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A Rapid Assessment of Scleractinian and Non-Scleractinian Coral Growth Forms Along the Saudi Arabian Coast, Red Sea

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Abstract In this study we assessed the current status of coral reefs along the Saudi Arabian coast of the Red Sea. Among the three growth forms of Acroporid corals, the branching forms were found to dominate in the Farassan Islands (44.55%±11.10% cover) followed by tabular forms in the Doga Islands (ranging between 18%±6.47% and 18.30%±9.47% cover). Digitate forms were rarely found along the coast except at Maqna. Among the five growth forms of non-Acroporid corals, we observed maximum cover of branching forms in the Yanbu offshore area (58.89%±15.11% cover) followed by the Jeddah coast (24.76%±14.04% cover). The *Millepora* spp., a non-Scleractinian coral, was abundant at all the near-shore sites, such as Jeddah (10.70%±8.21%) and Al-Wajh (9.81%±6.69%). The live coral cover (including both Scleractinian and non-Scleractinian corals) of Saudi Red Sea coast was seen to be higher in the north and gradually decrease towards the south. Principal Component analysis showed that the contribution of Acroporid corals was greater in the southern region than in the northern and middle regions, but vice-versa in the case of non-Acroporid corals. Bray-Curtis cluster analysis categorized all the study sites into two major clusters with 60% similarity. Among them, one cluster-forming sites from Maqna to Masturah (Northern region) and the second one comprised the middle and southern regions (Jeddah to Farassan Islands), and one outlier Rabigh.

Key words coral reef; growth forms; Saudi Arabia; coral diversity; scleractinian coral; Red Sea

1 Introduction

The Saudi Arabian coast of the Red Sea has a remarkable diversity of coral reef covers. The reefs of the Saudi coast extend from Haql in the north, through Jeddah in the center towards the south as far as the Farassan Islands. Coral community categorization studies on these reefs have been limited so far, and only the Farassan Island reefs have received much attention compared with other parts of the Saudi Arabian Red Sea (Rowlands *et al*., 2008). Urbanization of the Saudi Arabian Red Sea coast is continuously increasing, with most settlements in the coastal areas (El-Sayed, 2002a, b). Because the areas around the Corniches (beaches) are the main recreational spots in Saudi Arabia, the number of resorts and water sports centers has rapidly increased in the vicinity. Most resort developments cause disturbance to the coral reefs. Dredging or filling activities, for construction of jetties, induce sedimentation that results in the degradation of reef ecosystem (Rogers, 1990; Mohammed and Mohammed, 2005). Available information on the impact of urbanization and industrialization on these reef ecosystems is very scant (Dicks, 1984; Knap, 1987; Negri and Heywards, 2000; Ammar *et al*., 2007).

Biophysical status assessments of Coral reef ecosystems have been carried out worldwide to estimate the biodiversity pattern (Riegl *et al*., 2012a; Riegl and Purkis, 2012) and the impacts of natural disturbances such as bleaching (Baird and Marshall, 1998; Arthur, 2000; Kumaraguru *et al*., 2003; Marimuthu *et al*., 2011, 2013; Riegl *et al*., 2012b) and tsunamis (Kumaraguru *et al*., 2005; Wilson, 2009; Patankar *et al*., 2012). Similarly, the effects of anthropogenic disturbances (Wilson *et al*., 2005; Wilson, 2009) and the current status of affected reefs are also periodically reported (Edward *et al*., 2006; Marimuthu *et al*., 2010). This study is aimed at understanding the current status and threats to the Saudi Arabian coral reefs in the Red Sea.

2 Materials and Methods

In this study, 14 sites located at 9 regions (Fig.1) were selected to represent the entire Saudi Arabian coast of the Red Sea from north (Maqna) to south (Farassan Islands).

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Further, the study sites are classified into three regions such as North (Maqna to Yanbu), Middle (Masturah to Jeddah) and South (Al-Lith to Farassan Islands). The sessile benthic community was assessed using the line intercept transect method (English *et al*., 1997) from January to April 2012. A 20 m long flexible underwater tape was laid on the reefs roughly parallel to the shore with five replicates at each site. The benthos coming under the transition points were recorded using international codes.

