PKP
PUBLIC KNOWLEDGE PROJECT

Journal of Biological Studies
ISSN 2209-2560

JBS
An Open Access Peer Reviewed Journal

Research Full-Text Paper

Status and vulnerability of *Acropora* spp. assemblages at the Egyptian coasts of the red sea

Mohamed Ismail[1], M. Aminur Rahman[2]*

[1] *Department of Marine Science, Faculty of Science, Port Said University, Port Said 42526, Egypt*
[2] *Department of Fisheries and Marine Bioscience, Faculty of Biological Science and Technology, Jashore University of Science and Technology, Jashore 7408, Bangladesh*

Received: May 29, 2022; **Accepted:** June 8, 2022; **Published online:** August 30, 2022

Abstract: In the Red Sea, the availability of information about the status of *Acropora* spp. assemblages is more restricted, where a few comprehensive or even preliminary studies were conducted on the genus *Acropora* at this area, especially at the Egyptian coasts. Accordingly, our goal focused on the assessment of the status of genus *Acropora* assemblages at the Egyptian coasts of the Red Sea and addressing the main keystone species of *Acropora* at this area. Three sites at the Gulf of Aqaba, located in Ras Muhammad National Park in addition to two sites at the Red Sea proper (Hurgada and Marsa Alam) were selected to conduct the study during 2016. The line intercept transect methodology was used to estimate the cover of *Acropora* assemblages. Samples from different colonies of *Acropora* were collected for further analysis of the micromorphology of coral's exoskeletal structures. The study revealed that there were 16 common species of *Acropora* at the study sites. Also, the results indicated that Gulf of Aqaba had the higher benthic cover of *Acropora* assemblage than southern ones. On the other hand, some of the near threatened species of *Acropora*, proposed by IUCN Red List, showed high benthic cover compared to other species. The study concluded that more than 50% of the *Acropora* species at the Egyptian coasts of the Red Sea were threatened or vulnerable to different environmental perturbations according to IUCN criteria. Consequently, the coral reefs at the Gulf of Aqaba may represent a refugium for endangered species at the Red Sea.

Keywords: Corals, *Acropora*, Gulf of Aqaba, Ras Muhammad National Park, Hurgada, Marsa Alam, Red Sea, Egypt

*e-mail: amin2019@just.edu.bd / aminur1963@gmail.com

1 Introduction

Coral reef ecosystem is one of the most productive ecosystems on earth (Burke et al., 2012; Waheed, 2016). Coral reef areas were less than 0.1% of sea floors (Veron et al., 2009), they are home to one-third of all known marine species (Reaka-Kudla, 1997; Reaka-Kudla, 2001), containing very high biodiversity that providing ecosystem goods and services for human and marine lives such as coastal protection, habitat for fisheries and tourism attraction (Wild et al., 2011). Coral reefs are habitats for many fishes (Coker et al., 2013), for food security (Foale et al., 2013) and natural protection in the shore areas (Villanoy et al., 2012). They also have recreational and cultural importance (Waheed, 2016).

Recently, coral reefs have been suffered a massive, long-term decline in abundance, diversity and habitat structure due to both natural (e.g. coral bleaching, predation by crown of thorns starfish) and anthropogenic (e.g. overfishing, sedimentation, pollution, climate change, and tourism disturbances (Hughes et al., 2003; Pandolfi et al., 2003; Ismail et al., 2005; Bruno and Selig, 2007, Hagen, 2018; Hasan, 2018). Live coral cover is declining rapidly, up to an 80% decrease in the Caribbean and East Africa (Wilkinson, 2002; Gardner et al., 2003) and ~50% decrease in the Red Sea (Loya, 2007). One-third of all reef-building corals could be at risk of extinction (Carpenter et al., 2008); fully 75% of reefs are highly threatened by the compounding effects of local stressors and factors associated with global climate change (e.g., ocean acidification, sea level rise, thermal stress, disease, cyclones) (Hoegh-Guldberg, 1999; Buddemeier et al., 2004; Baker et al., 2008; Veron et al., 2009; Burke et al., 2012).

Egypt coastline has coral reefs found in the Red Sea with about 3800 km^2 of reef area (Spalding et al., 2001) and 1,800 km long (Persga, 2010). Moustafa (2000) estimated that 335 species of corals are found in the Red Sea, yet only approximately 35 species have been identified in the Gulf of Suez. Among the about 300 hard coral species found in the Red Sea, 2/3 are found in the Egyptian reefs, including some endemic species (Kotb et al., 2008). These are higher than those recorded in the Caribbean and equal to Indian Ocean. Egyptian reefs are fringing reefs alongside the coastline. Coral reefs extent in the North to the Gulfs of Suez and Aqaba to Ras Hedarba in the South at the border of Sudan. They are however not continuous because of periodic flooding from wadies created gaps within reef system. The northern part of the Red Sea has the highest coral diversity and number of islands, while the south has the highest terrestrial biodiversity for the whole country (Shaalan, 2005). Many intergovernmental organizations, like PERSG, are dedicated to the conservation of the

coastal and marine environments in the region by performing a permanent survey of reefs (Kotb et al., 2008; Persga, 2010). Live coral cover of Egyptian reefs averaged 48%.

Major fishes are the butterfly fish (Chaetodontidae) with 7.2/500 m^3, parrotfish (2.2/500 m^3), snapper and grouper (0.8/500 m3). The 50 genera of corals in the Red Sea are threatened by mismanagement of human activity in the area. Loss of biodiversity has resulted in numerous impacts including social, economic, cultural, managerial and scientific consequences (Crosby et al., 2000). In terms of environmental impacts, coral deterioration disturbs the coastal ecosystem, resulting in coral death, loss of the complex habitat structure and decrease of associated invertebrates as well as fish reduction, an increase in algal growth, planktivores, herbivores and detrivores (Khalaf and Kochzius, 2002). Tourism causes environmental impacts on coral reefs in Hurghada, besides urban expansion and landfilling are the leading cause of environmental degradation (El-Gamily et al., 2001). Coral reefs-based tourism is economically important along the Egyptian Red Sea with 90% of the tourism investment concentrated around the Gulf of Aqaba (Hilmi et al., 2018).

The genus *Acropora* is the most diverged reef building coral in the world (Wallace and Rosen, 2006), Florida and the Great Caribbean (Jackson, 1992). It is significantly contributing to the formation of islands and coastal protection (Bruckner, 2002). Their high growth rates have allowed them to keep up with changes in sea level. In addition, due to their branching morphologies, they are an important habitat for other reef organisms (Bruckner, 2002; *Acropora* Biological Review Team, 2005). They also provide amazing scenic values for recreational diving. Due to the combination of biological and anthropogenic stressors, *Acropora* has been suffered significant degradation with estimated population declines of up to 95% in some areas (Porter and Meier, 1992; Bruckner, 2002).

Acropora was listed as threatened in the US under the Endangered Species Act in 2006 (Hogarth, 2006) and as critically endangered in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species in 2008 (Aronson et al., 2008, Carpenter et al., 2008) as well as the American Samoa` Threatened Reefs in the Pacific (Kenyon et al., 2011). Both acroporid species exhibit particularly high growth rates relative to other corals (Glynn, 1973; Gladfelter et al., 1978), enabling sustained reef growth during previous sea level changes. Thus, it is unlikely that any other Caribbean reef-building species is capable of fulfilling these specific ecosystem functions. Therefore, it is probable that the continued decline of *Acropora* will cause considerable losses in reef function and structure (*Acropora* Biological Review Team, 2005; Hernández-Fernández et al., 2019). The International Union for Conservation of Nature (IUCN) Red List of Threatened Species is a tool that is widely used for focusing attention on species of potential conservation concern (G¨ardenfors et al., 2001; Rodrigues et al., 2006).

The IUCN Red List criteria and assessments allocate species to categorize the extinction risk, using quantitative rules based on population sizes, range areas and rate of declines. Categories are ranged from “Least Concern” with very little probability of extinction to high risk “Critically Endangered”. Three categories considered to be “threatened” and representing increasing extinction risk (Vulnerable, Endangered, and Critically Endangered) are intended to serve as this gives priority measures for biodiversity conservation (Carpenter et al., 2008). Marine protected areas, fishing regulation, and reef restoration approaches were ranked for five distinct latitudinal sections in the Red Sea and levels of interventions are recommended (Fine et al., 2019).

The main aim of the current study was to assess the status of the live colonies of *Acropora* spp. at the Egyptian coasts of the Red Sea based on ecological assessment and IUCN red list database. Identifying the main keystone species of *Acropora*, evaluating the benthic cover of *Acropora* species, and comparing between statuses of the *Acropora* assemblages at the Gulf of Aqaba and the Red Sea proper, were the major objectives of this research. Finally, the study was undertaken with a view to assess the vulnerability level of *Acropora* species as well as determine the status of this threatened species at the Egyptian coast of the Red Sea.

2 Materials and Methods

2. 1. The study sites

The study was carried out in the Egyptian Red Sea coast at three main locations: Ras Muhammad National Park, Sharm Al Sheikh, S. Sinai (Camp, Marsa Ghozlani and Old Quay), Satayeh, Marsa Alam and NIOF, Hurgada (Figure 1).

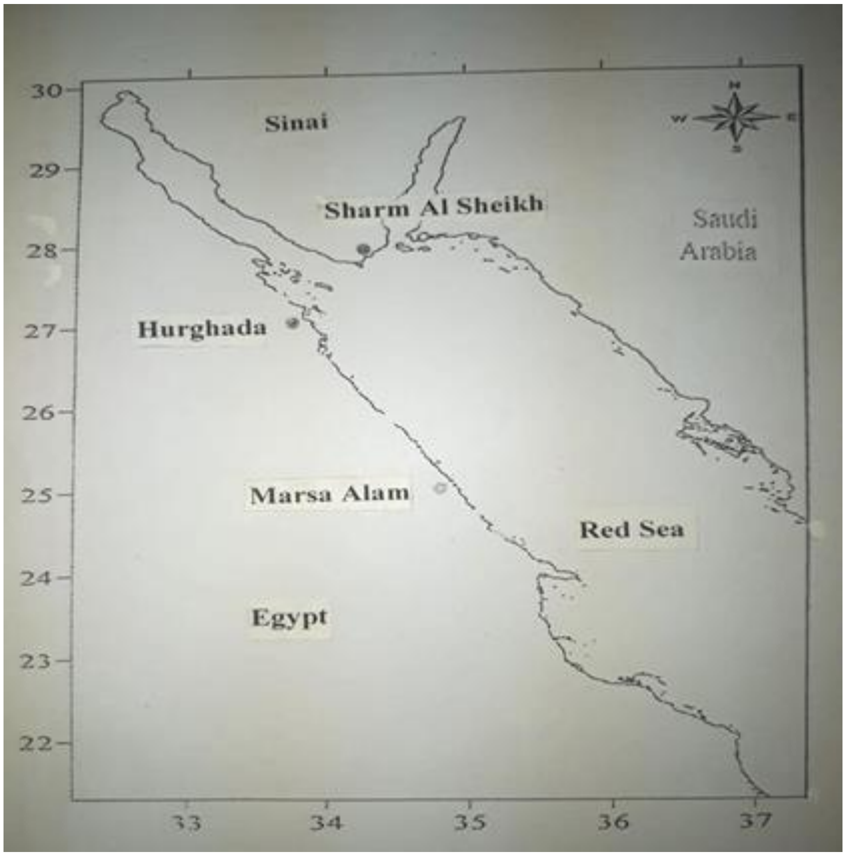


Figure 1: Map and location of the study area.

