THE ROLE OF MARINE PROTECTED AREAS IN MAINTAINING SUSTAINABLE FISHERIES IN THE EGYPTIAN GULF OF AQABA, RED SEA

By

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ABSTRACT

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The Egyptian Environmental Affairs Agency (EEAA) declared Ras Mohamed National Park the first Marine Protected Area (MPA) in Egypt in 1983 to conserve the Gulf of Aqaba coral reef ecosystem, sustain artisanal fisheries and encourage tourism activities in this region. The European Commission helped, initially, by providing the needed funding for the establishment of this MPA and for the establishment of two others, one in Nabq and the other in Abu Gallum. The creation of these managed resource protected areas established the entire Egyptian marine sector in the Gulf of Aqaba as a protected area by 1996. Artisanal fisheries were permitted in selected areas in these marine protected areas which were only conducted by the local people (Bedouin). This research assessed the role of the marine protected areas in conserving the fish populations of target and nontarget families in four regions of the Gulf of Aqaba, all of which were subjected to different regulations and fishing pressures over the last decade. In addition, I evaluated the impact of fishing and the catch dynamics at Nabq to ascertain whether specialized fishing regulations of take and no-take zones was effective in conserving the fisheries. Lastly, I conducted a pilot study on the dependency of the Bedouin fishers on the Nabq fisheries and their attitude towards the initiative of conservation measures and perceived needs for change to increase their effectiveness.

I found that the coral reef fish populations have changed over the years since the protected areas came into existence in terms of species richness, diversity, abundance and size; a result of

changing fishing pressure due to changes in the effectiveness of law enforcement and conservation. Nabq, which was relatively lightly fished in 2002, was the most affected region where species richness, total fish abundance, and the abundance of target and non-target families significantly declined by 2012 due to heavy fishing pressure and noncompliance to the regulations that applied to the no take zones in the region. In contrast, Dahab, the heavily fished region in 2002, exhibited an increase in species richness, diversity, total fish abundance, the abundances of the least commercially targeted herbivore families and other non-target fish families, by 2012; a result of reduced fishing pressure and increased law enforcement in this region. Additionally Ras Mohamed, which originally did not allow fishing, was found to have experienced illegal fishing beginning by 2003 ultimately resulting in a decline in the abundance of commercially valuable fish families by 2012.

Fishers from Nabq and Dahab depend on the Nabq fisheries for food security and livelihoods. However, many of the fishers were willing to change their occupations and work for tourism or other governmental secured job, as the fisheries currently were very poor. Although the local fishers were aware of the regulations for the protected area and noted the significant decline in the fisheries resources, they disagreed on the way that Nabq fisheries should be managed mainly due to the real and perceived lack of local engagement and enforcement. Lastly, it appears that tourism development that focused on having an intact healthy coral reef system and public awareness can play a role in reducing fishing pressure, increasing fish abundance and maintaining fish diversity in the future, and provide alternative sources of livelihoods for the local people.

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CHAPTER 1: OVERVIEW ON MARINE PROTECTED AREAS IN THE GULF OF AQABA, EGYPT

Introduction

There is no doubt now that fisheries resources around the world are in crises (Pauly et al. 2002, 2003, 2005, Myers & Worm 2005, FAO 2011, 2012), and the ecosystems on which they depend are being degraded. Watson and Pauly (2001) reported that global marine fisheries landings declined by about 0.7 million tons per year since the late 1980s and according to the FAO (2012) there was significant increase in the number of overexploited stocks worldwide (stocks producing lower yields than their biological and ecological potential). Today, it is reported that overexploited fish stocks have reached 30%, while those classified as fully exploited stocks have increased to 57% (FAO 2012). The non-fully exploited fish stocks decreased and now represent only 12.7% of all stocks available. Coral reef fisheries are among those threatened fisheries, and 75% of the coral reefs are located in developing countries (Pauly et al. 2002, Cesar et al. 2003). Coral reef fisheries are estimated to annually produce 6 million tonnes per year, with an annual economic benefit of USD 5.7 billion. Approximately 6 million fishers and over 400 million people living in the vicinity (within 100 km) of the coral reef (Ormond & Douglas 1996, Pauly et al. 2002, Cesar et al. 2003, Teh et al. 2013). Many of these people depend on the coral reef fisheries resource directly or indirectly for their livelihoods and food (Donner & Potere 2007). Although coral reef fisheries provide food security and income for millions of people, they are rarely well managed and over-fishing is considered to be one of the main threats to the coral reef fish populations throughout the world (Sale 2008). Coral reef fisheries are a multi-gear, multi-species fisheries (Ormond & Douglas 1996, Spalding et al. 2001, Ashworth et al. 2004) that are widely dispersed and hard to manage. As a result, many fisheries professionals have endorsed the concept of using Marine Protected Areas (MPAs) as a tool to conserve the marine ecosystems and fish stocks for these fisheries (Roberts & Polunin 1991, Halpern 2003, Roberts et al. 2005, Harborne et al. 2008, Selig & Bruno 2010, Al-Abdulrazzak & Trombulak 2012, Rossiter & Levine 2014, Kusumawati & Huang 2015). As a result, MPAs were promoted globally from the international conservation society e.g., IUCN, the Convention of Biodiversity CBD, World Wildlife Fund WWF, and UNDP as a central strategy of management approaches that aim to protect biodiversity, and support the social and economic wellbeing of human societies (IUCN-WCPA 2008, Mascia 2003).

The Egyptian government was a leader in recognizing the importance of conserving the coral reefs in the northern Red Sea and the Gulf of Aqaba for the local communities and the economy of the country. As a result, it established Ras Mohamed National Park in 1983, the first protected area in Egypt. With the financial and technical assistance of the European Commission, a network of protected areas on the Gulf of Aqaba was established by the declaration in 1992 of Nabq and Abo Gallum Protected Areas. The Egyptian marine sector of the Gulf of Aqaba was declared a protected area by 1996, leading to the first continuous network of the Marine Protected Areas (MPAs) in the Red Sea. One of the main objectives for establishing this network of protected areas was to maintain the traditional fisheries activities by the local people, while ensuring that the coral reefs were ecologically sustainable (Pearson & Shehata 1998). Earlier studies (Roberts & Polunin 1992, Galal 1999, Galal et al. 2002, Ashworth 2004, Ashworth & Ormond 2005) investigated the role of the MPAs including the use of the No Take Zones (NTZs) to determine if they could be effective in conserving the fish populations as well as the coral reef ecosystems. However, these studies were generally limited by focusing on a specific fish family, a specific area or by occurring on only one date. Additionally, no social assessment was conducted as part of these earlier studies to understand the relationship between the coral reef fisheries and the Bedouin fishers and how restrictive regulations would impact their food security and livelihoods.

Research Goals and Objectives

The goal of this dissertation was to investigate how MPAs in the Egyptian waters of the Gulf of Aqaba impacted the fish populations over the last decade (2002-2012). As a result, I studied the fish populations in different regions in the Gulf over this time period. Additionally I evaluated how alternating regulation of Take Zones (TZ) and No Take Zones (NTZs) in the Nabq MPA impacted the fish stocks and the Bedouin catch and further assess the relationship between the Bedouin fishers and the coral reef fisheries resources.

Dissertation Format

This dissertation consists of five chapters which include the following:

Chapter 1: Overview on Marine Protected Areas in the Gulf Of Aqaba, Egypt

This section describes the overall research program, study site and a review of the literature on MPAs and associated fisheries management for this region.

Chapter 2: The Effectiveness of Marine Protected Areas on Conserving the Fish Population in the Gulf of Aqaba, Egypt

This chapter describes how the MPAs influenced the fish population in the Gulf of Aqaba. Specifically, I assessed the changes in diversity, density and size of selected coral reef fish populations (9 families) over 10 years (2002-2012). Four regions were studied, with different levels of protection and fishing pressure.

Chapter 3: Evaluation of the Use of No Take Zones for Fisheries Sustainability, Nabq Protected Area, Gulf of Aqaba, Egypt

This chapter details the observed changes in species richness, diversity and abundance for select fishes in the NTZs and the TZs between 2000, 2002 and 2012. Moreover, I evaluated the sustainability of the Bedouin fisheries by assessing the catch and CPUE at El Ghargana village from 1999-2012.

Chapter 4: Resource Dependency and Compliance to Artisanal Fisheries Regulations in Nabq Protected Area, Gulf of Aqaba, Egypt

In this chapter I evaluated the relationship between the fishers in Nabq and the Nabq fisheries resources. I paid specific attention to the compliance of the fishers to the conservation measures, particularly over time and given the changes in governance in Egypt. Face to face interviews were conducted in Nabq with the local Bedouin fishers. A survey questionnaire was developed to: 1) assess the resource dependency of the fishermen in Nabq, 2) evaluate fishers attitudes to marine conservation and causes for their attitudes, 3) assess fishers perception to the changes in the fisheries resources and causes for any noted or perceived changes that they may have and 4) identify fishers attitudes to possible acceptance of changes to their livelihood.

Chapter 5: Conclusion

This chapter summarizes the main findings of this research program and highlights the implications for management of coral reef fisheries and proposes the needs for future management programs that will enhance the sustainability of these unique resources.

The Marine Protected Areas

An international definition of a protected area, including MPAs, is provided by the International Union for Conservation of Nature (IUCN) (IUCN-WCPA 2008): *"A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means,* *to achieve the long-term conservation of nature with associated ecosystem services and cultural values."*

The IUCN classifies MPAs into 6 categories, ranging from highly protected reserves, intended only for scientific research or wilderness conservation, to multiple-use areas, created to foster the sustainable use of natural ecosystems and resources (Table 1).

Table 1. IUCN protected area management categories (IUCN 2012)

Category	Name
Ia	Strict Nature Reserve: protected area managed mainly for science
Ib	Wilderness Area: protected area managed mainly for wilderness protection
II	National Park: protected area managed mainly for ecosystem protection and recreation
III	Natural Monument: protected area managed mainly for conservation of specific natural features
IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention
V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation
VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems

Although the IUCN identified the MPA and the corresponding categories, in practice interpretation can vary widely, from country to country or even within same country, depending on the local, national or international contexts (Agardy & Staub 2006, White et al. 2006, Christie et al. 2007). Different names and definitions have been used to describe MPA such as marine reserve, no take zone, marine sanctuary, marine park, and closed area (Lutchman 2005, Marine Protected Areas Center 2008). For example, a marine park in Jordon (Aqaba Marine Park) allows non-destructive fishing activities while the marine park in Egypt (Ras Mohamed National Park) prohibits all kinds of fishing. I will use the term MPA during this study as a general term that represent a wide range and levels of marine resources management. The IUCN in 2008 put forth a key concept for the MPA stating that "MPAs can offer a spectrum of management strategies ranging from full protection, or no-entry areas, to multiple-use areas which prohibit limited activities. No-take MPAs are spatial closures that prohibit all forms of resource extraction, especially fishing. Limited take MPAs include those MPAs with mixed harvest or restricted harvest prohibition areas"

Many scientists (Gell & Roberts 2002, Russ et al. 2004, Williamson et al. 2004, Roberts et al. 2005, Samoilys et al. 2007, Weeks et al. 2010, Oropeza et al. 2011) have highlighted the advantages of using MPAs in fisheries management and tout the role of MPA in protecting fish habitat and vulnerable species, extending age structures of target fish species, maintaining their genetic variability, preventing deleterious evolutionary change from the effects of fishing, with the assertion that fish species will be more resilient to environmental change due to the genetic diversity available. Besides conserving the fisheries and its surrounding habitats, MPAs also enhance the surrounding fisheries through spill-over (emigration of the adult fish or export of their offspring from the protected regions to the non-protected regions of the reserve). Halpern (2003) studied 89 MPAs around the world and showed that fish abundance increased between 60% to 150% inside the protected reserve, and fish diversity increased in 59% of the studied sites. MPAs have been reported to increase the fish stocks up to 5 times within 5-10 years (Gell & Roberts 2003).

According to the IUCN World Commission on Protected Areas (WCPA 2008), MPA can contribute to:

- Conserving biological diversity and associated ecosystems.
- Protecting critical spawning and nursery habitats.
- Protecting sites with minimal direct human impact to help them recover from stresses.

- Protecting settlement and growth areas for marine species and spillover benefits to adjacent areas.
- Providing focal points for educating the public about marine ecosystems and human impacts upon them.
- Providing nature-based recreation and tourism.
- Providing undisturbed control or reference sites that serve as baselines for scientific research and for designing and evaluating other areas.
- Sharing costs and benefits among local communities, the private sector, regional and national governments, and other stakeholders.
- Reducing poverty and increasing the quality of life of surrounding communities.

Based on the importance of MPAs in sustainable management of marine resources, the international community in 2002 at the World Summit on Sustainable Development and the Convention on Biological Diversity (CBD) committed to establishing an ecologically representative and effectively managed network of MPAs, covering at least 10% of the global marine and coastal ecological regions by 2012. Additionally, the World Parks Congress of 2003 recommended that 20–30% of every habitat in the sea be given full protection from fishing. As a result, the area of MPAs has risen 150% since 2003 and now includes approximately 5,880 MPAs covering over 4.2 million km^2 (1.6 million square mile), representing 1.17% of the marine area of the world (IUCN and UNDP 2010); far away from the 2012 target (10%), which according to Wood et al. (2008) will be achieved by 2047. However, in order for those MPAs to achieve their objectives they need to be designed and managed effectively, taking into consideration the socio-economic needs of their surrounding communities. Hastings et al. (2012)

proposed six strategies for designers and policymakers to speed up the establishment of effective and resilient MPAs, these include:

- Build public-private partnerships to change how MPAs are designed and financed.
- Strengthen links between MPAs, local communities and their livelihood needs.
- Manage MPAs to enhance carbon stocks and address climate change.
- Act on high seas conservation and initiate MPAs immediately.
- Reframe thinking about the direct and indirect benefits of MPAs.
- Use social media to connect people with the oceans to emphasize their importance.

The Marine Protected Areas in Egypt and the Role of Donors

Egypt established 29 protected areas covering 15% (150,000 km^2) of the total area of the entire country. Of these protected areas in Egypt, seven are marine, one is on the Mediterranean (El-Salum) declared in 2010 while the rest are on the Red Sea covering 46,400 km^2 (17,915 square miles). These MPAs have both terrestrial and marine components, with 6,000 km^2 (2,316 square miles) of marine environment predominantly located in the coral reef-based ecosystem. One of the main objectives of these MPAs is to maintain fisheries resources and conserve the coral reef ecosystem.

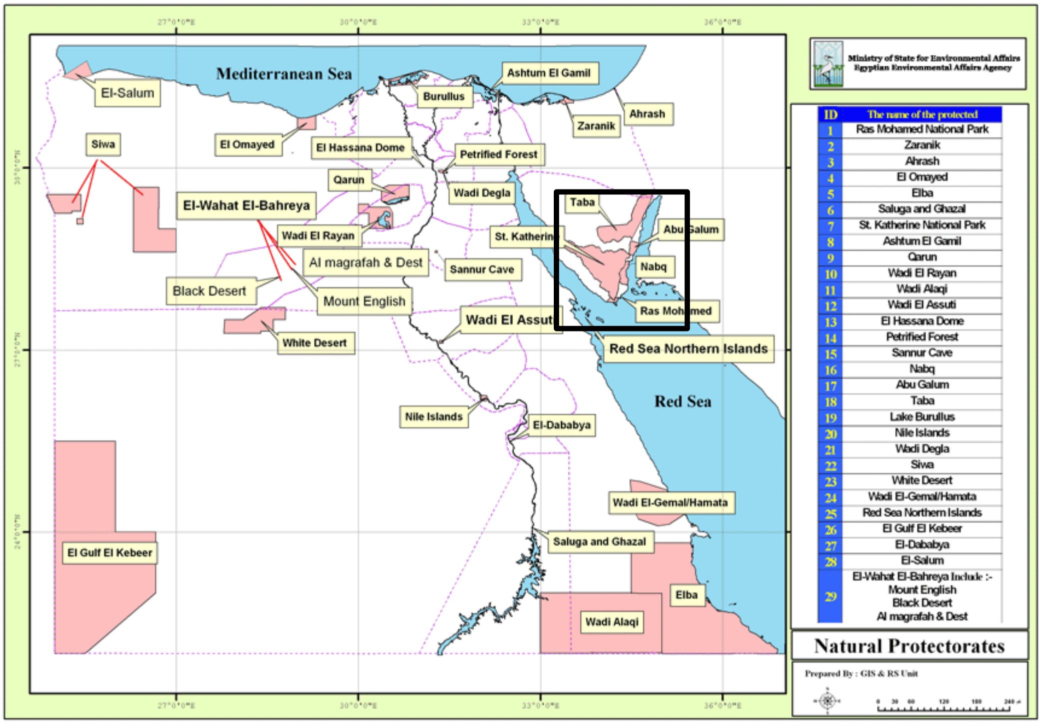

Figure 1. The protected areas of Egypt in pink, with the location of the MPAs in the Gulf of Aqaba, Red Sea

In 1983 Egypt declared its first protected area, Ras Mohamed National Park, a MPA on the southern tip of Sinai Peninsula. Ras Mohamed National Park is considered one of the best dive sites in the world, with a unique fringing coral reef ecosystem. However, the marine park was under the threat of tourists activities, overfishing and habitat degradation (Clarke 1992). Ras Mohamed National Park remained as a "paper park" where protection activities are insufficient to halt degradation until 1988 (Pearson & Shehata 1998). In 1989, the European Commission (EC) funded a 6-year joint project with the Egyptian Environmental Affairs Agency (EEAA) to restore the reef habitat of the park as part of its environmental plan (Clarke 1992). The Ras Mohamed National Park project was extremely successful and achieved its goals relatively quickly which allowed for its expansion from $97km^2$ to $240km^2$, and the establishment of two additional protected areas on the Gulf of Aqaba, north of Ras Mohamed, Nabq Managed

Resource Protected Area and Abu Gallum Managed Resource Protected Area (Figure 1). This encouraged the EC to extend financial and technical support for the project for an additional 7 years (1995-2002) with a donation of € 10 million to assist in the development of this network of protected areas (Gulf of Aqaba Protectorates project). Finally, in 2007, the EC funded a project called the South Sinai Regional Development Program (SSRDP) with € 64 million; 5.6 million of which was dedicated to purchase key equipment, vehicles and boats for monitoring and enforcement to increasing the status of these protected Areas in the Gulf of Aqaba.

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CHAPTER 2: THE EFFECTIVENESS OF MARINE PROTECTED AREAS ON CONSERVING THE FISH POPULATION IN THE GULF OF AQABA, EGYPT

Abstract

Fisheries on the Egyptian coast of the Gulf of Aqaba are conducted mainly by the local community (Bedouin). It is a traditional activity where fish are mainly used for subsistence and the surplus considered as a source of income. As part of the effort of the Egyptian government to protect the coral reef ecosystem and maintain this traditional activities, a network of three MPAs in the Gulf of Aqaba were established. It started with the declaration of Ras Mohamed National Park in1983, then Nabq and Abu Gallum in 1992. One of the main objectives for this conservation network was to maintain traditional fisheries and to ensure its their sustainability. Different conservation measures were implemented including prohibiting fishing as in Ras Mohamed National Park, and permitting fishing with unique regulations as in Nabq Protected Area. In this study, we investigated the change in diversity, density, and size of fish populations (9 families) over 10 years (2002-2012) of conservation efforts in the Gulf of Aqaba. Four regions were studied, with different level of protection and fishing pressure. Ras Mohamed National Park, where no fishing or development were allowed, Sharm El Sheikh Marine protected area where no fishing but development was allowed, Nabq Managed Resource Protected Area where fishing was allowed but no development, and Dahab Marine Protected Area where both fishing and development were allowed.

We found that the total number of fish species and diversity changed by water depths over time with the reef flats having the lowest in species richness and diversity. We found that the un-fished regions (Ras Mohamed and Sharm El Sheikh) were more abundant in total species and

more diverse than the fished regions (Nabq and Dahab). Additionally total fish species in Nabq decreased significantly by 2012, while Dahab significantly increased in both total species and diversity. Nabq and Ras Mohamed decreased significantly in fish abundance by 51% and 39%, respectively, while Dahab, which originally had the lowest fish abundance, increased by 75% over time. The commercially targeted herbivore species families Acanthuridae, Siganidae and Scaridae significantly decreased over time by 22%, 17%, and 51%, respectively. Additionally the target carnivore species families Serranidae, Lutjanidae, and Lethrinidae decreased significantly by 15%, 23%, and 42%, respectively, while the non-target species families Chaetodontidae and Pomacanthidae significantly increased by 5% and 23%, respectively. Sizes of the target herbivore and carnivore species were significantly decreased over time with Nabq and Dahab having the smallest fish sizes by the end of our study.

Fishing pressure has been increasing in Nabq and affecting the fish population dramatically, due to pressure from Dahab fishers and non-compliance by fishing in the No Take Zones. Even in the Ras Mohamed National Park, fishing occurred causing a decline in abundance of target species. Ensuring long-term effective law enforcement is critical for the MPAs to maintain and conserve the fish populations in the Gulf of Aqaba. Tourism development and public awareness can also play a role in reducing fishing pressure, increasing fish abundance, and maintaining fish diversity.

Introduction

Coral reef fishes in the Gulf of Aqaba are an important source of food and income for the local community (the Bedouin) and also for the tourism industry. Bedouin traditionally fish mainly for subsistence with the surplus considered a profit. Meanwhile for tourism, coral and coral reef fishes are the cornerstone of tourist activities such as diving and snorkeling. Marine protected areas have shown to be an effective tool to manage coral reef habitat and benefit both the local fisheries and tourism (Roberts & Polunin 1991, Halpern 2003, Robert et al. 2005, Harborne et al. 2008, Selig & Bruno 2010, Al-Abdulrazzak & Trombulak 2012, Rossiter & Levine 2014, Kusumawati & Huang 2015). The Egyptian government realized the importance of conserving the coral reef in the northern Red Sea and the Gulf of Aqaba for the local communities and the economy of the country. Subsequently, it declared Ras Mohamed National Park in 1983, the first protected area in Egypt, followed by the declaration of Nabq and Abo Gallum Protected Areas in 1992. By1996 the Egyptian marine sector of the Gulf of Aqaba was declared a protected area having the first network of the MPAs in the Red Sea. One of the main objectives of establishing this network of protected areas was to maintain the traditional fisheries activities and ensure its ecological sustainability (Pearson & Shehata 1998).

In this study we focused on four regions in the Gulf of Aqaba, each of them subjected to different conservation measures and different fishing pressure. The four regions were: Ras Mohamed National Park where fishing is prohibited and there is no coastal development allowed; Sharm El Sheikh Environmentally Managed Area where fishing is also prohibited but coastal development is allowed (the biggest resort in Egypt); Nabq Protected Area where traditional fishing is permitted for the Bedouin and no coastal development allowed; and Dahab Environmentally Managed Area where fishing is permitted for Bedouin and coastal development is allowed.

The goal of this study was to investigate the effectiveness of those four regions on maintaining the fish population structure in the Gulf of Aqaba over 10 years of conservation efforts, by monitoring the change in fish diversity, fish density and body size of 9 fish families between 2002 and 2012. Our main research questions was: whether the protected areas in the Gulf of

Aqaba were effective in protecting the fish population diversity, density, and size between the different regions over the studied years.

The Study Area

The study area covered 120 km of fringing reef on the Egyptian coast of the Gulf of Aqaba, representing four regions; Ras Mohammed National Park, Sharm El Sheikh, Nabq Protected Area and Dahab. Where Sharm El Sheik (sharm) is under the jurisdiction of Ras Mohammed National Park, while Dahab is under Nabq Managed Resource Protected Area (Figure 2).

Ras Mohammed National Park (NP)

Ras Mohammed National Park was established in 1983, IUCN (International Union for Conservation of Nature and Natural Resources) category (II) (Day et al. 2012), as the first National Park in Egypt. Located at the most southern tip of the Sinai Peninsula, with total land and marine area of 480 km^2. All fishing and development activities were prohibited, with only recreational activities (diving, snorkeling and camping) being allowed at designated areas.

Sharm El Sheikh (Sharm) Environmentally Managed Area

Sharm extends from the northern border of Ras Mohamed to the southern border of Nabq with 45 km of coast. Only the marine sector is protected in this area and all fishing activities are prohibited. Sharm coast has been developed mainly for tourism (hotels and resorts) under the supervision of the national park regulation.

Nabq Protected Area (PA)

Nabq was declared in 1993 as Managed Resource Protected Area, IUCN category (VI) (Day et al. 2012). Located north of Sharm with a total area (marine and land) of 600km^2. Inhabited only by a small settlement of Bedouin, development has been prohibited while traditional activities for the Bedouin such as subsistence fishing was regulated and permitted only in the designated areas (Take Zones).

Dahab Environmentally Managed Area

Dahab located north of Nabq with 24 km coast extends between Nabq Protected Area and the southern border of Abu Galum Protected Area. Only the marine sector is protected as part of Nabq PA, where fishing is allowed only for the Bedouin with little regulation. Coastal development was also allowed, mainly for tourism.

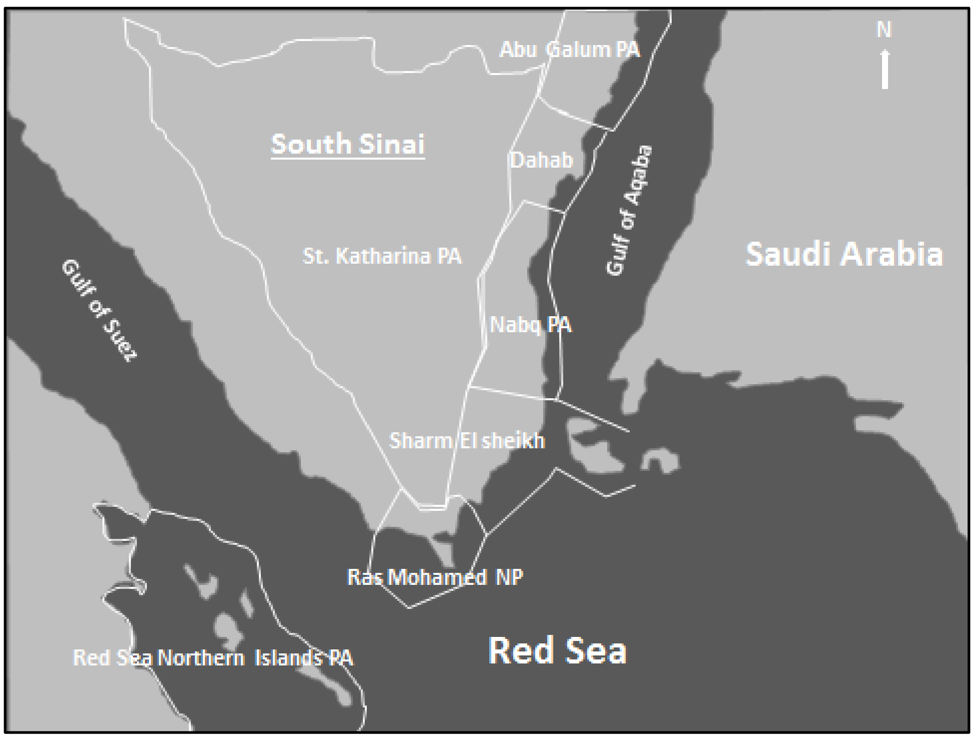

Figure 2. The location of the studied regions Ras Mohamed, Sharm El Sheikh, Nabq and Dahab on the Gulf of Aqaba, Egypt.

Methods

Underwater Visual Census

In order to assess the change in the fish populations in the Egyptian marine sector of Gulf of Aqaba over time, four regions (Dahab City, Nabq MRPA, Sharm El Sheikh City and Ras Mohamed NP) were surveyed in summer 2002 and 2012 using underwater visual census techniques. Underwater visual censuses are the most common, non-destructive methods to quantify fish abundances (Sale 1980, Brock 1982) in coral reef habitats. I surveyed 9 fish families, seven of them commercially targeted (Acanthuridae, Siganidae, Labridae, Mullidae, Serranidae, Lutjanidae and Lethrinidae), while the other two were non-commercial but used as indicators of the health of the coral reef (Chaetodontidae and Pomacanthidae, Soule et al. 1988, Crosby & Reese 1996). Members of the families were identified to species level with a total of 57 species evaluated (Appendix 1). The density of each species was estimated using underwater belt transects; fish species were counted and size was estimated to the nearest 5cm visually along 50m long and 10m wide transect ($500m^2$) using 4 replicates at each depth parallel to the reef edge (Figure 3). The survey covered the reef flat (1m depth), reef edge (3m depth) and reef slope (10m depth).

Nineteen sites were surveyed in 2002 while 25 sites were surveyed in 2012 (Appendix 2). Total species, diversity index H` (Shannon-Wiener index), species abundance and size at each transect were determined. The H` diversity values represent not only the number of species but also the abundance of each species in the community. High values of H` would be representative of more diverse communities (Magurran 2004).

The Shannon-Wiener index was calculated using the equation:

$$H` = \sum_{i=1}^{S} (Pi * \ln Pi)$$

where:

H` = the Shannon-Wiener diversity index

Pi = fraction of the entire population made up of species i

S = numbers of species encountered

∑ = sum from species 1 to species S

It was important to investigate the reef flat fish population where most of the net fishing by the Bedouin occurs. As a result, all surveys were conducted at high tide. The surveyed sites were selected to represent continuous fringing reefs with a typical reef flat, reef edge and reef slope, avoiding the contributions of other habitats like seagrass and mangrove, to reduce the habitat effect in order to clime that the change in the fish population is mainly due to fishing activities in those regions. Robert & Polunin (1992), and Ashworth (2004) assessed the reef habitats in the same regions and suggested that the substrate composition was similar over the studied regions and did not affect the fish communities.

Although Ras Mohamed was categorized as an unfished region in this study and by other scholars (Robert & Polunin 1992, Ashworth 2004), we observed and documented illegal fishing activities in the area by fishers from the nearby fishing harbors in the Gulf of Suez (2003-2012). This was also recorded earlier by Ashworth (2004). These illegal fishing operations were seasonally and species selective, where fishers targeted species like Emperors (*Lethrinus nebulosus*), Snappers (*Lutjanus bohar*), Jacks (*Carangoides sp.* and *Caranx sp.*) and Parrot fish (*Hipposcarus harid*) when aggregating in Ras Mohamed for spawning (pers. obs., Ashworth 2004, EEAA 2009). This in contrast to Sharm which was categorized as fished and lightly fished by Robert & Polunin (1992). In Sharm large part of the coast was undeveloped and the Bedouin were still having access to fish there, then 10 years later the region was unfished due to restrictive regulations and the rapid development and construction of resorts along the coast which enforced the law (Ashworth 2004).

Data Analysis

Data for species richness, diversity index H`, total abundance, and family abundance were analyzed using the General Linear Mixed Model (GLIMMIX) procedure SAS 9.2 software package which accommodates non-normal data that involve random effects. It has been reported to be a powerful tool for analyzing multilevel, clustered and repeated measures data (Bolker et al. 2009). In the GLIMMIX, we selected a Poisson distribution with a logarithmic link (typical for count data), and used the surveyed sites as subject and year (2002, and 2012), regions (Dahab City, Nabq MRPA, Sharm El Sheikh City and Ras Mohamed NP) and depths (Reef Flat, Reef Edge and Reef Slope) as the fixed factors. We used the nonparametric Kruskal Wallis Test for ANOVA analysis to compare the abundance and size of the species between years, regions and depth.

Analysis of fish assemblages using the species abundance data was conducted using Plymouth Routines in Multivariate Ecological Research (PRIMER) software package (Clarke & Warwick 2001). Multidimensional Scaling analysis (MDS) was used to represent the dissimilarity between sites and regions, and One-way Analysis of Similarity (ANOSIM) tests was used to evaluate the similarity between regions, depths, sites and years. Species contributions to the patterns observed were evaluated using the Similarity Percentages (SIMPER) routine (Clarke 1993, Clarke & Warwick 2001, Ashworth 2004).

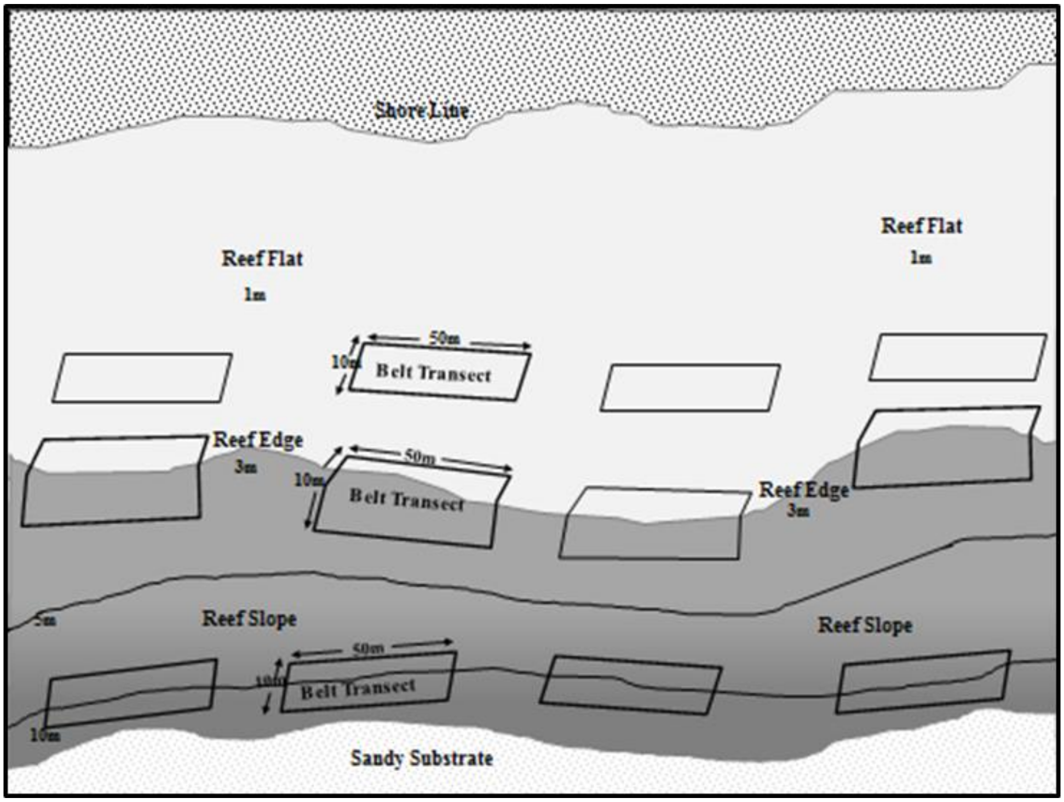

Figure 3. Location and dimensions of the belt transects on the reef flat and reef edge for the Underwater Visual Census fish survey technique in the surveyed sites in the Gulf of Aqaba, Egypt, 2002 - 2012.

