+	−	−	−	−	−	−
	Lethrinus sp.	+	−	−	−	−	−	−
	Lutjanus bohar	+	−	−	−	−	−	−
	Lutjanus decussatus	+	−	+	−	−	−	−
	Lutjanus fulvus	+	−	−	−	−	−	−
	Lutjanus fulviflammus	−	−	+	−	−	−	−
	Lutjanus monostigma	+	+	+	−	−	−	−
	Lutjanus stellatus	+	−	−	−	−	−	−
	Parupeneus indicus	+	−	−	−	−	−	−
	Monodactylus argenteus	+	−	−	−	−	−	−
	Pempheris moluca	+	−	−	−	−	−	−
	Pempheris vanicolensis	−	−	−	−	+	+	+
	Plectorhynchus unicolor	−	−	−	−	−	−	+
	Neoglyphidodon melas	+	+	+	+	+	+	+
	Chaetodon collare	+	−	+	−	−	−	−
	Chaetodon baronessa	+	−	+	−	−	−	−
	Chaetodon octofasciatus	+	+	+	+	+	+	+
	Chaetodon decussatus	−	−	+	−	−	−	−
	Cheatodon lineolatus	+	−	−	−	−	−	−
	Chaetodon andamanensis	+	+	+	−	−	+	+
	Halichoeres argus	+	−	+	−	−	−	−
	Halichoeres sp.	+	−	−	−	−	−	−
	Arothron hispidus	−	+	+	−	−	−	−
	Diodon liturosus	+	−	−	−	−	−	−
	Canthigaster margaritata	−	−	+	−	−	−	−
	Fistularuz	+	−	−	−	−	−	−
	Pentapodus sp.	+	−	−	−	−	−	−
	Plectorhinchus gibbosus	+	−	−	−	−	−	−
	Pseudodax moluccanus	+	−	−	−	−	−	−
	Pterois miles	+	−	−	−	−	−	+
	Sargocentron rubrum	−	−	−	−	−	+	+
	Scarus rivulatus	+	−	−	−	−	−	−
	Scolopsis ghanam	+	−	−	−	−	−	−
	Siganus lineatus	+	−	−	−	−	+	+
	Synodus variegatus	+	+	+	−	−	−	−
	Zebrasoma desjardinii	+	−	−	−	−	+	−
	Thalassoma sp.	+	−	−	−	−	−	−

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Table 1 (*continued*).

Type	Species	Island						
		HI	MI	MPI	POI	PUI	KI	SI
	eel yellow band common	+	−	−	−	−	+	−
	Himantura uarnak	−	+	−	−	−	−	−
	Himantura marginata	−	−	−	−	−	−	+
	Taeniura lymna	−	+	−	−	−	−	−
Reptiles	*Chelonia mydas*	+	−	−	−	−	−	−
	Lepidochelys olivaceea	+	+	−	−	−	−	−
	Hydrophis cyanocinctus	+	+	−	−	−	−	−
Seabirds	*Sterna sumatrana*	+	+	+	−	−	−	−
	Haliastur indus	+	+	+	−	−	+	+
	Milvus migrans	+	−	−	−	−	−	−
	Himantopus himantopus	−	+	−	−	−	−	−
	Phalacrocorax fuscicollis	+	+	+	−	−	−	−
	Egretta garzetta	−	+	−	−	−	−	−
	Mesophoyx intermedia	−	+	−	−	−	−	−
	Ixobrychus cinnamomeus	−	+	−	−	−	−	−
	Scolopacidae	+	+	+	−	−	−	+
	Anser sp.	+	−	−	−	−	−	−
	Halcyon smyrnensis	−	+	−	−	−	−	−
	Pavo cristatus	−	−	−	−	−	+	−
Mammals	*Dugong dugon*	−	−	−	−	−	+	−
	Sousa chinensis	−	−	−	−	−	+	−
	Grampus griseus	+	−	−	−	−	−	−
	Tursiops aduncus	+	+	−	+	−	−	−

Table 2
Univariate community parameters of reefs around seven islands in Mandapam.

