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Original Article

Different coral compositions reflect contrasting environmental patterns of inshore and offshore reef habitats in Thailand

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Abstract

Studies of inshore and offshore coral reef systems usually conclude that there are fundamental differences between them assuming that terrigenous influences diminish with distance from the mainland. However, with few exceptions reefs in Thailand are fringing reefs around continental islands, whether inshore or offshore. We describe patterns in coral community composition along a 70 km transect from the mainland to offshore islands in the southern Andaman Sea. We found that coral assemblages are comprised of two basic types. Differences in coral assemblages were associated with obviously different environmental conditions, including underwater visibility and level of suspended matter, which were not always aligned with distance from the mainland. While reef communities were quite variable between sites, the inshore coral assemblages tended to be characterized by higher numbers of *Montipora, Pectinia, Podabacia, and Acropora* compared to reefs around offshore islands. Offshore reefs were characterized by a relatively high number of *Lobophyllia* and *Plerogyra* colonies. The expected relationship between water quality and sensitive indicator groups like *Acropora* did not materialize with *Acropora* and *Montipora* being more common inshore. While there were strong inshore-offshore reef habitat differences in environmental conditions and reef communities in southern Thailand, they were not consistent with expectations from the literature.

Keywords: coral community, terrestrial influence, Andaman Sea, Satun Province, turbidity

1. Introduction

Proximity to terrestrial influences can substantially alter reef environments across a distance from the mainland (Cooper *et al.*, 2007; De'ath, 2007; Fabricius, 2005; Fabricius *et al.*, 2012). Coastal waters generally have a higher nutrient concentration and higher amounts of suspended terrigenous sediment than waters further from the mainland (Boyer & Briceño, 2006; Brodie, 2005; Cooper *et al.*, 2007; De'ath, 2007; Devlin & Fabricius, 2005; Schaffelke *et al.*, 2012). A terrestrial runoff from the adjacent catchments leads coastal waters to have elevated nutrient concentrations, extreme terrigenous sediment, and high amounts of dissolved matter, and suspended particulate matter (Fabricius, 2005; Schaffelke *et al*., 2012). Also, a phytoplankton biomass increases in high nutrient level conditions, which reduces the level of light irradiance through the water column (Fabricius, 2005). Where terrestrial influences are less, offshore reefs tend to experience clearer waters due to lower amounts of resuspended sediment. Nutrient and sediment levels tend to be lower and the light transmission parameter is inversely related with nutrient and sediment level (Cooper *et al*., 2007; Fabricius, 2005; Fabricius *et al*., 2012; Lirman & Fong, 2007; McCook, 2001; Schaffelke *et al*., 2012). In general, these broad trends in

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water quality parameters have characterized the inshore and offshore environments.

Differences in reef community composition and structure are often attributed to environmental gradients (Cleary *et al.*, 2006; Done, 1982; Fabricius *et al.*, 2012; Smith *et al.*, 2008). As such, it is expected that the composition and nature of coral communities will change along a water quality gradient associated with distance from the mainland which is the source of sediment and nutrients. Typically, a variation in coral reef characteristics between the inshore and offshore reefs assumes that terrigenous influences diminish with distance from the mainland to reveal a response of coral assemblages to terrestrial influence. The species richness and coverage of corals tend to be lower in coral communities adjacent to the terrestrial influence compared to the farther reefs. This trend was consistent in the Great Barrier Reef (Done, 1982; Fabricius *et al.*, 2012), Indonesia (Cleary *et al.*, 2005, 2008), and at the US Virgin Islands (Smith *et al.*, 2008). Interestingly, the Florida key reefs showed the reverse trend where the highest coral cover was in the inshore reefs and decreased significantly in the farther reefs (Lirman & Fong, 2007). Moreover, *Goniopora*, *Montipora*, *Galaxea*, *Porites* (Done, 1982) and *Turbinaria* (Fabricius *et al.*, 2012) were plentiful in the coral compositions of reefs close to the mainland. However, communities in the reefs distant from the mainland tended to be dominated by the coral genus *Acropora* spp. (Done, 1982; Fabricius *et al.*, 2012) or a high coverage of *Lobophyllia* compared to inshore reefs (Fabricius *et al.*, 2012).