Results

<u>Changes in Fish Assemblage Total Species (2002 and 2012)</u>

The mean number of species per 500 m^2 was significantly different between regions and with depth, and between regions over the study years 2002 and 20012 (Table 2). The highest number of species recorded was in Ras Mohamed (Figure 4), with the reef edge having significantly more species than the reef flat or reef slope (Figure 5). Pairwise comparison showed a significant difference in number of fish species between all regions except between Ras Mohamed and Sharm where differences observed were not significant. Additionally, Dahab had a significantly higher number of fish species in 2012 than 2002 at all depths, contrary to Nabq where number of species had significantly declined by 2012 (Figure 6).

Table 2. Results of generalized linear mixed model for total number of fish species, between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), depths (reef flat, reef edge and reef slope) and years (2002 and 2012), and their interactions. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMIX Test for Total Species				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	44.29	<.0001*
Depth	2	29	49.92	<.0001*
Year	1	15	0.06	0.8162
Region*Year	3	15	19.57	<.0001*
Depth*Year	2	19	0.34	0.7126
Region*Depth	5	29	8.8	<.0001*
Region*Depth*Year	3	19	1.58	0.227

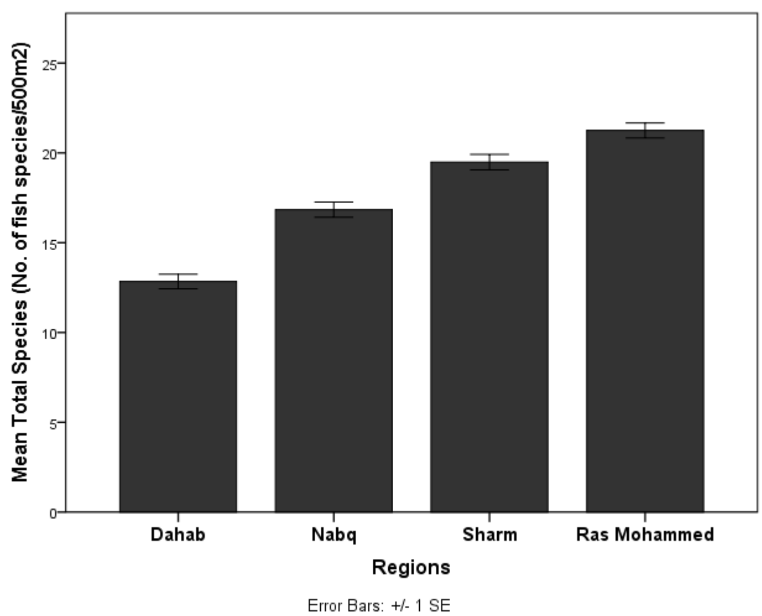

Figure 4. Comparison of the mean fish species between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

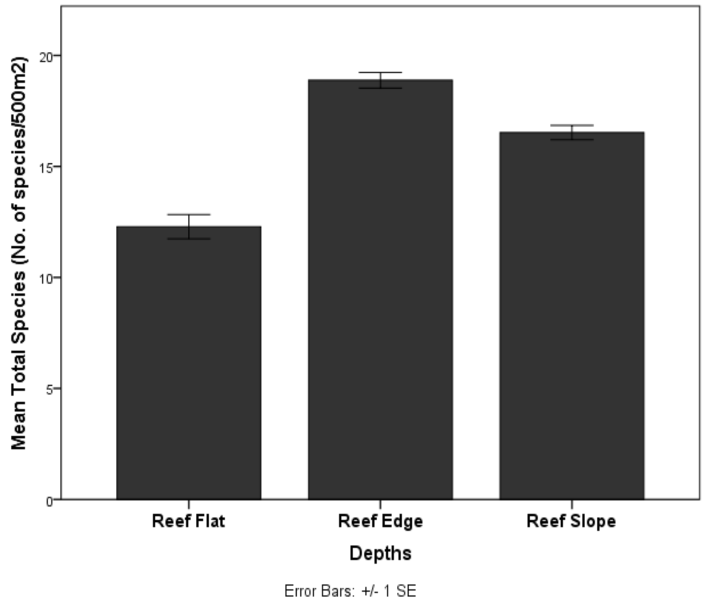

Figure 5. Comparison of the mean fish species between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

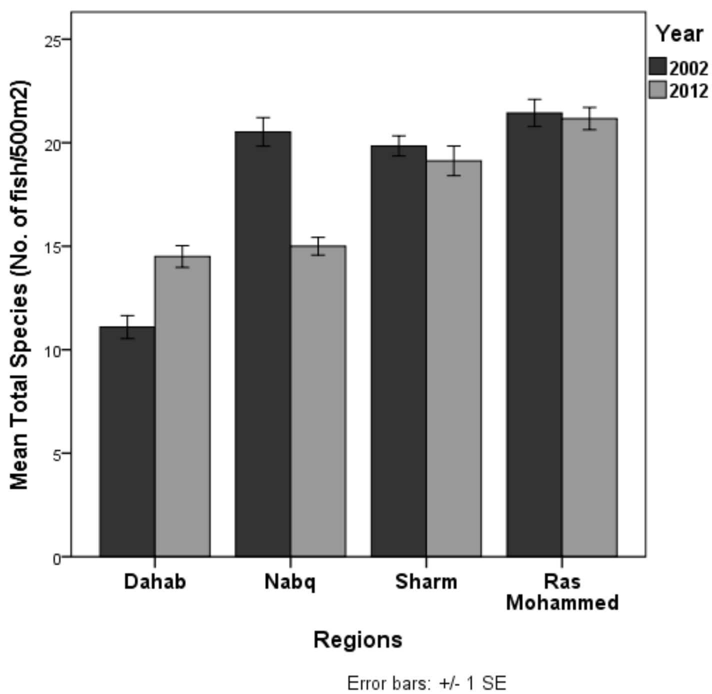

Figure 6. Comparison of the mean fish species between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

The Change in Fish Diversity H`

Fish diversity was different (P<0.0001) between depths (Table 3), with reef slope and reef edge having higher diversity than the reef flat (Figure 7). Additionally diversity was significantly different (P<0.001) between regions with Sharm and Ras Mohamed having higher diversity than Dahab and Nabq. However only Dahab was found to have significantly (adj. P<0.0001) higher fish diversity in 2012 than in 2002 (Figure 8 and 9).

Table 3 Results of Generalized Linear Mixed Model analysis for fish diversity, between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), depths (reef flat, reef edge and reef slope) and years (2002 and 2012) and their interactions. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMIX Test for Fish Diversity H				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	7.77	0.0011*
Depth	2	29	87.55	<.0001*
Year	1	15	1.26	0.2799
Region*Year	3	15	8.98	0.0012*
Depth*Year	2	19	1.53	0.241
Region*Depth	5	29	9.04	<.0001*
Region*Depth*Year	3	19	3.87	0.0258*

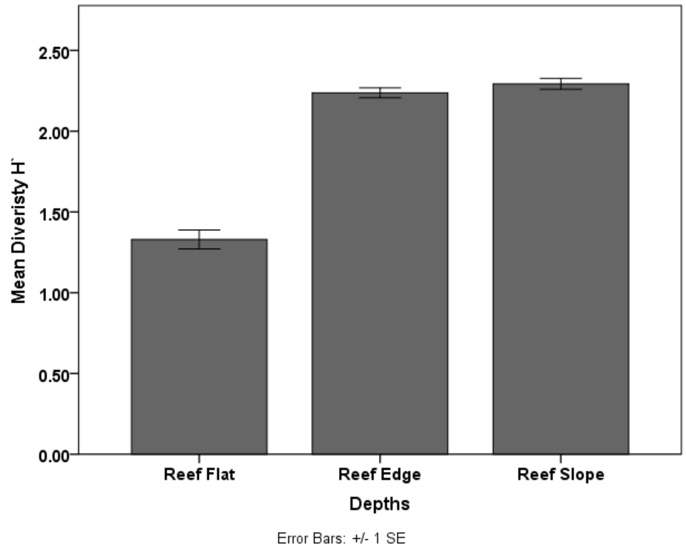

Figure 7. Comparison of the mean fish diversity H` between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

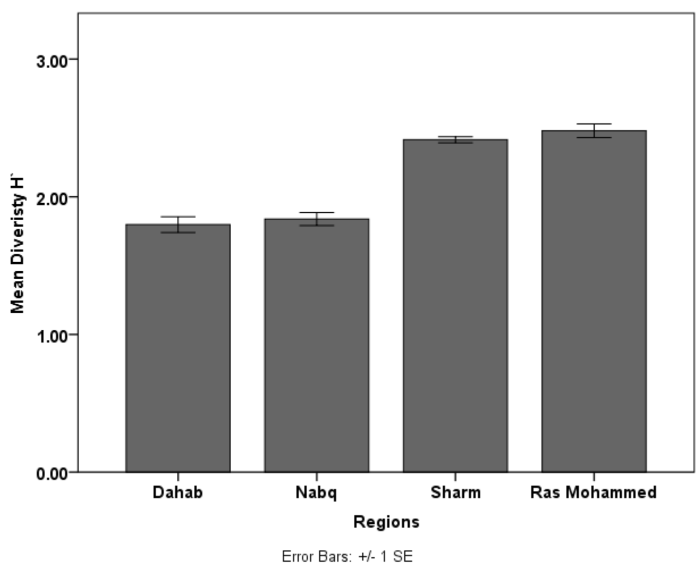

Figure 8. Comparison of the mean fish diversity H` between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

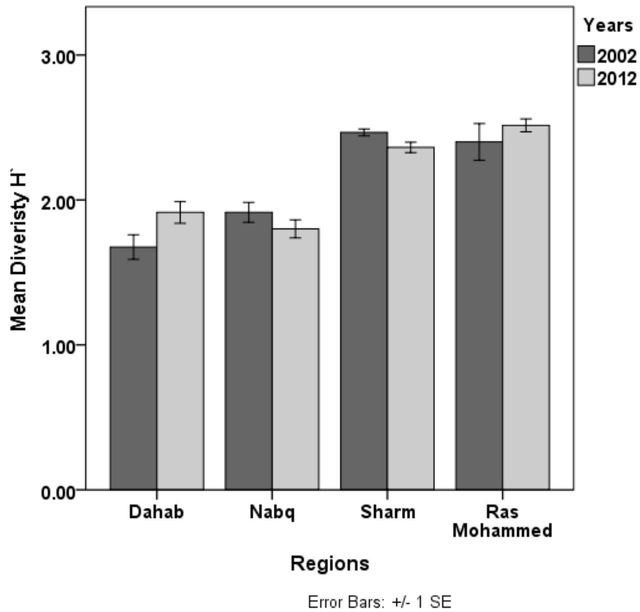

Figure 9. Comparison of the mean fish diversity H` between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

<u>The Change in Abundance of the Fish Assemblage</u>

Underwater census for the 9 families for the four regions during the summer months of 2002, and 2012 resulted in a total fish count of 63,220 individuals from surveying 416 total transects (208,000 m^2); 172 transects in 2002, and 244 in 2012. The Generalized Liner Mixed Model analysis for the fish density (Table 4) showed a significant difference for all the main factors (region, depth and year) and the interaction between them. The mean fish density for the fish assemblage decreased significantly from 2002 (167.3 fish/500m^2) to 2012 (141.16 fish /500m^2). The herbivores Acanthuridae, Siganidae and Scaridae decreased by 22%, 16% and 51% in 2012 while Mullidae increased by two fold in 2012 (Figure 10 and 11).

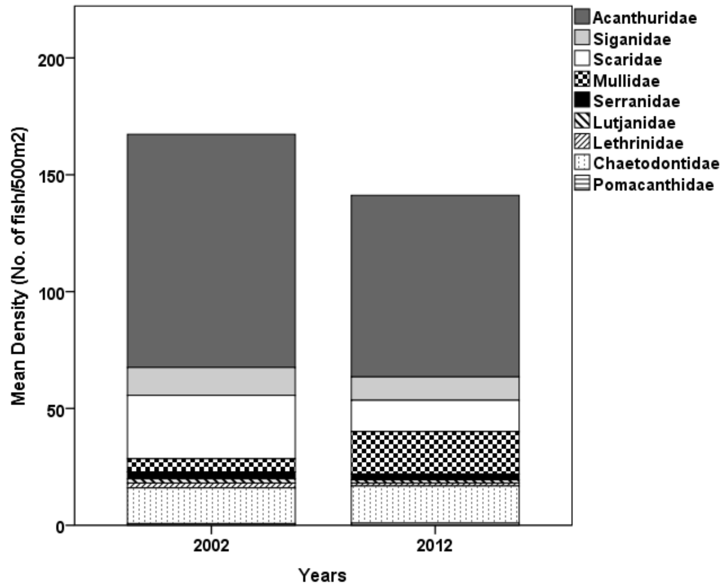

Figure 10. Comparison of the composition of each the fish assemblage (9 families) between 2002 and 2012 for the 4 studied regions.

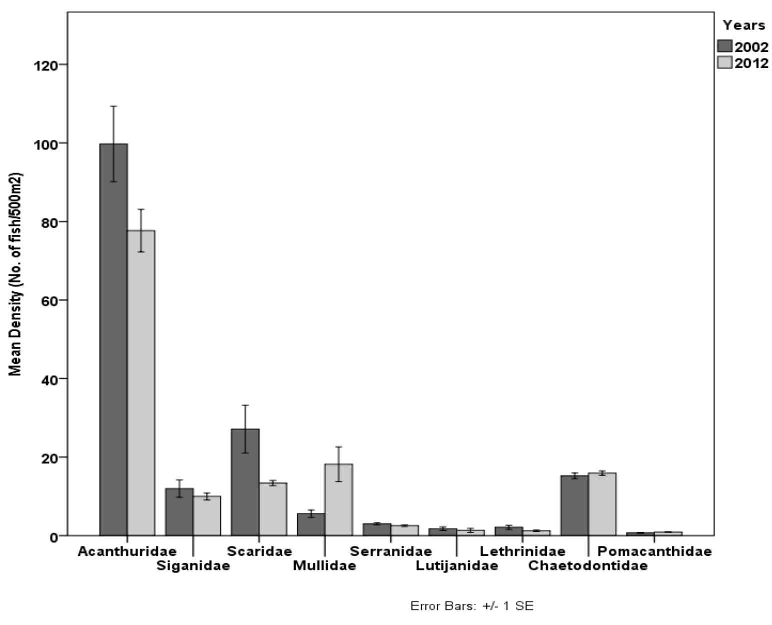

Figure 11. Mean fish density (No. of fish/500m²) of the 9 families during summer 2002, and 2012 in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Fish density was significantly different between depths, with reef flat having the highest abundance (219.3 fish/500m²) and reef slope the lowest abundance (90.6 fish/500m²). In particular we noticed that by 2012 both reef flat and reef edge abundance had significantly decreased (adj. $P<0.0001$) primarily due to the decrease of the herbivores (Acanthuridae, Siganidae and Scaridae) density, whereas density on the reef slope significantly increased (adj. $P<0.0001$) mainly due to increases in Siganidae, Mullidae and Chaetodontidae (Figure 12). Fish density was significantly different between regions with Nabq having the highest abundance (244 fish/500m^2) and Dahab the least abundant (93 fish/500m^2) (Figure 13). Pairwise comparison over the years studied showed a significant (adj. $P<0.0001$) decreased in mean fish density in 2012 for Nabq and Ras Mohamed by 49.75% and 39.04% respectively; in contrast Dahab showed a significant (adj. $P<0.0001$) increase in density (42.82%;Figure 14).

Table 4. Results of Generalized Linear Mixed Model analysis of fish mean density, between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), depths (reef flat, reef edge and reef slope) and years (2002 and 2012) and their interactions. Significant results

GLIMMIX Test for Fish Mean Density				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	17.81	<.0001*
Depth	2	29	940.51	<.0001*
Year	1	15	127.89	<.0001*
Region*Year	3	15	744.45	<.0001*
Depth*Year	2	19	52.39	<.0001*
Region*Depth	5	29	200.27	<.0001*
Region*Depth*Year	3	19	196.79	<.0001*

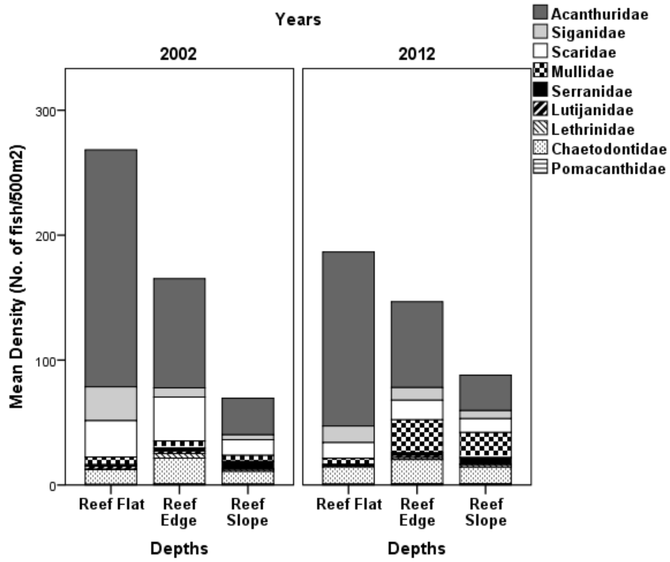

Figure 12. Comparison of the mean fish density between depths (reef flat, reef edge and reef slope) for the 4 studied regions showing the families composition at each depth in 2002 and 2012.

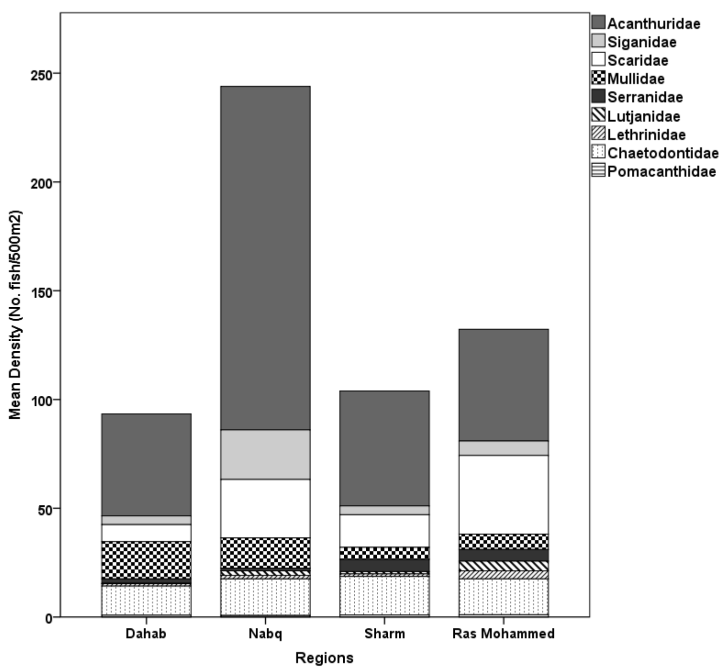

Figure 13. Comparison of the mean fish density of the fish assemblage between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) showing the families composition.

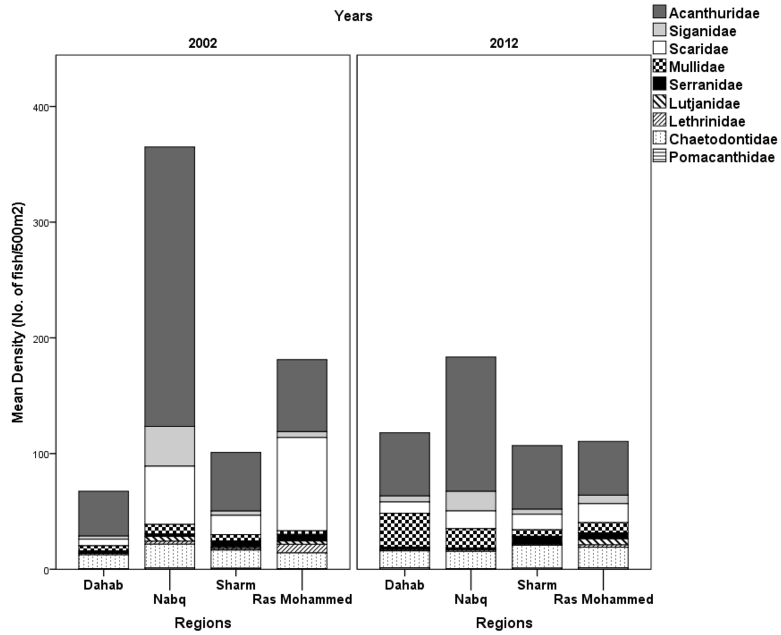

Figure 14. Comparison of the fish density between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) showing the families composition in 2002 and 2012, Gulf of Aqaba, Egypt.

Changes in Families Density

Changes in Density for Acanthuridae

There was a significant difference in density of Acanthuridae between2002 and 2012, between depths (Reef Flat, Reef Edge and Reef Slope) and also between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) (Table 5). Additionally the interactions between region and year, and region and depth were significantly. Pairwise comparison revealed that abundance was significantly higher in 2002 (99.7 fish/500m^2) by 22% than 2012 (Figure 15), and that density on the reef flat was significantly higher (160 fish/500m^2) than the reef edge (77 fish/500m^2) and reef slope (29 fish/500m^2) (Figure 16). Nabq had significantly ($P<0.0001$) higher density (158 fish/500m^2) than the other regions (Figure 17), and in 2012 mean density in Nabq (116 fish/500m^2) and Ras Mohamed (46 fish/500m^2) were found to have significant decreases of 52% and 25%, respectively, while Dahab (55 fish/500m^2) significantly increased by 29% (Figure 18).

Table 5. Results of the Generalized Linear Mixed Model test for the density of Acanthuridae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicat.

GLIMMIX Test for Acanthuridae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	21.99	<.0001*
Depth	2	29	28.14	<.0001*
Year	1	15	10.23	0.006*
Region*Year	3	15	14.04	0.0001*
Depth*Year	2	19	0.19	0.831
Region*Depth	5	29	10.87	<.0001*
Region*Depth*Year	3	19	0.74	0.5413

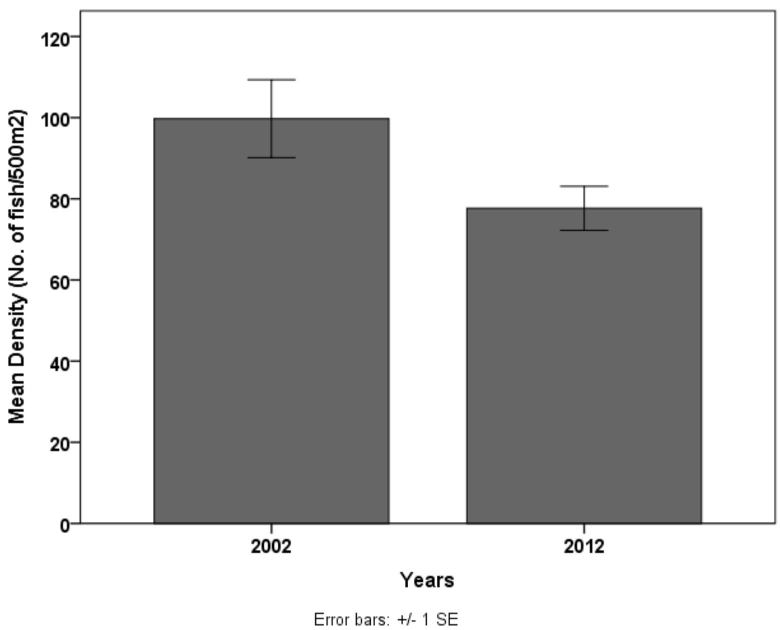

Figure 15. Comparison of mean density for Acanthuridae between 2002, and 2012 in the Gulf of Aqaba, Egypt.. Error bars represent +/-1 standard error.

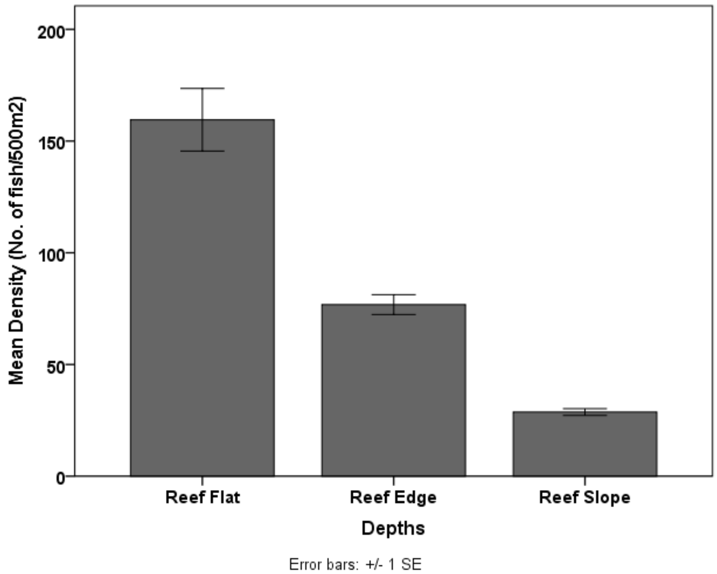

Figure 16. Comparison of the mean density for Acanthuridae between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

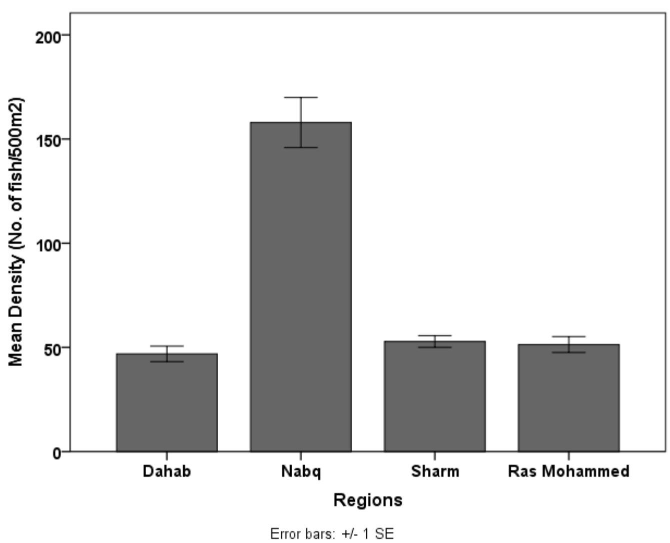

Figure 17. Comparison of the mean density for Acanthuridae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

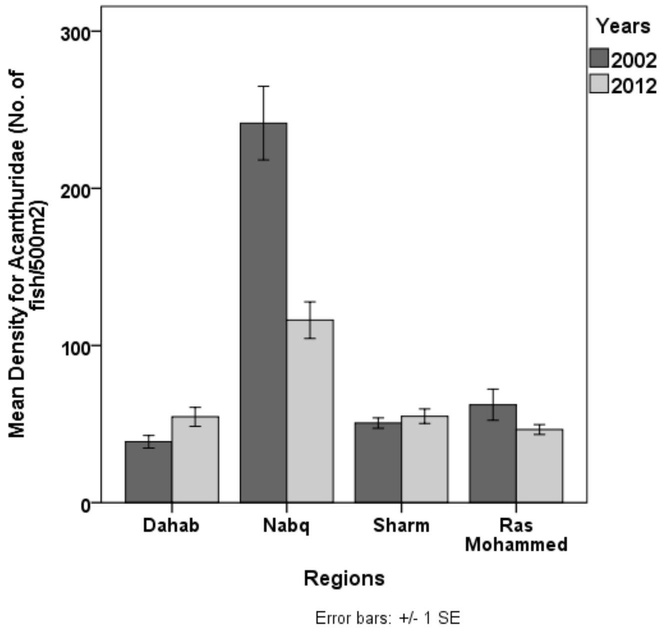

Figure 18. Comparison of the mean density for Acanthuridae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Siganidae

There was a significant difference in density for Siganidae for all the main factors (region, depth and year) and the interaction between them over the years studied (Table 6).

Pairwise comparison revealed that abundance was significantly higher in 2002 (12 fish/500m²) by 17% than 2012 (Figure 19), and that the reef flat had the highest density (19 fish/500m²) of Siganidae. Nabq was significantly higher in density (23 fish/500m²) than the other regions, however in 2012 mean density in Nabq (17 fish/500m²) was significantly decreased by 50%, while in Dahab (5 fish/500m²) it significantly increased by 66% (Figure 20), the other two regions Ras Mohamed and Sharm did not show significant differences between 2002 and 2012.

Table 6. Results of the Generalized Linear Mixed Model test for the density of Siganidae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated.

GLIMMIX Test for Siganidae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	28.37	<.0001*
Depth	2	29	33.88	<.0001*
Year	1	15	6.84	0.0195*
Region*Year	3	15	50.69	<.00018
Depth*Year	2	19	14.43	0.0002*
Region*Depth	5	29	77.54	<.0001*
Region*Depth*Year	3	19	13.81	<.0001*

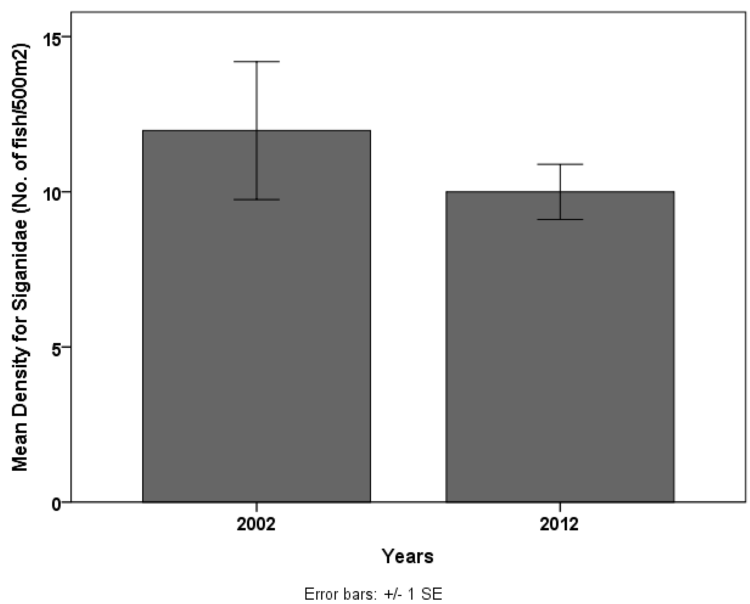

Figure 19. Comparison of mean density for Siganidae between 2002, and 2012 in the Gulf of Aqaba, Egypt.. Error bars represent +/-1 standard error.

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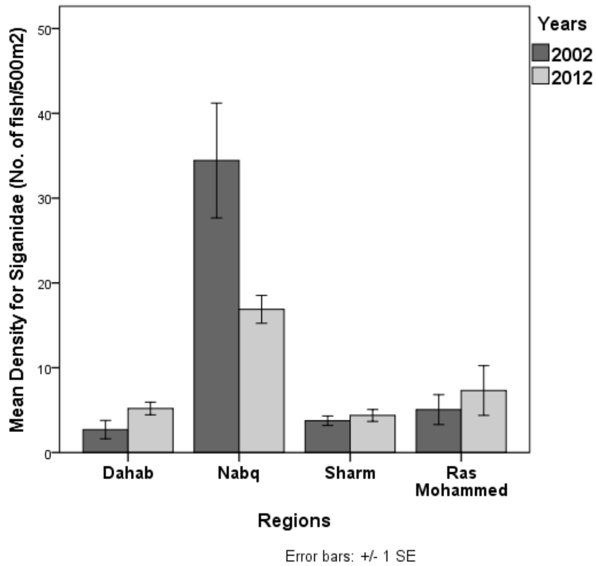

Figure 20. Comparison of the mean density for Siganidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Labridae (Scaridae)

There was a significant difference in density for Scaridae for all the main factors (region, depth and year) and the interaction between them (table 7). Pairwise comparison revealed that abundance was significantly higher in 2002 (27 fish/500m²) than 2012 (13 fish/500m²) (Figure 21), and that the reef edge was significantly the most abundant (24 fish/500m²) with Scaridae than the reef flat (19 fish/500m²) and reef slope (12 fish/500m²). Fish density in Ras Mohamed (36 fish/500m²) and Nabq (27 fish/500m²) were significantly higher in density than Dahab (8 fish/500m²). However fish density in Nabq (50 fish/500m²) and Ras Mohamed (80 fish/500m²) were seen to have significant decrease by 3 and 5 times respectively in 2012, while in Dahab (10 fish/500m²) they had significantly increased by 70% (Figure 22).

