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

Omar Attum¹, Mohammad Al Tawaha², Zachary Giuffre¹, Ehab Eid³, Abdullah Abu Awali⁴

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.

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.

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 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.

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

We found no significant difference between low and high-frequency diving density and mean coral cover at any depth category (0-10 m: F1,12=0.89, p=0.37; 11-20 m: F1,12=0.83 p=0.38; 21-30 m: F1,12=0.13, p=0.72).

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: F1,12=0.89, p=0.37; 11-20 m: F1,12=0.83 p=0.38; 21-30 m: F1,12=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 (F1,12=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 (F1,12=5.62, p=0.037) and 11-20 m (F1,12=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 (F1,12=2.22, p=0.16) (Fig. 2).

**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 (Tesfamichael et al., 2016). Jordan has a small artisanal fishing fleet that provides fish to the local market (Khalaf & Kochzius, 2002a; Tesfamichael 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 (Tynakav 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

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

Peer-review: Externally peer-reviewed.


Acknowledgments: We thank Indiana University Southeast for their logistical support. Appreciation goes to the Aqaba Marine Reserve staff members for facilitating this survey.

Conflict of Interest: The authors declare no conflicts of interest.

Financial Disclosure: This research was funded by the GEF Small Grants Programme.

References