The results of these studies have concluded the fundamental differences in coral communities between inshore and offshore reef systems. The systems described in these studies are lagoonal systems behind barrier reefs or atoll reef systems assuming that terrigenous influences diminish with distance from the mainland (Adjeroud *et al.*, 2010; Boyer & Briceño, 2006; Cleary *et al.*, 2008; Cooper *et al.*, 2007; Done, 1982; Fabricius, 2005), but the reefs in Thailand are continental island fringing reefs. Whether the reefs are inshore or offshore, they are still exposed to some level of terrestrial influence (Phongsuwan *et al.*, 2013). Therefore, studies of the literature of inshore and offshore reef systems in the other regions might create a false expectation of the nature of reef systems in Thailand. To test that hypothesis, this study aims to define spatial variations in coral communities and a diagnostic suite of community characteristics relevant to the habitat type. Coral community compositions may result from different environmental and physical factors in inshore and offshore habitats. This partly redresses the current lack of ecological knowledge on the key characters of reef habitats in the southern Andaman Sea of Thailand and suggests potential relationships between reef environments and coral communities that will provide key insights for protected area management planning in this area.

2. Materials and Methods

2.1 Study area

The study area was in the continental island fringing reefs located in Satun Province where the coast of southern Thailand is edged by estuaries and mangrove forests. The area of interest consisted of 3 island groups: Tarutao, Bulon, and Adang-Rawi. They exist in the same latitude forming a 70 km east-west transect out from the mainland to offshore (measured from Google Earth) and hypothetically influenced by the gradient of terrestrial influence and terrigenous sediments. Based on this idea, this study established the Tarutao Island group and Bulon Island group as the "inshore" group and Adang-Rawi archipelago as the "offshore" group (Figure 1). The inshore reefs are located from the Satun coast in a range of 10-30 km. According to a report from the Department of Fisheries (1999), the water transparency is 5-8 m according to Secchi disc measurements. The reefs form a narrow reef morphology that is 30-80 meters in width which are quite shallow with a maximal reef depth of 6-8 meters. In addition, the offshore reef is located at a distance of 50-70 km from the Satun coast. The Adang-Rawi reefs form broad reef flats that are often 50-300 m wide and the maximum depth of the reef ranges from 7 to 12 m. The water transparency is 8-15 m according to Secchi disc measurements (Department of Fisheries, 1999).

2.2 Field survey and data collection

A hierarchical sampling design was used to measure spatial variation in the coral assemblages in the southern Andaman Sea region. Within the region, there were two reef habitats. Ten inshore sites and 12 offshore sites were selected in a scattered pattern over the island group to represent communities of the habitats (Figure 1).

The field survey was conducted from December 2013 to July 2014. Three replicates of 25 x 1 m belt-transects were haphazardly laid at constant depth along the upper part of the reef slope zone (1-2 m below the reef edge) following the method of Adjeroud *et al.* (2010) by using a different transect size. Scleractinian colonies up to a distance of 50 cm in the transect area were identified to the generic level. Any colonies that appeared difficult to identify in the field were photographed using a high-resolution underwater camera for later confirmation using taxonomic references (Veron, 2000). The numbers of colonies in each genus were recorded separately.

To document the obvious environmental differences of reef habitat, key characters of the reef site were visually observed during the field data collection. The coastal geography was noted by the observer before descending to the reef. Maximal reef depth was noted by the observer while swimming across the reef to the end. The in situ depth was then recorded using SCUBA instrumentation and substrate type of the reef bottom. The level of underwater visibility, suspended particulate matter, and water motion were observed during the field survey and noted retrospectively with regards to upper and lower bounds of observed conditions after field work in all 22 reef sites was finished. These characters were categorized into 3 levels: low, moderate, and high.