Table 7. Results of the Generalized Linear Mixed Model test for the density of Scaridae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated

GLIMMIX Test for Scaridae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	10.91	0.0002
Depth	2	29	101.99	<.0001
Year	1	15	222.87	<.0001
Region*Year	3	15	150.9	<.0001
Depth*Year	2	19	16.29	<.0001
Region*Depth	5	29	74.64	<.0001
Region*Depth*Year	3	19	63.93	<.0001

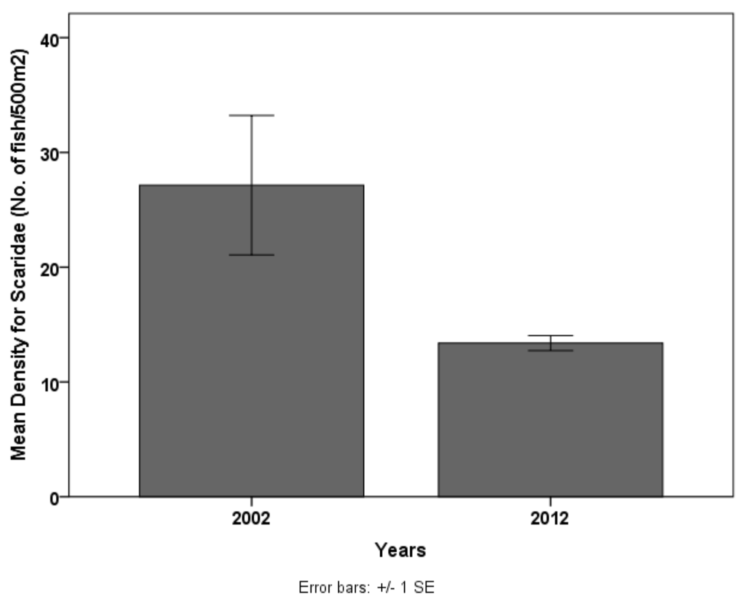

Figure 21. Comparison of mean density for Scaridae between 2002, and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

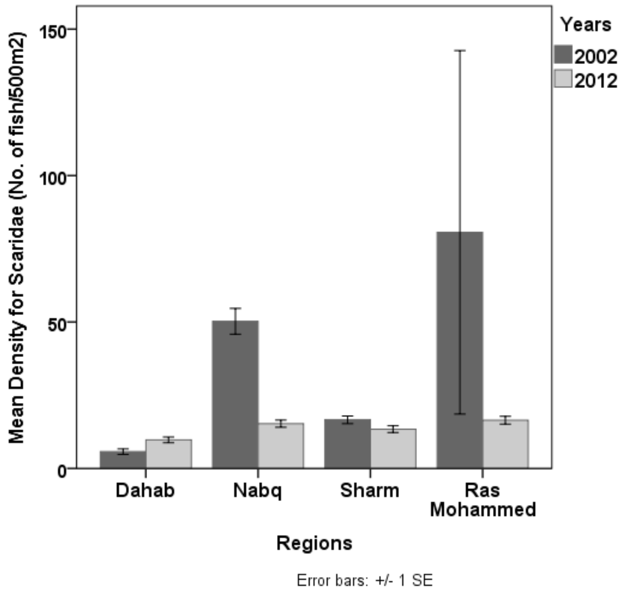

Figure 22. Comparison of the mean density for Scaridae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Mullidae

There was a highly significant difference in fish density for Mullidae between the years 2002, and 2012 (table 8), with 2012 is the highest 18.2 fish/500m² (Figure 23). Additionally density at reef edge (17.5 fish/500m²) was significantly higher than reef flat (5.3 fish/500m²) (Figure 24), and the interaction between the year and depth was also significantly different (Figure 25). Additionally pairwise comparison revealed that both reef edge (26.4fish/500m²) and reef slope (20 fish/500m²) significantly increased in 2012. There was no significant difference in density between regions but the interaction with year indicated a significant difference with Dahab (29.2 fish/500m²) increased significantly by 2012 (Figure 26).

Table 8. Results of the Generalized Linear Mixed Model test for the density of Mullidae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated.

GLIMMIX Test for Mullidae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	1.86	0.1673
Depth	2	29	92.35	<.0001
Year	1	15	61.69	<.0001
Region*Year	3	15	127.37	<.0001
Depth*Year	2	19	132.78	<.0001
Region*Depth	5	29	68.94	<.0001
Region*Depth*Year	3	19	2.4	0.0994

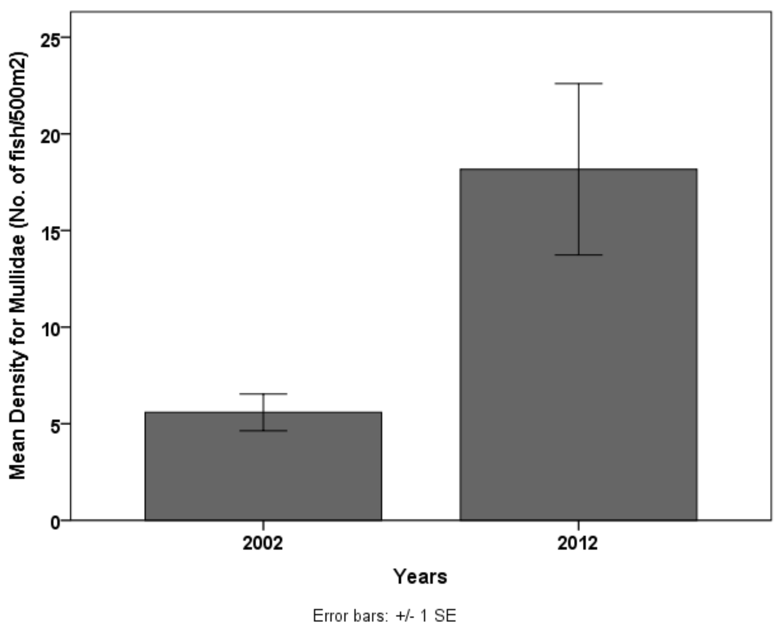

Figure 23. Comparison of mean density for Mullidae between 2002, and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

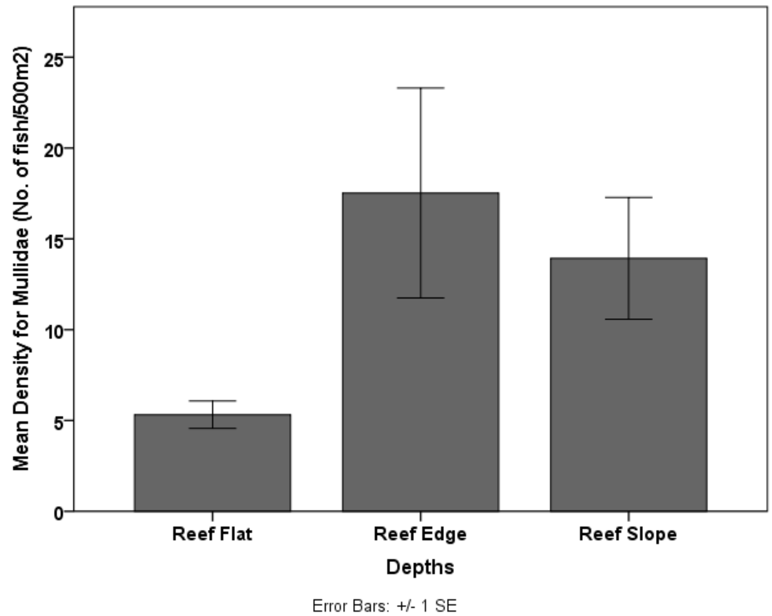

Figure 24. Comparison of mean density for Mullidae between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

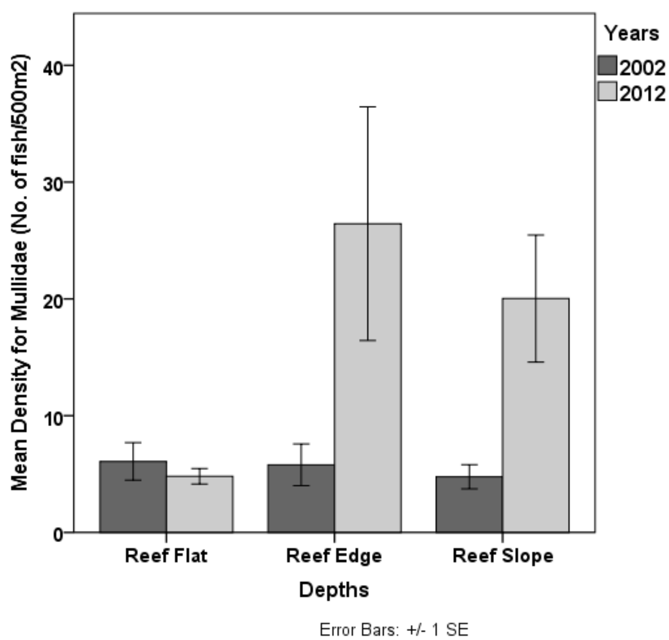

Figure 25. Comparison of mean density for Mullidae between depths (reef flat, reef edge and reef slope) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

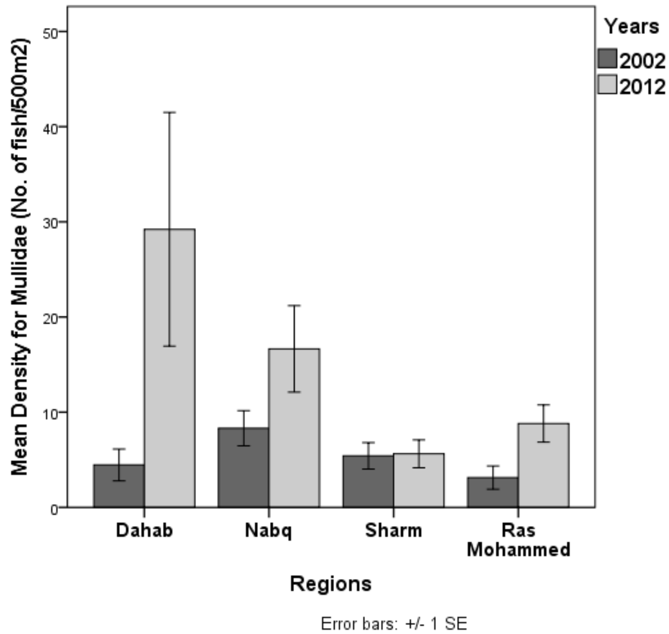

Figure 26. Comparison of the mean density for Mullidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Serranidae

There was a significant difference in the density of Serranidae between the `studied years 2002 and 2012 (Table 9), with 2002 higher in density (3.01 fish/500m²) than 2012 (2.55 fish/500m²) (Figure 27). Additionally there was a significant difference in fish density between depths with reef slope having the most abundant number of Serranidae (5.4 fish/500m²) and reef flat the least (0.9 fish/500m²) (Figure 28). There was a significant difference in density between regions (Table 9) and pairwise comparison showed that Sharm (5.67 fish/500m²) and Ras Mohamed (5.38 fish/500m²) were significantly higher than Nabq (1.23 fish/500m²) and Dahab (2.04 fish/500m²) (Figure 29). Additionally regions showed a significant difference in density with the year effect and pairwise comparison revealed that Ras Mohamed and Nabq had significantly decreased in density by 2012 with the later exhibiting 3 times decrease in density (0.75 fish/500m²) (Figure 30).

Table 9. Results of the Generalized Linear Mixed Model test for the density of Serranidae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated.

GLIMMIX Test for Serranidae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	9.4	0.0004
Depth	2	29	79.17	<.0001
Year	1	15	15.02	0.0015
Region*Year	3	15	14.87	<.0001
Depth*Year	2	19	0.19	0.826
Region*Depth	5	29	6.94	0.0002
Region*Depth*Year	3	19	2.89	0.0626

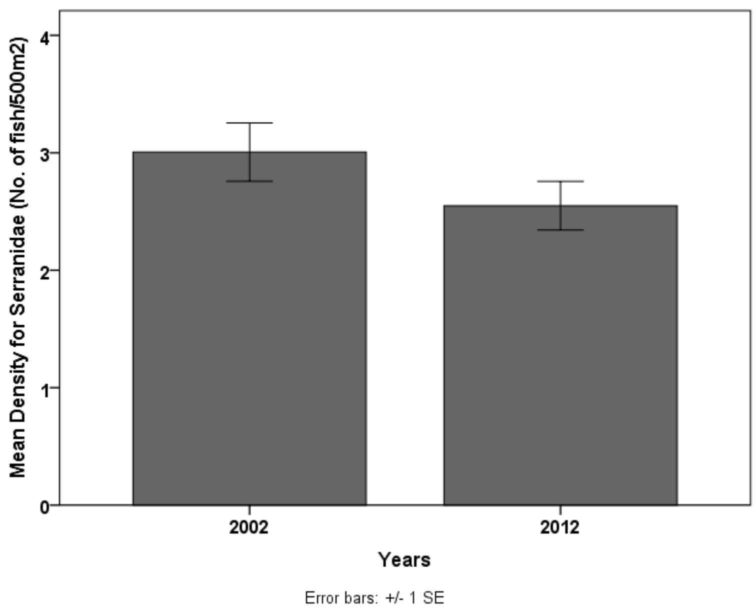

Figure 27. Comparison of mean density for Serranidae between 2002, and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

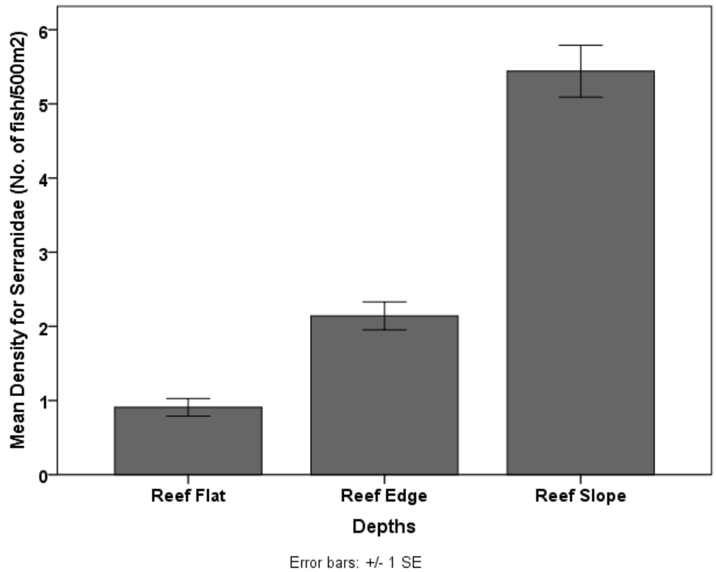

Figure 28. Comparison of mean density for Serranidae between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

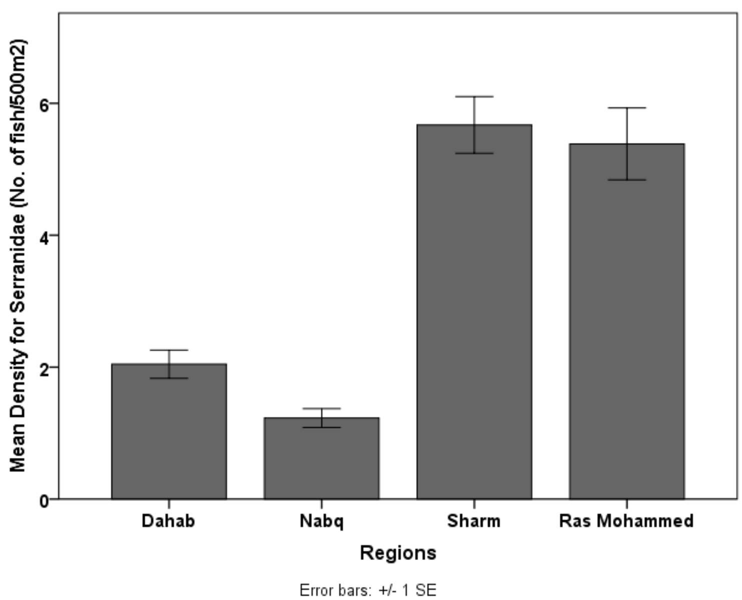

Figure 29. Comparison of the mean density for Serranidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

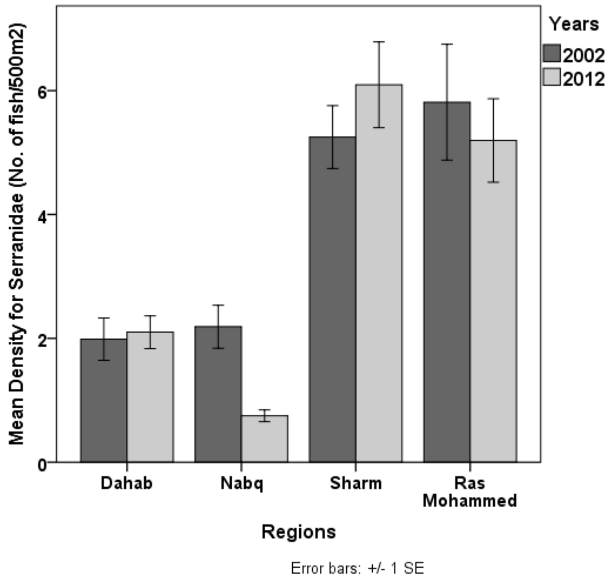

Figure 30. Comparison of the mean density for Serranidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Lutjanidae

Density of Lutjanidae was significantly different between the studied years with 2002 (1.75 fish/500m²) being higher than 2012 (1.34 fish/500m²) (Figure 31). Additionally there was a significant difference in fish density between depths (Table 10) with reef edge having the most abundance of Lutjanidae (1.9 fish/500m²) and reef slope the least (0.6 fish/500m²) (Figure 32). There was a significant difference in density between regions with Ras Mohamed the most abundant (4.4 fish/500m²) and Dahab the least (0.15 fish/500m²) for this family (Figure 33). Although the interaction between regions and year was insignificant for fish density, pairwise comparison indicated a significant (adj. P=0.05) decrease in density for Nabq in 2012 (Figure 33).

Table 10. Results of the Generalized Linear Mixed Model test for the density of Lutjanidae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated.

GLIMMIX Test for Lutjanidae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	4.34	0.0158
Depth	2	34	14.73	<.0001
Year	1	15	12.27	0.0032
Region*Year	3	15	0.28	0.8409
Depth*Year	2	22	9.12	0.0013

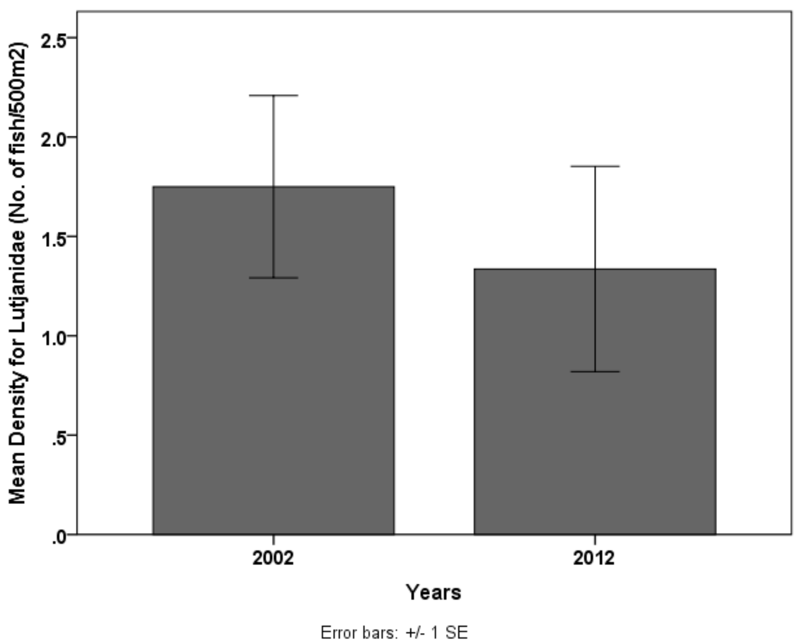

Figure 31. Comparison of mean density for Lutjanidae between 2002, and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

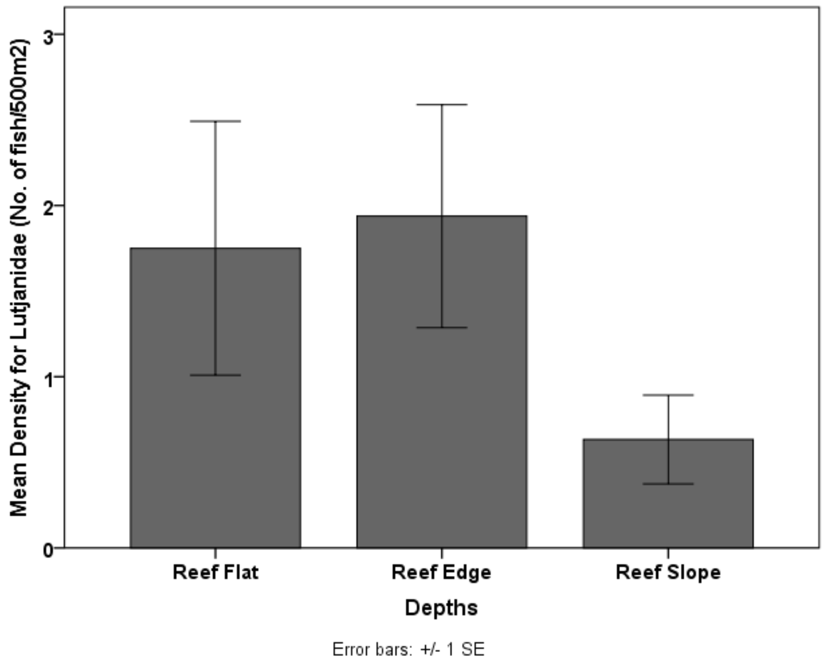

Figure 32. Comparison of mean density for Lutjanidae between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

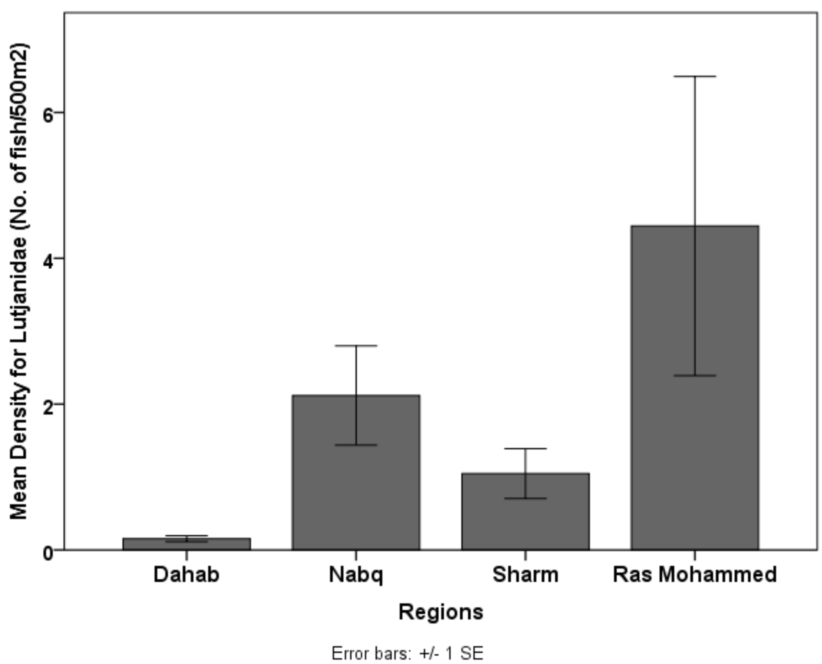

Figure 33. Comparison of the mean density for Lutjanidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

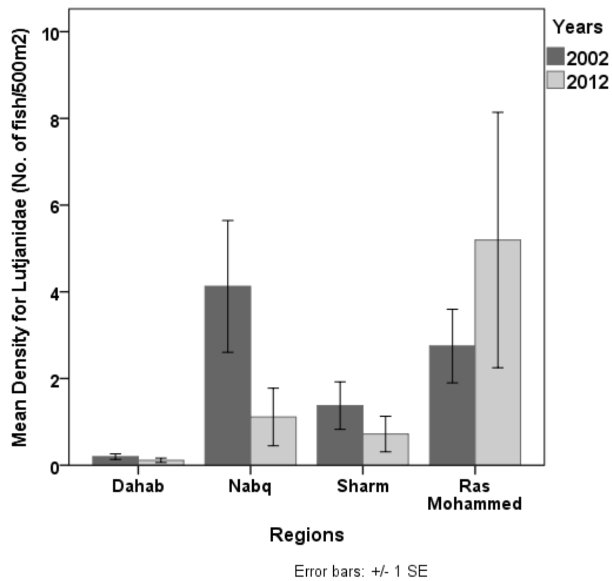

Figure 34. Comparison of the mean density for Lutjanidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Lethrinidae

There was a significant difference in the densities of Lethrinidae between 2002 and 2012 (Table 11), with 2002 exhibiting a higher density (2.1 fish/500m²) than 2012 (1.2 fish/500m²) (Figure 35). Additionally there was a significant difference in density between depths with reef edge being the most abundant (2.5 fish/500m²) and reef flat the least (0.2 fish/500m²) (Figure 36). Although there was no significant difference in density between regions, the interaction with the year effect was significantly different, and pairwise comparison between years showed that Nabq significantly decreased in density of Lethrinidae by 50% in 2012 (Figure 37).

Table 11. Results of the Generalized Linear Mixed Model test for the density of Lethrinidae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicat

GLIMMIX Test for Lethrinidae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	1.45	0.2579
Depth	2	34	70.7	<.0001
Year	1	15	18.21	0.0007
Region*Year	3	15	13.79	0.0001
Depth*Year	2	22	7.7	0.0029

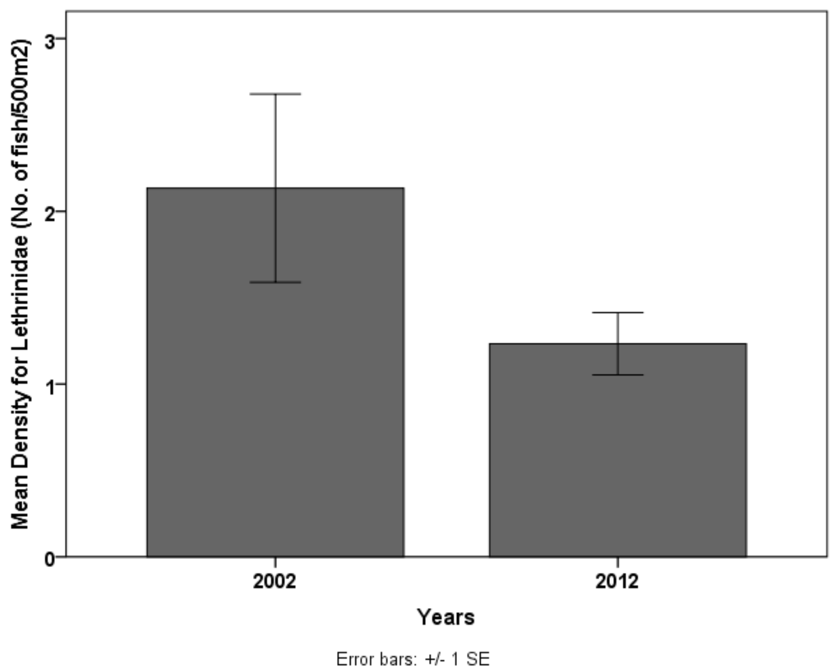

Figure 35. Comparison of mean density for Lethrinidae between 2002, and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

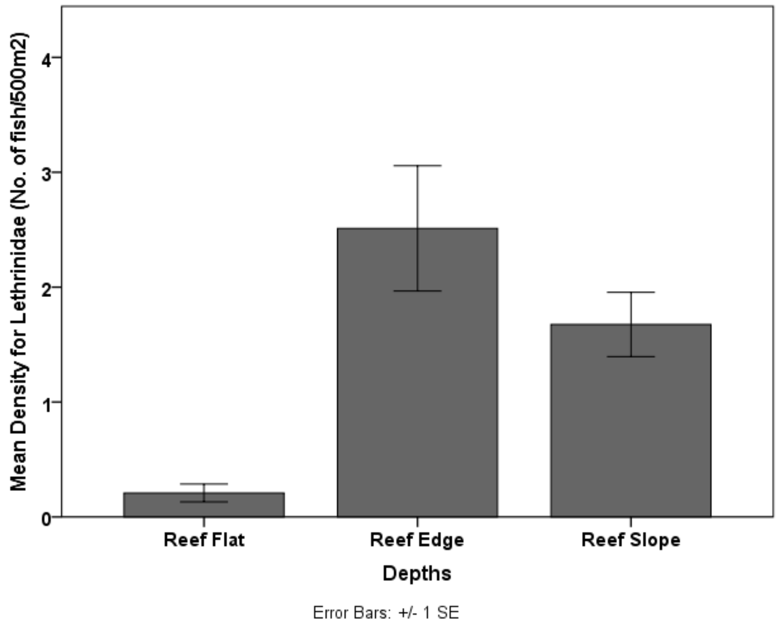

Figure 36. Comparison of mean density for Lethrinidae between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

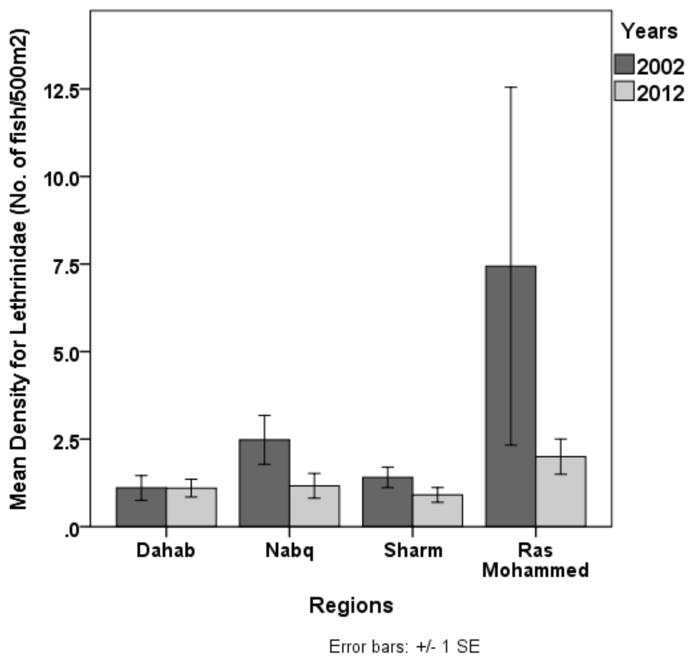

Figure 37. Comparison of the mean density for Lethrinidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Chaetodontidae

There was a significant difference in Chaetodontidae density between the studied years where we observed a higher number of fish in 2012 than 2002 (Table 12, Figure 38). Additionally depth was significantly different in density and pairwise comparison showed that reef edge was significantly higher in density for these fishes than the reef flat and reef slope (Figure 39). There was a significant difference in density between regions where Sharm had the greatest abundant of these fishes (17.7 fish/500m^2) and Dahab the least (13.4 fish/500m^2) (Figure 40).

Additionally the interaction between region and year was significantly different and pairwise comparison between years showed a significant density increase in Dahab, Sharm and Ras Mohamed in 2012 while there was a significant (adj. $P<0.0001$) density decrease in Nabq the same year (Figure 41).