Stations	d	J'	H'($\log^2$)	1-Lambda'
HI	3.277	0.9056	3.776	0.9132
MI	3.397	0.8952	3.659	0.9158
MPI	2.973	0.9706	3.792	0.932
POI	2.712	0.9262	3.32	0.9012
PUI	2.355	0.918	3.176	0.8865
KI	2.957	0.8807	3.441	0.8984
SI	2.695	0.9208	3.506	0.8999

Cluster analysis of samples and variables clearly formed these two components into one cluster (Figs. 5 & 6). NMDS 2D plot based on Bray–Curtis similarity revealed five distinct clusters of variables, of which, cluster 1 clearly displayed the relationship between coral and algal interactions. Whereas, cluster 2 forms mangroves and seabirds into a distinct cluster that pertains to stations MI & MPI (Fig. 6). Heat map analysis has clearly displayed the maximum diversity and distribution pattern in Hare Island (Fig. 7). The extensive underwater visual observations made in this study indicated that there was significant change in reef fish community composition and abundance, which was apparently related to massive bleaching event occurred during summer 2019 due to elevated sea surface temperature (Table 3). The abundance of fish diversity is found to associate with live coral reefs than the dead reefs and sedimented reefs. Thus the influence of bleaching events, algal invasion, and sedimentation impact on fish diversity and abundance is need to be validated from these islands. The present status of species diversity in Mandapam group islands shows declined diversity when compare to typical or iconic coral reefs found elsewhere (Díaz-Pérez et al., 2016).

Overall, all the study sites were found with rich algal diversity than other faunal components like invertebrates and fishes (Table 1). Algae were abundant in Hare, Krusadai, Shingle Islands (>90%), and followed by Manoliputti and Pullivasal Islands (>80%). Generalized linear model (GLM) analysis performed based on Poisson distribution using log link function has revealed significance impact of algae on fish diversity ($P = 0.0001$; $R^2 = 0.5932$) than cnidarian diversity ($P = 0.0001$; $R^2 = 0.6838$). Likewise, the variable cnidarians are appear to influence on the diversity of reef fish ($P = 0.041$; $R^2 = 0.7899$) (Fig. 8). Maximum diversity and abundance of corals was observed at Hare, Shingle and followed by Krusadai Islands. Hard coral assemblages were very heterogeneous and variable among sites. This is in accordance with previous study by Sukumaran and George (2010). However, the present study shows high H' value (3.441) than previous study, which is due to more number of transects investigated in this study than in previous study (3.04) by Sukumaran and George (2010). Based on comparative studies with earlier reports (Usha et al., 2001), and with present study data, the biodiversity of GOMMBR is known to be declined over the decades, indicating the role of climate change in declining diversity in GoM. Apparently, based on previous studies (Usha et al., 2001; Sukumaran and George, 2010) and present study, there was remarkable coral recruitment and survival pattern observed in different islands of Mandapam, where Hare island was found with maximum diversity of corals (25 species) in 2001, Krusadai Island (35 species) in 2010, and again Hare Island with 46 species during 2019. This evidence shows that environmental threats are playing a significant role in sustaining the biodiversity and their survival in GoM. Study sites with low coral cover indicate any of the following threats such as bleaching events, sedimentation, algal assemblage, destructive waves, and fishing activities. Based on arbitrary units, sedimentation is more during monsoon in the year 2018 at northern sides of all islands and the sediment deposition trend is changed to southern sides of all islands during summer 2019. Thus further studies on the effect of sedimentation and current patterns on corals are imperative for better understanding negative impacts on reef diversity. Depth was also appear to influence the rich diversity of reef associated algae, invertebrates, fish as well as coral species composition in the Mandapam group of Islands. Depth wise, Manoli (2.46 m) and Krusadai (1.91), Shingle (1.62) Islands were represented with more diversity of fish, algae, invertebrates and corals than the other islands. However, these important visual observations are needs to be assessed in further studies to understand the depth mediated biodiversity linked to multiple parameters.