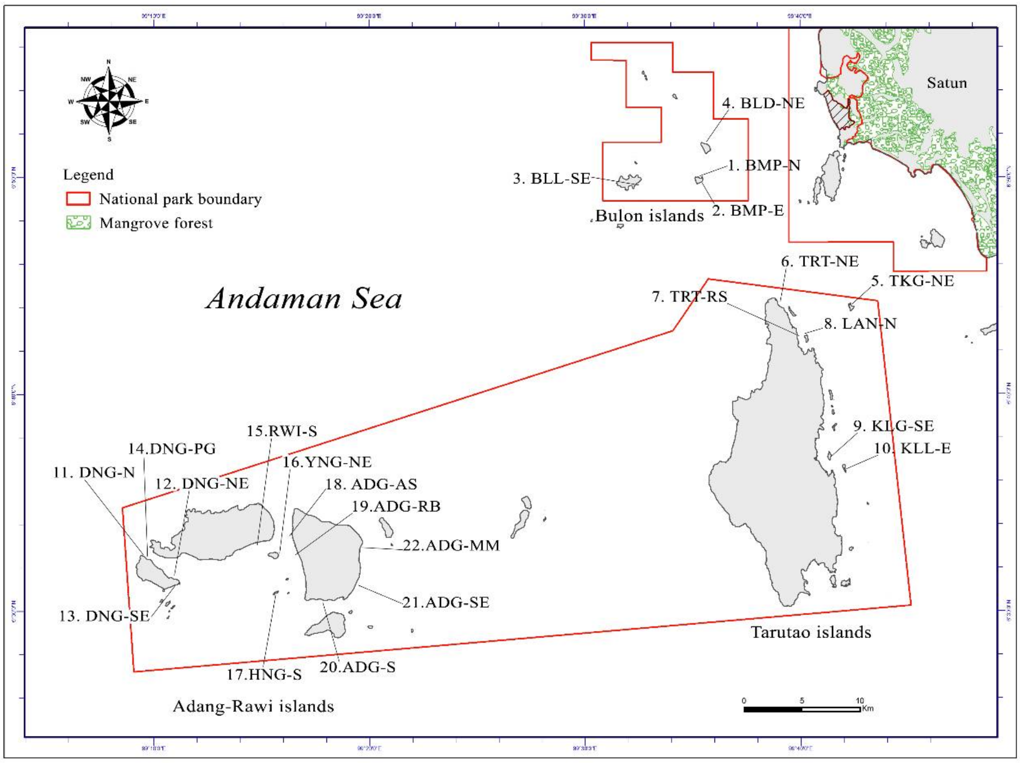

Figure 1. Study sites in the southern Andaman Sea in Satun Province. Ten inshore sites in the Bulon and Tarutao island groups, including BMP-N, North of Bulon Mai Pai Island; BMP-E, East of Bulon Mai Pai Island; BLL-SE, South-East of Bulon Le Island; BLD-NE, North-East of Bulon Don Island; TKG-NE, North-East of Ta Kiang Island; TRT-NE, North-East of Tarutao Island; TRT-RS, Rue Si Bay, Tarutao Island; LAN-N, North of Laen Island; KLG-SE, South-East of Klang Island; KLL-E, East of Klua Lo Island. Twelve offshore sites in the Adang-Rawi island group, including DNG-N, North of Dong Island; DNG-NE, North-East of Dong Island; DNG-SE, South-East of Dong Island; DNG-PG, Dong-Phung Island; RWI-S, South of Rawi Island; YNG-NE, North-East of Yang Island; HNG-S, South of Hin Ngam Island; ADG-AS, Song Bay, Adang Island; ADG-RB, Ruea Bai Bay, Adang Island; ADG-S, South of Adang Island; ADG-SE, South East of Adang Island; ADG-MM, Mae Mai Bay, Adang Island.

2.3 Data analysis

Seven physical characters were used to examine any associations between the reef stations and coral community compositions: 1) distance from the mainland, 2) coastal geography, 3) bottom substrate, 4) visibility, 5) level of suspended matter, 6) maximal reef depth, and 7) water motion. Categorical data for each site were analyzed by Principle Component Analysis (PCA) (Cooper *et al.*, 2007).

The numbers of colonies of each coral genus per transect were averaged (colony/25 m^2) to describe the coral community composition. Since the raw data were heteroscedastic to the point where standard parametric statistics were not possible, the average colony numbers in each transect were transformed by Log x+1 before subjecting them to PCA to examine the association between the coral community compositions amongst the sites. Then, cluster analysis was used to indicate a similarity level of coral assemblages in each group. All multivariate analyses used in this study were investigated using the statistical software PCORD5.10 (McCune & Mefford, 2006).

3. Results and Discussion

3.1 The environmental descriptive differences between inshore and offshore reefs

The PCA of environmental and geological characters across the reef sites highlighted differences between the environmental conditions experienced by coral communities at inshore and offshore sites (Figure 2). On the first axis, the relative suspended particulate matter and distance from the mainland were strongly associated with the differences between inshore and offshore reef sites. Distance and suspended matter vectors are shown in Figure 2. Visibility, bottom substrate, and water motion also secondarily contributed to the inshore-offshore differences. The visibility, bottom, and water motion vectors are shown in Figure 2.

