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RESEARCH

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Destruction of sea cucumber populations due to overfishing at Abu Ghosoun area, Red Sea

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Abstract

Background: Sea cucumber populations in the Egyptian Red Sea have been exploited by uncontrolled fishery with no management takes place. The sea cucumber populations were surveyed at Abu Ghosoun area, Red Sea, during three period intervals in 2000, 2006, and 2016.

Results: In 2000 and 2006, the total number of recorded species was 13 species, which decreased to only 7 species in 2016. The population density of sea cucumber were greatly affected by overfishing and showed a uniform pattern of very low density in 2006 and 2016 after the high density recorded in 2000. *Holothuria atra* recorded the highest density that reached 128.1 ind./100 m^2 in 2000 and decreased to 120.4 ind./100 m^2 in 2006 and 87.4 ind./100 m^2 in 2016. The dramatic decrease in densities was observed in other recorded species as in *Thelenota ananas* which decreased from 48.1 ind./100 m^2 in 2000 to only 5.6 ind./100 m^2 in 2006 and completely disappeared during 2016. The total abundance of all sea cucumber species recorded during 2000 was 13,880 individuals, which decreased to 7700 individuals in 2006, then to only 2420 individuals in 2016. The remaining individuals in 2016 comprise only 17.4% of the original population recorded in 2000, which means that 82.6% of the sea cucumber populations were lost during the 16 years. The study showed a difference in relative abundance between different species and years. In 2000, the relative abundance ranged between 3.03% for *Actinopyga miliaris* and 18.44 for *Holothuria atra*. In 2006, the relative abundance ranged between 2.08% for *Stichopus horrens* and 31.17% for *Holothuria atra*. While in 2016, the relative abundance ranged between 0% for several species and 71.9% for *Holothuria atra*. The total biomass recorded showed high decrease from 10,373.8 kg in 2000 to 5461 kg during 2006 and 1379.6 kg in 2016.

Conclusion: The study revealed that sea cucumber species diversity and density were much reduced from 2000 to 2016. It also revealed a difference in dispersion among the different years of investigation, indicating the high influence of overfishing on the sea cucumber populations.

Keywords: Sea cucumber, Overfishing, Red Sea, Density, Coefficient of dispersion, Density, Abundance, Biomass

Background

During the past two decades, sea cucumbers in the Egyptian Red Sea have been the target of a persistent fishery. Overexploitation of sea cucumber populations extensively takes place in the Red Sea, causing a critical depletion in population densities and abundance of almost all species (Hasan 2003), at almost all areas (Hasan and Hasan 2004). The overfishing of sea cucumber populations led to the reduction of many populations and the disappearance of others. Over the last decade, the increasing expansion of this activity and its potential impacts prompted the Egyptian authority to ban the entire fishery in 2000 (Hasan 2003).

The rapid sea cucumber stock depletion to support the beche-de-mer market (Conand 2001) has led to high exploitation of its population at the Red sea in 1998. Several years later, a severe depletion in sea cucumber populations took place in many areas of the

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Red Sea. This depletion occurred in all sea cucumber species of different economic values.

In spite of the fishery beginning in a small scale by small trawling boats, it rapidly expanded both legally and illegally. The ban on sea cucumber fishery had no effect in restoring the depleted stocks; as a result, an expansion of the fishery caused a serious depletion in its stocks. The sea cucumber fishery in the Red Sea was carried out without a baseline study or a monitoring procedure. The lack of awareness of the fishermen and the absence of management increased the problem.

Sea cucumber populations are being overfished all over the world. Some reports reported that sea cucumber populations in overfished grounds may demand as many as half a century in the absence of fishing activities to be rebuilt (Battaglene and Bell 1999; Bruckner et al. 2003; Skewes et al. 2000).