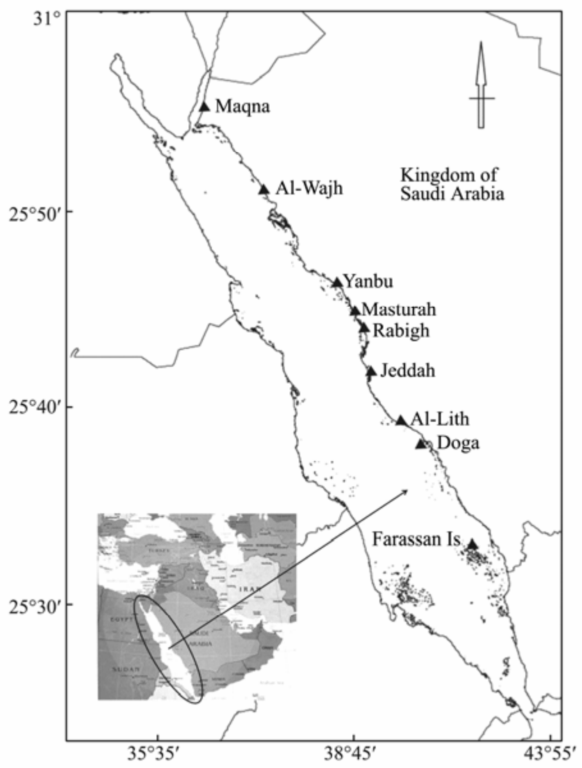

Fig.1 Map showing the study sites.

We classified the Scleractinian corals into two major categories: Acropora and non-Acropora (NAC). The Acroporid corals were further divided into three growth forms: Digitate, Branching and Tabular. The NAC forms were also sub-categorized as Massive Coral, Branching Coral, Encrusting Coral, Foliose Coral and Mushroom Coral. The non-Scleractinian coral group included *Millepora* and Soft Corals (SC). Abiotic forms included Dead coral with Algae (DCA), Rubble, and Rock. The algal covers, such as Coralline algae (including *Halimeda*), Macro algae and Turf algae were grouped as Algal Assemblage. Sponges were denoted as SP. Other associated organisms observed in the reef ecosystem, such as Sea stars, Sea cucumbers, Giant clams and Bivalves, were categorized as 'Others'.

The collected raw data were processed using AIMS Reef Monitoring Data Entry System (ARMDES, 1996). The percentage covers of Scleractinian and Non-Scleractinian corals, Abiotic forms and other associated organisms were estimated using this package. Further statistical analyses such as Principal Component Analysis (to identify the dominant coral growth forms) and Bray-Curtis Cluster analysis (for similarity study) were carried out using PAST Version 2.15 (Hammer, 2012).

3 Results

3.1 Biophysical Status of the Coral Reef Ecosystem

Among the three categories of Acroporid corals, Branching forms were found widely distributed at all the study sites, particularly in the Farassan Islands, with a maximum cover of 44.55%±11.10%. More tabular forms were observed in the Doga Islands (18.15%±7.97%) than at the other sites. At most of the study sites, few Digitate Acroporid corals were observed. Their maximum cover of 4.84% was observed in the Maqna coast (Fig.2). Among the five growth forms of non-Acroporid corals, the maximum cover of branching forms was in the Yanbu