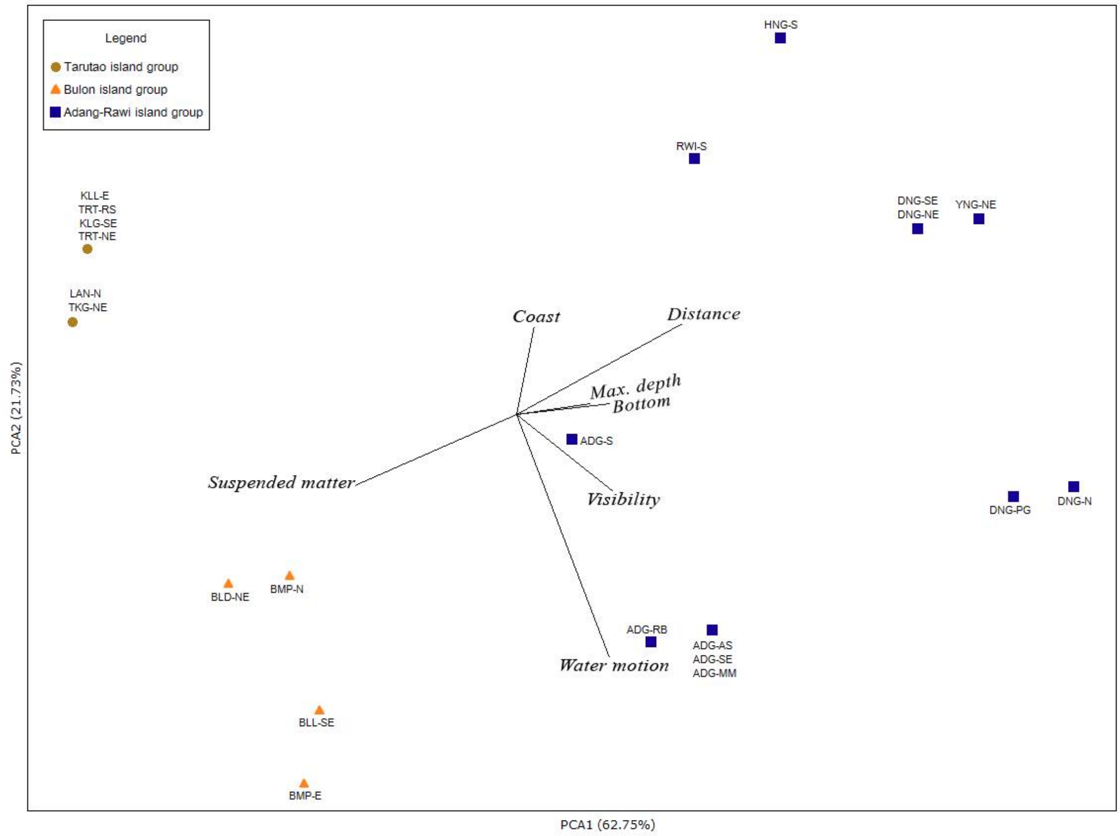

Figure 2. PCA biplot of environmental conditions observed across the reef sites: Distance, distance from the mainland; Suspended matter, level of suspended matter in the water column; Visibility, levels of underwater visibility; Max. depth bottom, maximal depth of reef; Water motion, levels of water motion; Bottom, reef bottom substrate; and Coast, coastal geography.