Overexploitation of sea cucumber has been reported not only from the Red sea, but also from many other parts of the world. There are an increasing number of studies reporting the decline of sea cucumber populations worldwide as in tropical and subtropical countries as reported in the Saudi Arabian coasts of the Red Sea (Hasan 2008, 2009), Egyptian coasts of the Red Sea (Hasan 2005), and Gulf of Aqaba (Hasan 2003; Hasan and Abd El-Rady 2012; Hasan and Hasan 2004). It was also reported from many other places of the world as in the Philippines (Dolorosa et al. 2017; Surtida and Buendia 2000), Malaysia (Choo 2008), Australia (Uthicke and Benzie 2000), Indonesia (Tuwo and Conand 1992), Mediterranean sea (Aydın 2017), Brazil (Souza Junior et al. 2017), and Africa and the Indian Ocean (Conand 2008).

The current study aims to describe the variations in sea cucumber populations in Abu Ghosoun area, Red Sea, due to the fishing activities. It investigates the effect of overfishing on sea cucumber species at the area. This study specifically aimed to (i) collect and identify sea cucumber species; (ii) determine the abundance, relative abundance, species diversity, and biomass of different sea cucumber population at the area; and (iii) determine the coefficient of distribution for sea cucumber species.

Materials and methods

Study site

Abu Ghosoun area lies on the Red Sea coast, south to Marsa Alam city (Fig. 1). The area is composed of a reef flat ranging from 140 to 220 m offshore with depth ranging between 0.5 and 1.7 m, followed by a reef slope ending at 12 m deep, then a sea bottom which have scattered and small coral patches extending to a depth of 40 m. The area is characterized by a shallow bay retreating inland and mainly composed of a sandy bottom area with depth ranging from 0.5 to 2.2 m, increasing depth. Mangroves are found in narrow spots along the shore and are extensive in the swamp area behind the coastline. The substrate is enriched by fine sand and mud in the bay and in some areas along the coastline. In other areas, it becomes sandy (medium to coarse grain sand).

Population estimates and distribution

Estimation of sea cucumber populations was carried out using underwater visual transects. Direct visual assessment

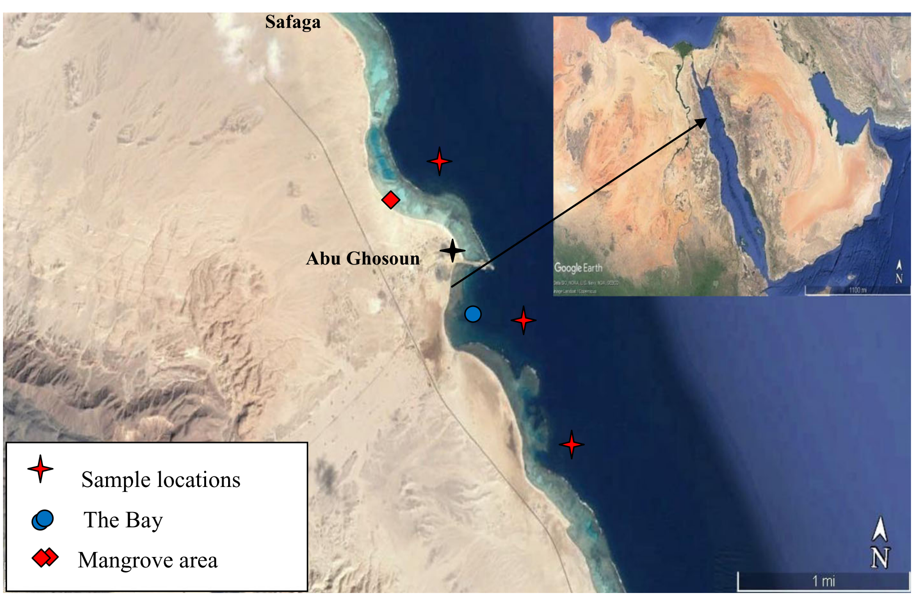

Fig. 1 The location of the study site at the Red Sea

is the method conventionally used and is effective for the direct enumeration of population (Lokani et al. 1996). At the study site, transects were made covering the different zones and habitats. The length of each transect was about 150 m. Between 5 and 9 replicates were made at each zone and/or depth. Along each transect, 10 quadrates were made of 10 m × 10 m (100 m^2). The shallow areas were surveyed by snorkeling, and the deep areas were surveyed by SCUBA diving.