2. 1. 1. Ras Muhammad national park, Sharm Al Sheikh, S. Sinai, Egypt

Ras Muhammad is the most famous national park in Egypt and one of the most famous diving sites in the world. A national park that is located between the rich coral reefs of the Red Sea and the inland desert of the Sinai, which covers the coral headland at the southernmost tip of Sinai. At the southern end of the headland, there is a small stand of Mangrove tree, *Avicennia marina*. Coral reefs teeming with life including a diversity of vertebrate and invertebrate species are found beneath the crystal-clear waters of the Red Sea. Slightly further offshore, there are spot dolphins, including Risso's dolphin (*Grampus griseus*). The area hosts White Stork (*Ciconia ciconia*) during their annual migrations. (Abdo, 2015). We studied three sub site areas in Ras Muhammad NP including Camp Site, Marsa Ghozlani and Old Quay, respectively (Figures 2. 1, 2. 2 and 2. 3).

2. 1. 1. 1. Camp site

Camp site is located at the southern side of Marsa Bereika bay (27°46.447'N; 34°12.760'E), Figure (2. 1). This site has a very narrow reef crest only a few meters in width. The reef then drops vertically to around 6-8 m and then slopes at around 45° down past the 50 m mark. Below a depth of 10 m, spur and groove formations of coral and sandy areas are evident. The large Bereika Bay is relatively sheltered from the prevailing conditions and hence, the site can be considered a low energy site. The area has recently been opened for boat diving, shore diving, snorkeling and safari boats. It is also the only location in Marsa Bereika Bay that is open to visitors (Abdo, 2015).

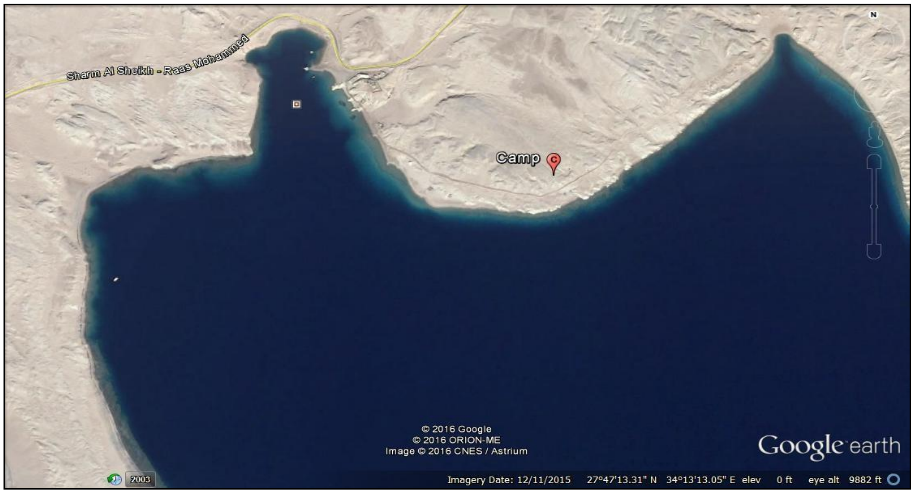


Figure 2. 1: Camp site at Ras Muhammad, Sharm Al Sheikh, S. Sinai, Egypt.

2. 1. 1. 2. Marsa Ghozlani (visitor centre) site

This site is located after 3 km of the entrance gate of Ras Muhammad National Park (27°49.319'N; 34°15.862'E), a small Bay is overlooked by the Ras Muhammad Visitor Centre Figure (2. 2). The reef flat in this area extends from a few meters at the sides of the Bay to around 15 m in the center, where a small sandy channel also exists. The Bay has a sandy central area, which slopes down to around 10 m, from where the reef begins. At the sides of the Bay, the reef crest drops vertically to around 4-5 m and then a narrow terrace extends for several meters. The deeper reef is a mixture of slope and steep wall dropping to around 35 meters, getting deeper as the reef extends out of the Bay. This site has been characterized by high sedimentation rate, and relatively sheltered with low energy environment. The site is also extremely popular with snorkeling day boats and the five moorings within the Bay are often fully occupied, possibly due to the proximity of sites to Marina Travco, where the majority of the boats depart from. Shore diving occurs at this site as well as from boats (Abdo, 2015).

Figure 2. 2. Marsa Ghozlani site at Ras Muhammad, Sharm Al Sheikh, S. Sinai, Egypt.

2. 1. 1. 3. Old Quay site

The Old Quay site is situated on the western side of the Ras Muhammad headland (27°44.257'N; 34°14.282'E) and technically in the Gulf of Suez (Figure 2. 3). This site is characterized by a very wide, extensive and shallow reef flat. However, the area around the Old Quay site has a small sandy lagoon about 50-70 m wide, with patchy seagrass beds occurring within the lagoon. The reef crest rises from the sandy bottom by around 1.5 m and extends about 5 m wide. On the seaward side, the reef drops as a wall to around 6 m in depth. This part of the reef is characterized by slight spur and groove formations, and many large overhangs and caves. Below this depth, the reef slopes gently at around 45° to below 50 m. Visibility at this site is often relatively poor at less than 10 m. Mixing of waters is visible, as the sediment load coming onto the reef itself from the reef flat, particularly at low tide when sediment can be seen flowing out through the reef. The site is relatively sheltered due to its geography, and the settled sediment load present suggests that it is a low energy site (Abdo, 2015).

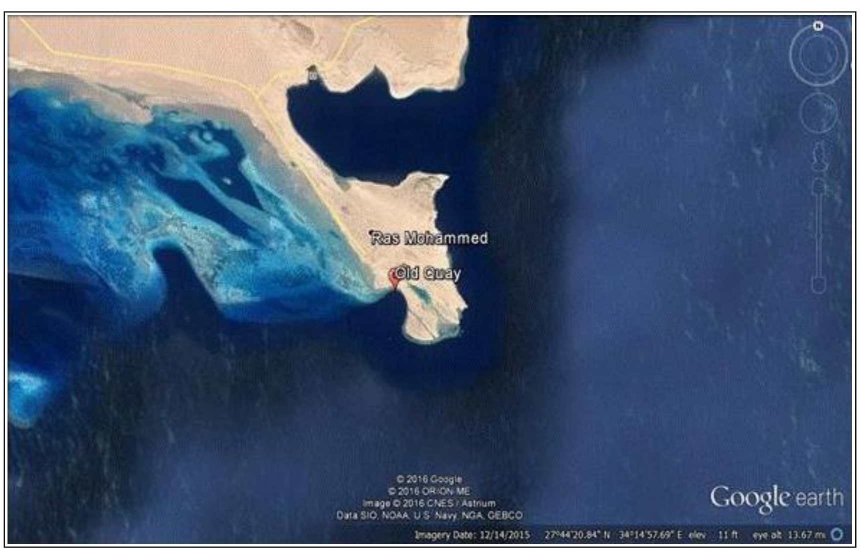


Figure 2. 3: Old Quay site at Ras Muhammad, Sharm Al Sheikh, S. Sinai, Egypt.

2. 1. 2. Satayeh, Marsa Alam, Red Sea, Egypt

Marsa Alam has one of the most important worldwide unique dolphin habitats in the Red Sea. Satayh reef, more commonly known as "Dolphin House", is the home to a large family of around 60 spinner dolphins. Home of around 60-80 dolphins attracts the snorkelers to take tour at Satayh Dolphin Reef from Marsa Alam (24°9'49.37"N; 35°41'55.03"E) (Figure 2. 4). It satisfies all lovers of these delightful friendly mammals. Clear waters around the lagoon are perfect for snorkeling. Satayh reef, also known as the “Dolphin Reef”, is located at the south-eastern tip of the Fury Shoal diving area off Marsa Alam. It has been named as the horseshoe shaped reef after the friendly mammals that can be spotted regularly on site. Additionally, the tourist peoples will be astonished by the amazing varieties of whitetips, fusiliers, Spanish dancers and parrotfish, which can be found at different depths from 4 to 40 m. The site can be reached by boat from Marsa Alam and the best way to the dive site is through the Red Sea dive safari trails. It is also a perfect destination for snorkeling if one is not really familiar to scuba diving.

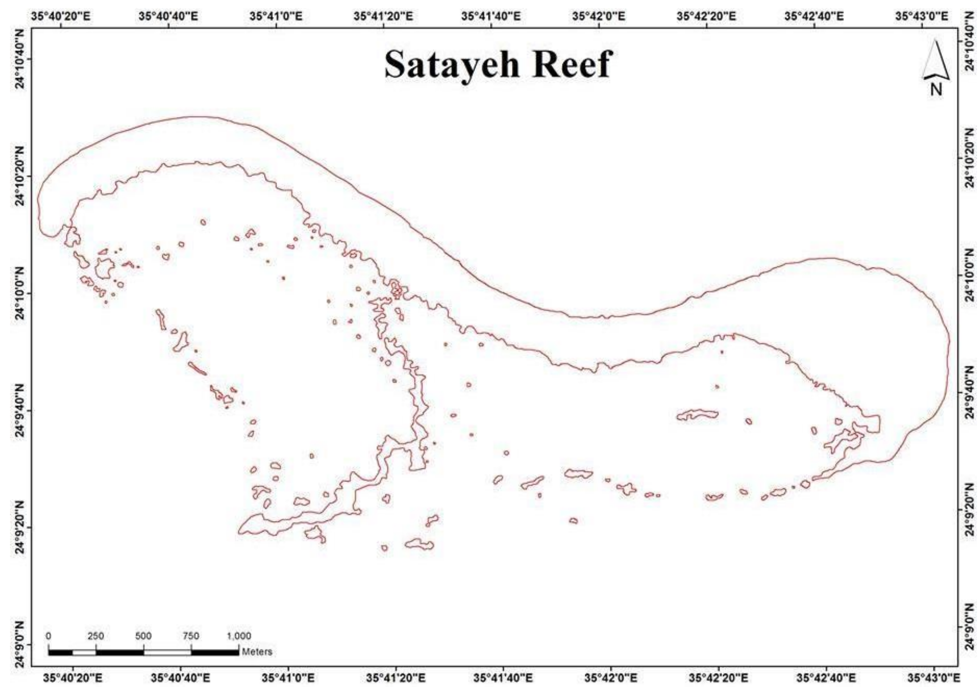


Figure 2. 4: Satayh at Marsa Alam, Red Sea, Egypt

2.1.3. NIOF, Hurghada, Red Sea, Egypt

The National Institute of Oceanography and Fisheries (NIOF) is located at the northern tip of the Red Sea (27°17'6"N; 33°46'22"E), and is about 5 km away from the center of Hurghada city (Figure 2. 5). It is characterized by a long patchy reef, representing the front edge of a wide and shallow reef flat with many depressions and lagoons. It is a small area that extends about 150 m seaward and ends with a lagoon of about 5 m depth. The lagoon had a sandy bottom covered by algal mats and seagrass, and is inhabited by many species of corals and fishes. *Acropora* spp., *Galaxia fascularis*, *Stylophora pistillata* and *Platygyra* spp. are the most common coral species in this area, and fishes are represented by the members of many families.

