

The effect of fishing pressure on the ecology of sea cucumber populations in the Gulf of Aqaba, Red Sea

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Abstract

Sea cucumber populations in the Gulf of Aqaba were surveyed in 2006, 10 years after fishing ended. Data here are compared with findings of previous surveys carried out in the same area in the years 1995, 2002 and 2003.

This study revealed that species diversity and density of sea cucumbers were significantly reduced between pre-fishing (1995) and post-fishing (2002–2006) periods in all study sites. In total, 18 species were recorded from 5 surveyed sites. The highest diversity in 1995 was found at Wadi Quny with 13 species, but decreased to only 4 species in 2006. The diversity of sea cucumbers at the Eel Garden was 12 species in 1995, but decreased to only 2 species in 2006. There was no available data for Shark Reef, Nakhlet El-Tall and Abu Negilla Lagoon for the years 1995 and 2002. Shark Reef and Nakhlet El-Tall recorded the same number of species between 2003 and 2006, while Abu Negilla Lagoon recorded a reduction in the number of species from 8 in 2003 to 5 in 2006. The study revealed that both diversity and density of sea cucumbers in the Gulf of Aqaba were below sustainable levels. This is a result of overfishing and the biological constraints that may have reduced their reproductive success.

Introduction

Populations of sea cucumber are being overfished worldwide. Some studies indicate that sea cucumber populations in overexploited fishing grounds may require as many as 50 years in the absence of fishing pressure to rebuild (Battaglene and Bell 1999; Bruckner et al. 2003; Skewes et al. 2000). The Gulf of Aqaba is valued for its unique environment and wide range of habitats and outstanding biodiversity (Head 1987). In spite of the suitable conditions for sea cucumber species to reach high population levels, low density and diversity have been recorded from the Gulf (Hasan 2003; Hasan and Hasan 2004; El-Ganainy et al. 2006). The rapid decline in sea cucumber populations worldwide to support the beche-de-mer market (Conand 2001) has led to the start of fishing activities in the Gulf of Aqaba in late 1996. Several years later, a severe depletion in sea cucumber stocks took place in many areas of the Gulf. This depletion occurred in populations of all sea cucumber species of different economic values. Although the fishery began on a small scale, it rapidly expanded and much of the fishery was illegal.

The expansion of the fishery led to serious depletion in sea cucumber stocks, in which both density and diversity were greatly reduced. This led to a ban in 2006 on all sea cucumber fishery operations in the Gulf of Aqaba.

The sea cucumber fishery in the Gulf of Aqaba was carried out without baseline biological data or a monitoring plan. The lack of awareness of fishermen and the absence of management (of fishing and trade) increased the problem.

The current study aims to describe the variations in sea cucumber diversity and population density in the Gulf of Aqaba between pre-fishing and post-fishing periods. It investigates the effect of overfishing on sea cucumber species in Iran.

Materials and methods

Sea cucumber populations at five sites in the Gulf of Aqaba (Shark Reef, Wadi Quny, the Eel Garden, Nakhlet El-Tall and Abu Negilla Lagoon) were surveyed during April and May 2006. The results were compared with other data previously collected

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during the same time in 1995, 2002 and 2003 from Wadi Quny and the Eel Garden. For Shark Reef, Nakhlet El-Tall and Abu Negilla Lagoon, previously collected data were only for 2003.

Field survey and sampling

Sea cucumber populations at the five study sites were estimated using underwater visual transects. Direct visual assessment is the conventional method used and is effective for directly counting specimens of epifauna (Lokani et al. 1996). At each site, transects were made starting from the highest watermark, parallel to the shore covering different depths, zones and habitats. The length of each transect was 150 m. Between five and nine replicates were made at each zone and/or depth. Along each transect 10, 100 m² (10 m × 10 m) quadrates were placed. The reef flat was surveyed by snorkeling, while the deep water was surveyed by scuba diving. The following data were collected:

- Sea cucumber faunal composition by recording all species found at each site.
- Population density, expressed as the number of individuals 100 m².
- A description of the biotope of each quadrat was made. The benthic composition of the substrate was described in terms of the percentage cover of sand, seagrasses, algae, rocks, dead and live corals.