Population density

The population density of different sea cucumber species inside each quadrate was counted and expressed as the number of individuals/100 m^2. At each quadrate, the different biotopes of the reef and type of substrate were described (sandy, rocky, corals).

Abundance

Abundance of sea cucumber populations were estimated by using the following formula:

$$T = X * N$$

where:

T = species abundance
X = mean number per transect
N = number of transects that fit into the total area (N = total area/transect area).

The total area of each site was calculated during this survey by using a boat with a fixed speed and the area was calculated by:

$$A = S * T$$

where A is the area, S is the boat speed, and T is the time.

Relative abundance

Relative abundance is the proportion of a species in an ecosystem or sample of a community. The relative abundance (pi) of each species was expressed as

$$pi = ni/N \times 100,$$

where ni is the number of individuals of the same species and N is the total number of individuals for all species.

Estimates of standing stocks

Biomass was calculated by collecting the different sea cucumber species from representative quadrates, weighting them, and returning them to the same site. Weight was recorded by gently drying the animals with a cloth and leaving them out of the water for 5 min. The animals were then weighted after expelling their water content. The standing stocks were calculated by the formula:

$$\mathrm{SS} = \mathrm{M.wt.} * \mathrm{TA/QA}$$

where SS is the standing stocks, M.wt. is mean weight at the representative quadrates, TA is the total area, and QA is the quadrates area.

Coefficient of dispersion

Coefficient of dispersion (CD) is a measure used to quantify whether a set of organisms are clustered or dispersed (Walag and Canencia 2016). It was expressed as:

$$CD = \mathrm{variance/mean};$$

where CD lesser than 1 (< 1) is regular/uniform, greater than 1 (> 1) is clumping, and equal to 1 (= 1) is random.

Results

Sea cucumber faunal composition

Abou Ghosoun area showed a reduction in the number of sea cucumber species recorded along the period of study. In 2000, the total number of recorded species was 13 species, and the same number of species was recorded in 2006, while in 2016 only 7 species were recorded (Table 1). The species composition included four high-value species: *Holothuria fuscogilva*, *Holothuria whitmaei*, *Holothuria scabra*, and *Thelenota ananas*; six medium-value species: *Actinopyga echinites*, *Actinopyga mauritiana*, *Bohadschia argus*, *Holothuria atra*,

Table 1 Sea cucumber species recorded at Abou Ghosoun area during the period of study (2000, 2006, and 2016)

Species	July 2000	July 2006	July 2016
Actinopyga echinites	+	+	+
Actinopyga mauritiana	+	+	–
Actinopyga miliaris	+	+	+
Bohadschia similis	+	+	–
Bohadschia argus	+	+	–
Bohadschia vitiensis	+	+	+
Holothuria atra	+	+	+
Holothuria scabra	+	+	–
Holothuria whitmaei	+	+	+
Holothuria fuscogilva	+	+	+
Stichopus hermanni	+	+	+
Stichopus horrens	+	+	–
Thelenota ananas	+	+	–
Total no. of species	13	13	7

Stichopus hermanni, *and Stichopus horrens*; three low-value species: *Bohadschia vitiensis*, *Actinopyga miliaris*, and *Bohadschia similis*.

Sea cucumber population estimates

Population density

The population density of sea cucumber species differed widely according to the period of survey due to the species behavior and level of exploitation. The surveyed site showed a uniform pattern of very low density in 2006 and 2016 after the high density recorded in 2000. *Holothuria atra* recorded the highest density among the recorded species; it recorded 128.1 ind./100 m^2 in 2000, which decreased to 120.4 ind./100 m^2 in 2006 and 87.4 ind./100 m^2 in 2016. *Holothuria fuscogilva* recorded the second highest density among the recorded species; it recorded 84.2 ind./100 m^2 in 2000, which decreased to 51.5 ind./100 m^2 in 2006 and only 5.7 ind./100 m^2 in 2016. The dramatic decrease in species densities was observed in the species recorded as in *Thelenota ananas* which decreased from 48.1 ind./100 m^2 in 2000 to only 5.6 ind./100 m^2 in 2006 and completely disappeared during 2016. The same situation was recorded for *Stichopus horrens*, which was 42.4 ind./100 m^2 in 2000 to only 8.8 ind./100 m^2 in 2006 and completely disappeared during 2016, and *Holothuria scabra*, which was 65.6 ind./100 m^2 in 2000, decreased to only 10.3 ind./100 m^2 in 2006, and completely disappeared during 2016 (Table 2).