In the broadest terms, the general characteristics of inshore and offshore reef habitats in this region were associated with distance from the mainland and water turbidity conditions. These generally were consistent with several studies that reported a water quality gradient along the proximity from the mainland (Boyer & Briceño, 2015; Caccia & Boyer, 2005; De'ath, 2007; Fabricius, 2005; Schaffelke *et al.*, 2012). The inshore reefs were located closer to the Satun coast than the offshore reefs and characterized as turbid water environments. The inshore environments typically were low to moderate visibility and had high amounts of suspended matter. The inshore reefs were muddy sand bottom and the maximum depth of the reefs varied from 5 to 8 meters. Within the inshore group, we found subtle differences between the Tarutao and Bulon reefs. The Tarutao reefs tended to be more turbid than the Bulon reefs. The higher turbidity of the Tarutao reefs was possibly due to the proximity to sources of terrestrial influence which were mangrove channels and waterfalls of Tarutao Island that flow through the eastern side of the island. The terrestrial influence from the Tarutao Islands causes the reef environments to be more turbid and have higher suspended matter in the water column. In contrast, the offshore reefs located further from the Satun coast experienced less input from rivers and thus tended to be surrounded by less turbid waters. Moreover, even though the slop of the continental shelf in the southern Andaman Sea is gentle, the offshore group generally was characterized by low to moderate suspended matter, moderate to high visibility, and moderate to strong water motion. The offshore reefs formed a depth range of 6-15 meters with a sandy bottom substrate. Although the water quality indicators of the offshore reefs were quite different to those from the inshore sites, many of the same characteristics of the reefs were apparent. It may be that there is a range of island sizes that are too small to exert significant "terrestrial influences". The nature of the reefs at Tarutao, and to a certain extent at Adang-Rawi, suggest they fall outside that range. This observation may be of some significance when considering the development of islands for tourism, since land use changes are linked to increased discharges of terrigenous sediments and nutrients.

3.2 Coral communities in the southern Andaman Sea of Thailand

In general, the southern Andaman reef is dominated by massive *Porites* in both the inshore and offshore locations, but a PCA result of Log x+1 transformed generic abundance across the 22 reef sites showed a division of coral assemblages into two groups associated with their locations. The first two axes of PCA explained 54.06% of the total variability of the data (Figure 3). The 10 inshore sites in the Tarutao and Bulon island groups were characterized by a higher occurrence of coral genera that included *Montipora, Pectinia*, *Podabacia*, and *Acropora* compared to the other group. The cluster analysis suggested 51% similarity of the generic compositions among the inshore sites. Twelve offshore sites in the Adang-Rawi Islands were included in the other group (Figure 3). They were generally characterized by a presence of *Lobophyllia* colonies and a relatively high number of *Plerogyra* or solitary fungiid corals. Notwithstanding these characteristics, they were not homogenous throughout the group. The cluster analysis suggested only 13% of similarity for generic compositions among reefs within the offshore sites. The coral assemblage compositions of the Rawi Island station (RWI-S), south of Adang Island station (ADG-S), Mae Mai Bay (ADG-MM), South of Hin Ngam Island (HNG-S), and northeast of the Yang Island station (YNG-NE), as highlighted by the dashed boundary in Figure 3, exhibited subordinate characters having low generic richness and low abundance of *Lobophyllia*, *Plerogyra*, and *Fungia* compared to most of the Adang-Rawi reefs and were implicitly different from most of the Adang-Rawi reefs.