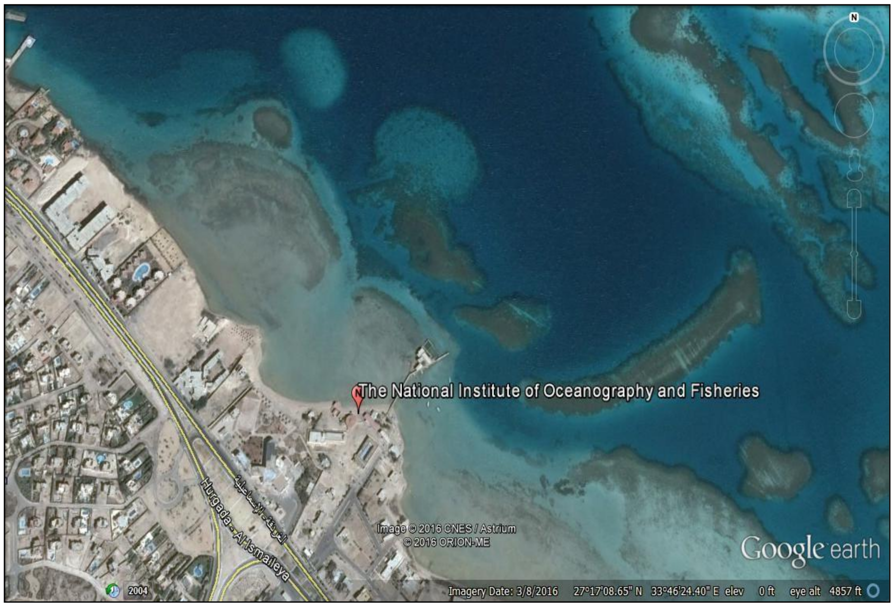


Figure 2. 5: NIOF at Hurghada, Red Sea, Egypt.

2. 2. Survey Methods

To determine the distribution of colonies, thickets and live fragments of *Acropora*, a direct observation census (snorkeling) was conducted and documented using GPS. *Acropora* samples were collected from the reef edge, reef flat and reef slope, at the depth range of 0.5-5.0 m for further laboratory works. We applied the monitoring protocol, proposed by Williams, et al. (2006) as well as established for the *Acropora* spp. in the Caribbean area. "Thickets" were defined when it was not feasible to demarcate individual colonies. At least three points were taken into account to determine the size of the thickets. For fragments, pieces of the colonies were selected, namely broken branches of *Acropora spp*. on the substrate, lacking a defined base (Martínez and Rodríguez-Quintal, 2012).

2. 2. 1. Transects

Transects provide a medium scale information. They are lines put on the reef floor where corals and other objects are counted underneath. Lines can be measured by tapes, ropes or chains of different lengths with measurements made under fixed points or where something happens e.g. counting chain links or where the benthic species change.

2. 2. 2. 1. Line Intercept Transects

Measurements on line transects are taken along the entire length of the line. Commonly used line transects are called ‘line intercept transects’ (LIT), which focused on the horizontal plane of the reef, and ‘chain intercept transects’ (CIT), which measured the benthic cover in 3-dimensional terms as the chain follows the contour of the reef. CIT enable the collection of information on reef rugosity (structural complexity) and are often used with LIT. The rugosity can provide information on the ‘spatial index’ of the reef, which is the ratio of reef surface contour distance to linear distance. As part of a long-term monitoring program, the spatial index provides a way to quantify changes in the topographical complexity of thereef.

2. 1. 2. 2. Video transects

A video camera is used for a permanent record of transects. Video transects are analyzed in the laboratory using point sampling techniques. Information obtained; A permanent record of percent cover and a visual record of the site. The video is analyzed on a TV screen, and data are reported as percent cover. The footage can also be used as qualitative information in monitoring reports to reinforce trends illustrated by graphs.

2. 3. Coral identification

Coral reef species were identified according to Veron (1986, 2000). To identify the observed coral types, a Red Sea comprehensive guidebook (Lieske and Myers, 2004) was used as well. Stereomicroscope was used to investigate *Acropora*. Stereomicroscopes with moderate magnification up to twenty-five power and good lighting made it possible to examine the finer details of colony morphology, polyp armatures, and other structures such as the apical branch tips.

2. 4. Statistical analysis

Data was analyzed using the computerized SPSS (V. 22) statistical package. A non-parametric analysis (Kruskal-Wallis test) was used to compare between means. An Excel (2016) was also used to represent the data.

3 Results and Discussions

3. 1. Reef check

NIOF site was represented by its highest covering value of hard coral (43.0%), followed by Marsa Ghozlani (17.0%), Old Quay (14.0%), and Satayeh and Camp site (13.0%) in this order (Figure 3. 1). Dead corals were highly present in the Camp site (28.5%) than the old Quay site (27%), Marsa Ghozlani (24.1%) and Satayeh (20.9%), while the NIOF site had a very rare (0.3%) dead coral cover. Marsa Ghozlani had the lowest (7.0%) covering of soft coral, the ratio of which was increased gradually from NIOF to Satayeh site with the covering values of 17.0% in NIOF, 22.0% in Old Quay, 26.0% in Camp and 28.0% in Satayeh site, respectively (Figure 3. 1). Algae and sand showed the highest percentage cover at Satayeh (93.0% and 69.0%, respectively). while other sites showed much lower values from 1.0% to 16.0% (Figure 3. 1). Our results revealed that hard coral cover was similar between all study sites except at NIOF, where the cover was mainly dominated by *Galaxea fascicularis* Figure (3. 2).

3. 2. *Acropora* assemblage benthic cover

The sites at the Gulf of Aqaba showed high mean benthic cover of *Acropora* assemblage compared to Red Sea proper assemblage (Kruskal Wallis test, $P < 0.05$). Among these sites, Camp is characterized by high mean benthic cover of *Acropora* assemblages (36.77%), followed by old Quay (27.05%) along the surveyed transects. The other three sites (Marsa Ghozlani, NIOF and Satayeh) were characterized by lower benthic covers (Figure 3. 3).

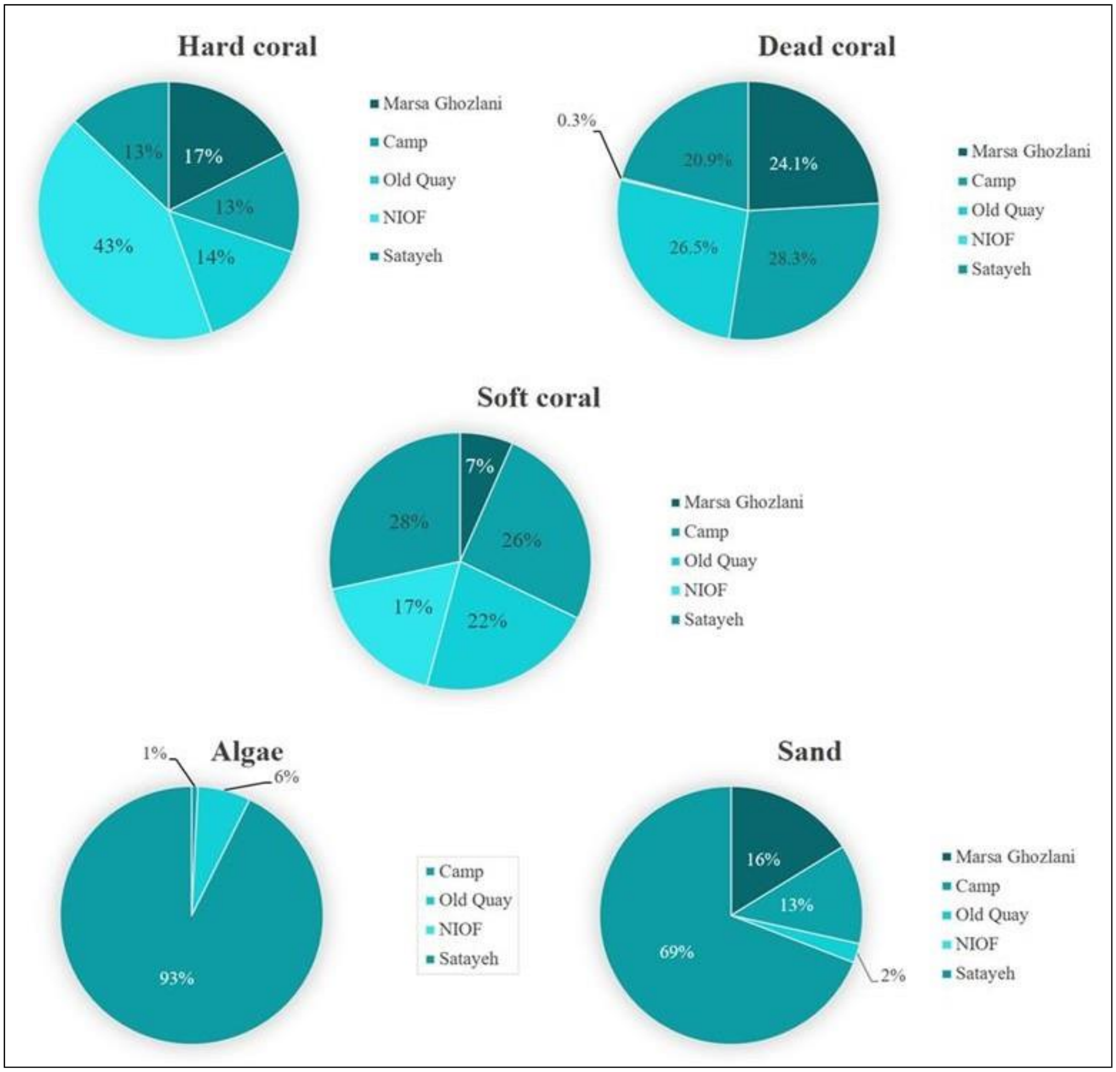


Figure 3. 1: Distribution of the main benthic categories at different study sites.