Table 12. Results of the Generalized Linear Mixed Model test for the density of Chaetodontidae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Chaetodontidae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	3.07	0.05
Depth	2	29	30.8	<.0001
Year	1	15	5.27	0.0366
Region*Year	3	15	8.35	0.0017
Depth*Year	2	19	2.92	0.0784
Region*Depth	5	29	2.64	0.0435
Region*Depth*Year	3	19	1.63	0.2161

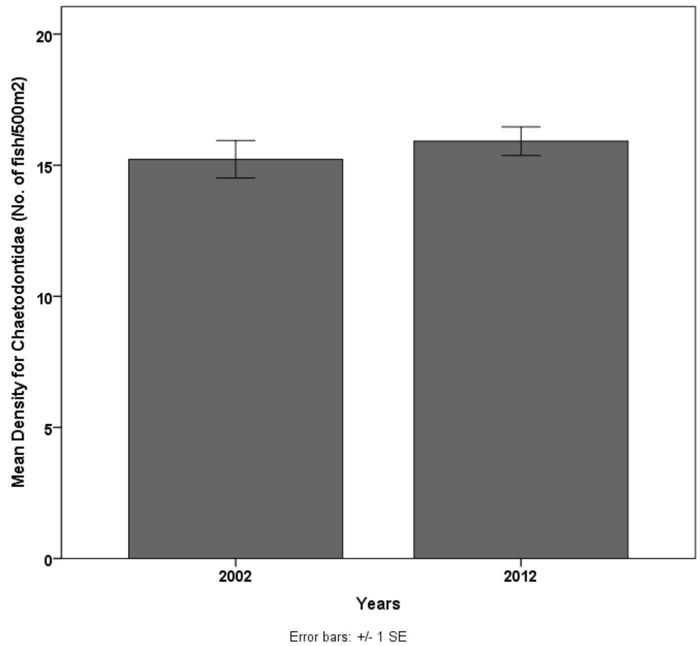

Figure 38. Comparison of mean density for Chaetodontidae between 2002, and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

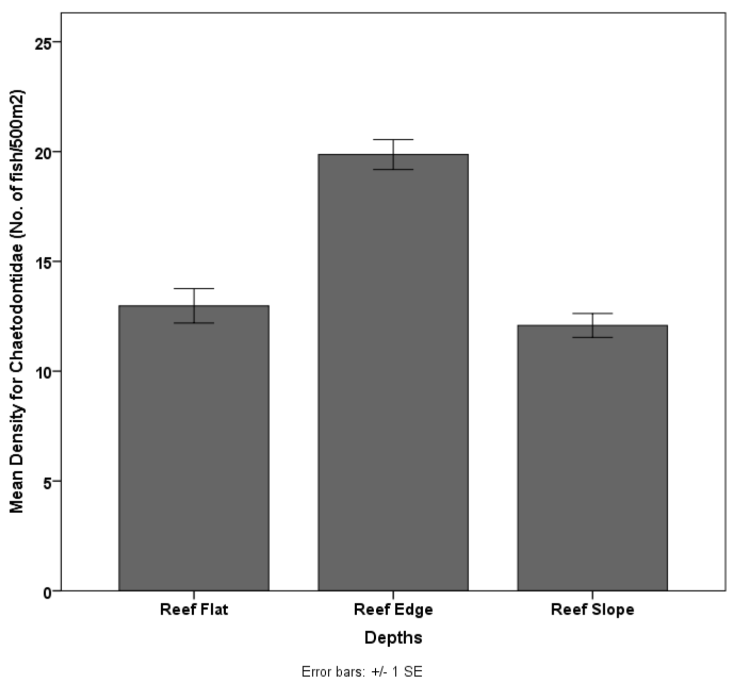

Figure 39. Comparison of mean density for Chaetodontidae between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

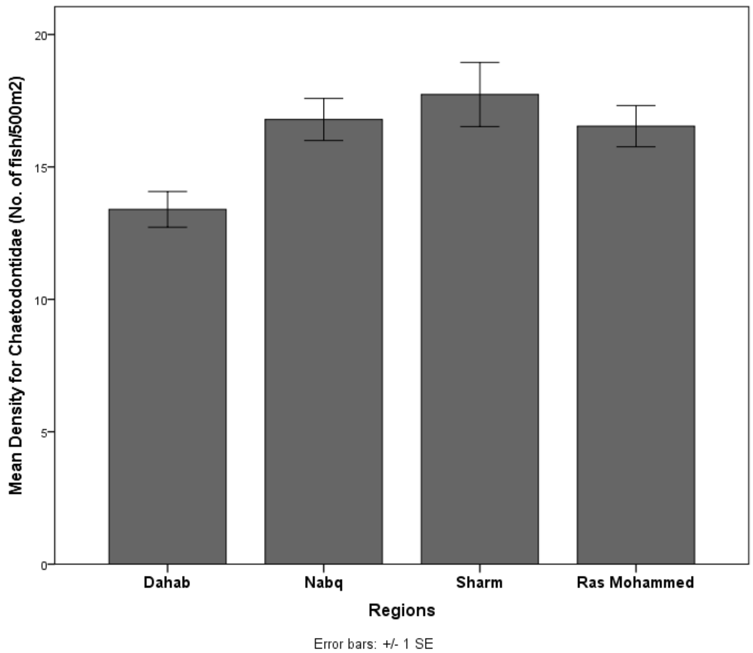

Figure 40. Comparison of the mean density for Chaetodontidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

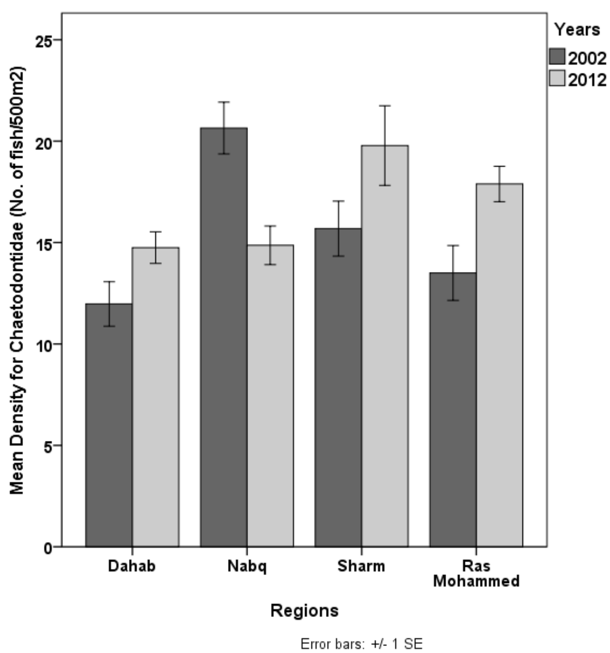

Figure 41. Comparison of the mean density for Chaetodontidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Pomacanthidae

Pomacanthidae had the least abundance measured for any family in this study. Only 351 fish were counted over the summers of the studied years 2002 and 2012 in the four regions. Using GLIMMIX test showed significant difference in density with the depth effect (Table 13), where reef edge had the most abundance (0.94 fish/500m^2) while the reef flat had the least for this family (0.63 fish/500m^2) (Figure 42). Although region and year didn't show a significant difference in density their interaction did. Additionally pairwise comparison between years showed that Nabq had a significant decrease in abundance of this family by 2012. furthermore Dahab was seen to significantly (adj. P<0.0001) increase by 2012 (Figure 43).

Table 13. Results of the Generalized Linear Mixed Model test for the density of Pomacanthidae in the four regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), over the studied years 2002 and 2012, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Pomacanthidae				
Effect	Num DF	Den DF	F Value	Pr > F
Region	3	21	0.09	0.9646
Depth	2	29	4.24	0.0243
Year	1	15	0.7	0.4152
Region*Year	3	15	4.42	0.0204
Depth*Year	2	19	2.08	0.1523
Region*Depth	5	29	1.25	0.3099
Region*Depth*Year	3	19	0.56	0.6468

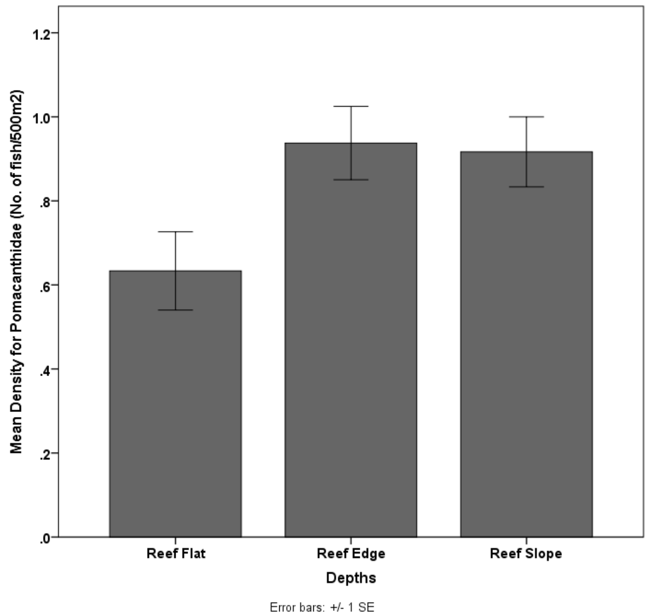

Figure 42. Comparison of mean density for Pomacanthidae between depths (reef flat, reef edge and reef slope) in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

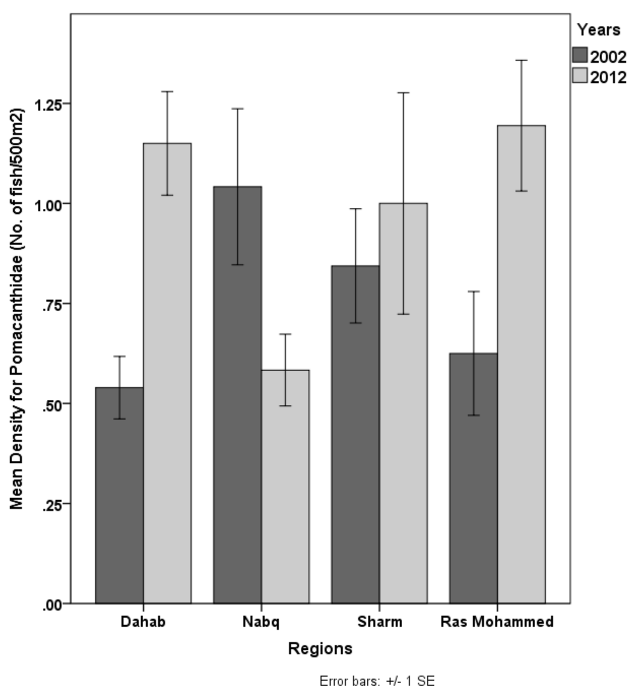

Figure 43. Comparison of the mean density for Pomacanthidae between regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab) over the studied years 2002 and 2012 in the Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Species Abundance

Testing the changes in species abundance using GLIMMIX was inapplicable to many of the 57 species, due to the fact that many of the target commercial species were very low in abundance causing the model not to converge. We therefore used the nonparametric Kruskal Wallis ANOVA to test the three main effects of year, region, and depth. We found that 22 species were significantly different in abundance between years (Table14), 49 species were significantly different between regions (Dahab, Nabq, Sharm, and Ras Mohamed) (Table 15) and 36 species were significantly different between depths (reef flat, reef edge, and reef slope) (Table 16). Comparing species densities between the years revealed that 15 species significantly decreased in density by 2012 (Table 14), with thirteen of these fishes being of the targets commercial fishery. These thirteen species were as follow: Three large bodied (TL>30cm) herbivore from Acanthuridae and Scaridae (*Naso unicornis, Cetoscarus bicolor, and Scarus frenatus*); five commercial carnivores species from Serranidae, Lutjanidae and Lethrinidae (*Cephalopholis miniata, Ploctropomus pessuliferus, Macolor niger, Lethrinus mohsena*, *and Lethrinus nebulosus*); and five lesser important commercial species from herbivores Acanthuridae, and Siganidae (*Acanthurus nigrofuscus, Siganus rivulatus,* and *Siganus argentus*), Invertivores Mullidae (*Parupeneus macronema*) and Carnivore Lutjanidae (*Lutjanus ehrenbergii*), (Figure 44), *Acanthurus nigrofuscus* was not included in figure (44) due to its high density (67 fish/500m^2 in 2002 and 49 fish/500m^2 in 2012). Additionally 7 species showed significant increases in density by 2012 and they were all small bodied species (TL<30cm), of them 5 had low commercial value from families Siganidae, Mullidae and Lethrinidae (*Siganus luridus, Parupeneus forsskali, Mulloides flavolineatus, Mulloides vanicolensis, and Lethrinus obsoletus*)

(Figure 45). The remaining two species were not targeted commercially and were from Chaetodontidae (*Chaetodon fasciatus* and *Chaetodon melannotus*).

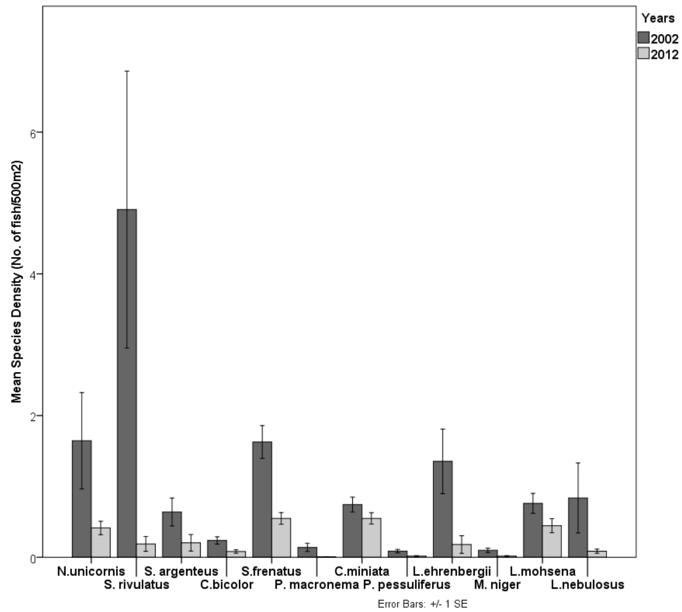

Figure 44. Mean abundance of herbivores and carnivores species during summers 2002, and 2012, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

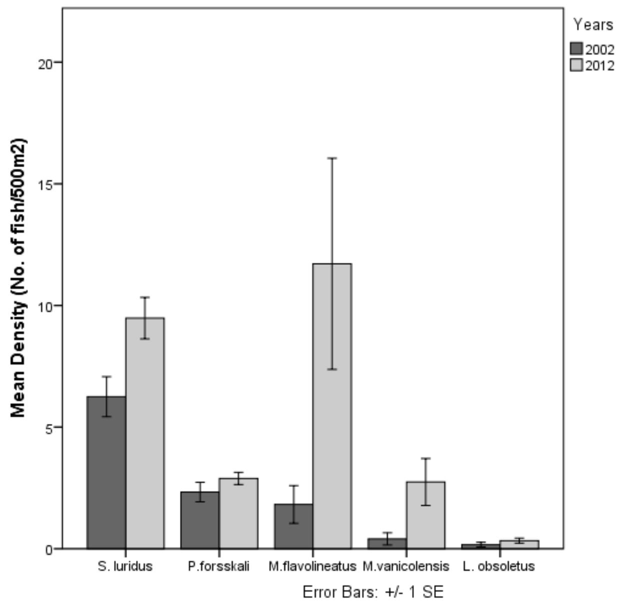

Figure 45. Mean abundance of small body herbivores and carnivores species during summers 2002, and 2012, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Comparing species density between regions (Dahab, Nabq, Sharm, and Ras Mohamed) showed that *Acanthurus nigrofuscus*, a relatively small bodied (10 cm) herbivore fish (which represented 37% of the total fish counted through the study) was significantly different in density between regions, with Nabq (fished) having the highest density (116.7 fish/500m2) and Ras Mohamed (unfished) is the least (10 fish/500m2) (Table 15). Additionally the large bodied herbivore species (*Naso liturstus, Naso unicornis, Scarus ferrugineus, Scarus niger*, and *Hipposcarus harid*) were significantly different in density with Ras Mohamed (unfished) having highest denstiy and Dahab (fished) the least (Table 15). The large bodied carnivorous species (*Cephalopholis argus, Cephalopholis miniata, Variola louti, Ploctropomus pessuliferus, Aethaloperca rogaa, Lutjanus bohar, Macolor niger, Monotaxis grandoculis*) were significantly higher in density in the unfished regions at Ras Mohamed and Sharm than in the fished regions Nabq and Dahab (Table 15).

Comparing species densities between the reef flat and reef edge revealed that depth plays an important role in fish (36 species) distribution over the reef. We found the herbivore species *Acanthurus nigrofuscus* (Acanthuridae) was the most abundant species on the reef flat (132.6 fish/500m^{2}representing 60% of the fish counted at the reef flat) (Table 16). Other herbivores species of families Acanthuridae (*Acanthurus sohal*, *Ctenochaetus striatus*, *Zebrasoma desjardinii*, *Naso liturstus*, and *Naso unicornis*) and Scaridae (*Cetoscarus bicolor*, *Scarus gibbus*, *Scarus frenatus*, *Scarus ferrugineus*, and *Scarus niger*) were significantly more abundant at the reef edge (Figure 46 and 47). For the carnivores we found 13 species from families Serranidae, Lutjanidae and Lethrinidae were significantly different in density between depths, with species *Cephalopholis miniata, Cephalopholis hemistiktos, Variola louti, and Ploctropomus* *pessuliferus* from family Serranidae being most abundant at the reef slope (Figure 48). In contrast, *Lutjanus bohar*, *Lethrinus mohsena*, *Lethrinus nebulosus*, *Lethrinus obsoletus and Monotaxis grandoculis* from families Lutjanidae and Lethrinidae were most abundant at the reef edge (Figure 49), and only *Epinephelus fasciatus* (Serranidae), and *Lutjanus monostigma* (Lutjanidae) were significantly more abundant on the reef flat. The corallivore and invertivore species *Chaetodon paucifasiatus, Chaetodon austriacus, Chaetodon trifascialis, Chaetodon semilarvatus* (Chaetodontidae) and *Pomacanthus imperator* (Pomacanthidae) were significantly more abundant at the reef edge (Figure 50).

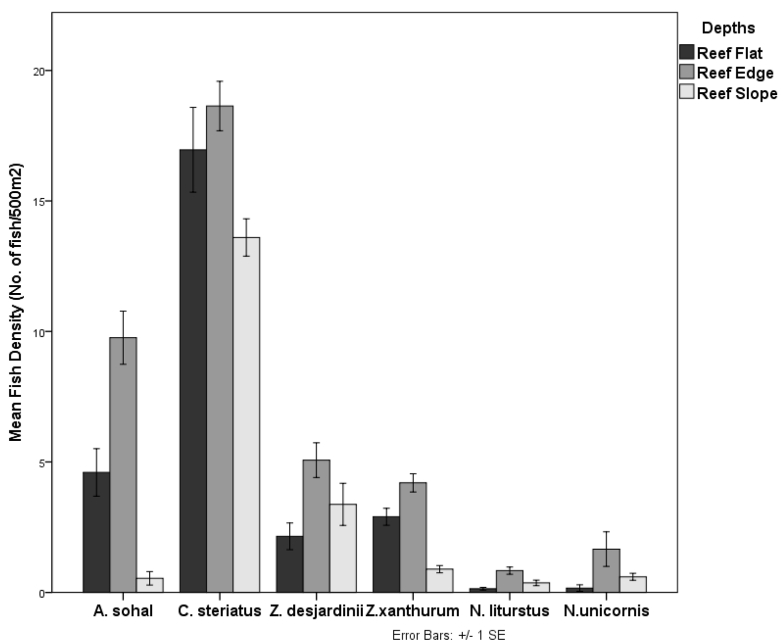

Figure 46. Mean abundance of large body herbivores species from families Acanthuridae at different depths for the studied regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

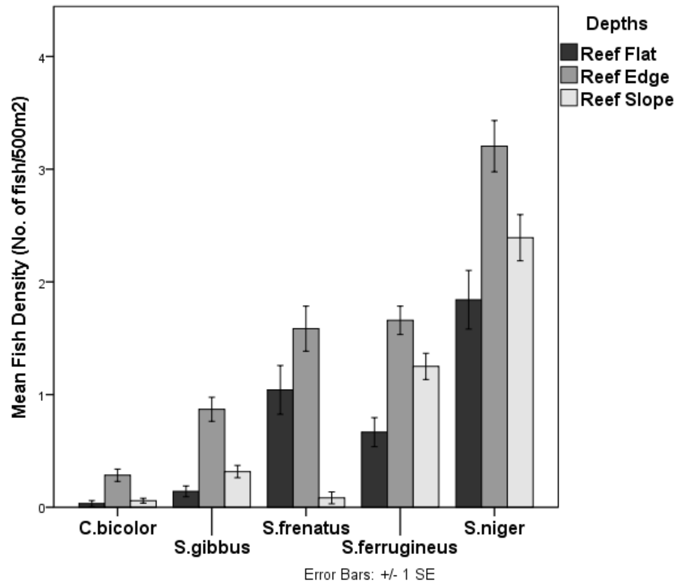

Figure 47. Mean abundance of large body herbivores species from families Scaridae at different depths for the studied regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

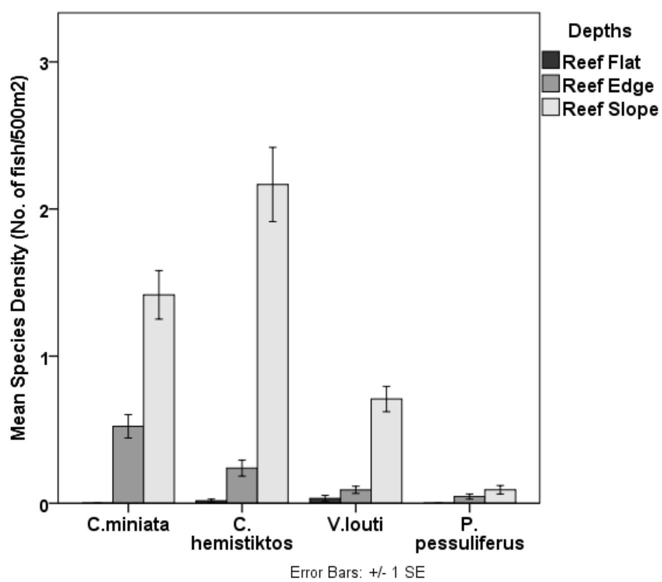

Figure 48. Mean abundance of carnivores species from families Serranidae at different depths for the studied regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

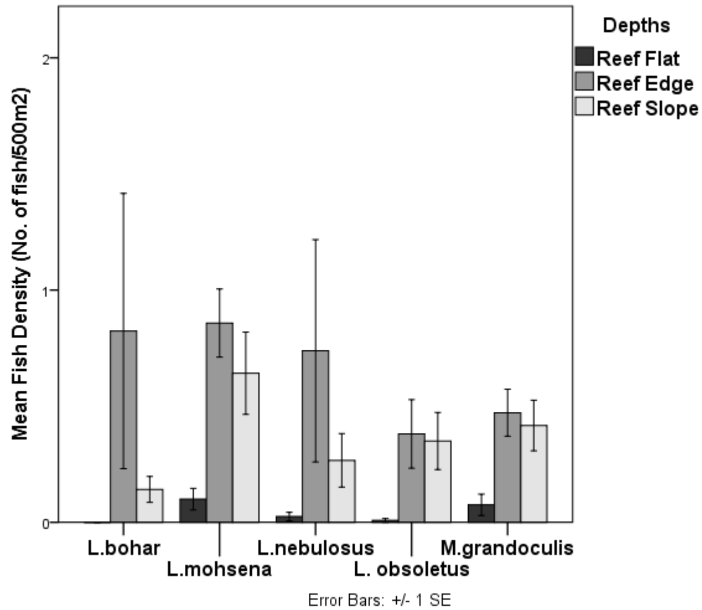

Figure 49. Mean abundance of carnivores species from families Lutjanidae and Lethrinidae at different depths for the studied regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

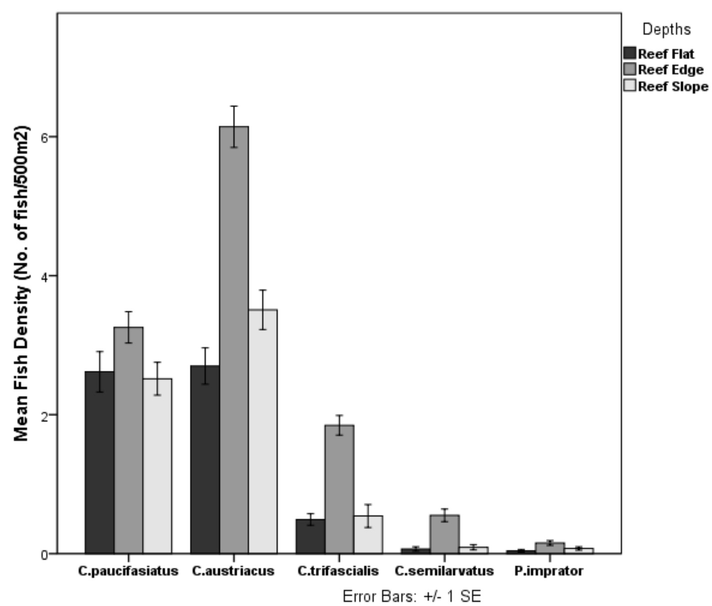

Figure 50. Mean abundance of corallivores and invertivores species from families Chaetodontidae and Pomacanthidae at different depths for the studied regions (Ras Mohamed, Sharm El Sheikh, Nabq and Dahab), Gulf of Aqaba, Egypt. Error bars represent +/-1 standard

Table 14. Mean species abundance per 500m² and results of Kruskal Wallis ANOVA tests for fish density between 2002 and 2012. Only species with significant difference between years are shown. Significant level is $p < 0.05$. Commercial species indicated by asterisk.

Trophic Level	Families	Species	Year 2002 Mean (fish/500m²)	Year 2012 Mean (fish/500m²)	Kruskal Wallis Asymp. Sig.
Herbivores	*Acanthuridae*	*Acanthurus nigrofuscus**	**67.15**	48.86	0.01
		Zebrasoma xanthurum	**3.20**	2.64	0.03
		*Naso unicornis**	**1.65**	0.41	0.00
	Siganidae	*Siganus luridus**	6.25	**9.48**	0.00
		*Siganus rivulatus**	**4.91**	0.19	0.01
		*Siganus argenteus**	**0.64**	0.20	0.00
	Scaridae	*Cetoscarus bicolor**	**0.24**	0.08	0.00
		*Scarus frenatus**	**1.63**	0.55	0.00
Invertivores	*Mullidae*	*Parupeneus forsskali**	2.33	**2.89**	0.00
		*Parupeneus macronema**	**0.14**	0.00	0.00
		*Mulloides flavolineatus**	1.82	**11.71**	0.00
		*Mulloides vanicolensis**	0.41	**2.75**	0.00
Carnivores	*Serranidae*	*Cephalopholis miniata**	**0.74**	0.55	0.03
		*Ploctropomus pessuliferus**	**0.09**	0.02	0.00
	Lutjanidae	*Lutjanus ehrenbergii**	**1.35**	0.18	0.00
		*Macolor niger**	**0.10**	0.02	0.01
	Lethrinidae	*Lethrinus mohsena**	**0.76**	0.45	0.00
		*Lethrinus nebulosus**	**0.84**	0.09	0.04
		*Lethrinus obsoletus**	0.17	**0.33**	0.02
Corallivores & Invertivores	*Chaetodontidae*	*Chaetodon fasciatus*	2.15	**3.36**	0.00
		Chaetodon melannotus	0.47	**0.80**	0.01
		Chaetodon lineolatus	**0.35**	0.14	0.05

Table 15. Mean species abundance per 500m² and results of Kruskal Wallis ANOVA tests for fish density between regions (Dahab, Nabq, Sharm, and Ras Mohamed). Only species with significant difference between regions are shown. Significant level is $p < 0.05$, commercial species indicated by asterisks and highest mean density indicated in bold.

Trophic Level	Families	Species	Regions				Kruskal Wallis
			Dahab	Nabq	Sharm	Ras Mohammed	
			Mean (fish/500m²)	Mean (fish/500m²)	Mean (fish/500m²)	Mean (fish/500m²)	Asymp. Sig.
Herbivores	*Acanthuridae*	*Acanthurus nigrofuscus**	33.39	**116.69**	14.66	10.04	.000
		*Acanthurus sohal**	.28	**10.54**	8.30	4.65	.000
		*Ctenochaetus steriatus**	7.40	**22.90**	22.73	19.98	.000
		Zebrasoma desjardinii	1.72	3.74	4.63	**8.67**	.000
		*Zebrasoma xanthurum**	**3.54**	2.56	1.67	3.19	.015
		*Naso liturstus**	.16	.43	.80	**1.35**	.000
		*Naso unicornis**	.34	1.05	.05	**3.40**	.000
		*Naso hexanthus**	.04	0.00	0.00	**.06**	.009
	Siganidae	*Siganus luridus**	3.95	**16.03**	3.09	5.10	.000
		*Siganus rivulatus**	0.00	**6.12**	.06	.10	.000
		*Siganus stellatus**	.03	.25	.09	**.27**	.000
		*Siganus argenteus**	0.00	.33	.81	**1.15**	.000
	Scaridae	*Cetoscarus bicolor**	.04	**.26**	.16	.13	.019
		*Scarus gibbus**	.15	.71	**.72**	.69	.000
		*Scarus sordidus**	3.90	**14.78**	6.48	7.17	.000
		*Scarus frenatus**	.31	**1.97**	.91	.46	.000
		*Scarus ferrugineus**	.72	1.26	1.66	**2.35**	.000
		*Scarus niger**	1.29	3.47	2.86	**3.62**	.000
		*Scarus psittacus**	.08	**.45**	0.00	.12	.001
		*Hipposcarus harid**	.83	3.35	1.72	**21.06**	.000

Table 15 (Cont'd)

Invertivores	*Mullidae*	*Parupeneus macronema**	.06	0.00	.02	**.27**	.001
		*Parupeneus cyclostomus**	.59	**1.27**	.48	.87	.005
		*Mulloides flavolineatus**	**14.08**	6.04	0.00	2.02	.010
		*Mulloides vanicolensis**	.10	**3.51**	2.73	.85	.016
Carnivores	*Serranidae*	*Cephalopholis argus**	.08	.31	1.00	**1.38**	.000
		*Cephalopholis miniata**	.28	.15	1.58	**1.85**	.000
		*Cephalopholis hemistiktos**	.69	0.00	**2.25**	1.02	.000
		*Epinephelus fasciatus**	**.62**	.56	.17	.48	.006
		*Variola louti**	.31	.06	**.45**	.37	.000
		*Ploctropomus pessuliferus**	.01	.04	.08	**.12**	.023
		*Aethaloperca rogaa**	.01	0.00	**.08**	**.08**	.002
	Lutjanidae	*Lutjanus ehrenbergii**	.05	**1.26**	.55	1.02	.004
		*Lutjanus monostigma**	.04	**.75**	.38	.56	.001
		*Lutjanus bohar**	.03	.11	.02	**2.71**	.007
		*Macolor niger**	.04	0.00	.11	**.15**	.000
	Lethrinidae	*Lethrinus obsoletus**	.35	.19	.11	**.40**	.037
		*Monotaxis grandoculis**	.13	.26	.44	**1.06**	.000
		*Lethrinus barbonicus**	0.00	.05	**.06**	0.00	.010
Corallivores & Invertivores	*Chaetodontidae*	*Chaetodon fasciatus*	2.12	**4.23**	2.83	1.31	.000
		Chaetodon paucifasiatus	**3.83**	2.38	2.09	2.21	.000
		Chaetodon austriacus	4.05	4.29	**5.30**	4.56	.042
		Chaetodon auriga	1.22	**2.47**	1.78	1.81	.000
		Chaetodon trifascialis	.90	.97	.94	**2.10**	.013
		Chaetodon melannotus	.15	1.01	.61	**1.31**	.000

Table 15 (Cont'd)

Corallivores & Invertivores		*Chaetodon lineolatus*	.08	.13	.41	**.73**	.000
		Chaetodon semilarvatus	.06	.13	**.80**	.73	.000
		Chaetodon larvatus	0.00	0.00	**.06**	**.06**	.004
		Heniochus intermedius	.98	1.19	**2.92**	1.73	.000
	Pomacanthidae	*Pygoplites diacanthus*	.74	.59	**.88**	**.88**	.022

Table 16. Mean species abundance per 500m² and results of Kruskal Wallis ANOVA tests for fish density between reef flat, reef edge and reef slope. Only species with significant difference between years are shown. Significant level is $p < 0.05$, commercial species.

Trophic Level	Families	Species	Depth			Kruskal Wallis
			Reef Flat	Reef Edge	Reef Slope	
			mean	mean	mean	Asymp. Sig.
Herbivores	*Acanthuridae*	*Acanthurus nigrofuscus**	**132.60**	36.62	9.29	.000
		*Acanthurus sohal**	4.60	**9.76**	.54	.000
		*Ctenochaetus striatus**	16.96	**18.64**	13.60	.014
		Zebrasoma desjardinii	2.15	**5.07**	3.38	.000
		*Zebrasoma xanthurum**	2.90	**4.20**	.89	.001
		*Naso liturstus**	.14	**.84**	.37	.000
		*Naso unicornis**	.17	**1.66**	.60	.000
	Siganidae	*Siganus rivulatus**	**6.81**	.39	.04	.008
	Scaridae	*Cetoscarus bicolor**	.03	**.28**	.06	.000
		*Scarus gibbus**	.14	**.87**	.32	.000
		*Scarus frenatus**	1.04	**1.59**	.08	.001
		*Scarus ferrugineus**	.67	**1.66**	1.25	.000
		*Scarus niger**	1.84	**3.20**	2.39	.000
		*Scarus psittacus**	**.51**	.12	.02	.000
Invertivores	*Mullidae*	*Parupeneus forsskali**	**3.83**	1.23	3.58	.000
		*Parupeneus cyclostomus**	.63	**.88**	1.01	.015
		*Mulloides vanicolensis**	.03	**2.73**	2.14	.001
Carnivores	*Serranidae*	*Cephalopholis argus**	.08	**.76**	.41	.000

Table 16 (Cont'd)

Carnivores	*Serranidae*	*Cephalopholis miniata**	0.00	.52	**1.42**	.000
		*Cephalopholis hemistiktos**	.02	.24	**2.17**	.001
		*Epinephelus fasciatus**	**.71**	.35	.54	.001
		*Epinephelus tauvina**	.07	**.12**	.04	.033
		*Variola louti**	.03	.09	**.71**	.050
		*Ploctropomus pessuliferus**	0.00	.05	**.09**	.027
	Lutjanidae	*Lutjanus monostigma**	**.76**	.37	.09	.014
		*Lutjanus bohar**	0.00	**.82**	.14	.005
	Lethrinidae	*Lethrinus mohsena**	.10	**.86**	.64	.000
		*Lethrinus nebulosus**	.03	**.74**	.27	.003
		*Lethrinus obsoletus**	.01	**.38**	.35	.001
		*Monotaxis grandoculis**	.08	**.47**	.42	.000
Corallivores & Invertivores	*Chaetodontidae*	*Chaetodon paucifasiatus*	2.62	**3.26**	2.52	.014
		Chaetodon austriacus	2.70	**6.14**	3.51	.000
		Chaetodon trifascialis	.49	**1.85**	.54	.000
		Chaetodon semilarvatus	.07	**.55**	.09	.000
		Heniochus intermedius	.28	1.90	**1.95**	.000
	Pomacanthidae	*Pomacanthus imperator*	.04	**.15**	.08	.010

<u>The Change in Fish Size</u>

Fish size data were analyzed using the nonparametric Kruskal Wallis ANOVA to test the effect of year and fishing on the fish species length. Dahab and Nabq were grouped as fished regions while Sharm and Ras Mohamed were unfished in order for us to evaluate the differences due to fishing. Analysis of the effect of fishing revealed that 14 fish species were significantly larger in size in the unfished areas while 12 species were significantly larger in the fished regions (table 17). Analysis of the year effect showed that 24 species were significantly larger in size in 2002 than 2012; of these 13 species were significantly smaller in 2012 from commercially targeted families Serranidae (6), Lutjanidae (3)and Lethrinidae (4) (Figure 51 and table 18).