Abundance and relative abundance

The total abundance of all sea cucumber species recorded during 2000 was 13,880 individuals and decreased to 7700 individuals in 2006 and then to only 2420 individuals in 2016. The remaining individuals in 2016 comprise only 17.4% of the original population recorded in 2000, which means that 82.6% of the sea cucumber populations were lost during the 16 years.

The different sea cucumber populations showed differences in abundance during the period of study. *Holothuria atra* showed the highest abundance among all the sea cucumber species, with 2560 individuals recorded in 2000; it also showed minimum loss in the number of individuals during the years of study (2400 and 1740 individuals in 2006 and 2016, respectively) and high remaining percentage (67.9%), and the loss in the population was only 32.1% of the population. For *Holothuria scabra*, 1300 individuals were recorded in 2000, which dramatically decreased to only 200 individuals in 2006 and completely disappeared in 2016; with 0% of remaining individuals and 100% of loss, all the population vanished in 2016. The same situation was recorded for *Actinopyga mauritiana* that decreased from 520 individuals in 2000 to 180 individuals in 2006 and was completely destroyed in 2016 and *Bohadschia similis* that decreased from 700 individuals in 2000 to 360 individuals in 2006 and was completely destroyed in 2016. The populations of *Bohadschia argus*, *Stichopus horrens*, *and Thelenota ananas* exhibit the same recorded pattern of 680, 840, and 960 individuals, respectively, in 2000 which decreased to 440, 160, and 100 individuals in 2006 and disappeared in 2016 (Table 3).

The relative abundance of different sea cucumber species were calculated, and it was obvious that there were differences in relative abundance between different species and during the different years. In 2000, the relative

Table 2 Temporal variation in species density of sea cucumber populations (no./100m^2) at the surveyed site

Species	July 2000	July 2006	July 2016
Actinopyga echinites	24.5	19.2	2.4
Actinopyga mauritiana	26.1	9.3	0
Actinopyga miliaris	21.6	11.7	3.7
Bohadschia similis	35.3	18.6	0
Bohadschia argus	34.9	22.6	0
Bohadschia vitiensis	54.7	31.8	10.8
Holothuria atra	128.1	120.4	87.4
Holothuria scabra	65.6	10.3	0
Holothuria whitmaei	78.8	67.5	13.9
Holothuria fuscogilva	84.2	51.5	5.7
Stichopus hermanni	55.2	14.3	1.3
Stichopus horrens	42.4	8.8	0
Thelenota ananas	48.1	5.6	0

Table 3 Abundances of different sea cucumber populations recorded during the period of study (2000–2016) at Abou Ghosoun area

Species	July 2000	July 2006	July 2016	Percentage remaining since 2000
Actinopyga echinites	480	380	40	8.3
Actinopyga mauritiana	520	180	0	0
Actinopyga miliaris	420	220	60	14.3
Bohadschia similis	700	360	0	0
Bohadschia argus	680	440	0	0
Bohadschia vitiensis	1080	620	200	18.5
Holothuria atra	2560	2400	1740	67.9
Holothuria scabra	1300	200	0	0
Holothuria whitmaei	1560	1340	260	16.7
Holothuria fuscogilva	1680	1020	100	5.9
Stichopus hermanni	1100	280	20	1.8
Stichopus horrens	840	160	0	0
Thelenota ananas	960	100	0	0
Total	13,880	7700	2420	17.4

abundance ranged between 3.03% for *Actinopyga miliaris* and 18.44 for *Holothuria atra*. In 2006, the relative abundance ranged between 2.08% for *Stichopus horrens* and 31.17% for *Holothuria atra*. While in 2016, the relative abundance ranged between 0% for several species and 71.9% for *Holothuria atra* (Table 4).