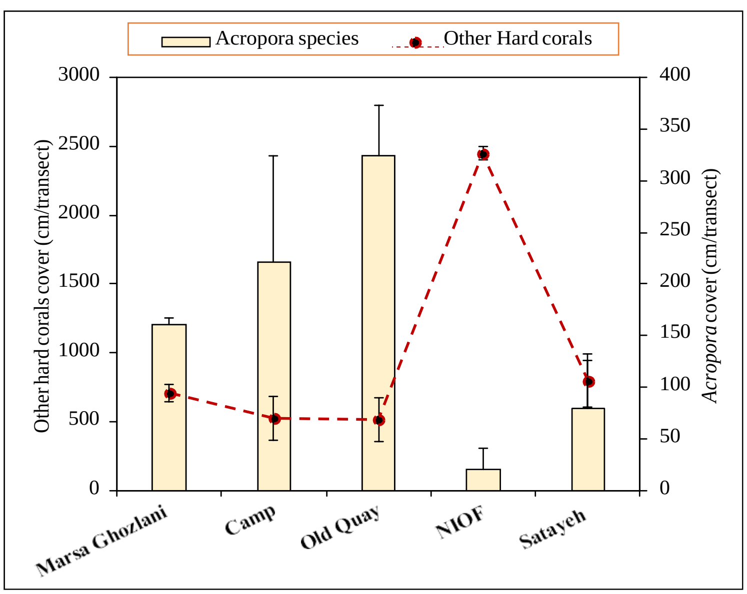


Figure 3. 2: Acropora and other hard coral covers at different study sites.

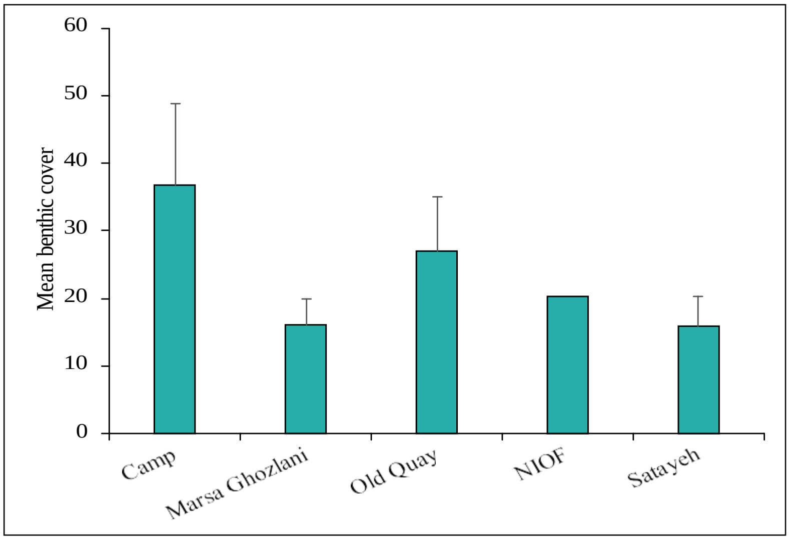


Figure 3. 3: Mean benthic cover (cm/25 m line transect) of genus *Acropora* at different study sites.

3. 3. *Acropora* species richness

The study revealed that there were 16 common species of *Acropora* at the study sites. For *Acropora* species richness, the number of species was ranged from 1 to 12 at NIOF and Old Quay site, respectively (Figure 3. 4). In general, the species richness at the Gulf of Aqaba was higher than that at the Red Sea proper. These species, however, showed significantly differences in their mean benthic covers (Kruskal Wallis test, $P < 0.05$) For example, *A. tenuis* represented the highest mean benthic cover at more than 0.5 m of 25 m transect followed by *A. digitifera* (Figure 3. 5). In the same context, *A. pharaonis*, *A. polystoma*, *A. listeri* and *A. selago* showed mean benthic cover lower than 0.1 m per 25 m surveyed transect, while mean benthic cover for other species was between 0.1 and 0.3 m per 25 m surveyed transect.

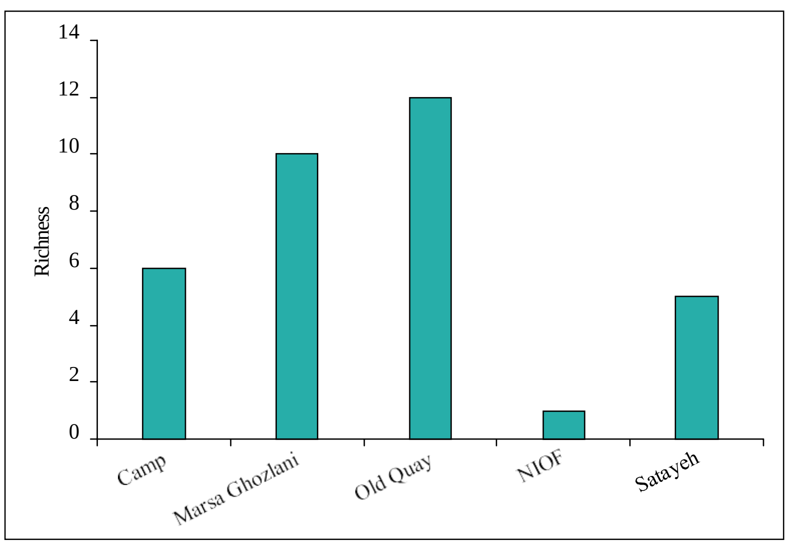


Figure 3. 4: *Acropora* species richness at different study sites.

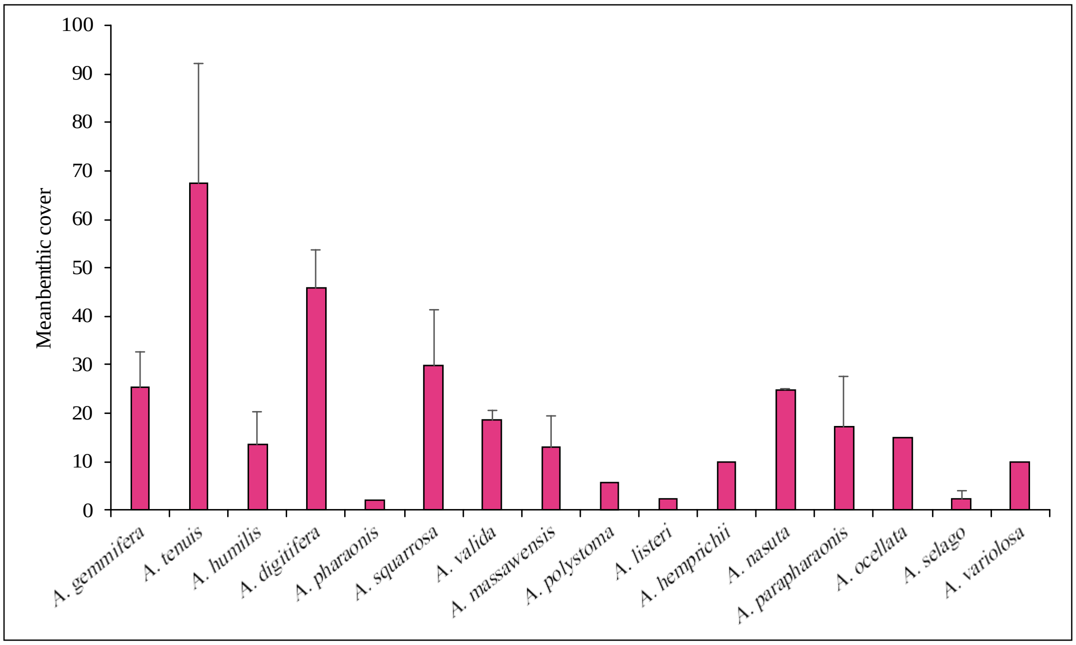
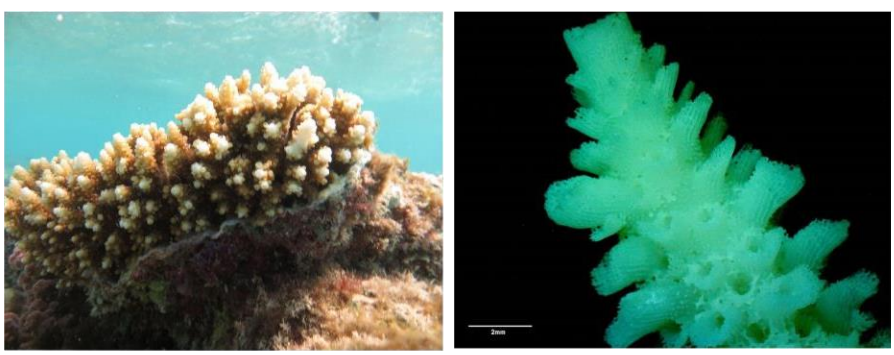


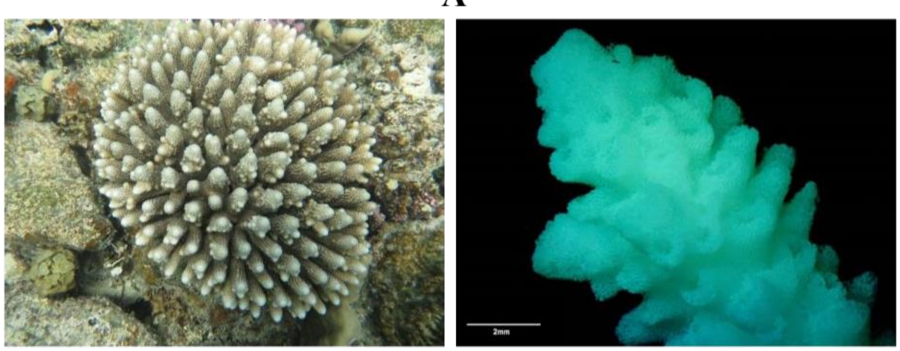
Figure 3. 5: Mean benthic cover of the 16, *Acropora* species at the study area.

