

RESEARCH ARTICLE

## The Effects of Local Aquatic Activities on Coral Cover in the Jordanian Gulf of Aqaba

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### Abstract

**Objective:** The reef flats at the Gulf of Aqaba, Jordan, are exposed to the accelerated development associated with increased interest in recreational marine activities such as diving and snorkeling. The physical damage from net entanglement and overfishing has also affected the coral reef. This research evaluated the effects of aquatic, commercial, and land-based activities on the total coral cover in the Aqaba Marine Park (Now the Aqaba Marine Reserve) and the power station located north of the reserve.

**Materials and Methods:** The line transect method was used to estimate the coral cover, followed by measuring the distance of the 13 diving sites to the different landscape disturbances and applying a linear regression analysis.

**Results:** The results showed no significant relationship between the distance to the nearest human disturbance and the entire coral cover in the depth categories. In addition, there was no significant difference between low and high-frequency diving pressure and the mean coral cover at any depth category and no significant difference in the mean coral cover between low and high-frequency snorkeling sites. Sites with higher fishing activity had significantly lower coral cover than sites with lower fishing activity. However, there was no significant difference in the mean coral cover between sights with higher and lower fishing activity at the 21-30 m depth range.

**Conclusion:** The study illustrated that local marine recreational activities (diving and snorkeling) do not affect the coral cover structure up to 10 meters depths. However, considerable coral degradation was found in high fishing zones less than 10 meters deep, which correlates with illegal fishing activities. We believe illegal fishing has negatively affected the coral cover, and recreational marine activities reduced coral cover, especially in diving areas requiring shore entrance.

**Keywords:** Aqaba marine reserve, Coral cover, Fishing activities, Jordan, Recreational marine activities

## Introduction

In the past 30 years, 60% of the world's coral reefs have vanished due to global and local anthropogenic activities (Gardner *et al.*, 2003; Côté *et al.*, 2005; Bruno & Selig, 2007; Carlson *et al.*, 2019). The Red Sea has a biologically rich coral reef ecosystem contains thousands of fish species and other associated fauna (Golani & Bogorodsky, 2010; Fine *et al.*, 2019). The reef system in the Gulf of Aqaba in Jordan consists of continuous and discontinuous fringing corals, which increase in depth as the distance from the reef crest increases (Khalaf & Kochzius, 2002a; Kotb *et al.*, 2008; Al Tawaha *et al.*, 2019). The Red Sea and Aqaba Gulf coral reefs are more resilient to global bleaching events but still vulnerable to local aquatic and land-based disturbances (Osman *et al.*, 2017). The Red Sea and Gulf of Aqaba are popular tourist destinations, making them prime locations to study the impact of aquatic recreational activities and coastal infrastructure development on coral reef health (Gladstone *et al.*, 2013). Our understanding of the anthropogenic effects on coral cover in the Red Sea and Gulf of Aqaba is a top priority, especially given that the coral reefs are suggested as a source of future translocation to assist in the global recovery of coral reef ecosystems (Osman *et al.*, 2017).

The reef flats are biodiverse habitats with high primary productivity rates that support global fisheries and comprise an estimated 35% of global marine biodiversity (Barbier *et al.*, 2011; Bellwood *et al.*, 2018). However, reef flats, such as those in Aqaba, Jordan, are threatened because they are adjacent to significant populations and industrial centers (Khalaf & Kochzius 2002a, 2002b; Kotb *et al.*, 2008). The reefs off Aqaba are accessible for recreational and diving activities, concentrated within Jordan's limited 27-kilometer coastline (Carlson *et al.*, 2019). Unsustainable large- and small-scale fishing practices can lead to a reduction of coral cover through the physical damage from net entanglement and overfishing that leads to trophic changes in the fish community (Dulvy *et al.*, 2004; Wilson *et al.*, 2010; Jessen *et al.*, 2014; Rizzari *et al.*, 2014; Ballesteros *et al.*, 2018). Urban development and runoff suffocate coral polyps, which causes corals to die (Diaz & Rosenberg, 2008; Carlson *et al.*, 2019).