Statistical analyses

At each site, paired *t*-test (Sokal and Rohlf 1995) was used to compare densities of sea cucumber populations recorded in pre-fishing (1995) and post-fishing (2002, 2003 and 2006) periods. Also, the same test was used to compare populations during post-fishing years 2002–2003 and 2003–2006. The analysis was done using Origin 6.1. The *t*-test values were compared with the *p*-value (probability) to indicate the level of significance.

Cluster analysis of years according to the densities of sea cucumber populations was performed to figure out the relationship between these years using an unweighted, pair-group average method. Linkage distances were measured using the Euclidian distance method according to Sneath and Sokal (1973), and the analysis was done using Statistica 5.5.

Study sites

Shark Reef

Shark Reef is a marine protected area inside Ras Mohamed National Park, thus, it is fully protected. It has a vast reef flat extending about 800 m, composed of dead and live corals with sandy patches. The site

is rich with algae and seagrasses. The reef slope is steep, dropping to about 15 m, and is composed of coral patches among clean coralline sand. The main coral species recorded were *Acropora pharonis*, *Stylophora pistillata* and *Favia favaus*. Then the reef drops again to 30 m, where it is composed of sand and seagrasses. The site is flourishing with marine life and has a high species index for major taxonomic groups, particularly corals and fishes. It also has a high abundance of molluscs and echinoderms.

Wadi Quny

Wadi Quny is located to the north of Dahab city along the coast of the Gulf of Aqaba. This site has a typical fringing reef, and the reef flat area is divided into three zones. The back-reef is composed of a fossil reef with very high algal cover (e.g. *Padina pavonia*, *Sargassum latifolium*, *Cystoseira myrica* and *Laurancia papillosa*). The mid-reef is composed of rocky and sandy patches over a rocky base from a fossil reef. The fore-reef is mainly composed of live corals (e.g. *Acropora hemprichi*, *Stylophora pistillata* and *Porites solida*) with a small percentage of dead corals. The reef slope has diverse coral formations. The slope ends at a depth of 20 m into a sandy substrate. This site has rich communities of fauna and flora. Benthic algae and seagrasses were recorded in high percentages, especially on the reef flat and surrounding sandy areas of the sea bed.

Eel Garden

The Eel Garden is characterised by a very long reef extending for approximately 1,100 m and inhabited by very rich benthic communities and a variety of ecological niches and substrates. The depth of the reef flat ranges from 0.5 m to 2.0 m. The reef flat begins with a rocky substrate followed by extensive sandy areas covered in a rich growth of algae and seagrasses. Live corals begin to appear on the fore-reef and reef slope (e.g. *Acropora pharoensis*, *Stylophora pistillata*, *Serriatopora* sp., and *Montipora* sp.). The reef slope drops to about 20 m where the sea bottom is composed of sandy substrate interrupted by small rocky and dead coral patches. A large community of Bedouins resides in the surrounding area. Their main business is fishing and tourism.

Nakhlet El-Tall

Nakhlet El-Tall starts with a moderate reef flat composed mainly of sand and rocks and extending to around 400 m. The reef slope drops to 25 m, ending in a sandy bottom of coralline white sand interrupted by coral patches. Coral patches rise 4–6 m from the sea bed. The site is characterised by a high abundance of invertebrates (e.g. sponges), a high percentage cover of algae and seagrasses, and low to moderate numbers of fishes.

Abu Negilla Lagoon

This site is a large protected lagoon with an extensive sandy substrate, characterised by a large seagrass bed of *Halidula uninervis* and *Halophilla stipulacea* and a high cover of diverse algal species. The depth of the lagoon ranges from 0.5 m at its edges to about 2.5 m towards the center. The lagoon has a small opening to the sea about 10 m wide, permitting the exchange of water between the lagoon and the sea. Very rich invertebrate communities and a low abundance of fishes were observed in the lagoon.

Results

Species diversity

In total, 18 sea cucumber species were recorded from all of the surveyed sites.