3. 4. *Acropora* species identification

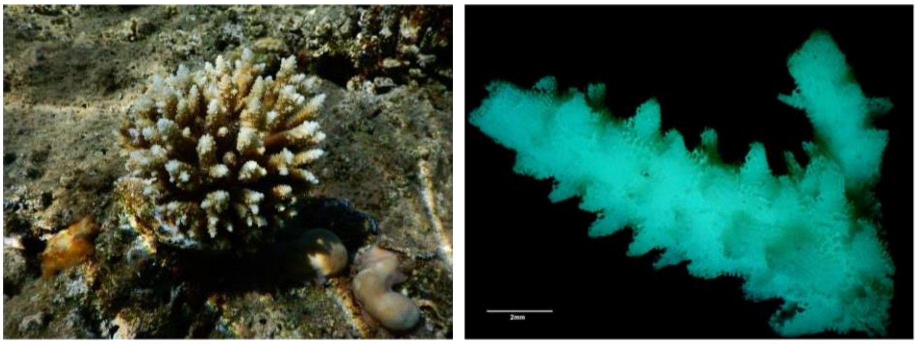
The species of *Acropora* were identified based on colony shape and microstructures of the hard skeleton of the collected samples. In total, 16 *Acropora* species were identified, showing a range of colony growth forms between the different species. On the other hand, within the same species, some samples collected from different sites showed a morphological plasticity as shown in Figure 3. 6.