A survey was conducted in the Aqaba Marine Park (hereafter called the Aqaba Marine Reserve), and the Power Station Center located north of the reserve (Fig. 1). The landside of the reserve is 350 meters from the coastline and extends for about seven kilometers off Aqaba. It contains around 28 active dive sites. The reef flat in Aqaba is the northernmost ecosystem in the Indo-Pacific region (Al Tawaha *et al.*, 2019). This research assessed the impact

of aquatic, commercial, and land-based activities on the coral cover of Aqaba, Jordan.



**Figure 1.** The Aqaba Marine Reserve and the Power Station Locations along the Gulf of Aqaba, Jordan.

## Materials and Methods

The cover of the living hard and soft coral was estimated using the linear transect method (English *et al.*, 1997) in May 2019, where three transects, each 20 m long and a meter on both sides, were studied at three depth zones of 1-10 m, 11-20 m, and 21-30 m at 13 diving sites approximately 500 m apart in the Aqaba Marine Reserve (Table 1), with transects performed in the Power Station Center north of the marine reserve, where data was recorded every 0.5 m using a special underwater writing board. We then measured the distance of the 13 sites to different landscape disturbances, such as distance to the nearest road, hotel, jetty, and port, using Google Earth (Table 1). There are large commercial ports at the northern and southern border of Jordan's Red Sea coast. The jetties are approximately 50 m long and are mainly used by swimmers, snorkelers, and small boats. In past surveys, we categorized the prevalence of fishing from local fishermen by examining the physical remains of entangled fishnets and/or fishing rope remnants. We ranked higher fishing density sites as those with fragments of torn fishing nets at more than one location at the dive site. In

contrast, lower-density fishing sites typically had little or no fishing net remnants at any given time. Based on interviews with local dive centers, we categorized snorkel sites as low- or high-frequency. There are roughly 32 licensed diving centers in Aqaba. Most dive sites are visited from the shore. We classified high frequency sites as those used by a dive center more than twice a week. Low-frequency sites are those visited once or less a week by a dive center.

of the depth categories (0-10 m):  $F(1,12)=0.013$ ,  $p=0.99$ , ii) (11-20 m):  $F(1,12)=0.085$ ,  $p=0.99$  and iii) (21-30 m):  $F(1,12)=0.013$ ,  $p=0.99$ ). The p-values ( $p=0.99$ ) for the depth categories are more significant than the typical significance level, indicating that differences in the distance of human disturbance have no impact on coral cover.

**Table 1.** Geographical location of the diving sites (decimal degrees) and respective distances (m) to different potential landscape disturbances.

Dive site	Latitude	Longitude	Road	Hotel	Port	Jetty
Black Rock	29.43495	34.97213	224	112	2847	93
Eel Canyon	29.41467	34.97518	288	259	3318	235
First Bay North	29.45067	34.97066	77	115	1161	406
Gorgon 1 & 2	29.41833	34.97285	213	713	3634	36
Japanese Garden	29.42695	34.97279	50	300	3722	425
King Abdullah Reef South	29.43902	34.97018	401	522	2389	577
King Abdullah Reef North	29.4433	34.96933	415	555	2010	500
Marine Science Station	29.45472	34.9725	8	570	657	874
Power Station Center	29.48806	34.98353	43	4138	1769	36
Power Station North	29.48958	34.98561	22	3756	1977	151
Power Station South	29.48283	34.98242	11	4453	1057	690
Rainbow Reef	29.4311	34.97428	115	70	3298	53
Seven Sisters	29.42264	34.97196	205	324	4056	191
<b>Mean + SE</b>			159.4+39	1222.1+462	2453.5+309	328.2+76
<b>Min – Max</b>			8 – 415	70 – 4453	657 – 4056	36 – 874

We performed linear regression analysis to determine how the coral cover percentage was affected by distance to the nearest human development (road, hotel, commercial port, and jetty). We then compared the mean coral cover at sites according to the categorically classified density of aquatic activities, such as diving, fishing, and snorkeling, using multiple ANOVAs. We analyzed the data separately for each depth class, 0-10 m, 11-20 m, and 21-30 m. We only compared the mean coral cover at sites with high and low snorkel density at the 0-10 m depth, as snorkeling rarely occurs in greater depths.