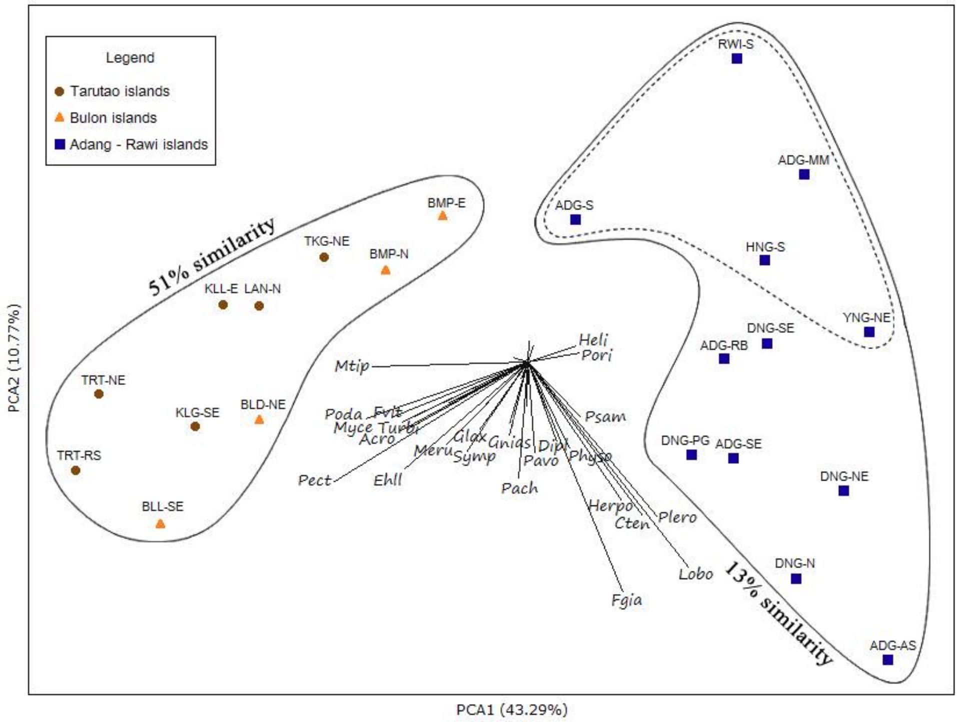

Figure 3. PCA biplot of Log x+1 transformed generic abundance in the 22 reef sites suggested an association among coral genera and reef sites in the southern Andaman Sea. The vectors represent the association of genera on coral community characteristics. Mtip, *Montipora*; Poda, *Podabacia*; Myce, *Mycedium*; Fvit, *Favites*; Turbi, *Turbinaria*; Acro, *Acropora*; Pect, *Pectinia*; Ehll, *Echinophyllia*; Meru, *Merulina*; Glax, *Galaxea*; Symp, *Symphyllia*; Gnias, *Goniastrea*; Pach, *Pachyseris*; Pavo, *Pavona*; Dipl, *Diploastrea*; Fgia, *Fungia*; Physo, *Physogyra*; Herpo, *Herpolitha*; Cten, *Ctenactis*; Lobo, *Lobophyllia*; Plero, *Plerogyra*; Psam, *Psammocora*; Pori, *Porites*; and Heli, *Heliopora*.

Composition patterns amongst the coral assemblages suggest that the southern Andaman coral community is at least partly shaped by the environmental difference of reef localities. However, the fringing reef system in the southern Andaman Sea does not show a strong patterning evident from barrier or atoll reef systems as in other regions. The distribution of *Acropora* corals in this study showed a contradicting pattern to the study of Done (1982) that suggested that *Acropora* dominated communities in the offshore reefs and Fabricius *et al.* (2012) who proposed *Acropora* as an indicator of clean, clear water with low nutrient conditions. This contradiction has been speculated to be the result of the 2010 mass coral bleaching in which *Acropora* in the southern Andaman region suffered more than 80% mortality (Excellence Center for Biodiversity of Peninsular Thailand, 2012), but the inshore turbid water might provide protection for corals from UV radiation by light absorption as well as scattering light by suspended particulate matter and colored dissolved organic matter (Alemu I & Clement, 2014; Phongsuwan, 1998; van Woesik *et al.*, 2012). This suggested that inshore reefs could be more resistant to bleaching events than offshore reefs. Apart from the *Acropora,* other groups of corals behaved more or less as predicted by previous reports. In the coastal locations, the association of *Pectinia* and *Montipora* corals with turbid water inshore reefs was expected, since this is one of their defining characteristics (Veron, 2000). The association of *Turbinaria* spp. with turbid environments was also consistent with reports from the GBR (Fabricius *et al.*, 2012) that proposed a negative relationship between *Turbinaria* coral and water quality gradient with distance from a river mouth.

4. Conclusions

This study has documented fundamental differences in the inshore and offshore fringing reef systems in the southern Andaman sea of Thailand that were based on the environmental attributes and coral community composition. The inshore and offshore differences in fringing reef systems revealed in this study are not exactly consistent with the literature that described patterns found on the Great Barrier Reef, the Caribbean Sea or in the southeast Asia (Indonesia) barrier reef systems. The environmental attributes in southern Thailand exhibit a similar trend to the other regions which show a gradient dependent on the proximity to terrestrial influences. However, the composition of coral assemblage attributes respond differently. The inshore coral assemblages tend to be characterized by higher occurrences of coral genera including *Montipora*, *Pectinia*, *Podabacia*, and *Acropora* compared to the offshore island reefs which are characterized by the presence of *Lobophyllia*, a relatively high number of *Plerogyra* colonies, and the free living forms of fungiid corals. Therefore, some attributes may agree in the fundamental differences presented in other regions, but there are also some other attributes, especially coral communities that work differently. This highlights the importance of identifying site-level factors for management plans and resilience assessments of the marine protected areas in the region.

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