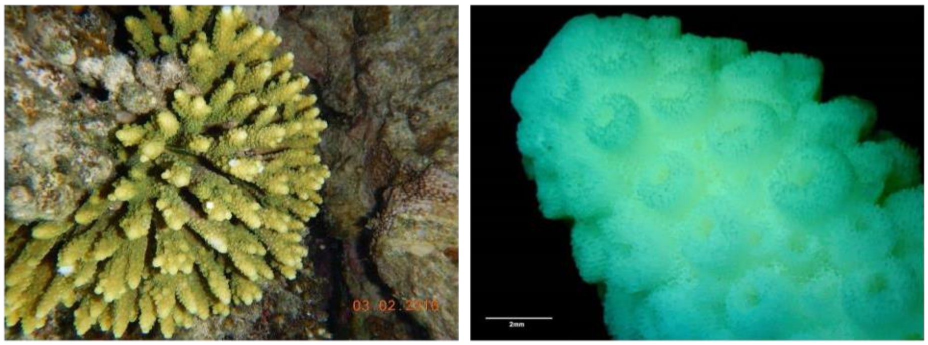
A



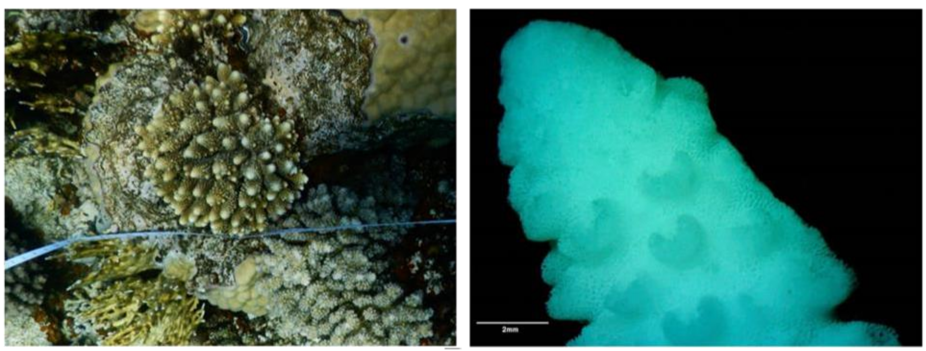
B



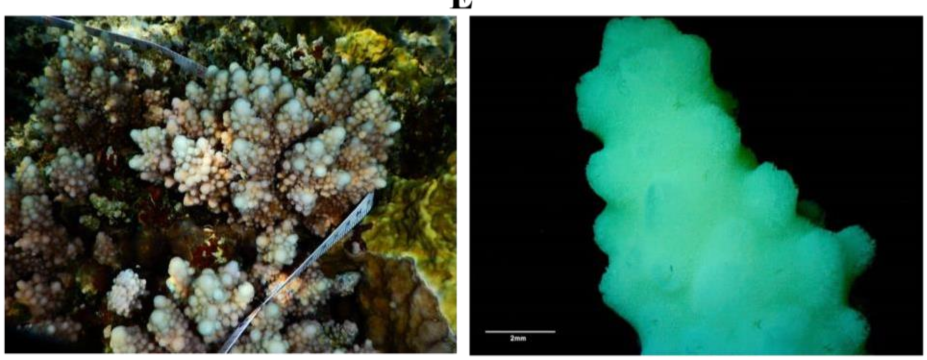
C



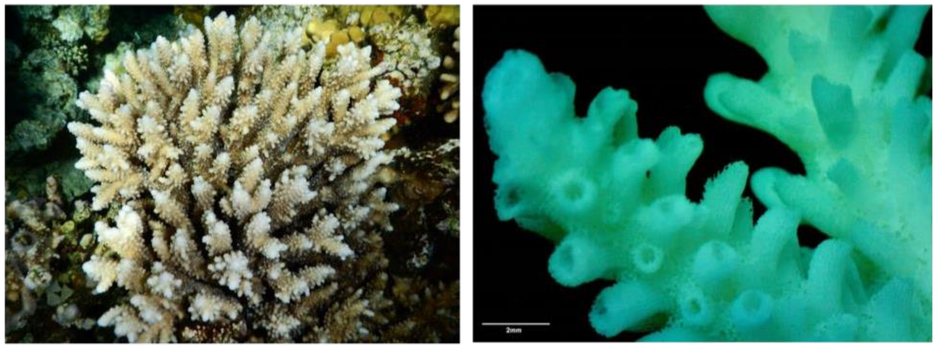
D



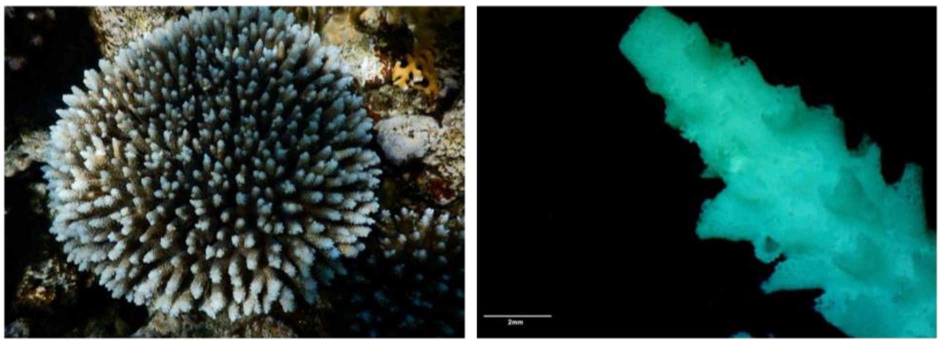
E



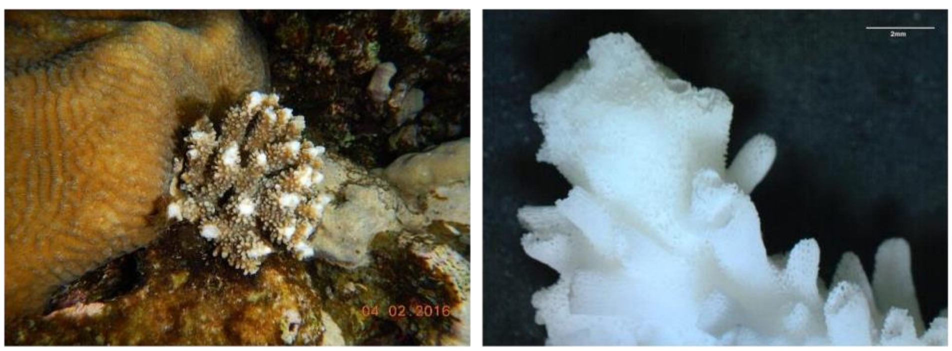
F



G

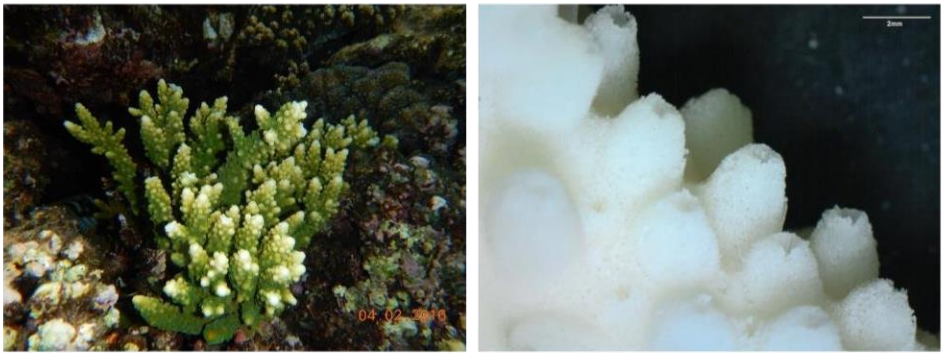


H

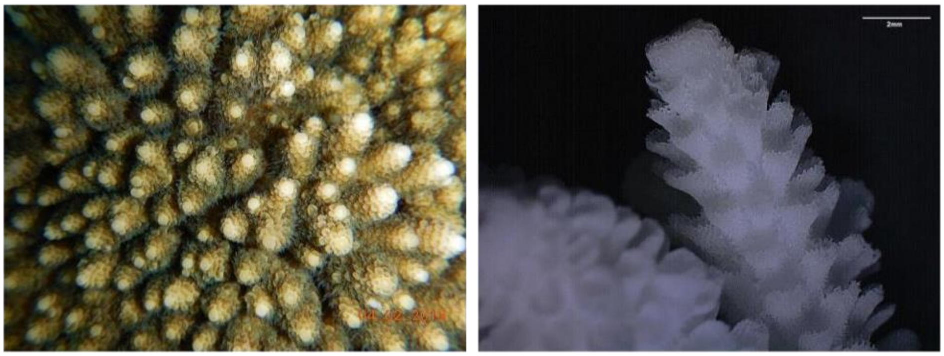


I

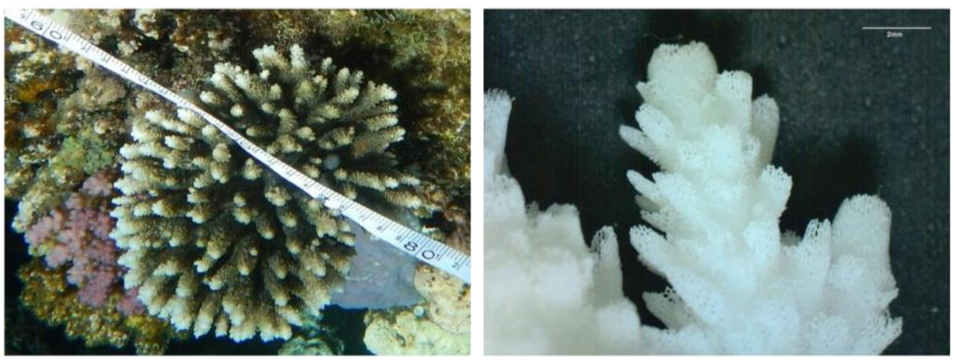
J



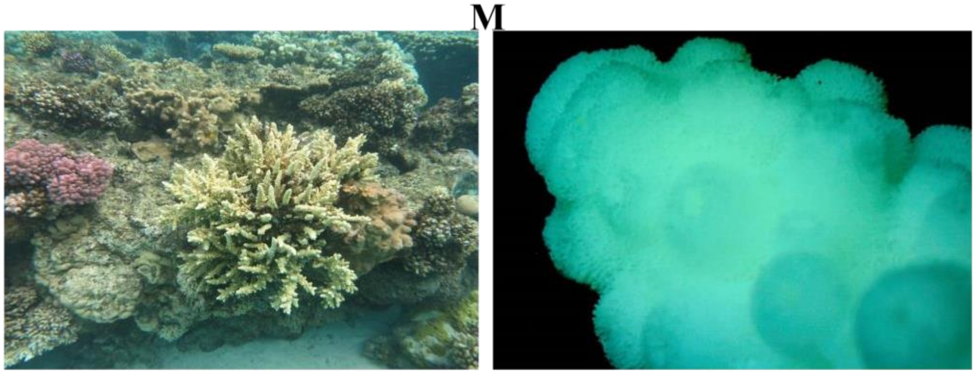
K



L



M



N

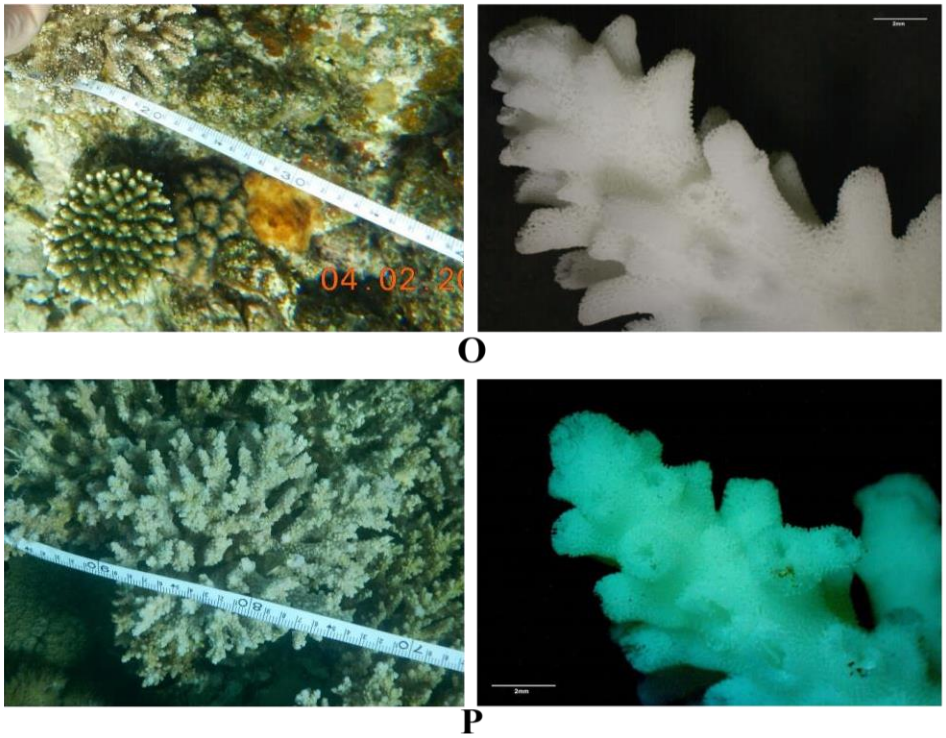


Figure 3. 6: Identification of different coral species belonging to the genus *Acropora* during the study. (A) *A. pharaonis*, (B) *A. gemmifera*, (C) *A. tenuis*, (D) *A. digitifera*, (E) *A. humilis*, (F) *A. squarrosa*, (G) *A. massawensis*, (H) *A. selago*, (I) *A. listeria*, (J) *A. polystoma*, (K) *A. hemprichii*, (L) *A. nasuta*, (M) *A. parapharaonis*, (N) *A. variolosa*, (O) *A. ocellata* and (P) *A. valida*.

3. 5. *Acropora* relative population structure

The relative structure of the more common *Acropora* species in the Gulf of Aqaba and Red sea proper attained the same trend of the benthic cover in which the Gulf of Aqaba was characterized by a high diversity of *Acropora* species compared to the Red Sea southern coasts. However, the population structure at each site was different.

At Old Quay, which has been characterized by highest diversity of *Acropora* assemblages, population was composed of 12 species, in which, *A. tenuis* and *A. digitifera* contributed with the highest benthic covers (Figure 3. 5). At the second order, Marsa Ghozlani population was composed of 10 species in which *A. digitifera* was the main contributor in the benthic cover of *Acropora* assemblage. At the southern coasts, however, *A. valida* was the only recovered species at the randomly laid 25 m transect (3 replicates) in NIOF, while 5 species were recorded in Satayeh that showed near benthic cover contributions of *A. gemmifera*, *A. tenuis*, *A. quarrosa* and *A. valida*.

The contribution of different species in *Acropora* assemblages at the study sites, on the other hand, showed that *A.valida*, *A. quarrosa*, *A. digitifera*, *A. tenuis* and *A. gemmifera* had the highest benthic covers in addition to abundances at the study sites. At the second order, *A. parapharaonis*, *A. nasuta*, *A. massawensis*, and *A. humilis* were recorded at Marsa Ghozlani, Old Quay and Camp sites. The other recorded species (i.e., *A. variolosa*, *A. selago*, *A. Ocellata*, *A. hemprichii*, *A. listeria*, *A. polystoma*, and *A. pharaonis*) were only identified individually from Marsa Ghozlani, Old Quay, and Satayeh (Figure 3.7).

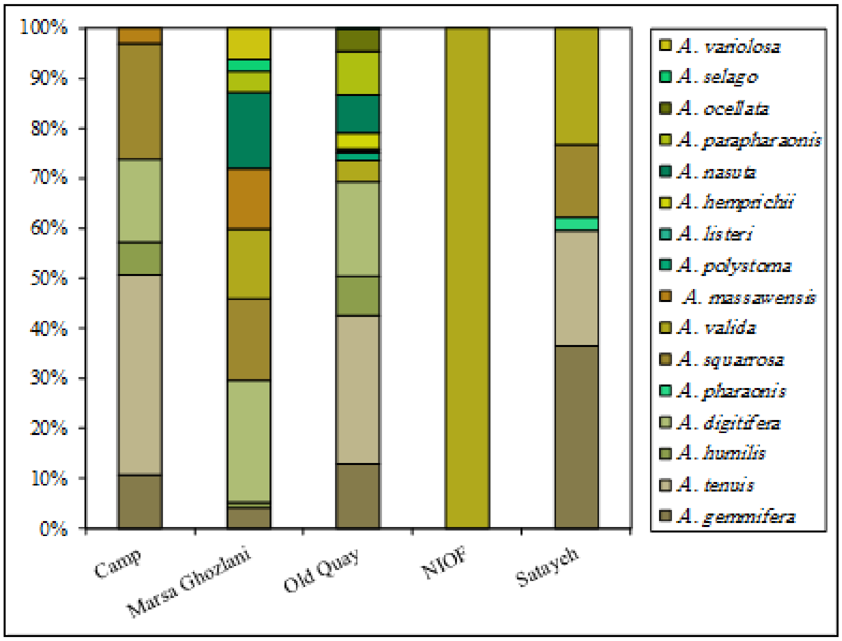


Figure 3. 7: The relative population structure of *Acropora* assemblages at different study sites.

The contribution of each species in *Acropora* assemblages at the study sites, on the other hand, showed that *A. valida*, *A. quarrosa*, *A. digitifera*, *A. tenuis* and *A. gemmifera* had the highest benthic covers in addition to abundances. At the second order, *A. parapharaonis*, *A. nasuta*, *A. massawensis*, and *A. humilis* were recorded at Marsa Ghozlani, Old Quay, and Camp sites. The other recorded species (i.e., *A. variolosa*, *A. selago*, *A. Ocellata*, *A. hemprichii*, *A. listeria*, *A. polystoma*, and *A. pharaonis*) were only identified individually from Marsa Ghozlani, Old Quay, and Satayeh (Figure 3. 8).

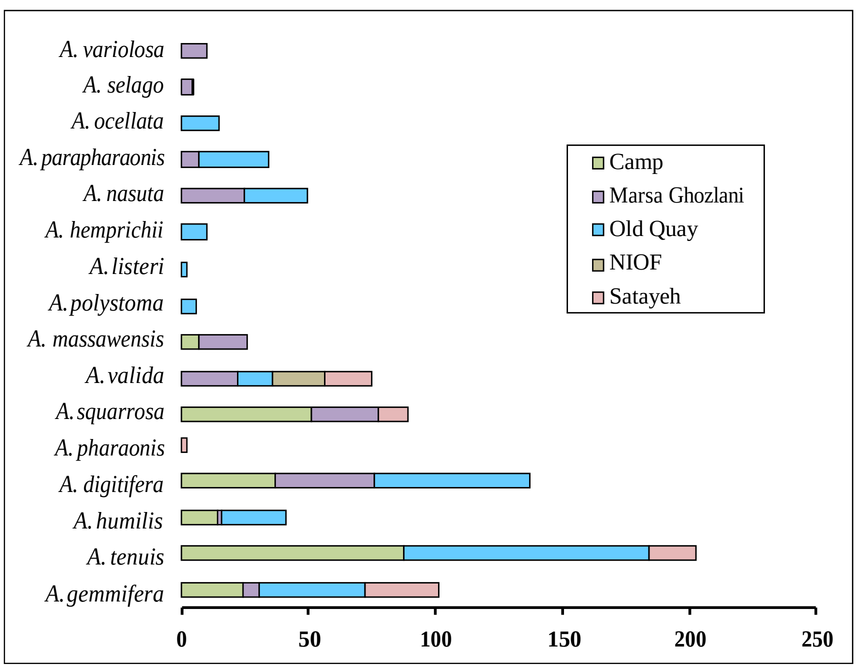


Figure 3. 8: Relative benthic cover of different *Acropora* species at different study sites.