Estimation of standing stocks (biomass)

The total biomass recorded showed a high temporal variation. It decreased from 10,373.8 kg in 2000 to 5461 kg during 2006. The decrease of the total biomass continued during 2016, recording 1379.6 kg (Table 5). *Holothuria atra* was recorded with the majority of the biomass with a total of 1254.4 kg wet wt in 2000 which decreased to 1176 kg wet wt in 2006 and to 852.6 kg in 2016. *Holothuria scabra* was one of the high-value species found during the current study, and it was recorded that its maximum biomass was 1254.4 kg wet wt in 2000 and decreased to only 176 kg in 2006, and completely disappeared in 2016.

The percentage of the remaining total biomass from the original population in 2000 was recorded at 50.86% in 2006; this represented a reduction equal to 49.24% in biomass, while in 2016 the remaining populations' total biomass was recorded at 12.85% with a reduction of 87.15% from the original populations in 2000 (Fig. 2). The reduction of *Holothuria atra* represented only 6.2% in 2006 and 27.5% in 2016. The remaining biomass of *Holothuria scabra* population was recorded at 15.4% in 2006 with an 84.6% reduction of the original population in 2000, completely disappearing in 2016.

Table 4 The relative abundances (%) of different sea cucumber populations recorded during the period of study (2000–2016) at Abou Ghosoun area

Species	July 2000	July 2006	July 2016
Actinopyga echinites	3.46	4.94	1.65
Actinopyga mauritiana	3.75	2.34	0
Actinopyga miliaris	3.03	2.86	2.47
Bohadschia similis	5.04	4.68	0
Bohadschia argus	4.9	5.71	0
Bohadschia vitiensis	7.78	8.05	8.26
Holothuria atra	18.44	31.17	71.9
Holothuria scabra	9.37	2.6	0
Holothuria whitmaei	11.24	17.4	10.74
Holothuria fuscogilva	12.1	13.25	4.13
Stichopus hermanni	7.93	3.64	0.82
Stichopus horrens	6.05	2.08	0
Thelenota ananas	6.92	1.3	0

Table 5 Standing stocks (kg) of different sea cucumber species during the period of study

Species	July 2000	July 2006	July 2016
Actinopyga echinites	297.6	235.6	24.8
Actinopyga mauritiana	353.6	122.4	0
Actinopyga miliaris	155.4	81.4	22.2
Bohadschia similis	434	223.2	0
Bohadschia argus	448.8	290.4	0
Bohadschia vitiensis	626.4	359.6	116
Holothuria atra	1254.4	1176	852.6
Holothuria scabra	1144	176	0
Holothuria whitmaei	1482	1273	247
Holothuria fuscogilva	1629.6	989.4	97
Stichopus hermanni	1100	280	20
Stichopus horrens	756	144	0
Thelenota ananas	1056	110	0
Total	10,737.8	5461	1379.6

Coefficient of dispersion

The distribution pattern of each sea cucumber species was determined using the coefficient of dispersion. The study revealed a difference in dispersion among the different years of investigation. In the year 2000, nine species out of the 13 species recorded exhibited regular distributions while the other four species exhibited regular or uniform dispersion (Table 6). The situation recorded little difference in 2006 where only four species recorded regular dispersion, six species recorded clumped dispersion, and for the first time three species showed random dispersion. In 2016, from seven species recorded, four species showed clumped dispersion and three species showed random dispersion. The species showed a clumped dispersion tendency in 2006 and random dispersion in 2006, indicating a change in species behavior during the years of study (2000–2016).

Statistical analysis

A one-way ANOVA statistics was carried out for the species density data during the current study; the analysis showed a significant difference in species density between the years of study (2000, 2006, and 2016) and for all species (Table 7).