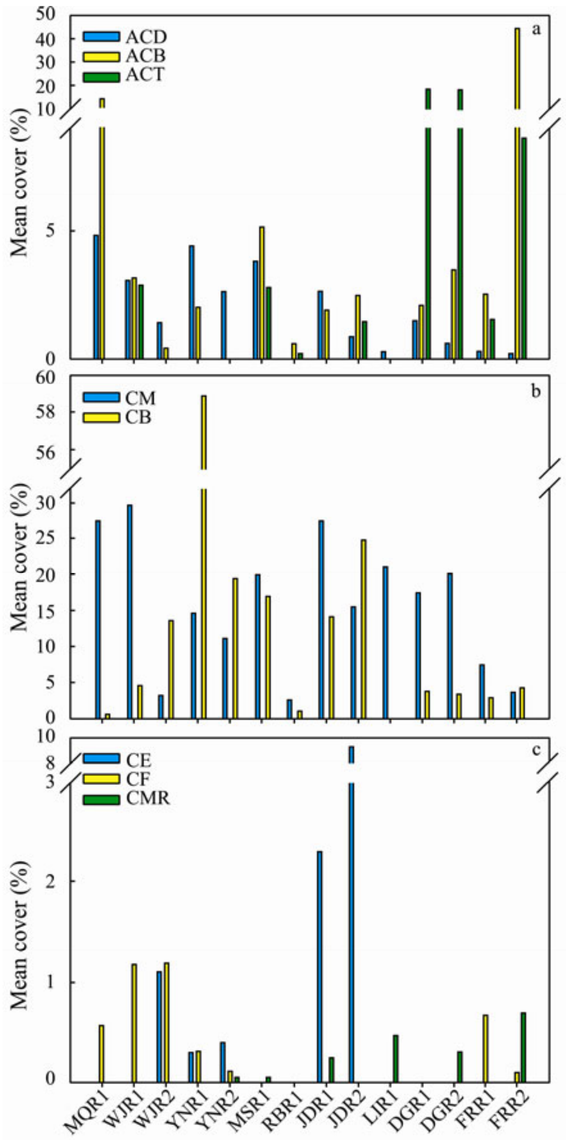

Fig.2 Scleractinian corals (Acroporid (a) and Non-Acroporid coral cover (b & c)) recorded along the Saudi Red Sea coast. ACD, Acroporid, Digitate; ACB, Acroporid, Branching; ACT, Acroporid, Tabular; CM, Coral, Masive; CB, Coral, Branching; CE, Coral, Encrusting; CF, Coral, Foliose; CMR, Coral, Mushroom; MQR, Maqna Reef; WJR, Al-Wajh Reef; YNR, Yanbu Reef; MSR, Masturah Reef; RBR, Rabigh Reef; LIR, Al-Lith Reef; DGR, Doga Reef; FRR, Farassan Reef; 1&2, Site no.

offshore area (58.89%±15.11% cover), followed by the Jeddah coast (24.76%±14.04% cover) (Fig.2). The non-Scleractinian coral *Millepora* spp. was recorded abundantly at the near-shore sites such as Jeddah (10.70%± 8.21%) and Al-Wajh (9.81%±6.69%) (Fig.3). More Abiotic forms were observed at the Al-Lith site: DCA at 39.45%± 17.89% cover and Rubble at 35.12%±24.43%. The maximum Rock cover (68.34%±8.08%) was observed at the Rabigh site.

Greatest SC cover was observed in the Al-Wajh (31.33%±7.66%), followed by the Masturah and Jeddah sites. Maxima of both Algae cover (5.46%±2.52%) and Sponge cover (0.49%±0.84%) were observed in southern areas such as the Farassan Islands (Fig.3). Zoanthids were observed maximally at the Doga Island (0.96%±0.86%) but were found scattered at all the other study sites.

Overall, the live coral cover (including both Scleractinian and non-Scleractinian corals) of Saudi Red Sea coast was seen to be higher in the north with a gradual decrease towards the south (Fig.4). In this study, coral predators such as Crown of Thorn Starfish (*Acanthaster* sp.) and coral eating snail (*Drupella* sp.) were also widely observed at all the study sites (Fig.5).