Factors such as temperature, wave intensity-exposure and current speed in some study sites with shallow and deeper depths at Hare Island, Krusadai Island and Shingle Island were appear to play an important role in the survival of coral reefs. These factors are directly linked and contribute to the appearance of healthy or damaged reef diversity. The reef patches in shallow sites of all study areas were almost affected due to high light

Table 3
Average values of environmental parameters such as pH, salinity, dissolved oxygen, and temperature recorded during monsoon and summer seasons.

Month year	Season	pH	Depth	Salinity	HDO	Temp
Aug-19	Monsoon	8.01 ± 0.11	1.54 ± 0.56	36.05 ± 0.73	6.70 ± 0.84	29.46 ± 0.47
Sep-19	Monsoon	8.01 ± 0.09	1.87 ± 1.14	35.89 ± 0.86	6.19 ± 0.35	29.61 ± 0.76
Oct-19	Monsoon	8.11 ± 0.05	1.7 ± 0.80	35.7 ± 1.12	6.2 ± 0.41	30.05 ± 0.52
Nov-19	Monsoon	8.2 ± 0.10	0.97 ± 0.30	33.82 ± 0.34	6.57 ± 0.39	29.04 ± 0.49
Dec-19	Monsoon	8.17	1.42	32.12	5.5	30.05
Feb-19	Summer	7.42 ± 0.20	1.29 ± 0.25	32.21 ± 1.57	6.57 ± 2.07	29.47 ± 0.36
Apr-19	Summer	7.49 ± 0.16	1.38 ± 0.41	34.14 ± 0.56	6.52 ± 0.68	31.6 ± 0.80
May-19	Summer	7.47 ± 0.09	1.58 ± 0.47	36.51 ± 0.15	5.86 ± 0.51	31.42 ± 2.69
Jun-19	Summer	7.48 ± 0.04	1.03 ± 0.47	36.03 ± 0.05	6.77 ± 0.33	31.41 ± 0.49

intensity, sediment deposition and subsequently profuse algal growth. A recent study observed the daily sediment deposition rate of 24.79 mg cm^{-2} d^{-1} at Krusadai Island (Dinesh, 2018). However, detailed studies on sediment deposition rate around the seven islands are needed to be conducted to study the actual impact of sediment on coral reefs in Mandapam region. Recent studies have demonstrated the algal interactions with live and dead coral reefs, and indicated the negative impact of algal communities on the survival of corals (Manikandan and Ravindran, 2017; Machendiranathan et al., 2016), which in turn could undoubtedly interrupt the ecological balance of species composition in reef areas of the seven islands in Mandapam. The impact of algae and sediment deposition on reef biodiversity were not assessed in this study since previous studies have already demonstrated such aspects (Manikandan and Ravindran, 2017; Machendiranathan et al., 2016; Dinesh, 2018).

The deeper reef sites such as in Shingle and Krusadai Islands were found with well diversified reef fauna and flora. In contrast to the other studies from Indo-Pacific, Europe, America, Red Sea, and Australia, the present study shows decline of reef diversity in context of climate change. Damage of coral reef patches via rough waves and current pattern are frequent and significantly more in some study sites around Shingle and Krusadai Islands. This study emphasizes the research gaps of sediment deposition rates, depth mediated diversity changes, and impact of environmental variables on biodiversity with respect to depth and geography that are needed to be assessed further from coral reefs of Gulf of Mannar Islands. These identified lacunas will help to understand the relationship between corals and environmental changes and to develop protection measures for biodiversity conservation in GoM.