3. 6. Vulnerability state of *Acropora* assemblages

Results showed that *A. pharaonis*, *A. polystoma*, *A. lesteri*, and *A. hemprichii* that were classified as IUCN vulnerable species, had lower coral cover. These species collectively form a 20%/transect forming 6.6% of the cover of *Acropora* species at the study area (Figure 3. 9). On the other hand, 50.9% of the *Acropora* assemblages was found to be the near threatened species during the current study. Among this category, *A. tenuis* and *A. digitifera* had formed a mean benthic cover of 67.5% and 45.8%/transect, respectively (Figure 3. 10). *Acropora selago*, however, had the same coverage as the vulnerable species. The results showed that *A. humilis* and *A. massawensis* had the similar vulnerability levels. Among the recorded species, three species including *A. massawensis*, *A. parapharaonis* and *A. ocellata* were unknown in their vulnerability state at the IUCN (Figure 3. 10).

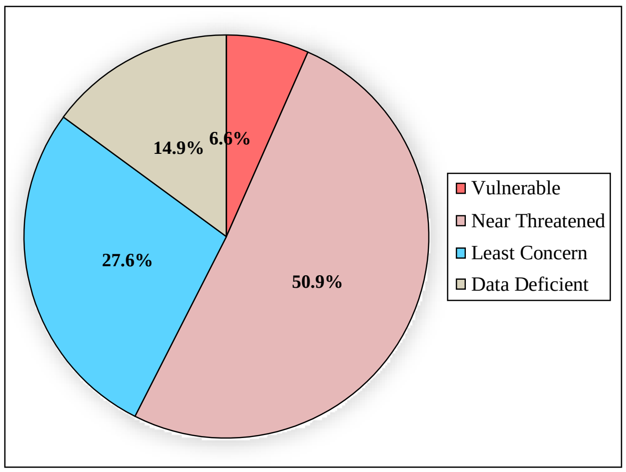


Figure 3. 9. Structure of *Acropora* assemblages at the Egyptian coast of the Red Sea according to the IUCN vulnerability state.

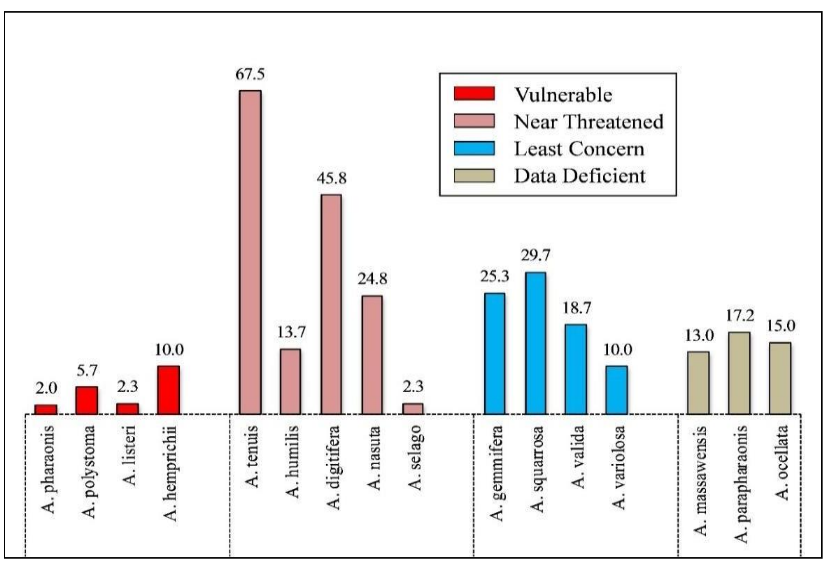


Figure 3. 10: The vulnerability state (given by IUCN Red List state) of some common *Acropora* species at the Red Sea. Numerical value above each column represents the mean cover (cm) per 25 m surveyed line transect.

Although there is increased awareness of the fragility of *Acropora* corals to further potential population decline, surprisingly little information on their density, structure, size, and population abundance is available in worldwide reef areas (Miller et al., 2009). At the Red Sea, the availability of information about the status of *Acropora* assemblages is more restricted as there have no comprehensive or even preliminary studies been conducted on the genus *Acropora* around this area, especially at the Egyptian coasts. Accordingly, our goal focused on the assessment of the status of genus *Acropora* assemblages at the Egyptian coasts of the Red Sea. The study also addressed the main keystone species of *Acropora* as well.

The current study indicated that Gulf of Aqaba has higher benthic cover of *Acropora* assemblage than southern assemblages at NIOF and Satayeh. This may be explained on the basis that the Gulf condition is more suitable for *Acropora* assemblages than the southern coasts. This study revealed that, when *Acropora* species richness is taken into consideration, the diversity within the genus *Acropora* is higher in the Gulf of Aqaba than those in the southern Red Sea coasts. In spite of the restricted number of transects surveyed in the current study, the common species of *Acropora* were easily detected. This limitation may also the main reason for the low diversity of *Acropora* species at the study sites.

The study addresses the perspective of the effects of the recent worldwide climatic and environmental changes that affects the biogeography of *Acropora* assemblages (Martínez et al., 2014). At the Red Sea, Fine et al. (2013) proposed that Gulf of Aqaba may serve as a refugium for coral species. The current study strengthened this concept by which some vulnerable *Acropora* species were more common at the Gulf but might be absent or rare at the southern reefs. These species including *A. polystoma*, *A. listeria*, and *A. hemprichii*, were only recorded from the Gulf. For *A. pharaonis*, however, it was recorded out of the surveyed transect at the Camp site.

The current study delivered the vulnerability state of the *Acropora* species by matching the benthic cover of the identified species and the state of each species on the IUCN Red List. On the other hand, some of the near threatened species of *Acropora* that was proposed by IUCN Red List showed high benthic cover compared to other species. These results indicated that coral reefs at the Red Sea comprised of a species that may be threatened at other reefs. *Acropora selago*, however, has the same coverage of the vulnerable species. So, the current study revealed that this species is in spite of being near threatened at many worldwide reefs, it is considered to be a vulnerable species at the Red Sea. The results also indicated that *A. humilis* and *A. massawensis* had similar vulnerability levels. The study is the first of it’s kind to provide valuable information on the vulnerability level of *A. massawensis*, *A. parapharaonis*, and *A. ocellata* at the Egyptian coasts of the Red Sea.

4 Conclusion

In spite of being near threatened at many worldwide reefs, *Acropora spp* is considered to be a vulnerable species at the Red Sea. The current study concluded that the *Acropora* assemblages at the Gulf of Aqaba are more diverged than that of outside the Gulf. The study also concluded that more than 50% of the *Acropora* species at the Egyptian coasts of the Red Sea are threatened or vulnerable to different environmental perturbations according to IUCN criteria. Accordingly, the coral reefs at the Gulf of Aqaba may represent refugium for endangered species at the Red Sea. Finally, the results obtained from this work could provide the basic data on the status of *Acropora* spp. populations and the possible threats in the Red Sea. It could also help the decision makers, scientists and other actors to develop, implement, management and conservation of these important coral species to a greater perspective.

Acknowledgments

Our special thanks goes to Ras Muhammad NP` and NIOF, Hurgada` staff, for all of their appreciable help. Finally, we want to acknowledge the work of the editors and the anonymous reviewers for their constructive comments on earlier drafts of the manuscript.

Conflict of interests

The authors declared that there is no conflict of interests regarding the publication of this paper.

References

Abdo, M. A. (2015). Transplantation and cultivation of some coral species on a reef of Marsa Bryka, Ras Muhammad National Park. M.Sc. Thesis, Faculty of Science, Suez Canal University, Egypt, 176 p.

Acropora Biological Review Team. (2005). Atlantic *Acropora* Status Review Document. Report to National Marine Fisheries Service, Southeast Regional Office. National Marine Fisheries Service, St. Petersburg, 152 p.

Aronson, R., Bruckner, A., Moore, J., Precht, B., & Weil, E. (2008). IUCN Red List of Threatened Species: *Acropora* cervicornis. Version 2011.2. Cambridge, United Kingdom: International Union for Conservation of Nature and Natural Resources. c2011; July 2010.

Baker, A. C., Glynn, P. W., & Riegl, B. (2008). Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. *Estuarine, Coastal and Shelf Science, 80*, 435-471. https://doi.org/10.1016/j.ecss.2008.09.003

Buddemeier, R. W., Kleypas, J. A., & Aronson, R. B. (2004). Coral reefs and global climate change: Potential contributions of climate change to stresses on coral reef ecosystems. Pew Center on Global Climate Change, Arlington, VA.

Bruckner, A. W. (2002). Proceedings of the Caribbean *Acropora* Workshop: Potential Application of the U.S. Endangered Species Act as a Conservation Strategy. NOAA Technical Memorandum NMFS-OPR-24, Silver Spring, MD, 184 p.