At Wadi Quny, 13 species were recorded in 1995 compared with 4 species in 2006. Species diversity decreased from 13 species in 1995, to 8 species in 2002 (with the disappearance of two high-value

species, *Holothuria fuscogilva* and *Stichopus variegatus*), and decreased further to five species in 2003 with the disappearance of another two species (*Holothuria nobilis* and *Holothuria atra*). By 2006, only four species were recorded.

At the Eel Garden, 12 species were recorded in 1995 compared with only 2 species in 2006. Diversity decreased from 12 species in 1995 to 7 species in 2002 (with the disappearance of several high-value species (*Holothuria scabra*, *Holothuria fuscogilva* and *Stichopus variegatus*), and sharply decreasing to 2 species in 2003 and 2006 with the disappearance of another high value species (*Holothuria nobilis*).

At Shark Reef, Nakhlet El-Tall and Abu Negilla Lagoon, there are no records for 1995 and 2002. At Shark Reef, four species were recorded in 2003 and 2006 with no record of any high-value species. The same situation was observed at Nakhlet El-Tall, where five species were recorded in 2003 and 2006. The number of species recorded from Abu Negilla Lagoon decreased from eight in 2003 to five in 2006 (Table 1).

Table 1. A comparison of species composition at the different survey sites between the period of pre-fishing (1995) and the period of post-fishing (2002, 2003 and 2006).

Species	Shark reef				Wadi Quny				Eel Garden				Nakhlet El-Tall				Abu Nigella Lagoon			
	1995	2002	2003	2006	1995	2002	2003	2006	1995	2002	2003	2006	1995	2002	2003	2006	1995	2002	2003	2006
<i>Actinopyga miliaris</i>	n.r.	n.r.			+				+	+			n.r.	n.r.			n.r.	n.r.		
<i>A. echinites</i>			+	+	+	+	+	+	+						+	+			+	+
<i>A. mauritiana</i>			+	+	+		+	+	+											
<i>A. crassa</i>															+	+			+	
<i>A. serratidens</i>																			+	
<i>Bohadschia marmorata</i>					+	+	+		+	+					+	+				+
<i>B. vitiensis</i>					+	+			+	+										+
<i>Holothuria atra</i>			+	+	+	+	+	+	+	+	+	+			+	+			+	+
<i>H. leucospilota</i>			+	+	+	+	+	+	+	+	+	+			+	+			+	+
<i>H. nobilis</i>					+	+			+	+										
<i>H. fuscogilva</i>					+				+											
<i>H. scabra</i>					+	+			+											
<i>H. hilla</i>					+				+	+										
<i>H. impatiens</i>																			+	
<i>Stichopus variegatus</i>					+				+											
<i>Thelonota ananas</i>					+	+														
<i>Synapta maculata</i>																			+	
<i>Synaptula resprocanus</i>																			+	

n.r. = not recorded; + = present

Species density

In addition to the fluctuation in species diversity, density has also changed during the years of investigation. The data showed a great reduction in species density at most surveyed sites from pre-fishing to post-fishing periods.

Wadi Quny showed a remarkable reduction in species density, not only between pre-fishing and post-fishing periods, but in post-fishing years as well (Fig. 1). The pattern of reduction was uniform among all recorded species, except for the non-commercial *H. leucospilota*, which showed a reduction in density only between 1995 and 2002. Its density even increased slightly from 2003 to 2006. Two high-value species were recorded in 1995, *Holothuria nobilis* and *Holothuria scabra*. The density of *Holothuria nobilis* in 1995 was as high as 16.7 ind. 100 m⁻²,

but dramatically declined to only 0.7 ind. 100 m⁻² in 2002. The species disappeared altogether in both 2003 and 2006. The density of *Holothuria scabra* was also high (19.4 ind. 100 m⁻²) in 1995, but decreased to 1.1 ind. 100 m⁻² in 2002 before completely disappearing in 2003 and 2006.