Table 17. Comparison of fish species lengths between fished and unfished regions. Results show species with statistically significant differences in size (Kruskal-Wallis test). Significant level is $p < 0.05$, highest mean lengths are indicated in bold.

	Status			
	Fished	Unfished		
	Mean	Mean	Chi-Square	Asymp. Sig.
A. sohal	33.32	**39.26**	951.247	.000
C. striatus	15.00	**15.49**	125.817	.000
Z. desjardinii	**23.34**	21.18	92.263	.000
N. unicornis	56.60	**59.50**	13.155	.000
N_hexacanthus	30.83	**60.00**	9.588	.002
S_luridus	**18.89**	18.25	33.868	.000
S_argentus	12.50	**25.00**	8.167	.004
S_sordidus	16.78	**17.35**	4.649	.031
S_ferrugineus	**29.49**	26.04	14.888	.000
S_frenatus	**25.40**	22.06	8.583	.003
S_niger	**23.62**	22.48	10.734	.001
S_ghobban	31.14	**35.00**	17.560	.000
S_fuscopurpureus	**27.12**	22.90	11.915	.001
H_harid	**32.45**	29.50	65.506	.000
P_forsskali	**14.10**	13.52	4.686	.030
P_macronema	**20.74**	13.00	15.677	.000
M_vanicolensis	15.92	**16.64**	5.858	.016
M_flavolineatus	15.00	**20.13**	237.682	.000
C_miniata	24.13	**26.97**	9.239	.002
E_fasciatus	17.28	**19.84**	4.096	.043
V_louti	30.27	**43.47**	14.908	.000
L_ehrenbergi	**24.38**	20.91	5.158	.023
L_monostigma	16.58	**22.36**	31.313	.000
L_mahsena	28.45	**44.06**	36.910	.000
M_grandoculis	**38.26**	32.19	7.647	.006
L_obsoletus	**19.17**	15.54	12.238	.000

Table 18. Comparison of fish species lengths between 2002 and 2002. Results show species with statistically significant differences in size (Kruskal-Wallis test). Significant level is $p < 0.05$, highest mean lengths are indicated in bold.

Species	Year		Chi-Square (d.f.=1)	Asymp. Sig.
	2002	2012		
	Mean (cm)	Mean (cm)		
Acanthurus sohal	**37.30**	36.15	9.37	0.00
Ctenochaetus striatus	**15.90**	14.99	365.32	0.00
Zebrasoma desjardinii	19.49	**23.86**	477.81	0.00
Zebrasoma xanthurum	14.74	**15.09**	5.84	0.02
Naso liturstus	**45.15**	32.32	123.76	0.00
Naso hexacanthus	**60.00**	40.56	5.58	0.02
Siganus stellatus	**26.88**	22.33	7.46	0.01
Scarus sordidus	**17.90**	16.64	19.61	0.00
Scarus ferrugineus	24.41	**29.47**	33.83	0.00
Scarus ghobban	**40.00**	31.78	7.56	0.01
Hipposcarus harid	29.79	**31.16**	10.80	0.00
Parupeneus forsskali	11.68	**14.53**	119.60	0.00
Parupeneus cyclostomus	**19.88**	18.85	11.52	0.00
Mulloides vanicolensis	**19.87**	15.81	98.50	0.00
Mulloides flavolineatus	**20.00**	14.77	1151.05	0.00
Cephalopholis argus	**37.62**	25.63	37.59	0.00
Cephalopholis miniata	**28.26**	24.78	16.62	0.00
Cephalopholis hemistiktos	**17.93**	14.07	58.04	0.00
Epinephelus fasciatus	**19.72**	17.23	6.05	0.01
Epinephelus tauvina	**42.50**	21.94	9.02	0.00
Aethaloperca rogaa	**44.00**	27.14	8.37	0.00
Lutjanus ehrenbergii	**23.37**	18.64	28.28	0.00
Lutjanus monostigma	**31.82**	16.39	63.73	0.00
Lutjanus bohar	48.75	**87.64**	33.67	0.00
Macolor niger	**60.59**	38.75	7.90	0.00
Lethrinus mahsena	**51.11**	24.14	108.36	0.00
Lethrinus nebulosus	**43.44**	28.86	63.63	0.00
Lethrinus obsoletus	**25.65**	15.91	66.03	0.00
Monotaxis grandoculis	**46.00**	29.32	43.35	0.00

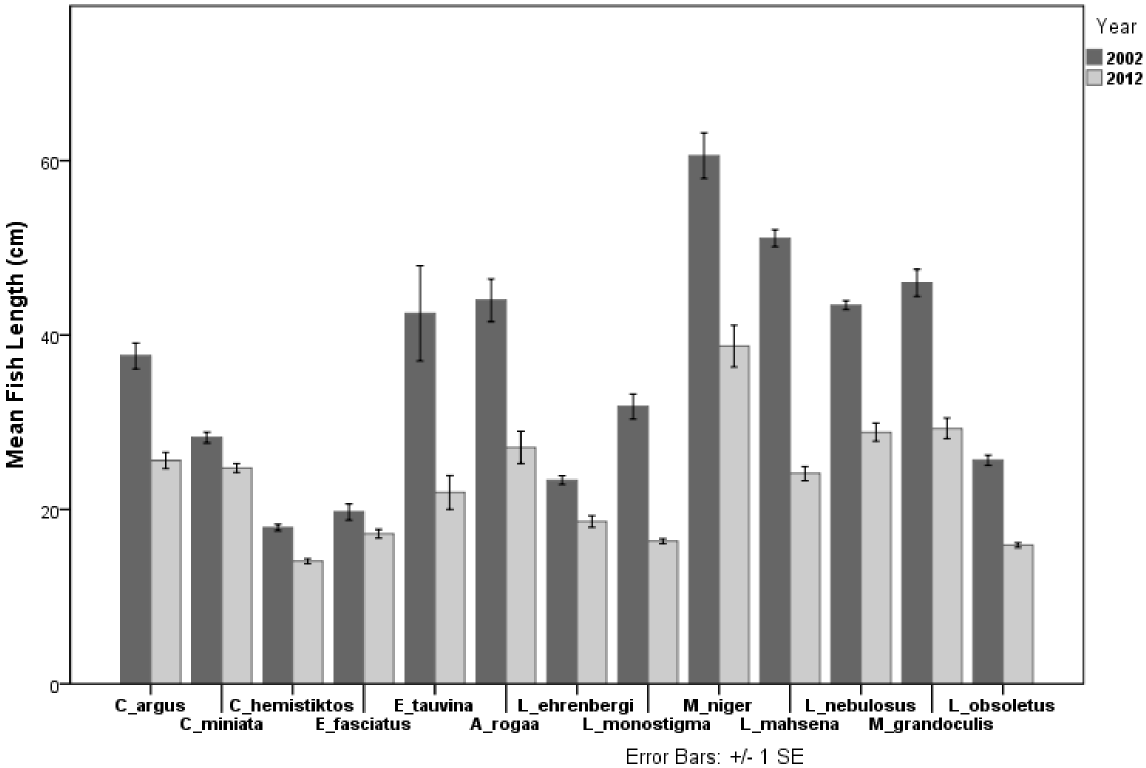

Figure 51. Compare fish mean lengths for the high commercial species from families Serranidae, Lutjanidae and Lethrinidae between 2002 and 2012. Only species with significant differences are shown.

Analysis of Fish Assemblages

Multi-Dimensional Scale ordination (MDS)

Using MDS ordination to display the dissimilarity in the fish assemblage abundance between the four studied regions in 2002 and 2012 revealed an excellent representation (Kruskal's stress value <0.001) of the dissimilarity with no prospect of misinterpretation (clarke 1993). The 2 dimensional ordination plot (Figure 52) showed that there was a high dissimilarity between Ras Mohamed (an unfished region) and both fished regions Nabq and Dahab in 2002, while the unfished Sharm was more similar in fish assemblage to Dahab than Nabq. Additionally the fished regions Dahab and Nabq were highly dissimilar in fish assemblage abundance. In 2012 the unfished regions of Ras Mohamed and Sharm was more similar in fish assemblage and both show high dissimilarity with the fished regions Nabq and Dahab. Moreover both fished regions became more similar over the years of the study (Figure 53).

Applying the MDS ordination using the average species abundance of fish assemblage for the studied sites within the four regions, showed an excellent representation for dissimilarities (distances between the sites) in 2002 with stress value = 0.05 (Figure 54). It also depicted the high similarity within species composition within Nabq and how it is highly dissimilar than other regions (Figure 54). While in 2012 MDS ordination showed a stress value = 0.09, showing the increase in dissimilarity between sites within regions especially in Nabq, and decrease in dissimilarity between Ras Mohamed and Sharm regions (Figure 55) .

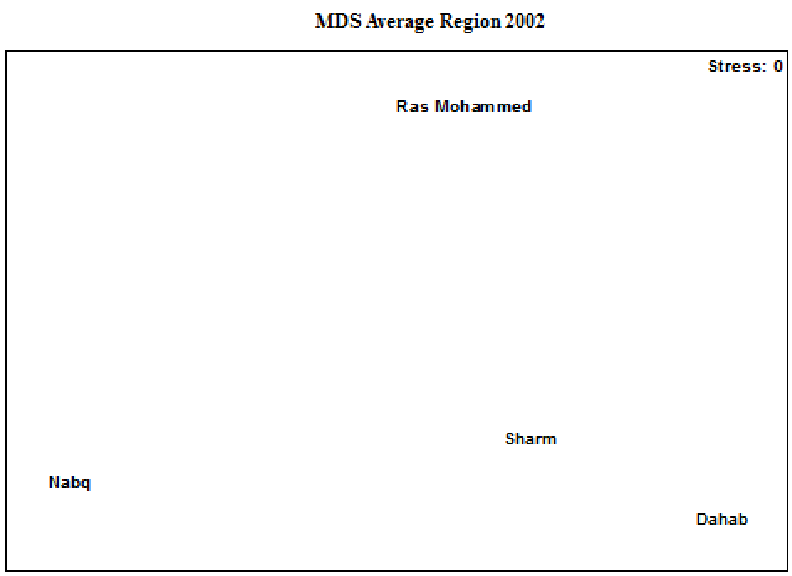

Figure 52. MDS (Multi-dimensional scaling) ordination of average abundance of the fish assemblage at the four studied regions using Bray-Curtis similarities, Gulf of Aqaba 2002. Kruskal's stress value <0.001.

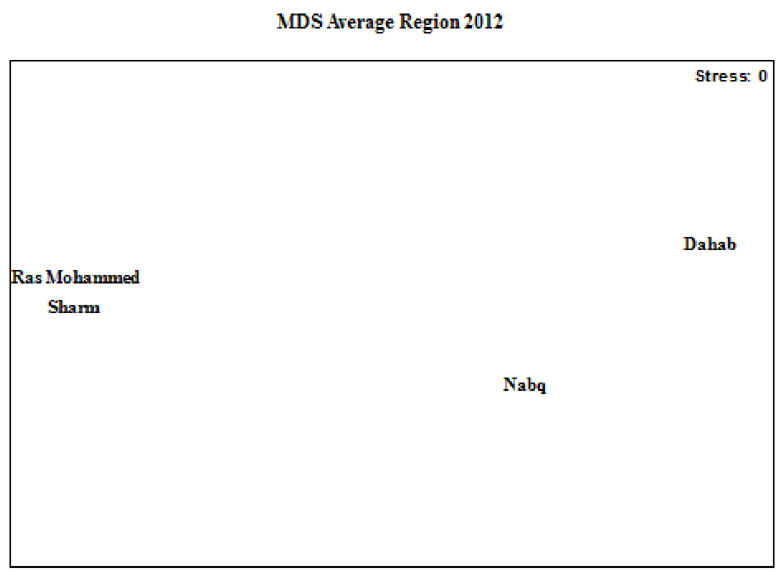

Figure 53. MDS (Multi-dimensional scaling) ordination of average abundance of the fish assemblage at the four studied regions using Bray-Curtis similarities, Gulf of Aqaba 2012. Kruskal's stress value <0.001.

Figure 54. MDS (Multi-dimensional scaling) ordination of average abundance of the fish assemblage in different sites at the four studied regions using untransformed data and Bray-Curtis similarities, Gulf of Aqaba 2002. Kruskal's stress value = 0.05.

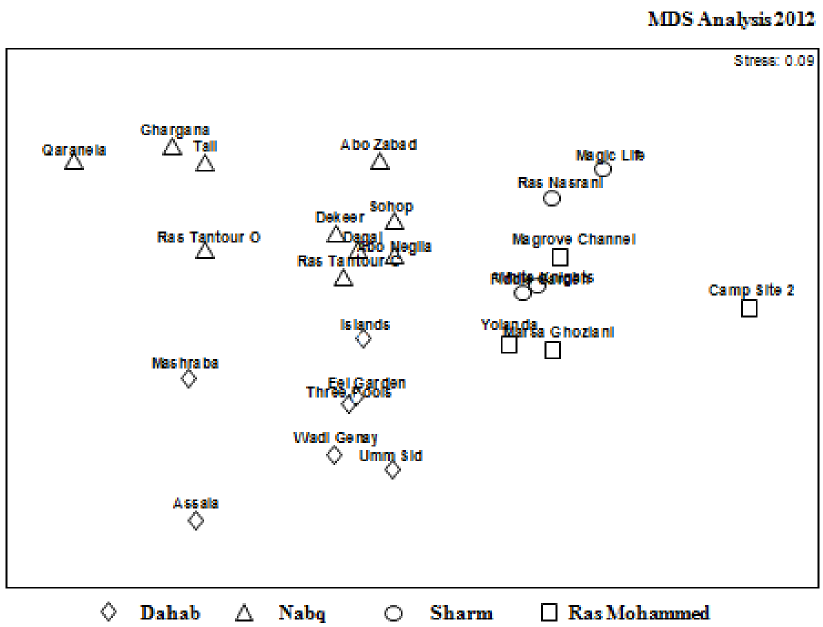

Figure 55. MDS (Multi-dimensional scaling) ordination of average abundance of the fish assemblage in different sites at the four studied regions using untransformed data and Bray-Curtis similarities, Gulf of Aqaba 2012. Kruskal's stress value = 0.09.

Analysis of Similarity (ANOSIM)

ANOSIM was used to examine the similarities in fish species composition between the four regions for the two years studied using two-way nested analysis, where sites were nested within regions. In 2002 the analysis showed an overall significant similarities between sites (Global R = 0.171, p = 0.001), the low Global R value indicates that sites within regions were hardly separable, while there was a highly significant dissimilarity in fish assemblage between regions (Global R = 0.73, p = 0.001). Pairwise tests between regions revealed a high dissimilarity between Nabq and the three other regions, additionally Ras Mohamed and Dahab were significantly dissimilar in their fish assemblages, (Table 19).

In 2012 the ANOSIM two-way nested analysis showed an overall significant similarities between sites (Global R = 0.114, p = 0.001), and between regions (Global R = 0.304, p = 0.002). Pairwise test resulted in a low R value indicating high similarities between regions with Sharm and Ras Mohamed having the highest similarity, and Dahab having a significant weak dissimilarity with the other three regions (Table 19).

Similarities in fish assemblage between different depths on the reef (Reef flat 1m, Reef edge 3m and Reef Slope 10m) were also investigated using ANOSIM in both years. In 2002 our analysis showed a low overall dissimilarities between depths (Global R = 0.403, p = 0.001). Pairwise test between depths however showed a significant high dissimilarities between fishes on the reef flat and those on the reef slope (R = 0.66, p = 0.001) and weak dissimilarities between reef edge and each of the reef flat and the reef slope (R = 0.32, p = 0.001 and R = 0.303, p = 0.001) respectively (Table 20). While in 2012 analysis showed a higher similarities in fish assemblage between depths (Global R = 0.169, p = 0.001), with reef edge and reef slope having the highest similarity in the species composition of the fish assemblage (Global R = 0.094, p = 0.001) (Table 20).

Table 19. Results of pairwise tests from ANOSIM for differences in fish assemblages between the four studied regions in 2002 and 2012 in the Gulf of Aqaba.

Groups	**2002**		**2012**	
	R Statistic	**P value**	**R Statistic**	**P value**
Dahab, Nabq	0.902	0.002	0.391	0.001
Dahab, Sharm	0.259	0.07	0.45	0.006
Dahab, Ras Mohammed	0.74	0.028	0.46	0.009
Nabq, Sharm	1	0.005	0.145	0.195
Nabq, Ras Mohammed	1	0.036	0.395	0.028
Sharm, Ras Mohammed	0.429	0.133	0.125	0.029

Table 20. Results of pairwise tests from ANOSIM for differences in fish assemblages between different depths on the reef (Reef Flat RF 1m, Reef Edge RE 3m, and Reef Slope RS 10m) in 2002 and 2012 for the four studied regions in the Gulf of Aqaba.

Groups	**2002**		**20012**	
	Statistic	**P value**	**Statistic**	**P value**
RF, RE	0.32	0.001	0.182	0.001
RF, RS	0.66	0.001	0.245	0.001
RE, RS	0.303	0.001	0.094	0.001

Similarity Percentages Analysis (SIMPER)

Similarity Percentages analysis was used to investigate which fish species were responsible for the similarities and dissimilarities within and between regions. In 2002 the analysis showed that within the regions, Dahab sites were the least similar in fish assemblage with average similarity of 36.33% and Nabq was the highest with 54.75% of species in common. By 2012 Nabq decreased in similarity to 37.33% (Table 21). *Acanthurus nigrofuscus* and *Ctenochaetus striatus* (Acanthuridae) contributed the most in the pattern of similarities within all regions in 2002 and 2012. Moreover, *Scarus sordidus* (Scaridae) and *Chaetodon austriacus* (Chaetodontidae) were also found to have contributed significantly to the similarity of fish assemblage in all four regions in both years. *Cephalopholis miniata* and *Cephalopholis hemistiktos* (Serranidae) also contributed consistently in the pattern seen at Sharm in both years, while in Ras Mohamed only *C. miniata* was contributed in 2002.

Dissimilarities between regions ranged from 57% to 76% in 2002 with Dahab and Nabq being the most different, and Sharm and Ras Mohamed being the most similar (table 22). In 2012 the dissimilarities between regions decreased to range between 53% to 67% (table 22) . We found that *Acanthurus nigrofuscus* and *Ctenochaetus striatus* (Acanthuridae) significantly contributed in the dissimilarities between regions in 2002 and 2012.

Table 21. Average similarity % of the fish assemblages from samples within each region in 2002 and 2012.

Region	2002	2012
	Average similarity %	Average similarity %
Dahab	36.33	36.7
Nabq	54.75	37.33
Sharm	52.5	51.58
Ras Mohammed	41.42	44.51

Table 22. Average dissimilarity of fish assemblages between each region in 2002 and 2012.

Region	2002	2012
	Average dissimilarity %	Average dissimilarity %
Dahab & Nabq	76.08	67.58
Dahab & Sharm	64.53	66.47
Nabq & Sharm	68.96	64.31
Dahab & Ras Mohammed	73.17	67.37
Nabq & Ras Mohammed	74.66	66.97
Sharm & Ras Mohammed	57.45	53.65

Discussion

Several earlier studies (Roberts & Polunin 1992, Galal 1999, Galal et al. 2002, Ashworth 2004, Ashworth & Ormond 2005) used Underwater Visual Census to assess the impact of fishing on fish population on the Egyptian coast of the Gulf of Aqaba but were limited by focusing on a specific fish families, a specific area, or conducted only on one date. In this study we sampled a large number (57) of fish species (9 families), large area with 120 km coastline covering four regions (Ras Mohamed, Sharm, Nabq and Dahab) with a 10 years' time difference.

Total Species and Fish Diversity

There was a significant difference in the total number of fish species and diversity between regions where the unfished regions (Ras Mohamed and Sharm) were higher than the fished regions (Nabq and Dahab), indicating that fishing reduced species richness and diversity. This was in contrast to the findings of Robert and Polunin (1992), who reported no difference in species richness between the studied regions Ras Mohamed, Sharm and Dahab. We suspect this difference in findings is due to the increase of fishing pressure that has occurred in the last 20 years. For instance, Dahab was not considered intensively fished by Robert and Polunin (1992) but it became over fished as we found here in 2002 and by Ashworth (2004). Comparing total number of species between regions over years revealed a significant decrease in Nabq in 2012, likely due to increased fishing activities and the state of fishing in the No Take Zones by the fishers (chapter 3 and 4). Meanwhile, species richness and diversity increased in the relatively heavily fished region Dahab (Ashworth 2004) by 2012, likely due to the enforcement of the Marine Protected Area law and increases in public environmental awareness through the environmental project funded by the European Commission (Mabrouk 2009). Further fishing activities declined in Dahab as it became no longer viable, leading the fishers to move to the nearby fishing grounds (Nabq) (pers. obs. and Abdelazeem pers.comm.). Both Sharm and Ras Mohamed (Unfished) regions showed no difference in total species between 2002 and 2012 or between each other, although there were some illegal fishing encountered in Ras Mohamed.

Comparing total species and species diversity between depths revealed that reef edge and reef slope were significantly higher than reef flat. This was expected as the reef edge and reef slope were higher in coral cover and diversity, providing good habitat for many coral reef fishes (Carpenter et al. 1981, Bell & Galzin 1984, Sano et al. 1984, Chabanet et al. 1997, Jones et al. 2004).

<u>The Total fish Density of the Fish Assemblage</u>

Investigating the difference in the total fish density of the fish assemblage (average of total number of fish/500m^2) between years showed a significant decrease in 2012, mainly due to the increased fishing pressure in both Nabq and Ras Mohamed, particularly in Nabq where fishers targeted the low important commercial herbivores species from Acanthuridae, Scaridae and Siganidae which inhabiting and dominating the reef flat and edge, and representing 88% of fish assemblage. Comparing the fish density between depths, revealed that the reef flat was the highest in fish density, and with increasing depth density decreased significantly. We found that this decrease was mainly due to the decrease in the density of the herbivores families with depth.

Additionally we found that by 2012 the reef flat decreased significantly in fish density while the reef slope increased. We suspect that this is due to the increased net fishing activities by the Bedouin particularly in Nabq where both reef flat and reef edge were significantly decreased in density by 2012. This was in contrast to the reef slope which significantly increased in fish density by 2012, mainly due to the increase of Mullidae, Siganidae and Chaetodontidae, where net fishing was not conducted.

Fish density between regions were significantly different with Dahab the least abundant in 2002 likely because it was heavily fished (pers.obs.& Ashworth 2004) while Nabq was the highest due to the high density of the herbivores families Acanthuridae, Siganidae and Scaridae (the least targeted families by the fishers), likely as a secondary effect resulting from targeting the high commercial carnivore families Serranidae, Lethrinidae and Lutjanidae (Roberts & Polunin 1992, Galal 1999, Ashworth 2004). In 2012 Dahab, the heavily fished region in 2002, increased significantly in fish density (by 75%) due to reduced fishing pressure, while Nabq fish density significantly decreased in 2012 by 51% due to increased fishing effort and non-compliance from the fishers fishing the No Take Zones. Density in Ras Mohamed National Park also decreased significantly by 39% as a result of the seasonal illegal fishing activities.

Changes in Families Density

Comparing the families density between the studied years revealed that the highly commercially valuable carnivore families Serranidae, Lutjanidae and Lethrinidae decreased significantly by 15%, 23% and 42% respectively by 2012. Additionally, the least commercially valuable herbivore families Acanthuridae, Siganidae and Scaridae significantly decreased by 22%, 17%, and 51% respectively, likely due to the heavy fishing pressure in Nabq and illegal fishing in Ras Mohamed. On the other hand, the least targeted family Mullidae (invertivores) was found to increase more than 3 times in density by 2012 as it was observed in big schools (100+) on the reef edge and reef slope where the net fishing was very limited.

Examine families densities between regions showed that Nabq (fished) was significantly the most abundant in the least commercially target herbivores (Acanthuridae, Siganidae, and Scaridae), while Ras Mohamed (unfished) was significantly more abundant in the highly commercially target families (Serranidae and Lutjanidae), this similar to earlier studies in the area (Ashworth 2004, Ashworth & Ormond 2005) and other studies elsewhere (Hawkin & Roberts 2004, Samoilys et al. 2007, Harborn et al. 2008, Stowar et al. 2008)

Investigating the families densities within each region over the studied years shown that all surveyed families (target and non-target) with the exception of Mullidae decreased significantly in abundance by 2012 in Nabq fished region due to the heavily fishing. In contrary to Dahab where the least target herbivores (Acanthuridae, Siganidae and Scaridae) and the invertivores (Mullidae) increased significantly by 2012, however the highly commercial carnivores families were still low in numbers and didn’t show significant increase. Additionally Ras Mohamed the unfished region showed a significant decreased in abundance for the least target Acanthuridae and Scaridae and also for the highly target family Serranidae, as a result of illegal fishing. While the unfished region Sharm only show a significant increase in abundance for Mullidae by 2012 and all the other families didn’t show any significant changes, we claim this to the absence of the Bedouin fishers in the region.

Change in Species Abundance

Comparing individual species abundance between regions showed that 8 species from the highly target commercial species families (Serranidae, Lutjanidae and Lethrinidae) were significantly higher in the unfished Ras Mohamed and Sharm than the fished Nabq and Dahab, Ashworth in

2004 found similar results with 7 species from the same families. The small bodied herbivore species *Acanthurus nigrofuscus* (Acanthuridae), was found to be the most dominant species on the reef in our study, confirming the finding of similar studies in the Gulf of Aqaba (Roberts & Polunin 1992, Mazeroll & Montgomery 1998, Ashworth 2004). *A. nigrofuscus* was most abundant in Nabq the fished region while in Ras Mohamed the unfished was the least, which indicating the impact of removing its predators from the carnivores due to heavily fishing in Nabq, similar results were found (Russ 1985, Roberts and Polunin 1992, Ashworth 2004). However other herbivores mainly the large bodied from families (Acanthuridae and Scaridae) were found to be more abundant in the Ras Mohamed (unfished) regions than Dahab (fished), which mainly due to the net fishing, similar pattern was found by Ashworth (2004). Individual species densities were also investigated between the studied years and showed that 13 target commercial species were decreasing in abundance by 2012 of them 5 large bodied highly commercial, likely as increasing fishing pressure.

<u>The Fish Size</u>

Comparing fish size (mean fish length) for individual species between the fished and unfished regions revealed that 14 commercially target species where larger in the unfished than the fished regions of them 5 from the highly target families Serranidae, Lutjanidae and Lethrinidae, similar to Ashworth (2004). In contrast, Roberts and Polunin (1992) found difference in size for Serranidae only; we feel this to be due to the lower fishing intensity at the time of his study. Over time, we found that 13 of the highly target species from the same families (Serranidae, Lutjanidae, and Lethrinidae) decreased significantly in size by 2012 contrary to Galal et al. who find them increasing in 2002 particularly in Nabq, where it was consider lightly fished at that time (Ashworth 2004).

The Fish Assemblage

Examining the similarities of the fish assemblage between years using the 2 way nested analyses ANOSIM revealed that in 2002 there was a significant dissimilarities in the fish assemblage between regions which indicating the different fishing intensity in the regions (Ras Mohamed was unfished and well enforced, Sharm unfished (but was lightly fished in 1992), Nabq was lightly fished, and Dahab was heavily fished) affected the species composition in those regions. This was in contrast to Ashworth (2004) who found no dissimilarities in the fish assemblage between regions. This difference between the two results could be due to using different analysis methods. However, this dissimilarities between regions decreased significantly in 2012 were Ras Mohamed the illegally fished became more similar to Sharm the unfished and Dahab and Nabq the heavily fished became more similar in fish assemblage.

Similarities between depths were investigated over the studied years and it shown that in 2002 there was a weak dissimilarities between the fish assemblage in the reef flat 1m and reef edge 3m, and between reef edge 3m and reef slope 10m. This is due to the proximity between reef flat and reef edge and between reef edge and reef slope, and also due to the distribution of the different fish species on the reef zones (Chabanet et al. 1996, Jones et al. 2004), which confirmed what we found earlier where different fish families were inhabiting different reef depths. Also confirming the finding of Ashworth (2004) between the reef edge and reef slope. While there was a significant dissimilarity in the fish assemblage between the reef flat and reef edge where both inhabited with different fish species and far from each other. However in 2012 similarities between reef flat and reef edge and between reef edge and reef slope increased significantly, moreover the dissimilarity between reef flat and reef slope was weak, which indicating that increasing fishing pressure can reduce dissimilarities in fish assemblage between reef zones and having the reef more homogenous.

The least commercially target herbivores species *Acanthurus nigrofuscus* and *Ctenochaetus striatus* (Acanthuridae) played an important role in the similarities within regions and between regions in both years, similar results was found by Ashworth (2004). Additionally we found that the highly commercially target carnivores species *Cephalopholis miniata* and *Cephalopholis hemistiktos* (Serranidae) were consistently contributed with the unfished regions Sharm and Ras Mohamed, since both were heavily fished in Nabq and Dahab.

Conclusion

Species richness and diversity were different between regions where the unfished regions Ras Mohamed and Sharm were higher than the fished regions Nabq and Dahab. Additionally both were found to be higher at the reef edge while the reef flat was the least.

Abundance of the fish assemblage significantly decreased over time in Ras Mohamed and Nabq while increased in Dahab. Increase fishing activities and fishing the NTZs decreased the abundance of the highly commercially target carnivores families (Serranidae, Lutjanidae, and Lethrinidae decreased) by 2012. Furthermore the least commercially target herbivore families (Acanthuridae, Siganidae and Scaridae) were also decreased.

Nabq the lightly fished in 2002 subjected to a significant decline in species richness, total fish abundance, families abundance of both commercially target and non-target due to the heavily fishing pressure and noncompliance to the NTZs. In contrast to Dahab the lightly fished in 1992 and heavily fished in 2002, which increased in species richness, diversity, total fish abundance, the abundances of the least commercially target herbivores families and the non-target families by 2012 as a result of reducing fishing pressure and increasing low enforcement.

Ras Mohamed National Park the unfished in 1992 and 2002 decreased in the abundances of the least commercially target herbivores families (Acanthuridae and Scaridae) and the highly commercially target carnivore family Serranidae by 2012 as a results of illegal fishing.

Size of the target herbivore and carnivore species were significantly decreased over time with the smaller fish size in the fished regions Nabq and Dahab. Fish assemblage were different between regions in 2002 where different fishing pressure shaped the dissimilarities and by increasing fishing pressure over time regions became more similar by 2012.

Establishing marine protected areas in the Gulf of Aqaba and the different fishing measures used seemed to be working in conserving fish population at the beginning of the study however this didn’t continue over the years. The MPAs management authority need to apply more efficient program, I believe that more restricted in enforcing the law and the participatory approach with the different stakeholders will result in better management of the fisheries in the regions. Dahab and Sharm cases shown that tourism development, enforcement and public awareness can play a role in reducing fishing pressure, increasing fish abundance species richness and maintaining fish diversity.

APPENDICES

<u>Appendix 1</u>

List of the surveyed species (57 species), their families and trophic levels

Table 23. List of the surveyed species (57 species), their families and trophic levels.

Trophic Level	Families	Species
Herbivorous	***Acanthuridae***	*Acanthurus nigrofuscus*
		Acanthurus sohal
		Ctenochaetus striatus
		Zebrasoma desjardinii
		Zebrasoma xanthurum
		Naso liturstus
		Naso unicornis
		Naso hexanthus
	Siganidae	*Siganus luridus*
		Siganus rivulatus
		Siganus stellatus
		Siganus argentus
	Scaridae	*Cetoscarus bicolor*
		Scarus gibbus
		Scarus fuscopurpureus
		Scarus ghobban
		Scarus sordidus
		Scarus frenatus
		Scarus ferrugineus
		Scarus niger
		Scarus psittacus
		Hipposcarus harid
Invertivores	***Mullidae***	*Parupeneus forsskali*
		Parupeneus macronema
		Parupeneus cyclostomus
		Mulloides flavolineatus
		Mulloides vanicolensis
Carnivores	***Serranidae***	*Cephalopholis argus*
		Cephalopholis miniata
		Cephalopholis hemistiktos
		Epinephelus fasciatus
		Epinephelus tauvina
		Variola louti
		Ploctropomus pessuliferus
		Aethaloperca rogaa

Table 23 (cont'd)

Trophic Level	**Families**	**Species**
	Lutjanidae	*Lutjanus ehrenbergii*
		Lutjanus monostigma
		Lutjanus bohar
		Macolor niger
Carnivores	***Lethrinidae***	*Lethrinus mohsena*
		Lethrinus nebulosus
		Lethrinus obsoletus
		Lethrinus barbonicus
		Monotaxis grandoculis
Corallivores & Invertivores	***Chaetodontidae***	*Chaetodon fasciatus*
		Chaetodon paucifasiatus
		Chaetodon austriacus
		Chaetodon auriga
		Chaetodon trifascialis
		Chaetodon melannotus
		Chaetodon lineolatus
		Chaetodon semilarvatus
		Chaetodon larvatus
		Heniochus intermedius
	Pomacanthidae	*Pomacanthus imperator*
		Pomacanthus maculosus
		Pygoplites diacanthus

Appendix 2

The surveyed sites, regions and depths in 2002 and 2012 in the Gulf of Aqaba

Table 24. The surveyed sites, regions and depths in 2002 and 2012 in the Gulf of Aqaba, surveyed depths are indicated with (+).