Hence, the one-way ANOVA analysis revealed a significant difference in all species in the different periods of study; we carried out a post hoc test (Scheffe test) to determine the significant difference between the different periods. The test revealed that there was significant difference recorded in species density between 2000 and 2006, 2000 and 2016, and 2006 and 2016 for, *Actinopyga echinites*, *Actinopyga mauritiana*, *Actinopyga miliaris*, *Bohadschia similis*, *Bohadschia argus*, *Bohadschia vitiensis*, *Holothuria*

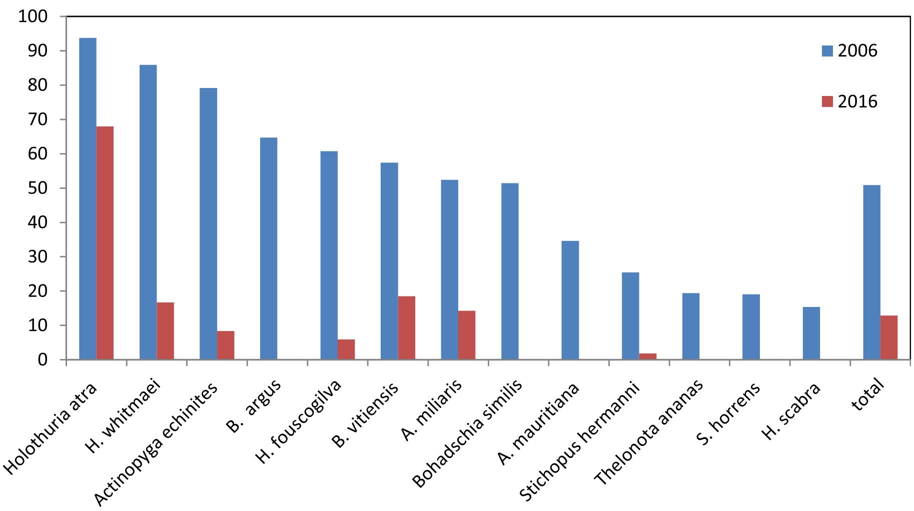

Fig. 2 The percentage of sea cucumber biomass remaining in 2006 and 2016 from the original populations in 2000

scabra, *Holothuria whitmaei*, *Holothuria fuscogilva*, *Stichopus hermanni*, *Stichopus horrens*, and *Thelenota ananas*, whereas *Holothuria atra* showed insignificant difference between the years 2000 and 2006, while the same species recorded a significant difference in its density between the years 2000 and 2016, and 2006 and 2016. The analysis showed that all species decreased significantly earlier (2000–2006) whereas only *Holothuria atra* decreased in a second phase (2006–2016).

Discussion

During the last two decades, the populations of sea cucumbers at Abu Ghosoun, as well as in many other areas in the Egyptian Red Sea (Hasan 2003, 2005), have decreased to low levels due to overfishing.

Table 6 The coefficient of dispersion (CD) of sea cucumber species recorded from the study site

Species	July 2000	July 2006	July 2016
Actinopyga echinites	0.87[b]	0.99[b]	1
Actinopyga mauritiana	0.91[b]	2.08[a]	–
Actinopyga miliaris	1.76[a]	1	1
Bohadschia similis	0.98[b]	1.54[a]	–
Bohadschia argus	1.12[a]	1.21[a]	–
Bohadschia vitiensis	0.98[b]	1.09[a]	1.01[a]
Holothuria atra	0.76[b]	0.91[b]	0.97[a]
Holothuria scabra	0.89[b]	2.11[b]	–
Holothuria whitmaei	1.21[a]	0.84[b]	2.12[a]
Holothuria fuscogilva	1.15[a]	1.23[a]	1.34[a]
Stichopus hermanni	0.98[b]	1.08[a]	1
Stichopus horrens	0.88[b]	1	–
Thelenota ananas	0.99[b]	1	–

[a]clumped
[b]regular/uniform

As the statistical analysis indicated all the species decreased significantly earlier (2000–2006) except for *Holothuria atra*, which decreased in the second phase (2006–2016), this is explained by the fishers' behavior which aimed to catch other species first and when the stocks begin to deplete, they tend to harvest *H. atra*, and also due to the more efficient reproduction of this species by asexual reproduction that compensate its population to a certain limit.