## Results

### *Distance to human disturbance*

The final linear regression models showed there was no significant relationship between the distance to the nearest human disturbance and total coral cover in any

### *Diving pressure*

We found no significant difference between low and high-frequency diving density and mean coral cover at any depth category (0-10 m:  $F_{1,12}=0.89$ ,  $p=0.37$ ; 11-20 m:  $F_{1,12}=0.83$ ,  $p=0.38$ ; 21-30 m:  $F_{1,12}=0.13$ ,  $p=0.72$ ).

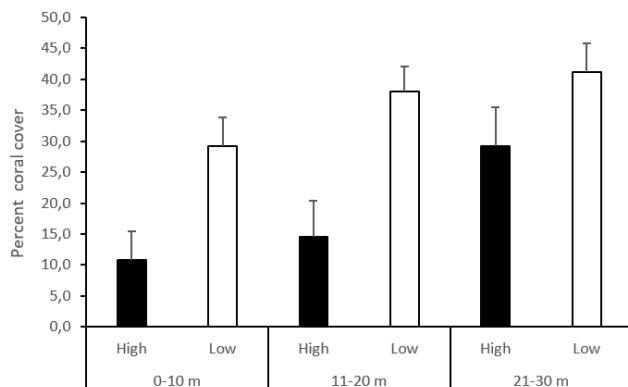
### *Snorkeling Sites*

There was also no significant difference in the mean coral cover between low and high-frequency snorkeling sites at the 0-10m depth range ( $F_{1,12}=0.38$ ,  $p=0.55$ ).

### *Fishing Activity*

Sites with higher fishing activity had significantly lower coral cover than sites with lower fishing activity at 0-10 m ( $F_{1,12}=5.62$ ,  $p=0.037$ ) and 11-20 m ( $F_{1,12}=10.29$ ,  $p=0.009$ ). However, there was no significant difference in mean coral cover between sights with higher or lower

fishing activity at the 21-30 m depth range ( $F_{1,12}=2.22$ ,  $p=0.16$ ) (Fig. 2).



**Figure 2.** The mean (+ SE) percent coral cover with high and low fishing activity at three depth zones is compared.

## Discussion

Our results suggest an association between illegal, small-scale fishing practices and coral cover. Study sites with high levels of fishing activity, such as the power station, as evidenced by fragments of ghost nets and fishing ropes, have reduced coral cover. The local fishermen often encircle small sections of the reef with nets, ropes, cages, nylon lines, anchors, and other angling devices that physically damage and trample corals and disrupt the ecological integrity of the coral reef (Chiappone *et al.*, 2005; Abu-Hilal & Al-Najjar, 2009; Gilardi *et al.*, 2010; Al Tawaha *et al.*, 2019). Furthermore, even after the fishing event, the remaining ghost fishing equipment continues to damage coral, entangle fish, and reduce the penetrating light (Gunn *et al.*, 2010). The effects of small-scale localized disturbance from local fishing can accumulate over time to significantly degrade coral (Edinger *et al.*, 1998; Asoh *et al.*, 2004; Shedrawi *et al.*, 2017). The decline in coral cover as a result of damage from fishing equipment could alter the coral reef fish community by reducing the abundance of corallivorous and carnivorous fish (Khalaf & Kochzius, 2002a; 2002b) while overfishing has led to the rarity of large natural predators and commercially valuable fish species. The association between higher fishing activity and the reduced coral cover was less apparent at depths greater than twenty meters (Fig. 2). We believe that local fishermen, including the limited practices in scale by visitors and picnickers who illegally fish nets, do so at the shallower and more accessible reefs with smaller nets, which allows poachers to quickly remove their nets and leave if pursued (personal observation, OA).