			2002			2012		
Site No.	Site Name	Region	RF	RE	RS	RF	RE	RS
1	Assala North	Dahab	+	+	+	+	+	+
2	Mashraba	Dahab	+	+	+	+	+	+
3	Eel Garden	Dahab		+	+	+	+	+
4	Islands	Dahab	+	+	+	+	+	+
5	Palm Trees	Dahab	+	+		+	+	
6	Three Pools	Dahab	+	+	+	+	+	+
7	Umm Sid	Dahab	+	+	+	+	+	+
8	Ras Tantour North	Nabq				+	+	+
9	Ras Tantour South	Nabq				+	+	+
10	Dagal	Nabq	+	+		+	+	+
11	Abo Negila	Nabq	+	+		+	+	+
12	Abo Zabad	Nabq					+	+
13	Qaraneia	Nabq				+	+	+
14	El Tall	Nabq	+	+		+	+	
15	Ghargana	Nabq	+	+		+	+	
16	Dekeer	Nabq	+	+		+	+	
17	Sohop	Nabq	+	+		+	+	
18	Magic Life	Sharm		+	+		+	+
19	Ras Nasrani	Sharm		+	+		+	+
20	White Knights	Sharm		+	+		+	+
21	Fiddle Garden	Sharm		+	+		+	+
22	Marsa Ghozlani	Ras Mohamed					+	+
23	Yolanda	Ras Mohamed		+	+	+	+	+
24	Mangrove Channel	Ras Mohamed		+	+	+	+	+
25	Camp Site 2	Ras Mohamed					+	

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CHAPTER 3: EVALUATION OF THE USE OF NO TAKE ZONES FOR FISHERIES SUSTAINABILITY, NABQ PROTECTED AREA, GULF OF AQABA, EGYPT

Abstract

Fisheries on the Egyptian coast of the Gulf of Aqaba in South Sinai are predominately artisanal, conducted on the fringing coral reef by the local Bedouin community as part of their traditional activities. The catch is mainly used to support their daily food needs with the surplus providing a source of income. As part of the effort of the Egyptian government to maintain these traditional activities and to protect the coral reef, Nabq Managed Resource Protected Area (MRPA) was established in 1992, where fishing was only allowed for the Bedouin. In 1995, alternating Take Zones (TZs) and No Take Zones (NTZs) were established on the reef to sustain artisanal fisheries for the Bedouin Community living in Nabq (MRPA) at Ghargana Village to reduce the potential conflict between fisheries and touristic activities (diving, snorkeling and camping). Over the last 17 years since the establishment of the NTZs, Nabq fisheries were subjected to changes in management programs from restricted enforcement to the NTZs and compliance from the fishers in these zones, to the lack of enforcement and non-compliance ultimately affecting their sustainability. In this study we evaluate the impact of the NTZs on the diversity and abundance of the fish assemblage and on the catch of this fishery from 1999 to 2012, in order to determine if the NTZs achieved its goals, and if the artisanal fishery in Nabq was sustainable under the changes occurred in the management.

In order to assess the impact of the No Take Zones (NTZs) on the fish population in Nabq, we sampled the fish assemblage of 50 species representing 9 families using underwater observation technique over the years 2000-2002 and again in 2012 in both the TZs and NTZs. From these

surveys we calculated species richness, diversity and abundance of these fishes. To evaluate the sustainability of this artisanal fishery a survey of the catch from Ghargana village fishers in the years 1999-2003, 2007-2008, 2010, and 2012 was conducted in order to collect information on the catch composition and success. We evaluated the catch based on the fishing ground and gear type used.

The mean species richness was significantly different over time and depth (reef flat and reef edge), with 2012 being lowest. All 9 families show a significant difference over this time period, with the primary target commercial species Serranidae and Lethrinidae decreasing the most, 75% and 84% respectively. The estimated catch from Ghargana fishing grounds also exhibited a decrease over the years dropping from 50% to 18% of the total catch. Overall, we found that the estimated CPUE for the main fishing techniques, drive netting and line, which responsible for 80% of the catch in 1999 decreased over the years of this study, and as a result their contribution to the total catch decreased to 53% in 2012. This decrease was compensated in part, by the increasing use of two other fishing techniques (Closure and Overnight netting) leading to change in the catch composition toward smaller and lower value commercial species like Gerres oyena.

Introduction

Nabq was declared in 1992 as the largest Protected Area (PA) on the Gulf of Aqaba, a total area of 736 km^2, 421 km^2 land and 315km^2 sea, including the marine sector of Dahab city north of Nabq, with a coast of 74Km of which 24Km is located in Dahab City. Nabq Managed Resource Protected Area (MRPA) is one of a network of 5 protected areas managed by South Sinai Protectorates, govern by the Egyptian Environmental Affairs Agency (EEAA), and is characterized by a great diversity of habitats and ecosystems, where the three main marine ecosystems coral reef, sea grass, and mangrove are interacting together in a uniquely setting on

Gulf of Aqaba coast (Mabrouk, 2007). The coral reefs are among the best and most diverse in the Egyptian Red Sea (208 species of hard coral), and are the home for a large number of fish (438 species) and marine invertebrates species.

Nabq encompass the extreme Northern mangrove forest in the Red Sea and Indian Ocean. This system is composed of 4.5 Kilometers of one species, *Avicennia marina*, and forms an important nursery habitat for economically important fishes and nesting sites for many of the region’s water birds (Por et al., 1977). Nabq also had a substantial sea grass bed providing meadow and nursery grounds for many fishes (Por et al.,1977; Gab-Alla ,1996; Galal, 1999; Ashworth et al., 2006) and for threatened marine species such as Green Turtle *Chelonia mydas*, and Dugong *Dugong dugong*. Wadi El Keed watershed in Nabq is one of the largest drainage basins to the Gulf of Aqaba on the Egyptian side. It is considered the best-vegetated wadi in the Gulf region, having one of the biggest aggregation of the Arak Sand Dunes *Salvadora persica* in the region representing a unique vegetation essential for the wildlife.

Nabq MRPA is inhabited by the local people (Bedouins) with only one main settlement on the coast at Ghargana village, where artisanal fishing is the main traditional activity. There are approximately 25fishers in winter and 43 during summer, mainly for subsistence but also as a means to supplement their income. The total population of Bedouin in this village is 227 inhabitants with 43 households according to the last survey in 2006, with an rate of increase of 2.9% per year. Nearly half of the Bedouin maintain the nomadic life style, and move in winter to Khriza village 15 km west of Ghargana at the mountain side mainly due to the bad weather conditions (Mabrouk, 2007).

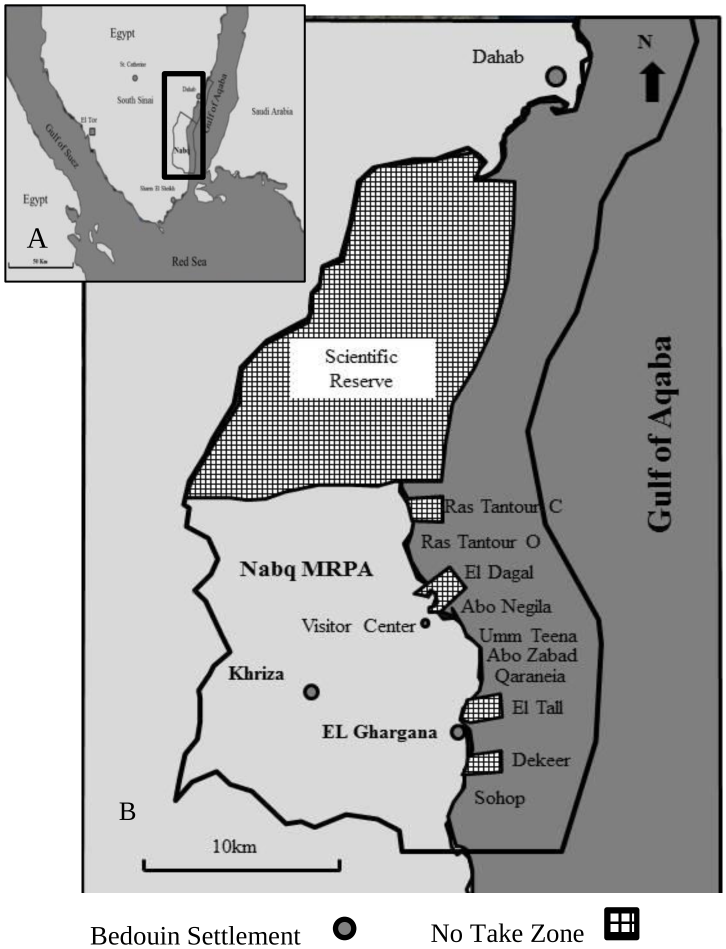

Figure 56. A. The location of Nabq Managed Resource Protected Area (MRPA) on the Gulf of Aqaba, B. The NTZs, Bedouin Settlement and fishing grounds in the Nabq.

The diversity and the interaction between the terrestrial and marine habitats are not only important for the ecological function of this region, it is also essential to support the artisanal fishery community. Additionally this diversity provides an attraction for tourism activities like snorkeling and diving. The interior of the PA is a complex pristine mountain wilderness, inhabited by a diversified wildlife, including several endangered species, and representing attractions for ecotourism. As a result, the Egyptian government classified Nabq as a Managed Resource Protected Area (MRPA) IUCN Category VI which is managed mainly for sustainable use of natural ecosystem (IUCN 2012). It is an area containing mostly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while at the same time providing a sustainable flow of natural products and services to meet the community needs (IUCN 2012).

The main management objectives developed by the EEAA for Nabq (Mabrouk 2007) were:

- To maintain the natural and cultural resources and conserve Nabq MRPA biodiversity.
- To enhance the sustainable use of natural resources in the PA.
- To promote Nabq MRPA as a focal point for ecotourism in the region, and supporting socio-economic benefits to the local community and the nation.
- To increase public understanding and appreciation of Nabq MRPA natural and cultural heritage.

Artisanal fishing by the Bedouin was one of the main use of the natural resources in Nabq, and if not managed properly could have an irreversible alteration to the marine resources, and affect negatively its sustainability in addition to causing conflict with other touristic activities such as diving and snorkeling. Nabq management authority realized the importance of managing the coral reef fishes to ensure the sustainability of this fishery, and reduce the potential for conflict with other users. As a result, the No Take Zones (NTZs) were proposed as a management tool for this multispecies multi-gear artisanal fishery. It was found by the earlier scholars that NTZs provides benefits to heavily exploited fish populations (Robert et al. 2005 and Hastings et al. 2012), by increasing fish abundance and spawning biomass, increased mean age and size, improved reproductive potential of local fishes with the additional benefit of potentially exporting fish (juveniles and adults) to nearby fished area (Bohnsack 1998 and 2004). Additionally, establishing NTZs should eliminate the physical damage to coral due to fishing activities (trampling, netting and using line) further protection of biodiversity, ecosystem structure, function and integrity (Ward et al., 2001).

In 1995 the Management authority of Nabq established an alternating NTZs and Take Zones (TZs) along the coast of Nabq in coordination with the Bedouin fishermen society, the first and only MRPA in Egypt to have such system. The management established 5 NTZs (Figure 56), with total reef area of 3.56 km² constituting 30% of the reef in Nabq. The NTZs total coast was 26.8km long representing 53.6% of the total coast of Nabq, of them an inaccessible scientific reserve zone with 20 km coast long and narrow reef flat (average 60m). The rest of the no take zones (4 zones) were with smaller coast 1.5-2 km in length and with reef areas ranged from 0.017 to 1.01 km² (Table 25) showed the coast length and reef area of the NTZs and TZs in Nabq. The NTZs was visibly marked and enforced by the local ranger and regulations were respected by the fishermen (Galal et al. 2002).

Table 25. The coast length (km) and reef area (km²) of the No Take Zones (NTZs) and Take Zones (TZs) in Nabq. Surveyed sites are indicated with asterisks.

Take Zones	**Coast Length (km)**	**Reef Area (km²)**	**No Take Zones**	**Coast Length (km)**	**Reef Area (km²)**
Saria	3	0.44	**Dekeer***	1.5	0.72
Sohop*	2.2	1.4	**Tall***	1.8	0.46
Ghargana*	1.5	0.7	**Dagal***	2	1.01
Qarania	1	0.26	**Ras Tantour**	1.5	0.17
Marsa Abo Zabad	1	0.73	**Scientific Reserve**	20	1.2
Umm Teena	2.3	1.01	**Total**	**26.8**	**3.56**
Rewisia	1	0.45			
Abo Negila*	4.5	1.51			
El Monqata	2.5	1.05			
Ghorabi	0.5	0.21			
Ras Tantour Opened	1.5	0.26			
Total	**21**	**8.02**			

The network of NTZs was selected to encourage spillover of fish from NTZs into fished areas, and the fished areas to be accessible to fishermen living in Nabq (Galal 1999). The goal of this study is to assess the state of the fish population and the fisheries in Nabq, giving the decision maker and the local community a clear vision on this fishery, the threats facing it and how we can overcome them to ensure its sustainability in the future. In order do to this we assessed the effectiveness of the NTZs in fisheries sustainability since its establishment in 1995 through 2012. Our objectives were to evaluate the changes in species richness, diversity and abundance for a fish assemblage of 9 fish families (50 Species) using results from earlier studies by Galal (1999), and Galal et al. (2002) and by counting these fishes using the Underwater Visual Census (UVC) technique, belt transects method in 2000, 2002 and 2012 for 3NTZs and 3 TZs. We also evaluated the sustainability of the Bedouin fisheries by assessing the catch at El Ghargana village from 1999-2012 through interviews with the fishers in the years 1999-2003, 2007-2008, 2010, and 2012 gathering information on the nature and extent of fishing operations, fishing grounds, fishing techniques, and catch composition .

Methods

Underwater Visual Census (Belt Transect)

Under Water Visual Census (UVC) is a technique to count fish underwater by snorkelers or divers, and it has been the preferred technique for sampling coral reef fishes since Brock (1954) designed this technique as a non-destructive, relatively accurate, and cost effective method to evaluate fish population (Sale 1981, Brock 1982). In this study we used the fixed belt transect method to assess coral reef fish diversity and abundance in both NTZs and TZs, where fish were identified to the species level and counted over a transect that is 50m long by10m wide (500m^2). The surveys were performed by a team of three observers (team leader and two assistants), the observer counts all fish from the target list on their sighted within the area of 5m on both sides at the same depth.

Six sites were surveyed, 3TZs (Sohop, Ghargana and Abo Negila) and 3NTZs (Dekeer, El Tall and El Dagal) (Figure 56). All surveys took place during summer (July-August) seasons through the year 2000, and 2002 and 2012. The selected reefs were all of similar habitat of continuous fringing reefs, with proper reef flat, reef edge and reef slope, in order to reduce the effect of the change in habitats. Eight transects (50mX10m) at each sites were surveyed, 4 at the reef flat (1m depth) and 4 at the reef edge (4m depth) (Figure 57), where most of the Bedouin fishing activities took place (Galal, 1999).

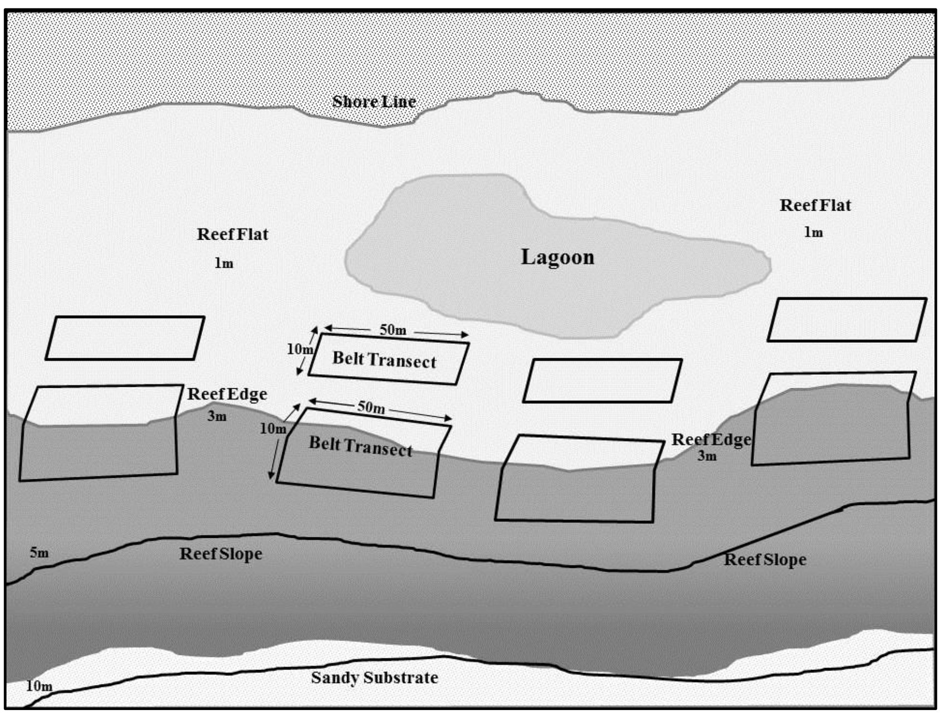

Figure 57. Location and dimensions of the belt transects on the reef flat and reef edge for the Underwater Visual Census fish survey technique in Nabq.

The surveys cover a fish assemblage consisting of 9 families with a total of 50 target species list (Appendix 1); seven of these families were selected because they were targeted by the Bedouin fisheries and commercially important (Acanthuridae, Siganidae, Scaridae, Mullidae, Serranidae, Lutjanidae and Lethrinidae). Acanthuridae, Siganidae, and Scaridae are herbivores, feeding mainly in schools on algae on the reef flat and reef edge where the algal cover was high (Russ, 2003). Members of the family Mullidae are mainly invertivores, living associated with the coral habitat mainly at the ref edge and reef slope as explained in chapter 2. Serranidae, Lutjanidae and Lethrinidae are carnivores, they are the top and second level predators living mainly on the reef edge and slope, and they are good indicators of the level of anthropogenic disturbance from fishing, (Green and Bellwood 2009, Obura and Grimsditch 2009).

The last two families, Chaetodontidae and Pomacanthidae, are both non-commercial non target groups, are mainly corallivores feed on coral polyp, invertivores feed on coral competitors like soft coral, sponge, or herbivorous feeding on algae, and so they were used as a secondary indicator to the health (high diversity and coral cover) (Harmelin-Vivien & Bouchon-Navaro 1983, Roberts & Ormond 1987, Hourigan et al. 1988 and Crosby and Reese 1996, Cadoret et al. 1999, O¨ hman et al. 1997, Kulbicki & Bozec 2005), and we used them as indicator to the intensity of the net fishing since they caught as by catch (Galal, 1999).

Fish were identified to species level, and were counted visually along 50m long and 10m wide transect (due to high visibility). Surveys were conducted at high tide for each site to allow the observer to survey the reef flat, and transects were parallel to the reef edge.

Shannon-Wiener index was calculated using the equation :

$$H` = \sum_{i=1}^{S} (Pi * \ln Pi)$$

where:

H` = the Shannon diversity index

Pi = fraction of the entire population made up of species i

S = numbers of species encountered

∑ = sum from species 1 to species S

Total species, diversity index H` (Shannon-Wiener index) and species abundance at each transect was calculated. H` value allows us to know not only the number of species but how the abundance of the species is distributed among all the species in the community. High values of H` would be representative of more diverse communities (Magurran 2004).

Data for species richness, diversity index H`, total abundance and family abundance were analysed using

Due to the non-normality, non-homogeneity and multilevel characters of the data, beside the interest in investigating the interactions between factors (year, depth, and fishing status) we used the General Linear Mixed Model (GLIMMIX) procedure using SAS 9.2 software package which considered the best tool for analyzing such count, nonnormal, multilevel, and repeated measures (Bolker et al. 2009). We used the surveyed sites as subject and year (2000, 2002, and 2012), status (NTZs and TZs) and depth (Reef Flat and Reef Edge) as the fixed factors. Testing the species abundance using the General Liner Mixed Model was only applicable for 18 of the 50 species observed, due to the scarcity of these species in the surveys especially in 2012. We used the nonparametric Kruskal Wallis Test for ANOVA analysis to compare the abundance of the species between years, status, location, and sites.

Fish Catch Data Collection

Artisanal fisheries by the Bedouin in Nabq is a typical coral reef fishery, being prosecuted with multiple gears and targeting many species (Ormond & Douglas 1996 & Ashworth et al, 2004). The fishers applied traditional fishing techniques using different types of gear including nets, fishing over the reef flat and in Nabq lagoons, and using hook and line at the reef edge or near shore.

A description of the four main traditional fishing techniques used in Nabq (Mabrouk, 2007) is:

Hand Line Fishing

Mainly conducted off shore by day, and dependent on calm sea condition, fishermen used a small boat 3-6 m in length dropping lines to 50-200m depth with mainly 2 hooks per line. Fishers targeted commercial fish mainly from carnivorous families such as Serranidae, Lethrinidae and Lutjanidae, Bedouin also used line fishing at the reef edge but it was limited to low tide and calm sea condition and is primarily done by women.

Drive Netting Fishing

Fishing using this technique occurred mainly by day on the reef flat at high tide, where often two fishers spread one or 2 trammel nets, 30-50 m length over the reef flat, the fishers walked over the reef flat disturbing the fish driving them in to the net over a 2 hour period. This technique was mainly targeting commercial herbivores families such as Acanthuridae, Scaridae, and Siganidae.

Overnight Netting Fishing

In this technique often one to two fishers were using trammel nets (1to 3 nets) 30-50 m length each over the reef flat, the fishermen deploy the net before sunset and leave it overnight for 12-16 hour and collect it the next morning. This technique mainly targeted nocturnal commercial fish principally carnivores from the families Holocentridae, Haemulidae, Lethrinidae and Sparidae.

Closure (Surround) Netting Fishing

Fishers used closure techniques mainly by day. Fishers (2-3) use a combination of trammel and gill nets (more than 12-14 nets) spread over the reef flat closing the inlet of a lagoon at high tide, and collecting fish 6 hours later at low tide. This technique targeted schools of fish of different commercial carnivorous and herbivorous families such as Muglidae, Siganidae, Sparidae, and Gerreidae.

Bedouin fishers in Nabq were mainly settled at Ghargana Village (Fishermen Village) on the coast of Nabq, where approximately 25 fishers conducted fishing activities on daily bases. A monitoring system to collect the fish catch data of Nabq fishers was established in 1999 but suspended for three years (2004 to 2006) due to funding problems, and was monitored again in the years 2007, 2008, 2010, 2012.

This monitoring system established by hiring a Bedouin fisher from Ghargana village as assistant ranger, who was trained in fisheries data identification and collection methods. Data on the catch composition, size, abundance, total weight, landing and gear used were collected from Ghargana fishers on a daily basis for at least 21 days a month (number of working days of the assistant ranger). Estimated total catch and effort per year was calculated, CPUE for the fishing ground and for each fishing technique was calculated as follows (FAO 2002):

CPUE (tech.) = W / TN , where W is total catch wet weight in Kg., T is the active soak time by hours and N is the number of gear units net or line.

For the fishing grounds catch per unit effort was calculated as follows:

CPUE (ground) = W/N , where W is total catch wet weight in Kg., N is number of landing at this fishing ground.

Results

<u>Fish Assemblage Total Species (2000, 2002 and 2012)</u>

The mean number of species per transect differed significantly over time (P=0.0006) and with depth (P=0.0024). The highest number of species recorded occurred in 2002 while the lowest mean number of species was observed in 2012 (Figures 58). Reef edge had significantly higher species richness than the reef flat (Figures 59). Pairwise comparison between years showed a significant difference between 2000 and 2012 (adj. $p<0.0001$) and between 2002 and 2012 (adj. $p<0.0001$). However, there was no significant difference between NTZs and TZs or any of the interactions between the three fixed effects (year, fishing status and depth). Comparing sites using Kruskal Wallis Test showed a significant ($p= 0.004$) difference with Ghargana village fishing ground being the lowest in the mean total species between the six sites studied (Figure 60).

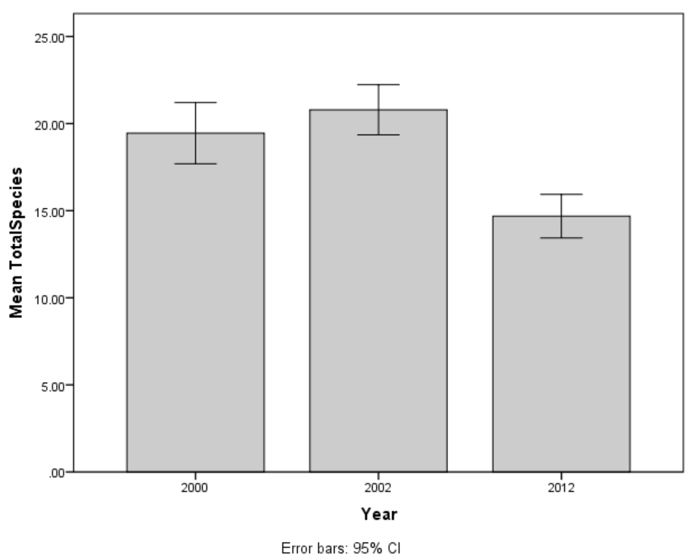

Figure 58. Comparison of the mean total species (No. of species/500m²) for the fish assemblage between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

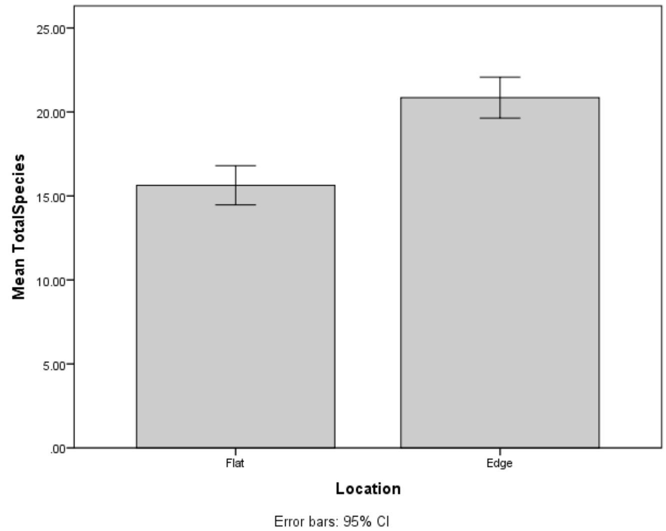

Figure 59. Comparison of the mean total species (No. of species/500m²) for the fish assemblage between the reef flat and reef edge in Nabq. Error bars represent +/-1 standard error.

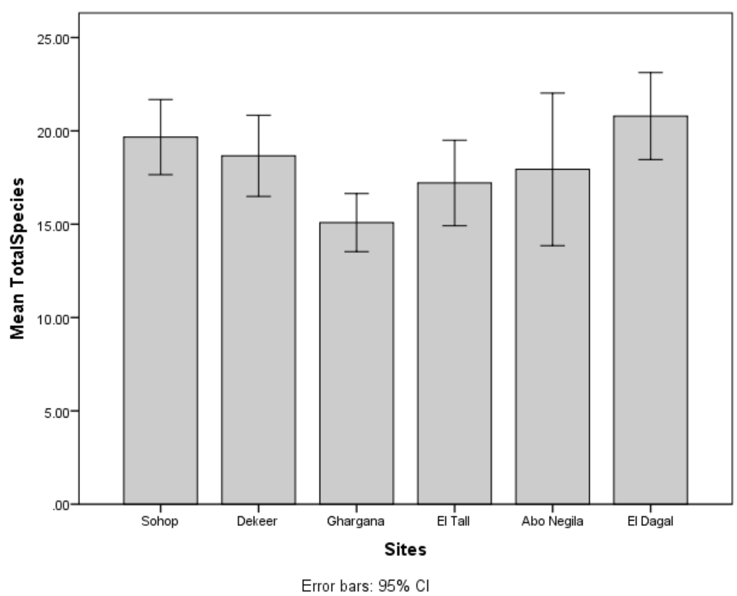

Figure 60. Comparison of the mean total species (No. of species/500m²) for the fish assemblage between the six surveyed sites in Nabq. Error bars represent +/-1 standard error.

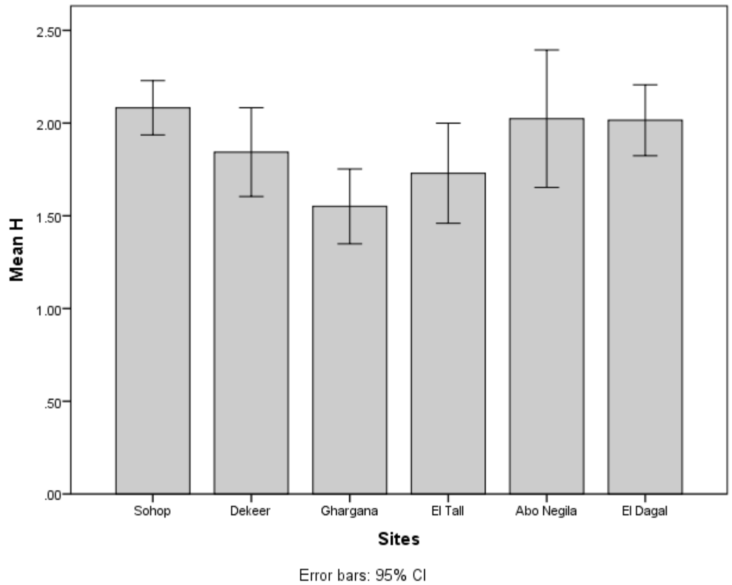

Figure 61. Comparison of the mean Shannon diversity index H for the fish assemblage between the six surveyed sites in Nabq. Error bars represent +/-1 standard error.

Diversity Index H`

Only depth was significantly (*p*= 0.0359) different with regards to species diversity with diversity being the highest at the reef edge. Diversity index was significantly different between sites (p= 0.005) and with Ghargana the fished sites the lowermost (Figure 61).

The Change in Families Abundance from 2000, 2002 and 2012

Underwater census for the 9 families during summer months of 2000,2002, and 2012 resulted in a total fish count of 36,149 individuals from surveying 136 total transects (68000 m^2); 40 transects in 2000, 48 in 2002, and 48 in 2012. As can be seen in Figure 7 the mean density of fish increased significantly from 2000 (243.8 fish/500m^2) to 2002 (395.7 fish /500m^2) and then declined precipitously in 2012 (185.5 fish /500m^2). The Generalized Liner Mixed Model analysis for fish density (table 3) showed a significant difference between years ($P<0.0001$), and pairwise comparison for the fish density between year 2000*2002, 2000*20012 and 2002*2012 were also significantly different (adj. P<0.0001).

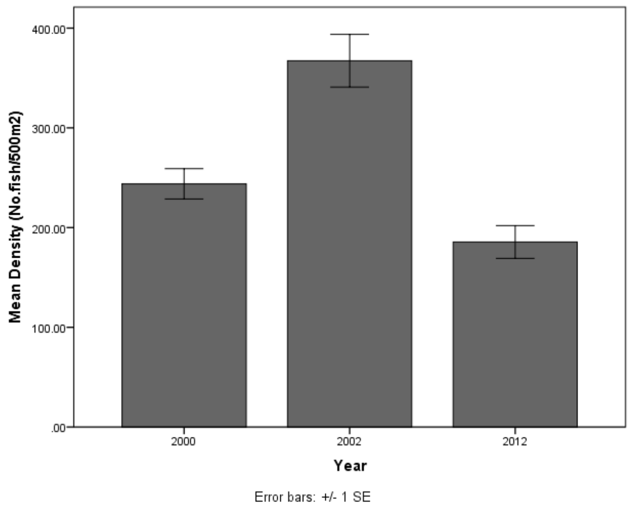

Figure 62. Comparison of the mean fish density (No. fish/500m²) for the 9 families during summer (2000,2002, and 2012) at Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Fish density varied among depths (P<0.0001) with reef flat (337.53 fish/500m²) having 1.7 times the density of reef edge, and over the studied years reef flat was significantly higher in fish density than the reef edge, following the same pattern of the year effect having 2012 the least abundant (Figure 63). There was no statistically significant difference in the total fish density of the 9 families between the NTZs and the TZs in general, but the interaction between the three fixed factors fishing status, depth, and year showed a significant difference in fish density using the GLIMMIX analysis (Table 26). Specifically, we found that the pairwise comparison for the fish density between NTZs and TZs across the reef flat over the years showed a high significant difference for 2000, and 2002 with NTZ being the highest, while in 2012 there was no significant different (Figure 64).