The results acquired from the current study not only showed a high reduction in sea cucumber populations before and after heavy exploitation started, but also the reduction was obvious between successive years of investigation, indicating the continuity of the overfishing process. The sea cucumber fishery began in the Egyptian Red Sea in 1998 with low-level collection by trawling boats. The expansion of the fishery was recorded in 2000, leading to the expectation of overexploitation. Driven by this expectation, a ban on sea cucumber fishery was declared by the Red Sea Governorate in 2001. The ban was not effective because it caused illegal unregulated and unreported fishery (IUU), and as a dangerous practice, this caused a dramatic decreased in sea cucumber population. And as a result of the continuous pressure exerted by the General Authority of Fish Development, the Red Sea Governorate lifted its ban in 2002. This decree led to an expansion of sea cucumber fishery, and a serious decline in its population occurred, leading to a new ban that was decreed in March 2003. After declaring the ban, illegal fishing started again with more vigorous activities, and this led to a severe depletion in sea cucumber stocks.

Table 7 The analysis of one way ANOVA for different species during the period of study (2000, 2006 and 2016)

	Sum of Squares	df	Mean Square	F	Sig.
Actinopyga echinites					
Between Groups	3555.571	2	1777.786	127.218	0
Within Groups	545.000	39	13.974		
Total	4100.571	41			
Actinopyga mauritiana					
Between Groups	4857.190	2	2428.595	221.964	0
Within Groups	426.714	39	10.941		
Total	5283.905	41			
Actinopyga miliaris					
Between Groups	2186.476	2	1093.238	156.095	0
Within Groups	273.143	39	7.004		
Total	2459.619	41			
Bohadschia similis					
Between Groups	8540.333	2	4270.167	341.41	0
Within Groups	487.786	39	12.507		
Total	9028.119	41			
Bohadschia argus					
Between Groups	8574.429	2	4287.214	562.56	0
Within Groups	297.214	39	7.621		
Total	8871.643	41			
Bohadschia vitiensis					
Between Groups	13552.048	2	6776.024	485.72	0
Within Groups	544.071	39	13.951		
Total	14096.119	41			
Holothuria atra					
Between Groups	17232.048	2	8616.024	150.49	0
Within Groups	2232.929	39	57.255		
Total	19464.976	41			
Holothuria scabra					
Between Groups	34977.190	2	17488.595	1220.29	0
Within Groups	558.929	39	14.332		
Total	35536.119	41			
Holothuria whitmaei					
Between Groups	35503.000	2	17751.500	771.13	0
Within Groups	897.786	39	23.020		
Total	36400.786	41			
Holothuria fouscogilva					
Between Groups	42740.143	2	21370.071	1575.487	0
Within Groups	529.000	39	13.564		
Total	43269.143	41			
Stichopus hermanni					
Between Groups	22525.190	2	11262.595	873.367	0
Within Groups	502.929	39	12.896		
Total	23028.119	41			

Table 7 The analysis of one way ANOVA for different species during the period of study (2000, 2006 and 2016) *(Continued)*

	Sum of Squares	df	Mean Square	F	Sig.
Stichopus horrens					
Between Groups	14792.333	2	7396.167	924.309	0
Within Groups	312.071	39	8.002		
Total	15104.405	41			
Thelonota ananas					
Between Groups	15376.000	2	7688.000	181.434	0
Within Groups	1652.571	39	42.374		
Total	17028.571	41			

The banning procedure did not seem to have an effect on the depletion of sea cucumber population. The trend of sea cucumber overexploitation was not only evident due to the current study but there are an increasing number of studies which reported the decline of sea cucumber populations worldwide as in tropical and subtropical countries and as reported in the Saudi Arabian coasts of the Red Sea (Hasan 2008, 2009), Egyptian coasts of the red Sea (Hasan 2005), and Gulf of Aqaba (Hasan 2003; Hasan and Abd El-Rady 2012; Hasan and Hasan 2004). It was also reported from many other places of the world as in the Philippines (Dolorosa et al. 2017; Surtida and Buendia 2000), Malaysia (Choo 2008), Australia (Uthicke and Benzie 2000), Indonesia (Tuwo and Conand 1992), Mediterranean sea (Aydın 2017), Brazil (Souza Junior et al. 2017), and Africa and Indian Ocean (Conand 2008).