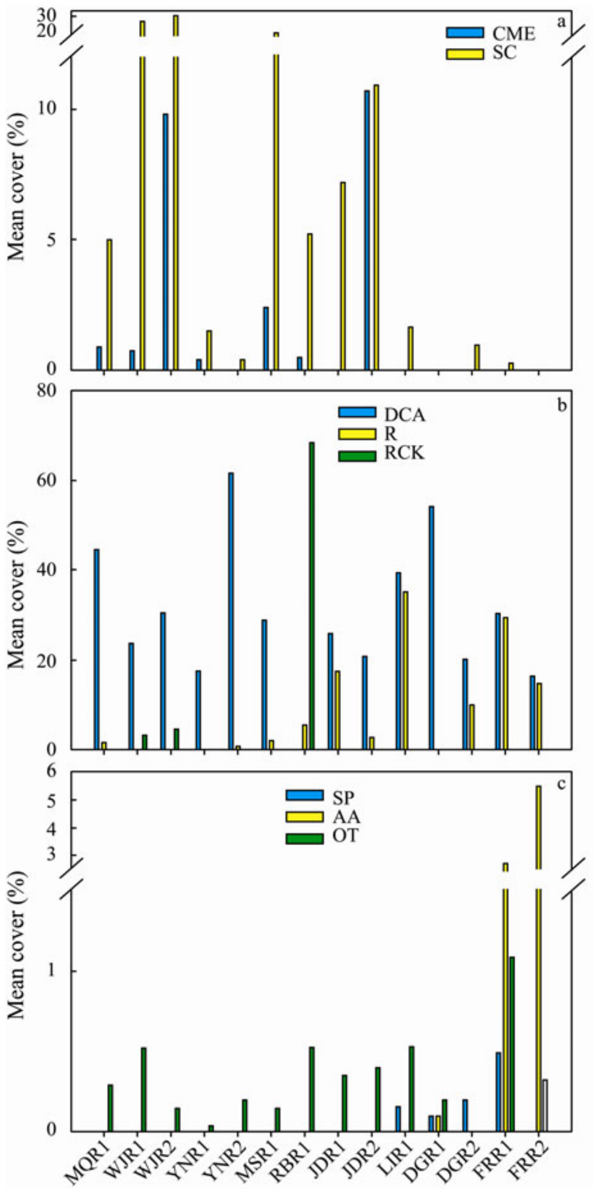

Fig.3 Non-Scleractinian corals (a), Abiotic (b), and Other associated organisms (c) recorded along the Saudi Red Sea coast. CME, Coral, Millepora; SC, Soft Coral; DCA, Dead Coral with Algae; R, Rubble; RCK, Rock; SP, Sponge; AA, Algal Assemblage; OT, Others; MQR, Maqna Reef; WJR, Al-Wajh Reef; YNR, Yanbu Reef; MSR, Masturah Reef; RBR, Rabigh Reef; LIR, Al-Lith Reef; DGR, Doga Reef; FRR, Farassan Reef; 1&2, Site no.

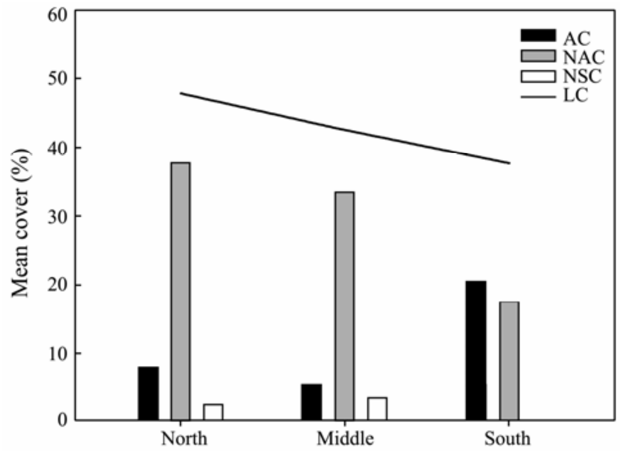

Fig.4 Region-wise coral cover recorded in the Saudi Red Sea coast. AC, Acroporid coral; NAC, Non-Acroporid coral; NSC, Non-Scleractinia; LC, Live Coral.

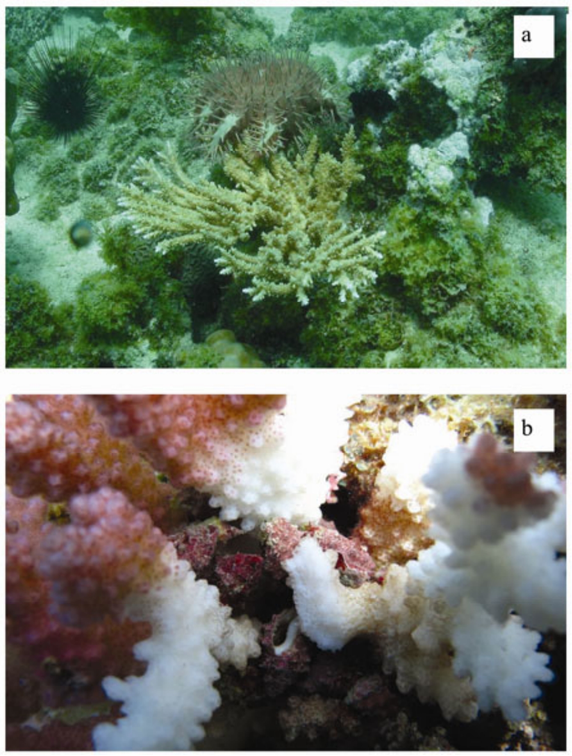

Fig.5 Coral predation by (a) Crown of Thorn star fish, and (b) *Drupella* sp.