Table 26. Results of General Linear Mixed Model analysis for mean fish density, between status (no take zones and take zones), depth (reef flat and reef edge) and years (2000, 2002 and 2012) and their interactions. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for the Total Species				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr>F**
Year	2	7	1479.78	<.0001*
Status	1	4	5.47	0.0794
Depth	1	4	2090.18	<.0001*
Year*Status	2	7	30.19	0.0004*
Year*Depth	2	7	149.63	<.0001*
Status*Depth	1	4	166.58	0.0002*
Year*Status*Depth	2	7	95.51	<.0001*

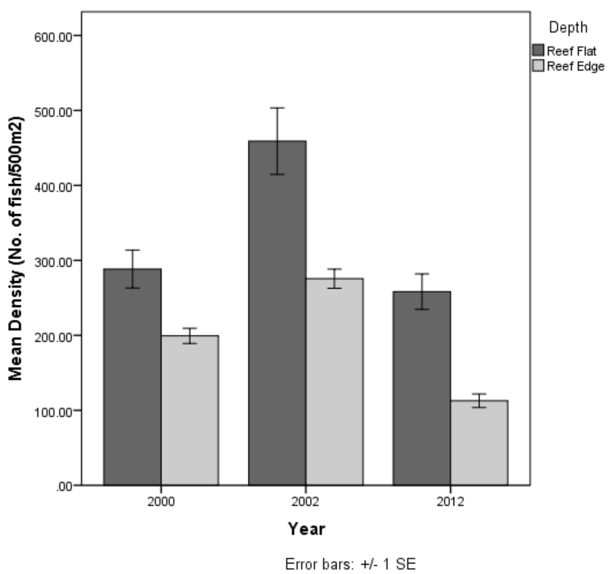

Figure 63. Comparison of the mean fish density between reef flat and reef edge during summer 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

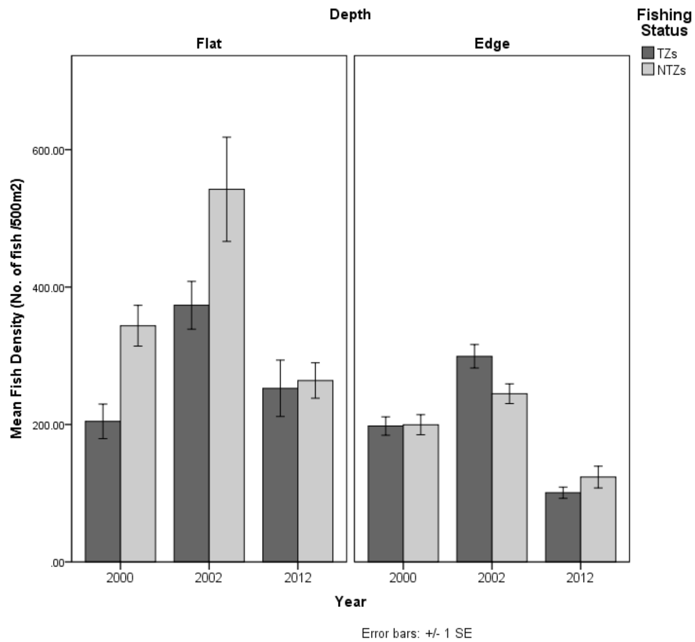

Figure 64. Comparison of the mean fish density between the take and no take zones at the reef flat and reef edge during summer 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

The analysis of the composition of each the 9 families showed that the herbivore families (Acanthuridae, Labridae and Siganidae) were the dominant group representing 88.7%, 89.4% and 85.1% of the total fish abundance over the years 2000, 2002, and 2012 respectively. Acanthuridae the most dominant family comprising 68.3%, 66.2% and 68.7% of the total fish abundance in 2000,2002, and 2012 respectively (Figure 65). The second most numerous fishes were from families that reflected the health of the coral reef community (Chaetodontidae and Pomacanthidae) with these families representing 7.9%, 5.9% and 9.2% of the total abundance over the years 2000, 2002, and 2012 respectively. The third most abundant group was the invertivores family, Mullidae which represented 1.8%, 2.3% and 4.1% over the years 2000, 2002, and 2012 respectively, while the carnivores grouping (Serranidae, Lutjanidae, and Lethrinidae) were least abundance, representing only 1.6%, 2.4%, and 1.6% over the years 2000, 2002, and 2012 respectively.

Comparing sites using the Kruskal Wallis Test for ANOVA revealed that 5 families were significantly different between sites (Scaridae, Serranidae, Lutjanidae, Chaetodontidae, and Pomacanthidae) (Table 27). Ghargana site, where the fishermen live, had the lowest mean abundance (No. of fish/500m²) for these families (Figure 66) with the lowest density for the target carnivore families Serranidae 0.29 fish /500m², and Lutjanidae 0.13 fish /500m², additionally it had the lowest density of the non-target (coral health indicators) families Chaetodontidae 14.21 fish /500m² and Pomacanthidae 0.04 fish /500m².

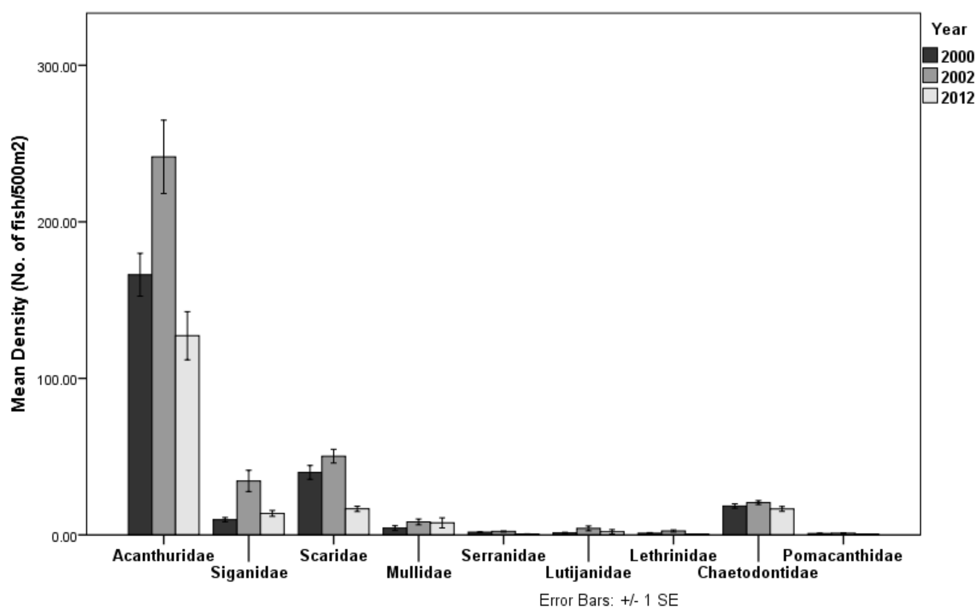

Figure 65. Mean fish density (No. of fish/500m²) of the 9 families during summer 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Table 27. Results of Kruskal Wallis ANOVA tests for the 9 families fish density between the surveyed sites in Nabq. Significant level is $p < 0.05$, families with significant difference between sites are indicated by asterisks.

Families	Chi-Square	df	Asymp. Sig.
Acanthuridae	3.288	5	0.656
Siganidae	9.419	5	0.093
Scaridae	31.644	5	0.000*
Mullidae	10.807	5	0.055
Serranidae	19.179	5	0.002*
Lutjanidae	21.478	5	0.001*
Lethrinidae	8.948	5	0.111
Chaetodontidae	16.731	5	0.005*
Pomacanthidae	31.266	5	0.000*

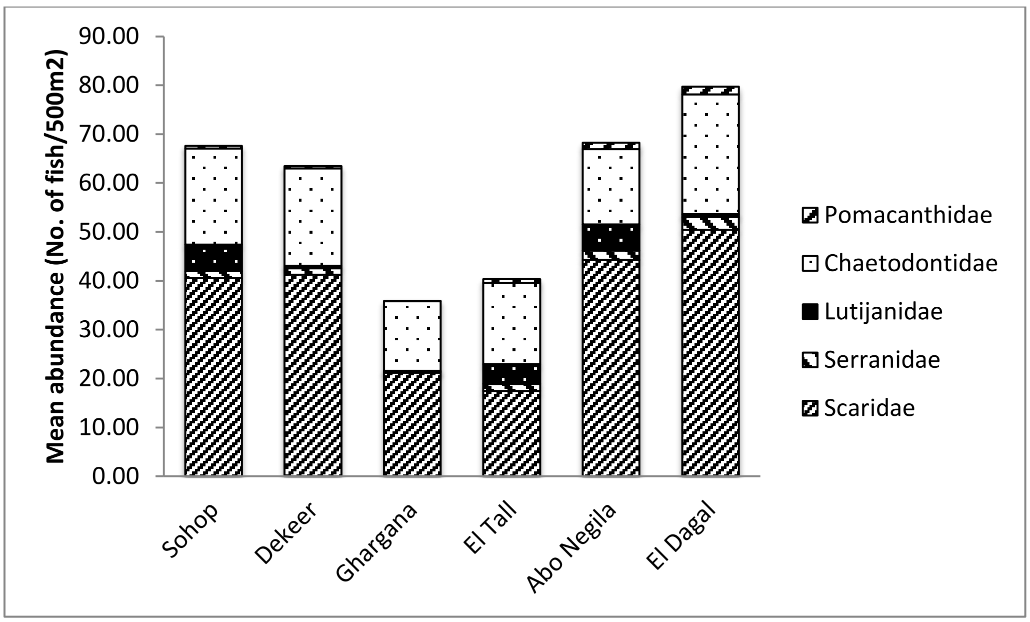

Figure 66. Comparison of mean abundance for fish families which shown significant difference in density between the surveyed sites in Nabq, Gulf of Aqaba, Egypt.

Changes in Density for Acanthuridae

The density of Acanthuridae varied with year and depth (Table 28), with 2002 having the most fish (242 fish/500m²) and 2012 the least (127 fish/500m²). Density on reef flats (243 fish/500m²) was two times greater than fish density observed at the reef edge (Figure 67,68).

All interactions between the three fixed factors fishing status (NTZs and TZs), depth (Reef Flat and Reef Edge) and years (2000, 2002, and 2012) showed a significant difference (P<0.0001) using the GLIMMIX analysis (Table 28). Pairwise comparison showed that Acanthuridae was significantly higher in density on the reef flat in both NTZs and TZs over the three years (Table 29), (Figure 69). However pairwise comparison between NTZs and TZs showed a high significant difference (adj. P<0.0001) only at the reef flat in 2000 and 2002 with NTZs being higher in density (Figure 70).

Table 28. Results of the Generalized Linear Mixed Model test for the density of Acanthuridae, in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Acanthuridae				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Year	2	7	931.69	<.0001*
Fishing Status	1	4	1.68	0.2649
Depth	1	4	2548.01	<.0001*
Year*Fishing Status	2	7	46.83	<.0001*
Year*Depth	2	7	244.83	<.0001*
Fishing Status*Depth	1	4	201.72	0.0001*
Year*Fishing Status*Depth	2	7	65.17	<.0001*

Table 29. Results of the pairwise comparison for Acanthuridae using GLIMMIX analysis between the reef edge and reef flat across the No Take Zones (NTZs) and Take Zones (TZs) during summer 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

Year	**Fishing Status**	**Status Pairwise Contrasts**	**t**	**df**	**Adj. Sig.**
2000	**TZs**	**Reef Flat – Reef edge**	2.7	124	0.007*
	NTZs	**Reef Flat – Reef edge**	9.7	124	0.007*
2002	**TZs**	**Reef Flat – Reef edge**	6.1	124	<0.0001*
	NTZs	**Reef Flat – Reef edge**	10.2	124	<0.0001*
2012	**TZs**	**Reef Flat – Reef edge**	10.1	124	<0.0001*
	NTZs	**Reef Flat – Reef edge**	10	124	<0.0001*

The sequential Bonforoni adjusted significance level is .05.

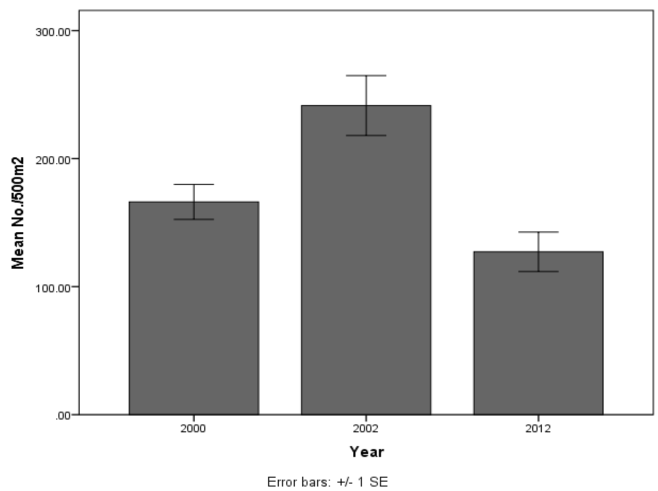

Figure 67. Comparison of mean density for Acanthuridae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

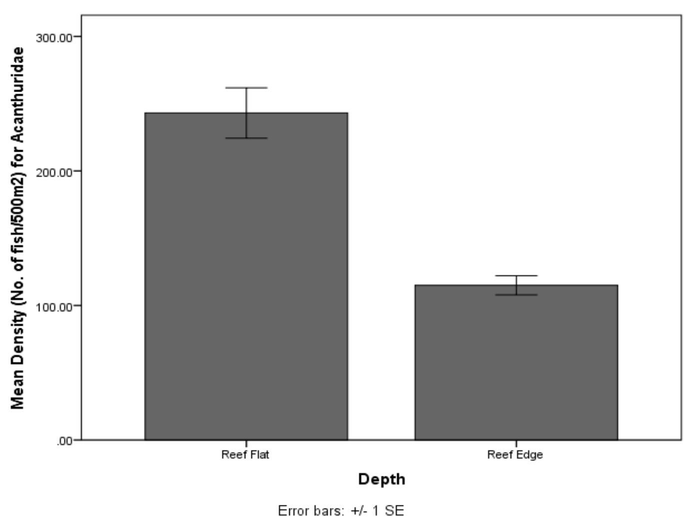

Figure 68. Comparison of mean density for Acanthuridae between reef flat and reef edge in Nabq. Error bars represent +/-1 standard error.

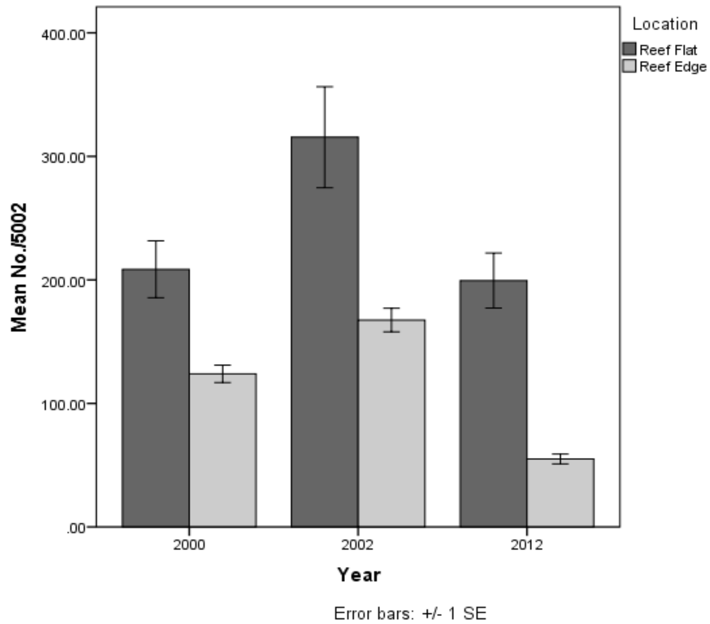

Figure 69. Comparison of mean density of for Acanthuridae between Reef Flat and Reef Edge over the years (2000, 2002, and 2012) in Nabq. Error bars represent +/-1 standard error.

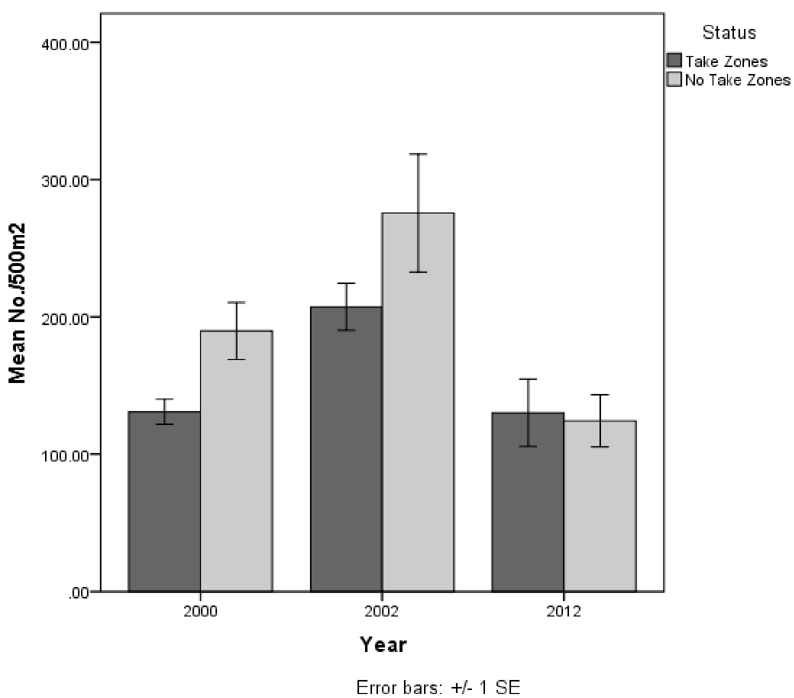

Figure 70. Comparison of mean density for Acanthuridae between Take Zones and No Take Zones over the years (2000, 2002, and 2012) in Nabq. Error bars represent +/-1 standard error.

Changes in Density for Siganidae

Similar to Acanthuridae, the density of Siganidae differed across years and depth, but not between NTZs and TZs. Density of Siganidae was highest in 2002 (34.4 fish/500m²) and lowest in 2000 (9.8 fish/500m²); pairwise comparison between 2000, 2002, and 2012 were all highly significant (adj. P<0.0001). The density on reef flats (29.3 fish/500m²) averaged nearly three times higher than reef edge. The interactions between the three effects year, fishing status and depth were significant(Table 30).,Pairwise comparison for density between NTZs and TZs at different depths over the years, revealed that NTZs were significantly(adj. P=0.002) higher only in 2012 at the reef flat (Figure 71), while pairwise comparison between the reef flat and reef edge showed that reef flat was significantly (adj. P<0.0001) higher than reef edge in density in both the NTZs and TZs over 2000, 2002, and 2012, except at TZs in 2012 (adj. P=0.41) it was not significant (Table 31).

Table 30. Results of the Generalized Linear Mixed Model test for the density of Siganidae, in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Siganidae				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Year	2	7	250.16	<.0001*
Fishing Status	1	4	0.24	0.652
Depth	1	4	320.52	<.0001*
Year*Fishing Status	2	7	21.57	0.001*
Year*Depth	2	7	22.95	0.0008*
Fishing Status*Depth	1	4	15.32	0.0173*
Year*Fishing Status*Depth	2	7	6.6	0.0245*

Table 31. Results of the pairwise comparison for Siganidae using GLIMMIX analysis between the reef edge and reef flat across the No Take Zones (NTZs) and Take Zones (TZs) during summer 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Significant results (p <0.05) are indicated with an asterisk.

Year	Fishing Status	Status Pairwise Contrasts	Contrast Estimate	t	df	Adj. Sig.
2000	**TZs**	**Reef Flat – Reef edge**	7.3	4.5	124	<0.0001*
	NTZs	**Reef Flat – Reef edge**	10.7	6.1	124	<0.0001*
2002	**TZs**	**Reef Flat – Reef edge**	39.7	7.7	124	<0.0001*
	NTZs	**Reef Flat – Reef edge**	33.6	7.5	124	<0.0001*
2012	**TZs**	**Reef Flat – Reef edge**	1.1	0.8	124	0.41
	NTZs	**Reef Flat – Reef edge**	14.9	6.2	124	<0.0001*

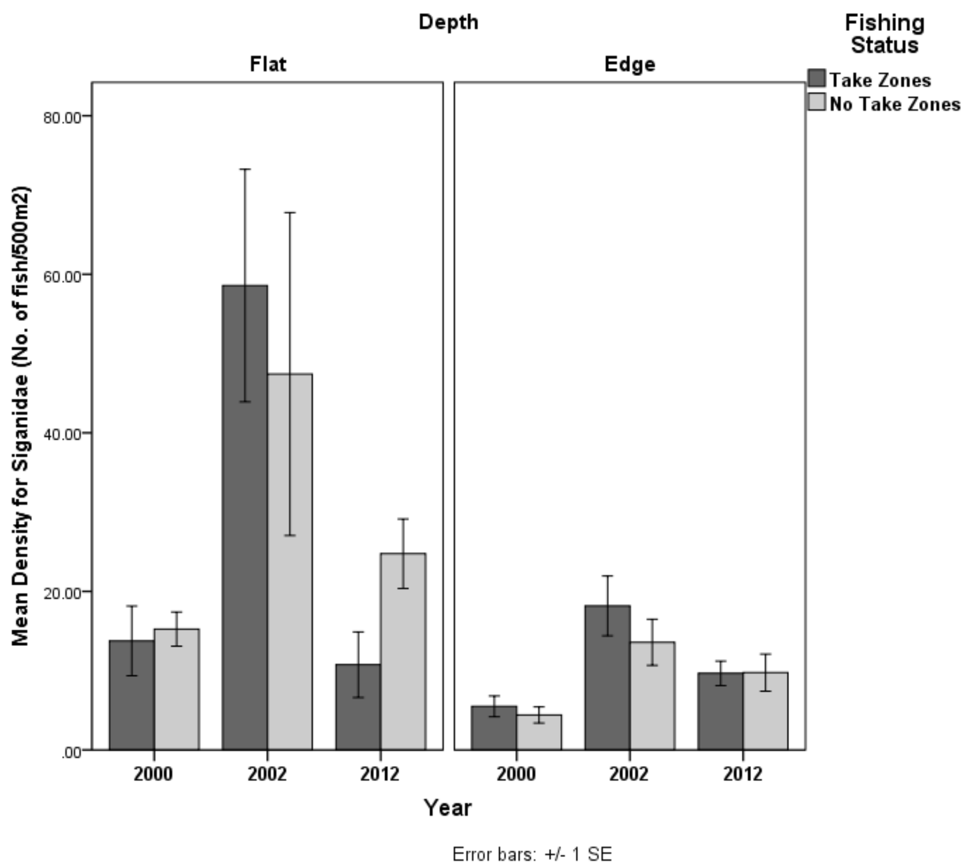

Figure 71. Mean fish density for Siganidae at reef flat and reef edge in the take and no take zones during summer 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Labridae (Scaridae)

Scaridae didn't show a significant difference in density between NTZs and TZs (Table 32), but it was highly significant (P<0.0001) between years 2000, 2002, and 2012 with 2002 the highest (50.3 fish/500m²) and 2012 the lowest (16.6 fish/500m²) (Figure 72), and all pairwise comparison between years were also highly significant (adj. P<0.0001). Density was significantly higher (P=0.0031) on the reef flat (39.3 fish/500m²) than the reef edge. Although the interaction between year and depth was not significant but pairwise comparison between reef flat and reef edge over the 2000, 2002, and 2012 were significant with reef flat higher in density than reef edge in the three years with 2012 the lower most (Table 33) and (Figure 73) .

Table 32. Results of the Generalized Linear Mixed Model test for the density of Scaridae, in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Scaridae				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Year	2	7	358.94	<.0001*
Fishing Status	1	4	0.03	0.8758
Depth	1	4	40.63	0.0031*
Year*Fishing Status	2	7	2.52	0.1497
Year*Depth	2	7	0.54	0.6077
Fishing Status*Depth	1	4	30.57	0.0052*
Year*Fishing Status*Depth	2	7	4.2	0.0634

Table 33. Results of the pairwise comparison for Scaridae using GLIMMIX analysis between the reef edge and reef flat during summer 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

Year	**Status Pairwise Contrasts**	**Contrast Estimate**	**t**	**df**	**Adj. Sig.**
2000	**Reef Flat – Reef edge**	9.7	3.4	124	0.001*
2002	**Reef Flat – Reef edge**	8.5	3.3	124	0.001*
2012	**Reef Flat – Reef edge**	2.9	2.3	124	0.021*

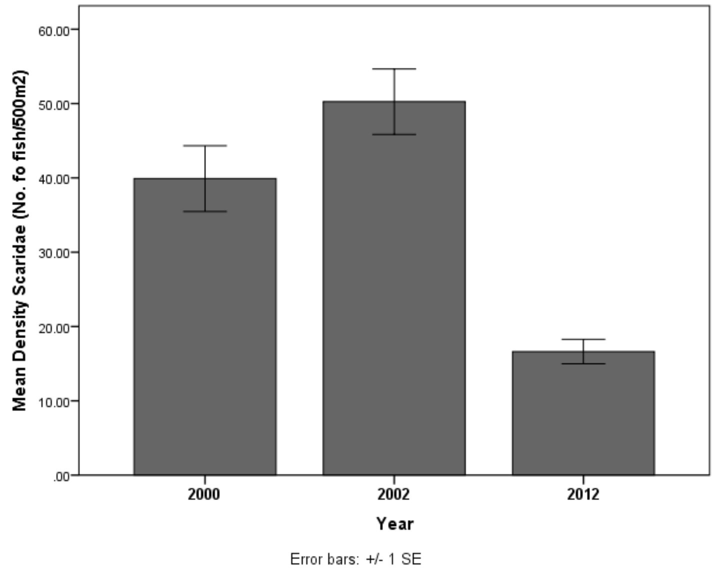

Figure 72. Comparison of mean density for Scaridae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

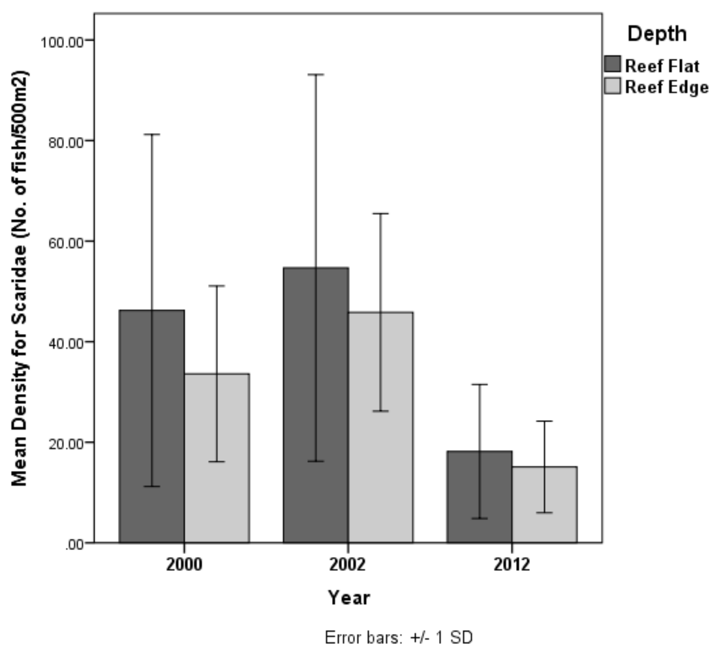

Figure 73. Comparison of mean density of for Scaridae between Reef Flat and Reef Edge over the years (2000, 2002, and 2012) in Nabq. Error bars represent +/-1 standard error.

Changes in Density for Mullidae

There was a high significant difference in fish density between the years 2000, 2002, and 2012 (table 32), with 2002 is the highest 8.3 fish/500m² and 2000 is the lowest with 4.3 fish/500m² (Figure 74), and pairwise comparison between years were also significantly different. Additionally density at reef edge (8.2 fish/500m²) was significantly higher than reef flat (5.7 fish/500m²), and the interaction between the year and depth was also significantly different (Figure 75), also the interaction between fishing status and year was significantly different (Table 34) with higher density in the NTZs (13.3 fish/500m²) than TZs (2.1 fish/500m²) in 2012 (Figure 21).

Table 34. Results of the Generalized Linear Mixed Model test for the density of Mullidae, in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Mullidae				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Year	2	7	47.96	<.0001*
Fishing Status	1	4	1.08	0.3575
Depth	1	4	20.04	0.011*
Year*Fishing Status	2	7	51.84	<.0001*
Year*Depth	2	7	32.11	0.0003*
Fishing Status*Depth	1	4	5.02	0.0885
Year*Fishing Status*Depth	2	7	13.26	0.0042*

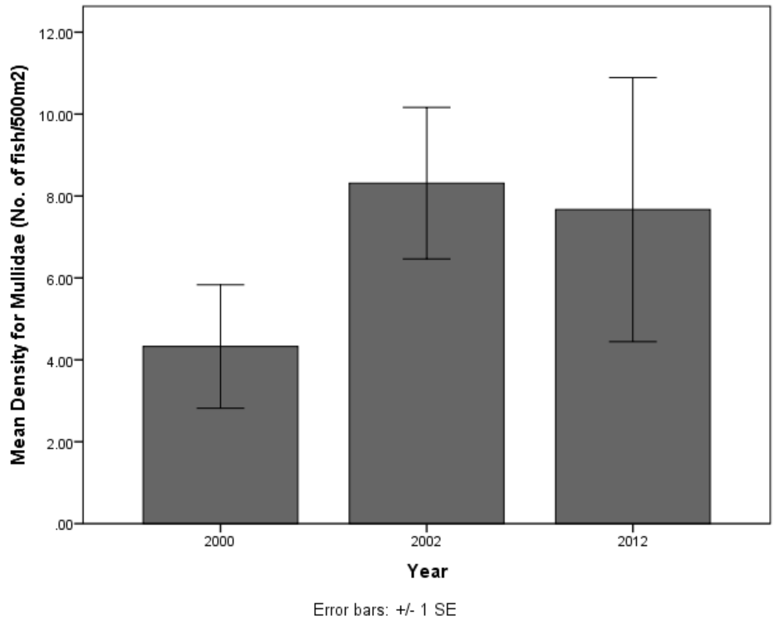

Figure 74. Comparison of mean density for Mullidae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

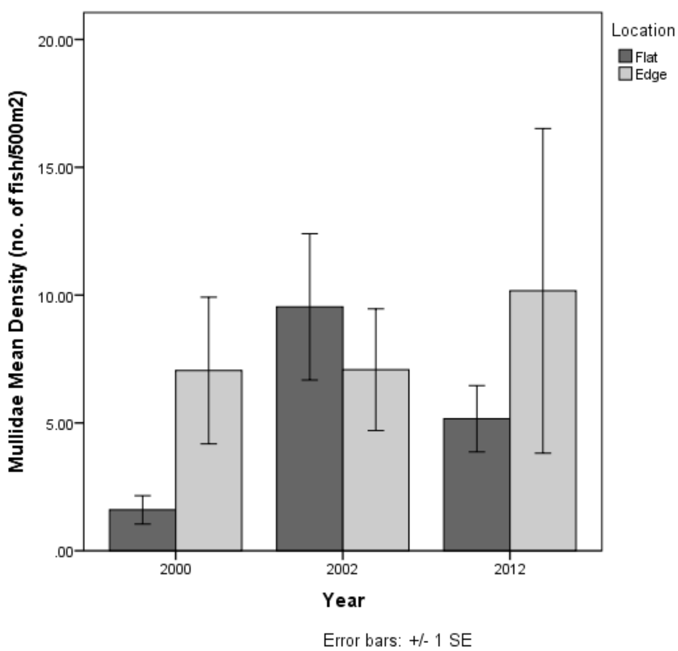

Figure 75. Comparison of mean density of for Mullidae between Reef Flat and Reef Edge over the years (2000, 2002, and 2012) in Nabq.

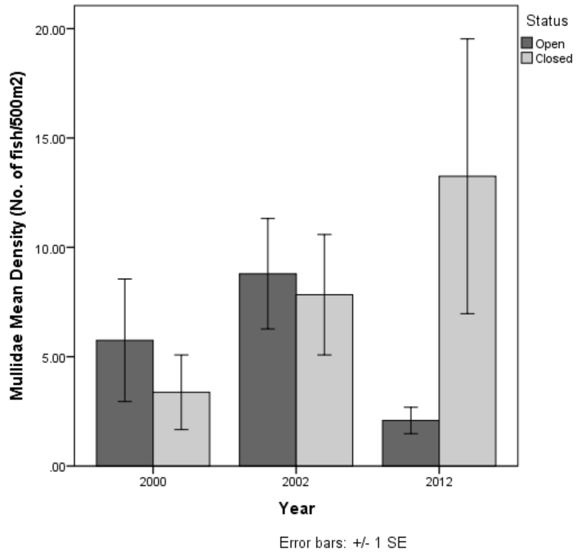

Figure 76. Comparison of mean density for Mullidae between Take Zones (Open) and No Take (Closed) Zones over the years (2000, 2002, and 2012) in Nabq. Error bars represent +/-1 standard error.

Changes in Density for Serranidae

There was a significant difference between reef flat reef edge (Table 35), with reef edge higher in density 1.9 fish/500m² than the reef flat (Figure 77). Additionally there was a significant difference in density between years, with 2002 having the most fish (2.2 fish/500m²) 4 times greater than fish density observed 2012 the least (Figure 78). Although Serranidae disappeared from the reef flat in the take zones in 2012(Figure 79), there was no significant difference in density for any of the interaction between the three fixed effects year, fishing status and depth.

Table 35. Results of the Generalized Linear Mixed Model test for the density of Serranidae, in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Serranidae				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Year	2	7	18.54	0.0016*
Fishing Status	1	4	0.86	0.4057
Depth	1	4	17.17	0.0143*
Year*Fishing Status	2	7	0.25	0.7851
Year*Depth	2	7	2.33	0.1531
Fishing Status*Depth	1	4	0.67	0.4595
Year*Fishing Status*Depth	2	7	18.54	0.0016*

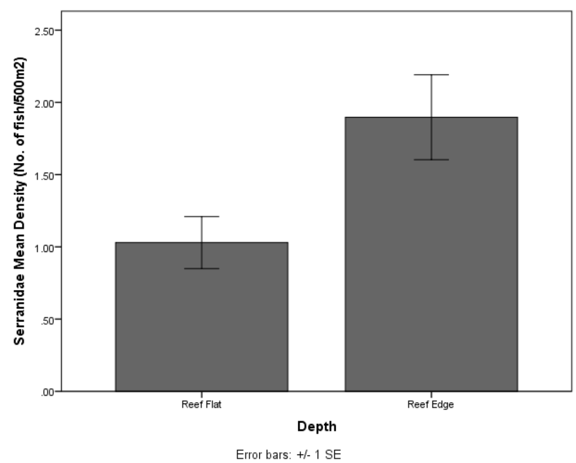

Figure 77. Comparison of mean density for Serranidae between reef flat and reef edge in Nabq. Error bars represent +/-1 standard error.