Evidently, algal assemblages are increasing in the Mandapam group of islands, and also the fish diversity is being decreased in reef areas when compared to the typical habitats. We hypothesize that the underlying reasons behind the reduced reef faunal diversity is possibly due to migration of faunal species from shallow water reefs to deeper waters. Such incidence of shift of shallow water reef fish to deeper water was stated as disappearance of shallow water reef fish such as *Lutjanus lutjanus, L. malabaricus, Pterois russelii, Sargocentron rubrum, Scarus ghibbus,* and *Siganus canaliculatus* and their abundant appearance in deeper water (over 20 m depth) (Edward et al., 2017). Nevertheless, further studies are needed to demonstrate the above hypothesis and statement. We believe that this migration is primarily due to by deterrent activity caused by dense algal assemblages of invasive seaweed genera such as *Caulerpa*, *Kappaphycus*, *Turbinaria*, and *Sargassum* which are known to produce deterrent chemicals (Ramesh et al., 2019). Previous studies also indicated that deterrent activity of algae (Stiger et al., 2004) or loss of coral reefs (Pratchett et al., 2011) causes shift of reef diversity or reduced biodiversity, especially decline of fish diversity (Ainsworth and Mumby, 2015). Results of this study indicate that high sediment deposition, declined population of herbivorous sea urchin like *Diadema* sp. and overfishing of herbivorous fish in the reef environments might be responsible for abundant algal growth and declined invertebrate and fish communities in Mandapam group of Islands. On the other hand, a study indicated that high diversity of reef-dwelling organisms is linked to reef areas with high amount of crustose coralline algae (Weiss and Martindale, 2017). The present study observations reinforce and in accordance with previous study by Weiss and Martindale. Also, parrotfishes are known to play significant role in structuring the reefs by either grazing on algae or corals (Johnson et al., 2019). A previous study demonstrated that reef areas with abundant fish community had low abundance of algal assemblage (Hughes et al., 2007). Considerably, removal of herbivorous fish from reef areas resulted outburst of algal growth which inhibited coral fecundity, resilience, and survival (Hughes et al., 2007). These observations are in coincidence with the present study, where parrotfish abundance and diversity was observed very less in the study areas, indicated that reef diversity is severely threatened by multifactorial impacts including fishing. Less abundance of reef fish in the present study sites is possibly either due to overfishing or shifts to deeper waters. An earlier study from Sri Lanka inferred that habitat alteration in reef fish communities was due to destructive fishing (Öhman et al., 1997). Therefore conservation of reefs by effective fishing management practices is urgent to prevent phase shifting of reef biodiversity caused by potential threats and abundant algal assemblages.

4. Conclusions

We infer that faunal biodiversity of shallow water fringing reefs in the Mandapam group of Islands has declined when compared with typical reef ecosystems. The depletion of coral associated fauna is observed to be due to increasing temperatures, sedimentation, macroalgal invasion, and species migration to deeper water. Significantly, algal dynamics are showing potential threat to reef resilience via competition for space. Therefore, in current scenario of climate change, it is imperative to monitor the interactions between algal and faunal diversity on reef flats of Mandapam region. Further research on gap areas such as comparative studies on reef fish abundance patterns in dead reefs, sedimented reefs, and healthy reefs is needed to be studied. Also, correlation between fish abundance and temperature and bleaching events is needed to be analyzed. The increasing algal dynamics in reef areas is further to be quantified for effective reef management. Also, it is essential to practice effective conservation and management steps to facilitate the healthy reef environment by involving researchers, local fisher folk, conservators, policy makers and industries. Further, the present study information will helpful to make decisions on conservation and utilization of reef associated biodiversity for sustainable livelihood.

CRediT authorship contribution statement

CH. Ramesh: Conceived and designed the experiments, Performed the field stud, Analyzed the data, Wrote the paper. **S. Koushik:** Performed the field studies, Wrote the paper. **T. Shunmugaraj:** Conceived and designed the experiments, Performed the field studies, Wrote the paper. **M.V. Ramana Murthy:** Wrote the paper.

Declaration of competing interest

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

Acknowledgments

We are thankful to the Ministry of Earth Sciences, New Delhi, for financial support. We also thank Chief Wildlife Warden, Department of Environment and Forest, Government of Tamil Nadu for granting research permissions.

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