3.2 Statistical Analysis

Fig.6 shows the Principal Component analysis of different life-form categories with their site description. Acroporid coral forms were found more in the southern parts of the Saudi Red Sea such as the Farassan and Doga

Islands. Greater percentages of NAC were recorded in the northern and central coastal regions such as Yanbu, Al-Wajh, Masturah and Jeddah. *Millepora* corals were observed more in the Al-Wajh and Jeddah near-shore regions. DCA and Rubble covers were abundantly observed in the polluted areas such as Al-Lith and Yanbu, where shrimp farming and refinery activities are more intense.

Bray-Curtis cluster analysis, based on the life-form categories (Fig.7), showed two major clusters with 60% similarity. Among them, one cluster-forming sites from Maqna to Masturah and the second one comprise the middle and southern regions (Jeddah to Farassan Islands), and one outlier Rabigh. The Rabigh site was separated from the other study sites, due to the occurrence of maximum Rock cover (68%) rather than the other life forms. Sewage discharge from Oil refineries and warm water from Power stations probably have detrimental effects on the corals of Rabigh.

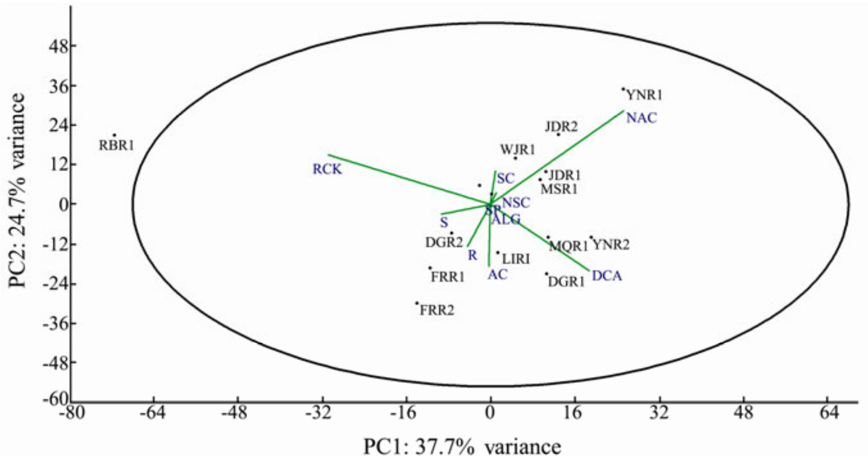

Fig.6 Principal Component Analyses (PCA) of life-form categories at study sites. AC, Acroporid coral; NAC, Non- Acroporid coral; DCA, Dead Coral with Algae; RCK, Rock; R, Rubble; NSC, Non-Scleractinia; ALG, Algal assemblage; SC, Soft Coral; SP, Sponge; S, Sand; MQR, Maqna Reef; WJR, Al-Wajh Reef; YNR, Yanbu Reef; MSR, Masturah Reef; RBR, Rabigh Reef; LIR, Al-Lith Reef; DGR, Doga Reef; FRR, Farassan Reef; 1&2, Site no.

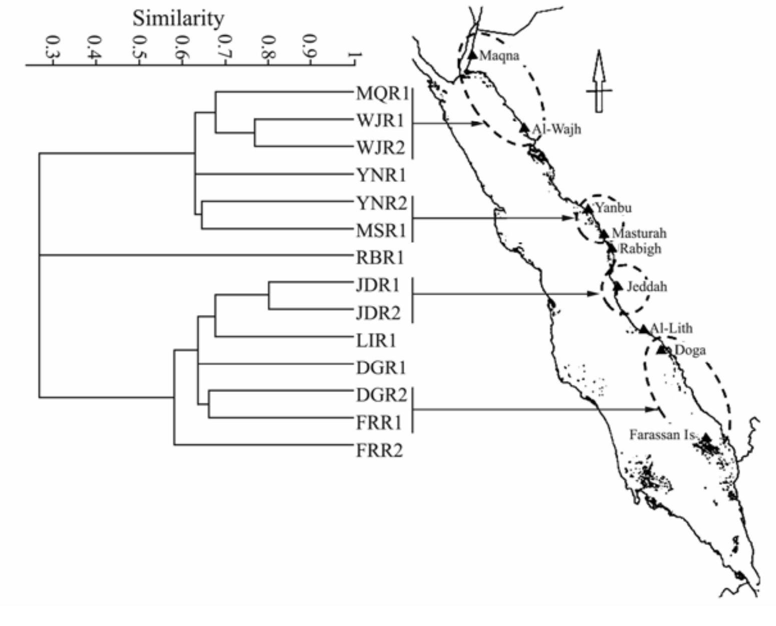

Fig.7 Bray-Curtis Cluster analysis based on life-form categories recorded in the Red Sea reef ecosystem. MQR, Maqna Reef; WJR, Al-Wajh Reef; YNR, Yanbu Reef; MSR, Masturah Reef; RBR, Rabigh Reef; LIR, Al-Lith Reef; DGR, Doga Reef; FRR, Farassan Reef; 1&2, Site no.