The Eel Garden showed a great reduction in species density from pre-fishing (1995) to post-fishing (2002) periods (Fig. 2). After 2002, all commercial species disappeared except for *Holothuria atra*, which showed a significant reduction in density, but could still be found. The high-value species *Holothuria nobilis* was recorded at a density of 18.7 ind. 100 m⁻² in 1995, but decreased to 1.3 ind. 100 m⁻² in 2002, and totally disappeared in 2003 and 2006. There was a reduction in density of *Holothuria leucospilota* from 1995 to 2002, but its density increased in the following survey years of 2003 and 2006.

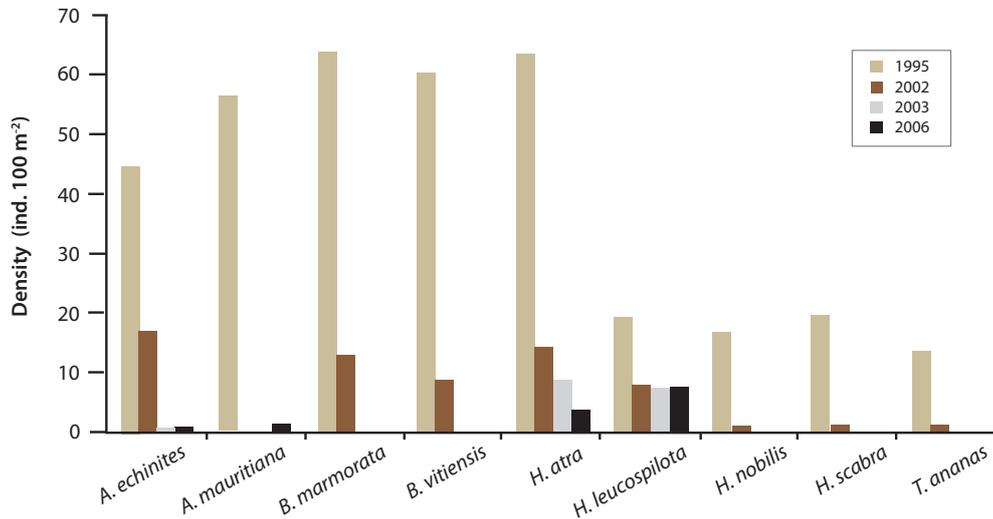


Figure 1. Variation in densities (ind. 100 m⁻²) of sea cucumber species recorded in 1995, 2002, 2003 and 2006 at Wadi Quny, Gulf of Aqaba.

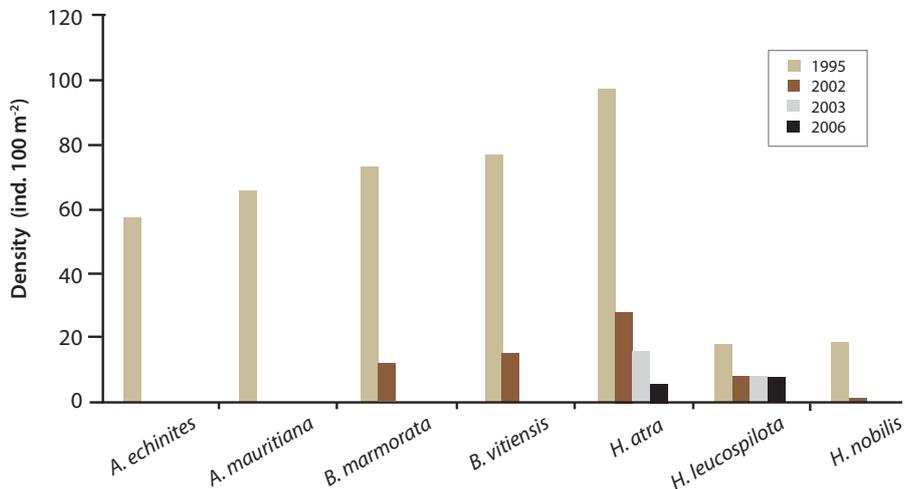


Figure 2. Variation in densities (ind. 100 m⁻²) of sea cucumber species recorded in 1995, 2002, 2003 and 2006 at Eel Garden, Gulf of Aqaba.