Bruno, J. F., & Selig E. R. (2007). Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. *PLoS ONE*, *2(*8), e711. https://doi.org/10.1371/ journal.pone.0000711

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2012). Reefs at Risk Revisited. World Resources Institute, Washington, DC, 86 p. http://pdf.wri.org/reefs_at_risk_revisited.pdf

Carpenter, K., Abrar, M., & Aeby, G. (2008). One-third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science*, *321*, 560-563. https://doi.org/10.1126/science.1159196

Coker, D. J., Wilson, S., & Pratchett, M. S. (2013). Importance of live coral habitat for reef fishes. *Reviews in Fish Biology and Fisheries*, *24*(1), 89-126. https://doi.org/10.1007/s11160-013-9319-5

Crosby, M. P., Abu-Hilal, A., Al-Homoud, A., Erez, J., & Ortal. R. (2000). Interactions among scientists, managers and the public in defining research priorities and management strategies for marine and coastal resources: Is the Red Sea Marine Peace Park a new paradigm? *Water, Air and Soil Pollution*, *123*, 581-594. https://doi.org/10.1007/978-94-011-4369-1_45

El-Gamily, H. I., Nasr, S., & El-Raey, M. (2001). An assessment of natural and human-induced changes along Hurghada and Ras Abu Soma coastal area, Red Sea, Egypt. *International Journal of Remote Sensing*, *22*, 2999-3014. https://doi.org/10.1080/01431160120421

Foale, S., Adhuri D., Porfiro Aliño, P., Allison E. H., Andrew, N., Cohen P., Evans, L., Fabinyi M., Fidelman, P., Gregory, C., Stacey, N., Tanzer, J, & Weeratunge, N. (2013). Food security and the Coral Triangle Initiative, *Marine Policy*, *38*, 174-183. https://doi.org/10.1016/ j.marpol.2012.05.033

Fine, M., Cinar, M., Voolstra, C. R., Safa, A., Rinkevich, B., Laffoley, D., Hilmi, N., & Allemand D. (2019). Coral reefs of the Red Sea — Challenges and potential solutions. *Regional Studies in Marine Science*, *25*, 100498. https://doi.org/10.1016/j.rsma.2018.100498

Gardner, T. A., Côté, I. M., Gill, J. A., Grant, A., & Watkinson, A. R. (2003). Long-term region-wide declines in Caribbean corals. *Science, 301*(5635), 958-960. http://dx.doi.org/10.1126/science.1086050

G¨ardenfors, U., Hilton-Taylor, C., Mace, G. M., & Rodr´ıguez J. P. (2001). The application of IUCN Red List criteria at regional levels. *Conservation Biology*, *15*(5), 1206-212. https://doi.org/10.1111/j.1523-1739.2001.00112.x

Gladfelter, E. H., Monahan, R. K., & Gladfelter, W. B. (1978). Growth rates of five reef-building corals in the northeastern Caribbean. *Bulletin of Marine Science*, *28*, 728-734.

Glynn, P. W. (1973). Aspects of the ecology of coral reefs in the western Atlantic region. In: Jones OA, Endean R, editors. Biology and geology of coral reefs. Vol. 2. Academic Press. New York, pp. 271-324.

Hagen, R. (2018). Underwater and Underrated: Coral Reefs and Climate Change, American Security Project. https://www.jstor.org/stable/resrep19816

Hasan, M. H. (2018). Effect of tourism activities on coral communities at the Gulf of Suez, Red Sea. *Journal of Water Resource and Protection*, *10*, 794-808. https://doi.org/10.4236/jwarp.2018.108045

Hernández-Fernández, L., González de Zayas, R., Olivera, Y. M., Pina Amargós. F., Bustamante López, C., Dulce Sotolongo, L. B., Bretos, F., Figueredo Martín, T., Lladó Cabrera, D., & Salmón Moret, F. (2019). Distribution and status of living colonies of *Acropora* spp. in the reef crests of a protected marine area of the Caribbean (Jardines de la Reina National Park, Cuba). *PeerJ*, 7, e6470. https://doi.org/10.7717/peerj.6470

Hilmi, H., Safa, A., Reynaud, S., & Allemand, D., (2018). Coral based tourism in Egypt's Red Sea. *In*: Prideaux, B., & Pabel, A. editors, Coral Reefs: Tourism, Conservation and Management. Taylor and Francis Group.

Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research*, *50*, 839-66. http://dx.doi.org/10.1071/MF99078

Hogarth, W. T. (2006). Endangered and threatened species: final listing determinations for the elkhorn coral and staghorn coral. *Federal Register*, *26*, 852-861.

Hughes, T. P., Baird, A. H., & Bellwood, D. R. Connolly, S. R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J. B. C., Kleypas, J., Lough, J. M., Marshall, P., Nystrom, M., Palumbi, S. R., Pandolfi, J. M., Rosen, B., & Roughgarden, J. (2003). Causes of coral reef degradation—response. *Science*, *302*, 1503-1504. https://doi.org/10.1126/science.302.5650.1502b

Ismail, M., Kimura, T., Suzuki, Y., & Tsuchiya, M. (2005). Seasonal and spatial variations of total mass flux around coral reefs in the Southern Ryukyus, Japan. *Journal of Oceanography 61*(3), 631-644. https://link.springer.com/article/10.1007/s10872-005-0071-x

Jackson, J. B. C. (1992). Pleistocene perspectives on coral reef community structure. *American Zoology*, *32*(6), 719-731. https://doi.org/10.1093/icb/32.6.719

Kenyon, J., Maragos, J., & Fenner, D. (2011). The Occurrence of coral species reported as threatened in federally protected waters of the US Pacific. Hindawi Publishing Corporation, *Journal of Marine Biology, 2011* (Article ID 358687), 1-12. https://doi.org/10.1155/2011/358687

Khalaf, M. A., & Kochzius, M. (2002). Changes in tropic community structure of shore fishes at an industrial site in the Gulf of Aqaba, Red Sea. *Marine Ecology Progress Series*, *239*, 287-299. https://www.jstor.org/stable/24866067

Kotb, M. M. A., Hanafy, M. H., Rirache, H., Matsumara, S., Al-Sofyani, A. A., Ahmed, A. G., Bawazir, G., & Al-Horani, F. (2008). Status of coral reefs in the Red Sea and Gulf of Aden Region. *In*: Status of Coral Reefs of the World: 2008, Wilkinson, C.E., editors. Townsville (Australia): Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, pp. 67-78.

Lieske, E., & Myers, R. F. (2004). Coral Reef Guide Red Sea. Collins Publishers, London.

Loya, Y. (2007). How to influence environmental decision makers? The case of Eilat (Red Sea) coral reefs. *Journal of Marine Biology and Ecology*, *344*, 35-53. https://doi.org/10.1016/j.jembe.2006.12.005

Martínez, K., & Rodríguez-Quintal, J. G. (2012). Estructura poblacional de *Acropora* palmate (Scleractinia: Acroporidae) en el Parque Nacional San Esteban, Venezuela. *Boletín del Institute Oceanográfico de Venezuela*, *51*, 129-137.

Martínez, K., Bone, D., Cróquer, A., & López-Ordaz, A. (2014). Population assessment of *Acropora* palmate (Scleractinia: Acroporidae): relationship between habitat and reef associated species. *Revista de Biología Tropical*, *62*, 85-93.

Miller, S. L., Chiappone, M., Rutten, L. M., & Swanson, D. W. (2009). Population status of *Acropora* corals in the Florida Keys. Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, FL, pp. 775-779.

Moustafa, F. (2000). Status of Coral Reefs in the Middle East. AIMS, 2000. Retrieved from the World Wide Web in June 2007. http://www.aims.gov.au

Pandolfi, J. M., Bradbury, R. H., Sala, E., Hughes, T. P., Bjorndal, K. A., Cooke, R. G., McArdle, D., McClenachan, L., Newman, M. J., Paredes, G., Warner, R. R., & Jackson, J. B. (2003). Global trajectories of the long-term decline of coral reef ecosystems. *Science*, *301*(5635), 955-958. https://doi.org/10.1126/science.1085706

Persga. (2010). The Status of Coral Reefs in the Red Sea and Gulf of Aden: 2009. PERSGA Technical Series Number 16, PERSGA, Jeddah.

Porter, J. W., & Meier, O. W. (1992). Quantification of loss and change in Floridian reef coral populations. *American Zoologist*, *32*, 625-640.

Reaka-Kudla, M. L. (1997). Global biodiversity of coral reefs: A comparison with rainforests. *In*: Reaka-Kudla, M. L., & D. E. Wilson, editors. Biodiversity II: Understanding and protecting our biological resources. Joseph Henry Press, Washington, D.C., pp. 83-108.

Reaka-Kudla, M. L. (2001). Known and unknown biodiversity, risk of extinction and conservation strategy in the sea. *Waters in Peril*, 19-33. https://doi.org/10.1007/978-1-4615-1493-0_2

Rodrigues, A. S. L., Pilgrim, J. D., Lamoreux, J. F., Hoffmann, M. & Brooks T. M. (2006). The value of the IUCN Red List for conservation. *Trends in Ecology and Evolution*, *21*(2), 71-76. https://doi.org/10.1016/j.tree.2005.10.010

Shaalan, I. M. (2005). Sustainable tourism development in the Red Sea of Egypt: threats and opportunities. *Journal of Cleaner Production*, *13*(2), 83-87. https://doi.org/10.1016/j.jclepro.2003.12.012

Spalding, M., Spalding, M. D., Ravilious, C., & Green, E. P. (2001). World atlas of coral reefs. University of California Press, Berkeley, USA.

Veron, J. E. N. (1986). Corals of Australia and in the-Pacific. University of Hawaii Press, Honolulu, Hawaii, USA, 644 p.

Veron, J. E. N. (2000). Corals of the World Vol. 1 AIMS and CRR. Australian Institute of Marine Science. Townssville, Queensland, Australia, 463 p.

Veron, J. E. N., Hoegh-Guldberg, O., Lenton, T. M., Lough, J. M., Obura, D. O., Pearce-Kelly, P., Sheppard, C. R., Spalding, M., Stafford-Smith, M. G., & Rogers, A. D. (2009). The coral reef crisis: the critical importance of < 350 ppm CO_2. *Marine Pollution Bulletin*, *58*(10), 1428-1436. https://doi.org/10.1016/j.marpolbul.2009.09.009

Villanoy, C., David, L., Cabrera, O., Atrigenio, M., Siringan, F., Aliño, P., & Villaluz, M. (2012). Coral reef ecosystems protect shore from high-energy waves under climate change scenarios. *Climatic Change, 112*, 493-505. https://doi.org/10.1007/s10584-012-0399-3

Waheed, Z. (2016). Patterns of coral species richness and reef connectivity in Malaysia. PhD thesis. Leiden University, Netherland.

Wallace, C. C., & Rosen, B. R. (2006). Diverse staghorn corals (*Acropora*) in high-latitude eocene assemblages: implications for the evolution of modern diversity patterns of reef corals. *Proceedings of the Royal Society B: Biological Sciences, 273*(1589), 975-982. https://doi.org/10.1098/rspb.2005.3307

Wild, C., Hoegh-Guldberg, O., Naumann, M. S., Colombo-Pallotta, M. F., Ateweberhan, M., Fitt, W. K., Iglesias-Prieto, R., Palmer, C., Bythell, J. C., Ortiz, J. C., Loya, Y., & van Woesiket, R. (2011). Climate change impedes scleractinian corals as primary reef ecosystem engineers. *Marine & Freshwater Research, 62*, 205-215. https://doi.org/10.1071/MF10254

Wilkinson, C. (2002). Status of coral reefs of the world: 2002. Global Coral Reef Monitoring Network and Australian Institute of Marine Science, Townsville.

Williams, D. E., Miller, M. N., & Kramer, K. L. (2006). Demographic monitoring protocols for threatened Caribbean *Acropora* spp. Corals. Vol. 543. NOAA Technical Memorandum NMFS-SEFSC, 93 p.