4 Discussion

The assessment of coral reef ecosystem by estimating the percentage covers of their different growth forms has been periodically reported worldwide. The Global Coral Reef Monitoring Network (GCRMN) publishes both global (Wilkinson, 2008) and regional reports (Hassan *et al*., 2002; Tamelander and Rajasuriya, 2008) on the status of coral reefs. The natural event, coral bleaching, is one of the main causes for the reduction in coral reef cover (Winter *et al*., 1998; Al-Sofyani, 2000; Celliers and Schleyer, 2002; Kumaraguru *et al*., 2003; Krishnan *et al.,* 2011; Vinoth *et al*., 2012; Marimuthu *et al*., 2013). This may be due to a sudden transition in the water temperature, either globally or locally. Similarly, the recent 2004 tsunami event damaged a considerable amount of coral reefs (Kumaraguru *et al*., 2005; Edward *et al*., 2006) of Indian coasts. Post-bleaching and post-tsunami surveys are essential to assess the impacts (Marimuthu *et al*., 2011, 2013; Wilson and Marimuthu, 2012). These natural impacts on the corals may vary according to the coral growth forms. Hence the assessment of coral growth forms will be helpful to identify the level of impacts.

In this baseline study, uneven distribution of coral cover was observed in the Saudi Arabian coast of the Red Sea. We observed a gradual increase in the non-Acroporid coral cover from south to north, and found Acroporid coral to dominate in the southern region. Overall, the non-Acroporid coral cover contributed more to the live coral cover than the other life forms. Therefore, the overall Live Coral cover also increased from south to north (Fig.4). During summer, a large amount of water from the Gulf of Aden intrudes into the southern end of the Red Sea through the Bab el Mandab region (Al-Saafani and Shenoi, 2004; Smeed, 2004). This results in the influx of nutrients into the Red Sea, which may influence the algal competition on the nearby reefs such as those off Farassan Island (Figs.3 and 4). Recently, John (2012) reported the algal competition on coral cover in the near Gulf waters.

Indicator organisms can be used to assess the health of the reef ecosystem. The coral predators such as Crown of Thorn Starfish (*Acanthaster* sp.) and coral eating snail (*Drupella* sp.) were commonly observed indicators in this study. The abundance of these organisms may be due to various natural and anthropogenic factors. Possible reasons for the increase of these organisms (McClanahan, 1994) include increased nutrients due to coastal development and agricultural practices, indirect effects from coastal tourism and exploitation of natural predators of the coral predators, such as Trumpet Triton (*Charonia* sp.) shell, Pufferfish (*Arothron* sp.), Triggerfish and Humphead Maori wrasse (Nelson, 2009; Mallon, 2010).

Sewerage pollution was the main human threat to the coral reef environment observed in this study. The Jeddah coast is known to receive more than 100000 m^3 of domestic sewage per day (El-Sayed, 2002b). In addition to this, industrial sewage discharges from the Oil refineries, Power plants and Shrimp farms also pollute the coastal waters. These discharges kill most of the corals in their vicinity and simultaneously induce the growth of SC. This was indicated by the presence of more DCA and SC percentage covers in all transects at polluted sites such as Al-Lith and Yanbu.

This rapid assessment provides a baseline dataset about the present scenario of Saudi Red Sea corals; however, a long term study to evaluate their status is the need of the hour for framing suitable management strategies. The non-Acroporid corals were more common than the Acroporid corals and dominated all the study sites. The overall live coral cover significantly decreased towards the south. Oil refining, desalination, sewage discharges and aquaculture activities are the major threats observed in this study. More extensive studies are essential to conserve vulnerable coral species. Public awareness of marine pollution and the importance of conservation strategies can play a major role to improve the situation. Increased implementation of Marine Protected Areas is crucial for the preservation of Saudi Arabian Red sea coral reefs.

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