There were no available records for 1995 and 2002 for Shark Reef, Nakhlet El-Tall or Abu Negilla Lagoon, but in both 2003 and 2006 four to six species total were recorded. At Shark Reef, the densities recorded in both years were low, but with no significant changes from one year to the other, despite the increase in densities of all species from 2003 to 2006, except for *H. atra*, which showed a slight decrease between the two years. At Nakhlet El-Tall, there were significant reductions in densities of commercial species between 2003 and 2006 (*Actinopyga crassa*, *A. echinites*, *Bohadschia marmorata* and *Holothuria atra*). The density of the non-commercial species *Holothuria leucospilota* did not change from 2003 to 2006. At Abu Negilla Lagoon there were no significant differences in the density of any species between 2003 and 2006, except for *Actinopyga crassa*, which was recorded at 3.9 ind. 100 m⁻² in 2003 and completely disappeared in 2006.

Sea cucumber populations at all study sites were statistically analysed (Table 2). Significant differences in sea cucumber populations were detected between pre-fishing (1995) and post-fishing (2002–2006) periods. Also, significant differences were evident between 2002 and 2003 at all sites. Differences in densities, however, were not significant between 2003 and 2006 at any of the sites except at Nakhlet El-Tall, which recorded a significant decline between the two periods.

Study sites were grouped according to their sea cucumber population densities in time, using a cluster analysis (Fig. 3). The results of the cluster analysis revealed three different groups: the first group included sea cucumber populations in 1995, the second included populations in 2002, and the third included populations in 2003 and 2006.

Discussion

During the past few years, overexploitation of sea cucumbers has occurred in the Gulf of Aqaba, causing a severe decline in population densities of almost all species (Hasan 2003) at almost all sites (Hasan and Hasan 2004). The high fishing pressure exerted on sea cucumber species led to the disappearance of

Table 2. Statistical analysis of sea cucumber populations at different surveyed sites using t-test (paired) at a 0.05 significance level.

Site	Compared years	P value
Abu Negilla Lagoon	2003–2006	0.07061 ^o
	1995 and 2002–2006	0.00189 ^{**}
Eel Garden	2002–2003	0.03065 [*]
	2003–2006	0.16799 ^o
Nakhlet El Tall	2003–2006	0.01647 [*]
	1995 and 2002–2006	4.8 x 10 ^{-4**}
Wadi Quny	2002–2003	0.03618 [*]
	2003–2006	0.37176 ^o
Shark reef	2003–2006	0.60418 ^o

o = not significant; * = significant ($p < 0.05$); ** = highly significant ($p < 0.01$).

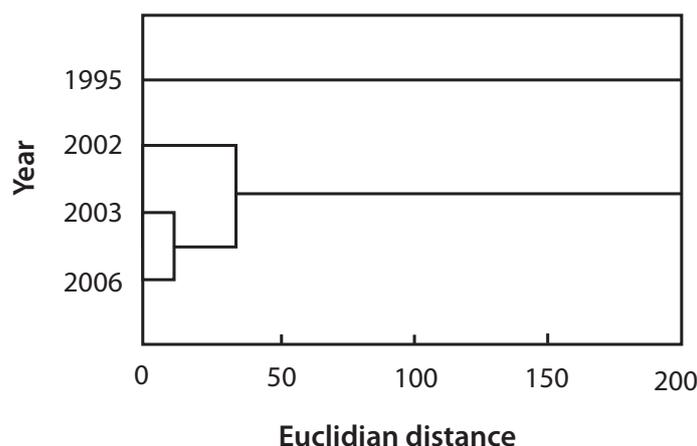


Figure 3. Tree cluster analysis of sea cucumber populations at the investigated sites for 1995, 2002, 2003 and 2006.