Fishing activities are not allowed within 350 m of the coast to encourage catching pelagic species such as (*Thunnus albacares*), one of the primary target species for artisanal fisheries (Tsfamichael *et al.*, 2016). Jordan has a small artisanal fishing fleet that provides fish to the local market (Khalaf & Kochzius, 2002a; Tsfamichael *et al.*, 2012). However, fishermen can use throw nets inside the 350m to catch small planktivorous and pelagic species for bait. The legal enforcement is inconsistent as illegal fishing near the reefs was observed at sunrise at some of the survey sites in small motorboats (3-5 m length) using seine and gill nets in addition to amateur fishermen who use ropes and nylon to fish from shore in the evening and early morning hours.

We found no association between coral cover and diving and snorkeling activities. We may not have found any association with these aquatic recreations because the coral damage may have already taken place from long-term recreation in such a small area, and what remains is the reduced coral cover that can endure (Hawkins & Roberts, 1993; Tratalos & Austin, 2001; Barker & Roberts, 2004; Hasler & Ott, 2008; Lamb *et al.*, 2014). Most of the entrances to the beaches and dive sites are heavily damaged (Al Tawaha *et al.*, 2019), given the high levels of recreation used to create dive sites that have alleviated the diving density at natural coral reefs (Tynyakov *et al.*, 2017). Most inexperienced open-water divers, discovery divers, and snorkelers visit these wreck sites. In contrast, experienced divers are more likely to visit the less frequented dive sites with higher coral cover (Lynch *et al.*, 2014). In the Gulf of Aqaba, the damage that results from the irresponsible practice of amateur divers, such as touching, grabbing, or standing on coral reefs, which causes coral breakage, has been documented.

Unlike other studies, our study found no association between coral cover and landscape disturbance for several reasons (Fabricius, 2005; Carlson *et al.*, 2019). One limitation of our analysis is that the study scale is relatively small as the dive sites are located close the disturbances because of current derived mass transport of contaminants (Table 1), therefore, the whole reserve is subjected to the same disturbance (Abelson *et al.*, 1999; Carlson *et al.*, 2019). Also, our study treats all developments equally, regardless of scale or year built. The dive sites examined are likely remnants of areas that already experienced disturbances and are degraded compared to their original state (Walker & Ormond, 1982). However, a direct relationship between the coral reef distance is significantly meaningful, and a necessary landscape disturbance is not



always essential. A landscape disturbance is not always needed, not consistently substantial, and not always a crucial significant predictor of coral cover (Lirman & Fong, 2007). Establishing a comprehensive registry for diving records, including the number of divers, duration of dive, site, level of diving professionalism, and other information, is highly recommended.

An alternative explanation could be related to the flash flood events that happen in Aqaba and contribute to massive sedimentation running into the Gulf. This was discussed by several scholars who stated that the hyper-arid environment surrounding the Red Sea could mitigate local coastal disturbances, such as sedimentation and pollution from rainfall and rivers (Freiwan & Kadioğlu, 2007; Katz *et al.*, 2015; Carlson *et al.*, 2019). Landscape effects are often noticeably apparent after heavy rainfall carrying sediments and terrestrial contaminants run into the Gulf, negatively impacting coral health (Acevedo *et al.*, 1989; Butler *et al.*, 2015; Carlson *et al.*, 2019).

In 2020, the Jordanian government changed the administration classification of the Aqaba Marine Park (AMP) to the Aqaba Marine Reserve (AMR) after direct orders from His Majesty King Abdulla II bin Al-Hussein to bolster its management and legal enforcement with support at the national and international levels (Eid *et al.*, 2021). A management plan was developed for the reserve, and a bylaw was prepared to strengthen governance and conservation aspects. This study investigated recreational marine activities as a growing industry in the Gulf of Aqaba, Jordan, which will add an essential baseline for future research and monitoring attempts. Hopefully, this increased enforcement of no fishing in the shallow reefs and proper monitoring of recreational marine activities will contribute to the recovery of the coral reef community.

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