The depletion of sea cucumber population densities at Abu Ghosoun area not only caused the populations' destruction but the more dangerous effect is that the depleted density make the recovery of the populations very difficult because sea cucumber species are broadcast spawners, and the success of their reproduction depends on the population density (Purcell et al. 2002). The reduction of population density may render remaining individuals unable of successful reproduction. It is now apparent that depleted stocks of sea cucumber species may take decades to recover (Hasan 2005) as a result of reproduction failure.

For some taxa, the abundance of species in a particular habitat shows little change with time (Endean and Cameron 1990); sea cucumber species does not share that phenomena as it has a very little temporal variation (Hasan 2005). The abundance was high before the heavy harvesting of species started. The abundance dramatically decreased in 2006, and an even more severe depletion in abundance was recorded in 2016 due to the increasing of fishing pressure, which began on a small scale and gradually increased to reach its maximum capacity after 2000 till the stock was decimated in 2006 and totally destructed in 2016. Since the abundance of all sea cucumber species at Abu Ghosoun area is much lower after the fishing period than when it began, it is reasoned that the lower abundance was caused by high fishing mortality. Other natural factors may have affected abundance but are probably negligible. The same conclusion was reported by many other authors (Conand 1990; Kethakeni 2001; Lokani 1995; Preston and Lokani 1990; Tuwo and Conand 1992; Uthicke and Benzie 2000).

The relative abundance of the species is a reflection of its high existence among other species (Bos et al. 2008; Scheibling and Metaxas 2008). The most abundant species was *Holothuria atra* with relative abundance of 18.44% in 2000; the species relative abundance increased to 31.17% in 2006 and to 71.9% in 2016. *Holothuria scabra* was recorded with a relative abundance of 9.37% which decreased to 2.6% before it completely disappeared in 2016. The lowest relative abundance recorded for *Holothuria scabra*, *Holothuria fuscogilva*, and other species is due to active collection, while both the low collection and asexual reproduction strategy of *H. atra* may explain its relatively high abundance.

The study revealed that the total biomass of sea cucumber species were very high during 2000, and this was likely due to the high food availability, low natural mortality, low disturbance, low energy environment, and low fishing mortality. All these factors enable the animal to gain weight and grow to large sizes. When the fishing increased in 2006, there was a major decline in biomass because the smaller animals were left behind and the large animals were picked up first. In 2016, a dramatic decrease in the biomass occurred due to the severe overfishing of the species, which eliminated all the medium- and large-sized individuals from the area. The weight reduction caused by over harvesting has also been reported by Uthicke and Benzie (2000) for *H. whitmaei* at the Great Barrier Reef.

The heavy overfishing for the sea cucumber populations at the study area not only affected the population densities, but also affected the species behavior inside the ecosystem. During 2000, the most recorded species had regular (uniform) distribution due to the availability of food at the area and the high density of the species, while, in 2006, the situation was different when most of the recorded species turned to clumped distribution as the fishing pressure increased and the bigger individuals were picked up leaving the smaller ones, which have a tendency towards clumping for protection and moving to more deeper areas to have protection. The clumped distribution may be explained by spatial variation of habitat availability and limited dispersal ability (Medrano 2015). In 2016, only seven species remain in the area, four of them had clumped dispersion for the same reason as in 2006, while three of the species were randomly distributed due to the very low density and high fishing activities in the area.

Conclusion

The heavy overfishing for the sea cucumber populations at the study area not only affected the density, abundance, and biomass of different populations but also affected the species behavior inside the ecosystem. This conclusion was clearly obvious during the current study in which the coefficient of dispersion of the recorded species was studied. The heavy reduction of sea cucumber species was due to the illegal unregulated unreported overfishing, and this is the reason that the ban exerted by the Egyptian government on the sea cucumber fishery has a limited effect.

Abbreviation

SCUBA: Self-contained underwater breathing apparatus

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