many commercial species and the reduction of others. The results obtained from this study not only showed a high reduction in sea cucumber populations between pre-fishing and post-fishing periods, but also the reduction was evident between successive years at post-fishing periods, indicating the continuity of the fishing process. This trend of sea cucumber overexploitation has been recorded not only from the Gulf of Aqaba, but also from many other parts of the world. There are a growing number of reports indicating that sea cucumber populations are declining worldwide in tropical and subtropical countries, including from areas in Australia (Uthicke and Benzie 2000), the Philippines (Surtida and Buendia 2000), Indonesia (Tuwo

and Conand 1992), Japan (Conand and Byrne 1993), New Caledonia (Conand 1990), Fiji Islands (Adams 1992), East Africa (Kithakeni 2001), Mozambique (Mmbaga and Mgaya 2004), Yemen (Conand 2004), the Gulf of Aqaba (Hasan 2003), the Egyptian Red Sea (Hasan 2005), Eritrea (Kalaeb et al. 2008) and Saudi Arabian Red Sea (Hasan 2008).

The study of the spatial distribution of sea cucumber populations provided an understanding of the extent of the impact of environmental factors affecting the animals' lives (Young and Chia 1982; Kerr et al. 1993). Most of the sites surveyed have excellent conditions for sea cucumber survival, including suitable substrate, high food availability, a wide variety of ecological niches, different depths that meet with the difference in depth preferences for different species, and a low number of natural enemies. However, there was a severe drop in these species during successive years and all of the stocks in the visited sites were destroyed with no sign of recovery. Holothurians are susceptible to overexploitation due to their late maturity, density-dependant reproduction, and low rate of recruitment.

The data obtained from the pre-fishing (1995) and post-fishing (2002–2006) periods from the different areas were compared, and a high reduction in population was evident. Despite the low density and diversity recorded at Shark Reef, there was no fishing effort recorded at the site because it is a marine protected area with full protection. The low density at this site may be attributed to other factors because it is not a traditional ground for sea cucumber populations and because of the high level of tourism activities at the area. Abu Negilla Lagoon, which has excellent conditions for sea cucumber establishment, has a very low level of tourism and a healthy sea cucumber population. The site showed an insignificant decline in its population between 2003 and 2006, indicating low fishing pressure due to tight control by the South Sinai marine park authorities. The opposite occurred at the other three investigated sites, which showed a high reduction of population not only between the pre-fishing and post-fishing periods, but also between successive years of post-fishing (2002 and 2003), indicating the continuity of fishing effort at least until 2003. At Wadi Quny and the Eel Garden, a very significant reduction in sea cucumber populations was recorded between pre-fishing (1995) and post-fishing (2002–2006) years. No decline was recorded between 2003 and 2006, indicating the cessation of fishing operations after 2003.

Nakhlet El-Tall was the only site with a significant decline in sea cucumber populations between 2003 and 2006, revealing that fishing operations started late at the site and continued until 2006 due to the availability of populations there. The data indicated

that the decline in population reduction after 2003 at the fished sites was not due to good management regimes, but to the disappearance of the populations from the area as a result of overfishing. This presumption is accentuated by the cluster analysis, which indicates that 1995 represents a separate case because it represents the condition of pre-fished populations (i.e. virgin population). On the other hand, no intrinsic variation was noticed between 2003 and 2006. The study revealed that fishing effort ended but recovery was not evident.

The same conclusion was obtained by Skewes et al. (2000) who reported that after seven years of the *Holothuria scabra* fishery being closed in the Torres Strait, the biomass estimated was less than 8% of the virgin biomass. Sea cucumber populations are greatly depleted to the extent that there are doubts as to their ability to recover. The recovery of overfished sea cucumber stocks is a lengthy process, sometimes taking several years (Purcell et al. 2002) because holothurians, like many other invertebrates, are broadcast spawners and fertilisation success is highly dependent on population density (D'Silva 2001). A reduction in population density by overfishing may render remaining individuals incapable of successful reproduction. It is now apparent that depleted stocks of high-value sea cucumber species at the surveyed sites may even take decades to recover. Not only was the density negatively affected, but also, species diversity. For sea cucumber populations that show chronically low levels in the Gulf of Aqaba, remnant species need to be protected. The present study suggests that the use of marine protected areas in this respect could be an effective management tool.

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