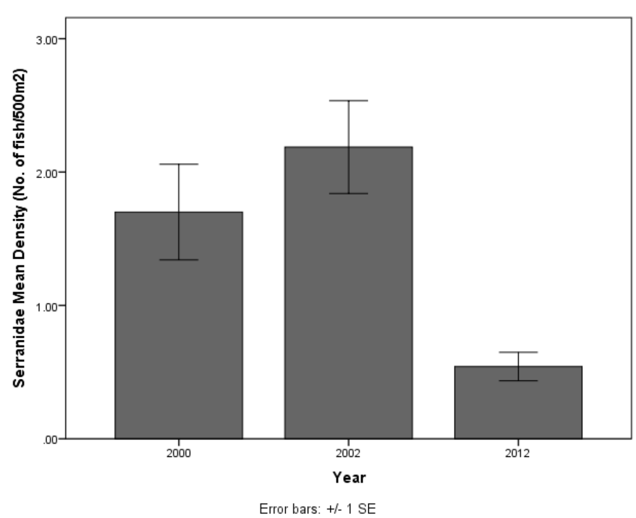

Figure 78. Comparison of mean density for Serranidae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

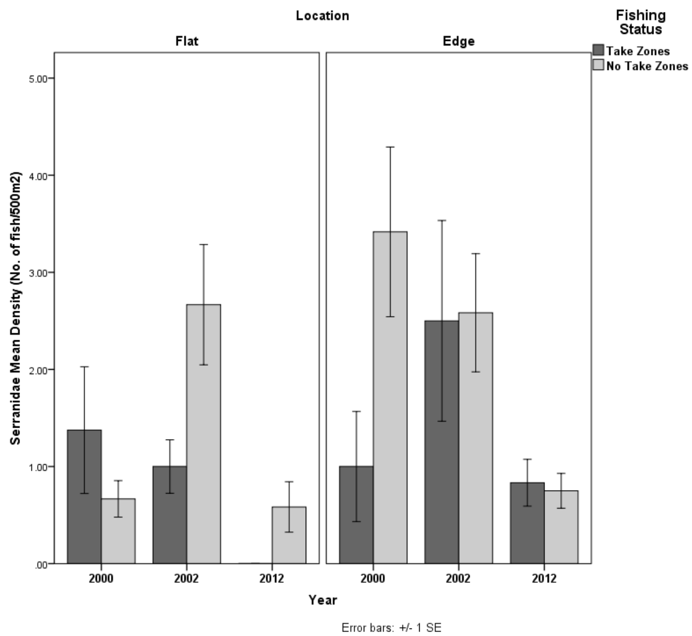

Figure 79. Mean fish density for Serranidae at reef flat and reef edge in the take and no take zones during summers 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error

Changes in Density for Lutjanidae

Density of Lutjanidae was significantly different between the studied years with 2002 the highest (4.1 fish/500m²) and 2000 (1.2 fish/500m²) the lowest (Figure 80). Although reef flat was more abundant than reef edge and the TZs were more abundant than the NTZs, both were not significantly different in density. However across the studied years (2000, 2002 and 2012) both depth and fishing status were significantly different in Lutjanidae density (Table 36). Additionally Lutjanidae disappeared from the reef flat of the NTZs in 2012 (Figure 81).

Table 36. Results of the Generalized Linear Mixed Model test for the density of Lutjanidae, in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

GLIMMIX Test for Lutjanidae				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Year	2	7	40.53	0.0001*
Fishing Status	1	4	0.21	0.6692
Depth	1	4	0.13	0.7354
Year*Fishing Status	2	7	10.23	0.0084*
Year*Depth	2	7	17.36	0.0008*
Fishing Status*Depth	1	4	26.52	0.0067*
Year*Fishing Status*Depth	2	7	40.53	0.0001*

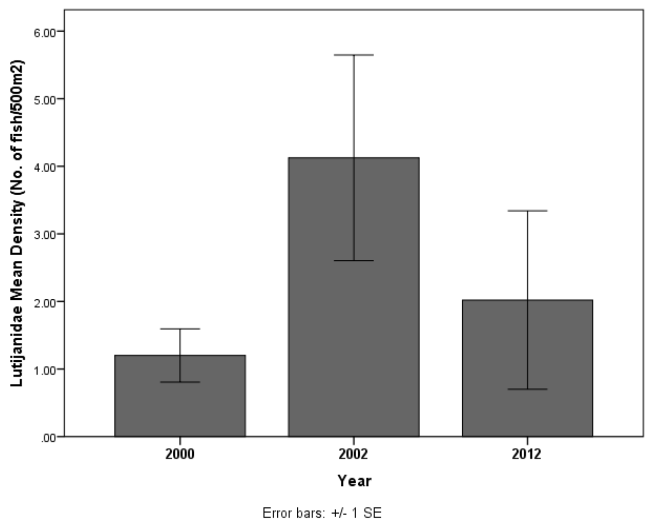

Figure 80. Comparison of mean density for Lutjanidae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

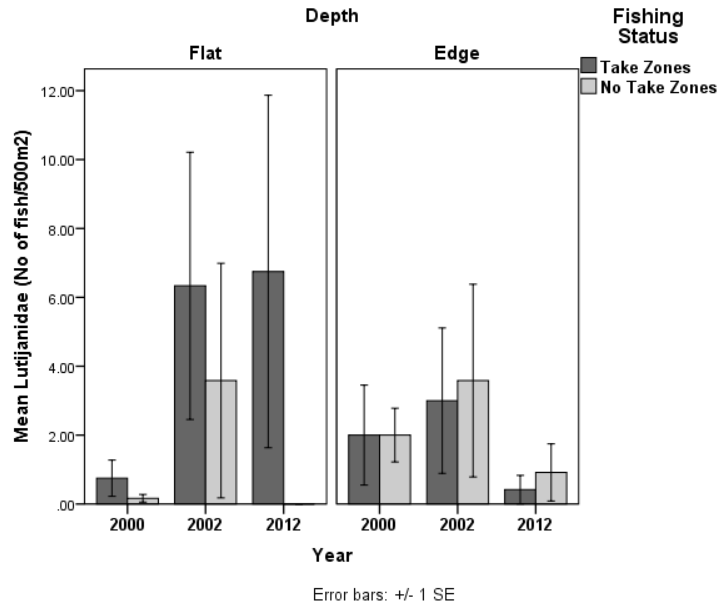

Figure 81. Mean fish density for Serranidae at reef flat and reef edge in the take and no take zones during summers 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Lethrinidae

Lethrinidae was the least carnivore family observed over studied years, only 182 individuals were counted. It showed a high significant difference in density between years (P=0.0004) with 2002 the highest (2.5 fish/500m²) 5 times greater than 2012 the lowest (Figure 82). Additionally reef edge was significantly (P=0.0004) higher in density (2.4 fish/500m²) than reef flat (0.25 fish/500m²) (Figure 83). However NTZs didn't show a significant difference in density from the TZs, and the interaction between the fishing status and year was insignificant.

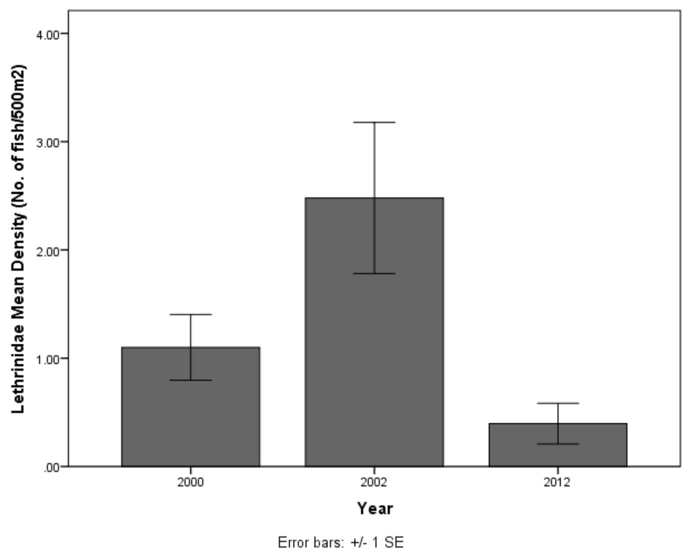

Figure 82. Comparison of mean density for Lethrinidae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

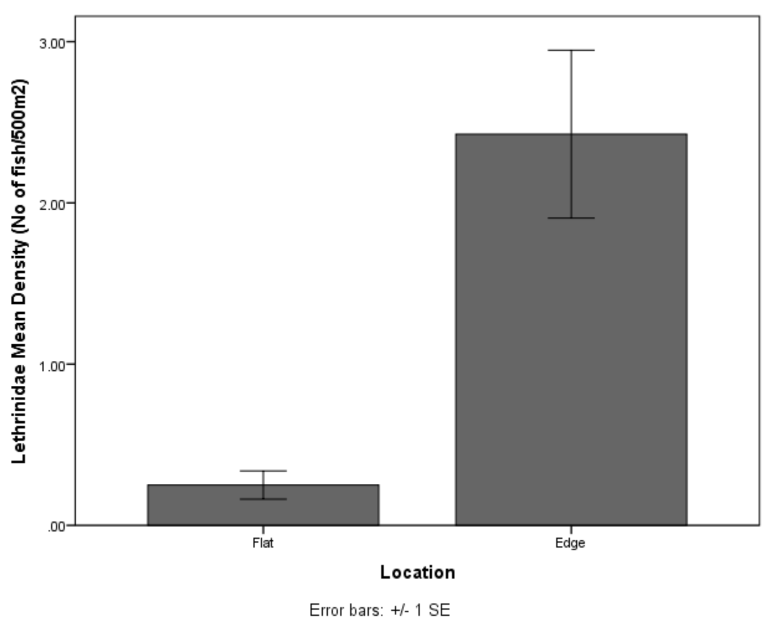

Figure 83. Comparison of mean density for Lethrinidae between reef flat and reef edge in Nabq. Error bars represent +/-1 standard error.

Changes in Density for Chaetodontidae

There was a significant difference (P=0.0028) in Chaetodontidae density between the studied years where 2002 was the most abundant 20.7 fish/500m^{2}and 2012 was the least 16.6 fish/500m^2 (Table 37) and (Figure 84), and all the pair wise comparison for density between the three were also significant. Additionally the reef edge was significantly higher in density than the reef flat (Figure 85). There was no significant difference in density between the NTZs and the TZs in general, while there was a significant difference between the years with 2012 the least abundant. Pairwise comparison showed that the NTZs where significantly (adj. P=0.001) higher than the TZs in 2012 (Figure 86). The interactions between the fixed effects year, fishing status, and depth were significantly different and pairwise comparison showed that NTZs were significantly (adj. P<0.0001) higher in density than TZs on the reef flat in 2012 (Figure 87).

Table 37. Results of the Generalized Linear Mixed Model test for the density of Chaetodontidae, in Nabq, Gulf of Aqaba, Egypt. Significant results (p < 0.05) are indicated with an asterisk.

GLIMMIX Test for Chaetodontidae				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Year	2	7	15.24	0.0028*
Fishing Status	1	4	2.85	0.1668
Depth	1	4	82.06	0.0008*
Year*Fishing Status	2	7	18.07	0.0017*
Year*Depth	2	7	0.44	0.6586
Fishing Status*Depth	1	4	7.22	0.0549
Year*Fishing Status*Depth	2	7	8.13	0.0149*

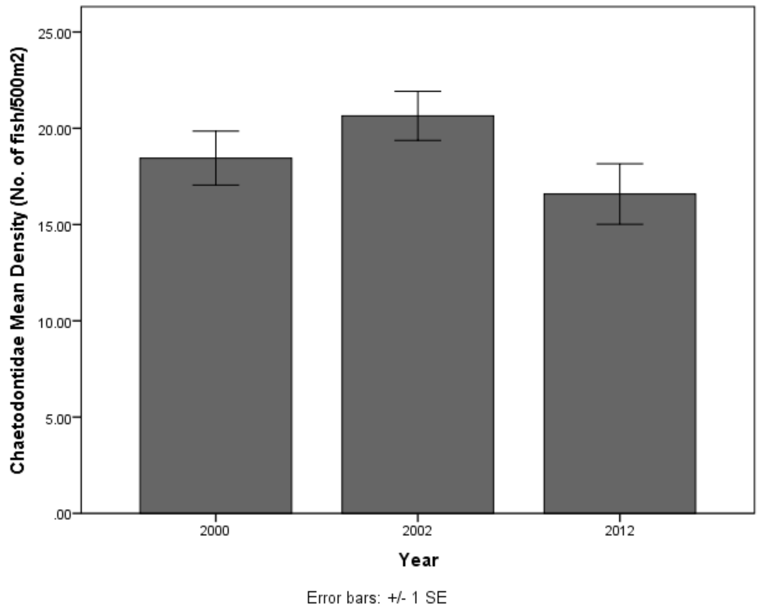

Figure 84. Comparison of mean density for Chaetodontidae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

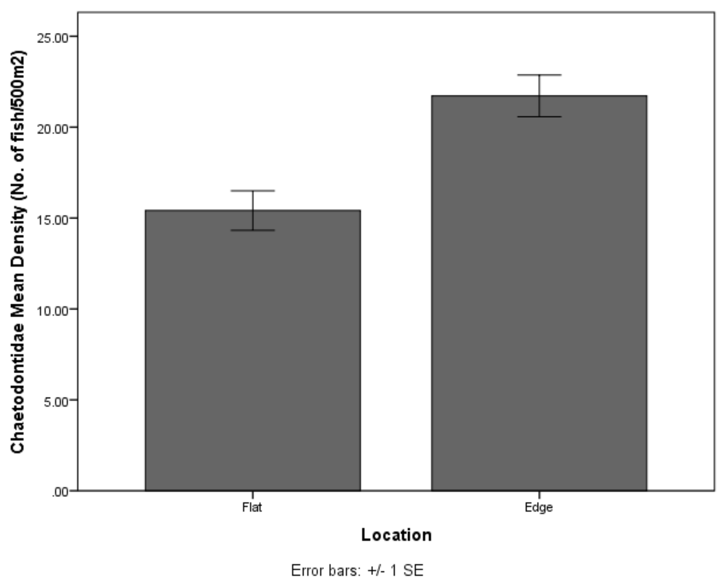

Figure 85. Comparison of mean density for Chaetodontidae between reef flat and reef edge in Nabq. Error bars represent +/-1 standard error.

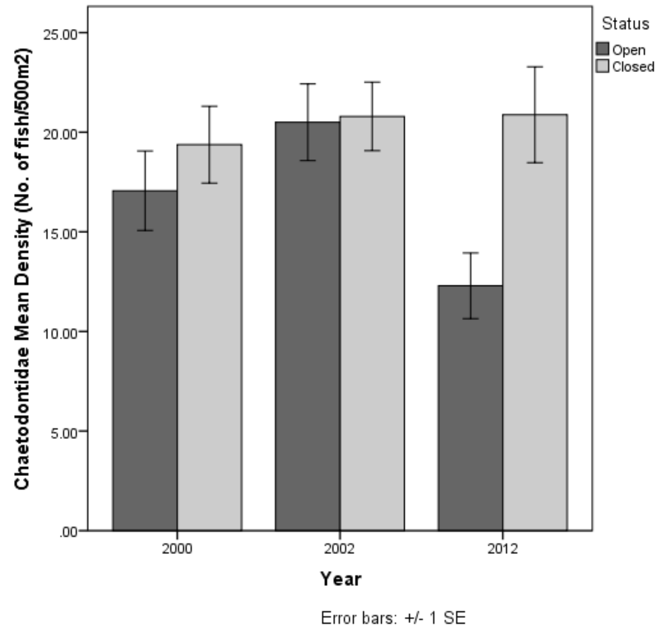

Figure 86. Comparison of mean density for Chaetodontidae between Take Zones (Open) and No Take Zones (Closed)over the years (2000, 2002, and 2012) in Nabq. Error bars represent +/-1 standard error.

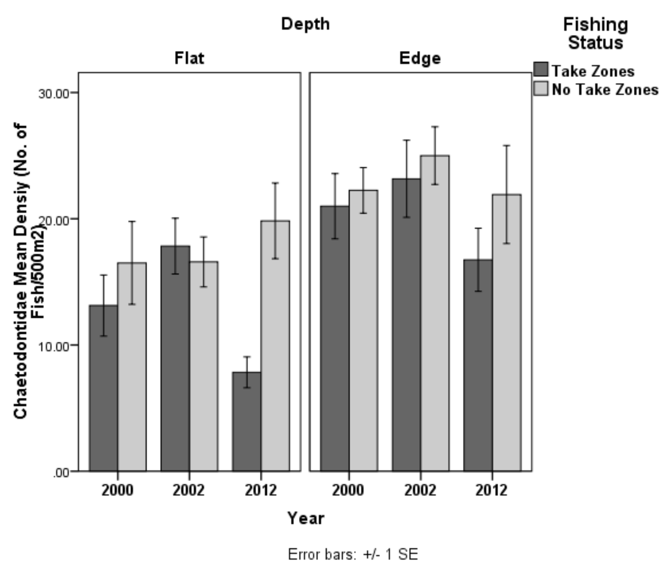

Figure 87. Mean fish density for Chaetodontidae at reef flat and reef edge in the take and no take zones during summers 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Changes in Density for Pomacanthidae

Only 103 fish were counted across the three years of the study, having Pomacanthidae the least family in abundance, it showed only a significant (P=0.0323) difference in density between years where 2002 was the most abundant (1.04 fish/500m²) and 2012 was the least (0.4 fish/500m²) (Figure 88). Additionally the reef edge was significantly (P=0.0358) higher in density than the reef flat (Figure 89). Although the NTZs was higher in density than the TZs (Figure 90) it was not significant, and the interactions between the fixed effects fishing status, depth and the year effect was not significant too.

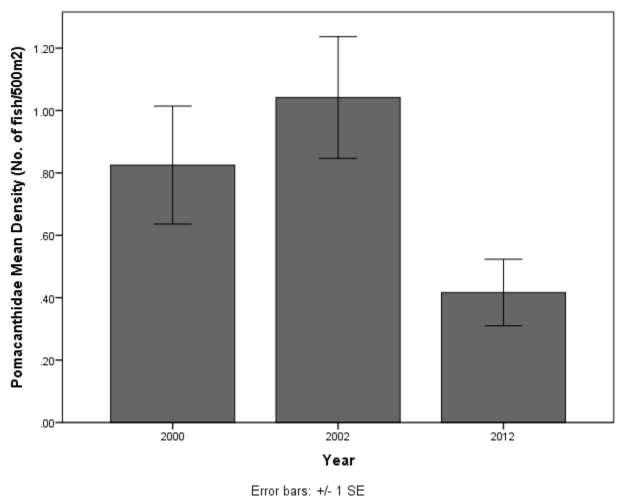

Figure 88. Comparison of mean density for Pomacanthidae between 2000, 2002, and 2012 in Nabq. Error bars represent +/-1 standard error.

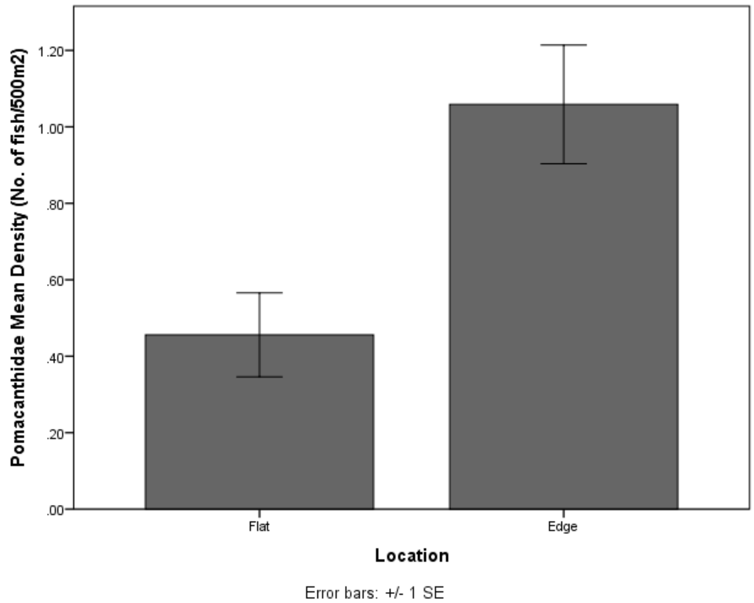

Figure 89. Comparison of mean density for Pomacanthidae between reef flat and reef edge in Nabq. Error bars represent +/-1 standard error.

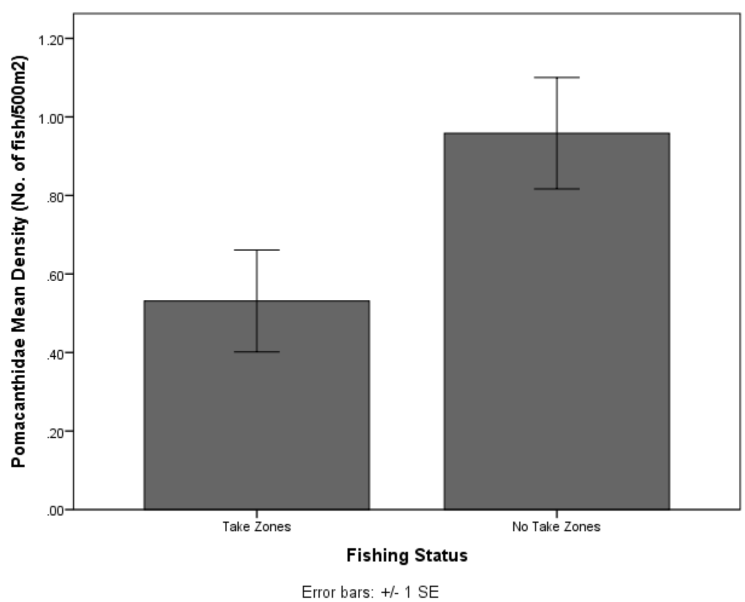

Figure 90. Comparison of mean density for Pomacanthidae between TZs and NTZs in Nabq. Error bars represent +/-1 standard error.

Changes in Species Abundance

Testing the species abundance using GLIMMIX was only applicable for 18 species from the 50, due to the fact that many of the target commercial species in the surveys especially in 2012 were rare causing the model not to converge. We therefore used the nonparametric Kruskal Wallis ANOVA to test the three main effects year, fishing status, and depth. We found that 22 species were significantly different in abundance between years (Table 36), 9 species were significantly different between NTZs and TZs (Table 39) and 34 species were significantly different between reef flat and reef edge (Table 40).

Comparing species densities between the years revealed that there is a pattern in almost all the 22 significantly different species where they increased in density in 2002 then decreased sharply by 2012. This pattern was more obvious in the large bodied herbivore species (TL>30cm) (*Naso unicornis, Cetoscarus bicolor, Scarus ghobban, Scarus frenatus, Hipposcarus harid*) (Figure 91), and also for the target carnivore species (*Epinephelus fasciatus, Epinephelus tauvina, Lutjanus ehrenbergii, Lutjanus bohar, Lethrinus mohsena and Lethrinus nebulosus*) (Figure 92). Additionally by 2012 we found that 8 species disappeared from the survey, 6 of them were commercially target species (*Acanthurus gahhm, Naso unicornis, Scarus ghobban, Lutjanus ehrenbergii, Macolor niger,* and *Lethrinus nebulosus*), with the remaining 2 considered indicators to the coral reef health (*Chaetodon semilarvatus* and *Pomacanthus maculosus*).

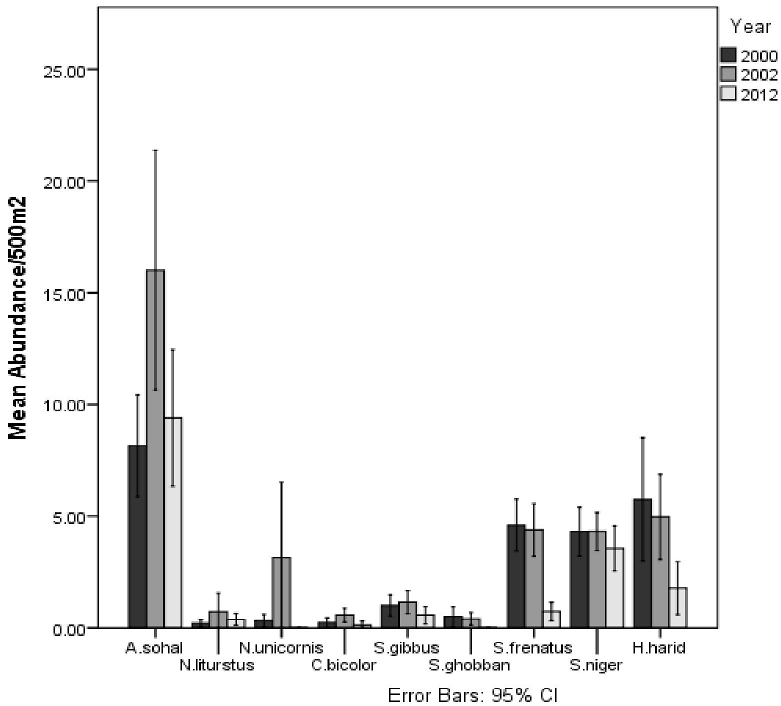

Figure 91. Mean abundance of large body mid trophic level herbivores species from Families Acanthuridae and Scaridae during summers 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

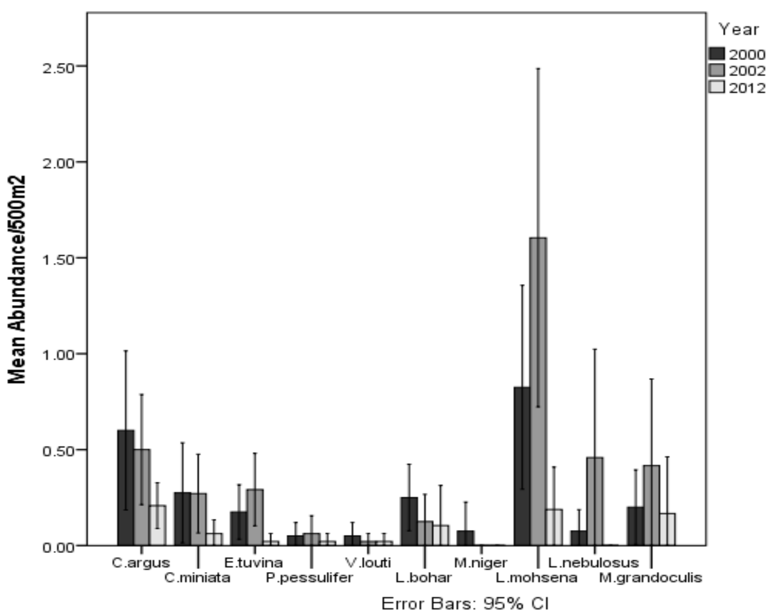

Figure 92. Mean abundance of large body top trophic level species (Serranidae, Lutjanidae, and Lethrinidae) during summers 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error.

Comparing species density between NTZs and TZs showed that only 5 commercial species were significantly higher in the NTZs than the TZs (Table 37) with the carnivores target species *Cephalopholis miniata*, *Epinephelus tauvina,* and *Macolar grandoculis* the lowest in density 0.09 fish/500m², 0.06 fish/500m², and 0.16 fish/500m² respectively. Comparing species densities between the reef flat and reef edge revealed that depth was the main factor in species (34 species) distribution over the reef. On the reef flat only 8 species were significantly higher than on the reef edge (Table 40), 6 of them were herbivores (*Acanthurus nigrofuscus, Ctenochaetus striatus, Siganus luridus*, *Siganus rivulatus*, , *Scarus psittacus, and Scarus Sordidus*) and constitute 84% of the total fish abundance on the reef flat, with *Acanthurus nigrofuscus* the dominant species 59%. These herbivores group were observed moving together in schools over the reef flat, meanwhile *Epinephelus fasciatus* was found to be the only carnivore with significant higher density on the reef flat.

In contrary to the reef flat, 26 species were significantly higher in density on the reef edge representing 26% of the total fish abundance on the reef edge, dominated by large bodied herbivores 16%, coral reef health indicator (Chaetodontidae, and Pomacanthidae) 8%, and the commercial carnivores species 2% (Table 40).

Table 38. Mean species abundance per 500m² and results of Kruskal Wallis ANOVA tests for fish density between 2000, 2002 and 2012 in Nabq, only species with significant difference between years are shown. Significant level is $p < 0.05$. Commercial species indicated by asterisks.

Families	Species	Year			
		2000	2002	2012	Kruskal Wallis
		Mean	Mean	Mean	Asymp. Sig.
Acanthuridae	*Acanthurus nigrofuscus**	123.33	181.77	91.98	.000
	*Ctenochaetus striatus**	27.55	31.10	20.06	.000
	*Zebrasoma desjardinii**	3.43	4.85	3.56	.004
	Zebrasoma xanthurum	3.25	3.92	1.88	.008
	*Naso unicornis**	.33	3.15	0.00	.000
Siganidae	*Siganus luridus**	7.48	16.40	13.10	.000
	*Siganus rivulatus**	1.93	17.58	.46	.002
Scaridae	*Cetoscarus bicolor**	.23	.56	.13	.018
	*Scarus ghobban**	.50	.40	0.00	.003
	*Scarus sordidus**	20.60	31.94	7.46	.000
	*Scarus frenatus**	4.60	4.38	.73	.000
	*Hipposcarus harid**	5.75	4.96	1.77	.000
Serranidae	*Epinephelus fasciatus**	.55	1.04	.21	.001
	*Epinephelus tauvina**	.18	.29	.02	.017
Lutjanidae	*Lutjanus ehrenbergii**	.70	3.77	0.00	.003
	*Lutjanus bohar**	.25	.13	.10	.020
Lethrinidae	*Lethrinus mahsena**	.83	1.60	.19	.001
	*Lethrinus nebulosus**	.08	.46	0.00	.032
Chaetodontidae	*Chaetodon paucifasiatus*	3.00	3.29	1.65	.002
	Chaetodon austriacus	4.60	5.81	3.63	.025
	Chaetodon semilarvatus	.15	.33	0.00	.012
Pomacanthidae	*Pomacanthus maculosus*	.13	.06	0.00	.047

Table 39. Mean species abundance per 500m² and results of Kruskal Wallis ANOVA tests for fish density between NTZs and TZs in Nabq, only species with significant difference between years are shown. Significant level is $p < 0.05$, commercial species indicated by a

Families	Species	Fishing Status		Asymp. Sig.
		TZs Mean	NTZs Mean	
Acanthuridae	*Zebrasoma desjardinii*	4.6406	3.3889	.046
	*Zebrasoma xanthurum**	1.6563	4.1944	.000
Scaridae	*Scarus frenatus**	2.3906	3.8333	.028
Serranidae	*Cephalopholis miniata**	.0938	.2917	.018
	*Epinephelus tauvina**	.0625	.2500	.033
Lethrinidae	*Macolar grandoculis**	.1563	.3611	.047
Chaetodontidae	*Chaetodon paucifasiatus*	2.1563	3.0417	.006
	Chaetodon trifascialis	.8750	1.7361	.008
Pomacanthidae	*Pomacanthus diacanthus*	.4375	.7639	.032

Table 40. Mean species abundance per 500m² and results of Kruskal Wallis ANOVA tests for fish density between reef flat and reef edge in Nabq, only species with significant difference between years are shown. Significant level is $p < 0.05$, species higher in density over the reef flat indicated by asterisks.

Families	Species	Depth		
		Reef Flat Mean	Reef Edge Mean	Asymp. Sig.
Acanthuridae	*Acanthurus nigrofuscus**	199.1765	66.6029	.000
	Acanthurus sohal	8.0294	14.6912	.000
	*Ctenochaetus striatus**	29.0000	23.3235	.013
	Zebrasoma desjardinii	3.7647	4.1912	.021
	Naso liturstus	.0588	.8235	.000
	Naso unicornis	.0882	2.3235	.000
Siganidae	*Siganus luridus**	16.1618	9.0588	.001
	*Siganus rivulatus**	12.8235	1.0441	.007
Scaridae	*Cetoscarus bicolor*	.0441	.5735	.000
	Scarus gibbus	.2059	1.5882	.000
	Scarus ghobban	.3676	.2059	.044
	*Scarus sordidus**	26.0441	13.8824	.030
	Scarus ferrugineus	1.2794	1.8088	.012
	Scarus niger	3.4412	4.6471	.009
	*Scarus psittacus**	.7941	.3676	.025
Mullidae	*Parupeneus forsskali**	3.8529	1.2794	.003
	Parupeneus cyclostomus	.8676	1.7647	.000
Serranidae	*Cephalopholis argus*	.0735	.7794	.000
	Cephalopholis miniata	0.0000	.3971	.000

Table 38 (cont'd)

Serranidae	*Epinephelus fasciatus**	.8088	.3971	.018
	Epinephelus pessuliferus	0.0000	.0882	.023
	Variola louti	0.0000	.0588	.043
Lutjanidae	*Lutjanus bohar*	.0147	.2941	.001
Lethrinidae	*Lethrinus mohsena*	.2059	1.5441	.000
	Lethrinus nebulosus	.0294	.3382	.030
	Macolor grandoculis	.0147	.5147	.001
Chaetodontidae	*Chaetodon paucifasiatus*	2.2059	3.0441	.036
	Chaetodon austriacus	3.0294	6.3382	.000
	Chaetodon trifascialis	.6912	1.9706	.000
	Chaetodon semilarvatus	0.0000	.3235	.001
	Heniochus intermedius	.2647	1.7206	0.0000
Pomacanthidae	*Pomacanthus imperator*	.0294	.1471	0.0160
	Pomacanthus maculosus	.0147	.1029	0.0294
	Pomacanthus diacanthus	.4118	.8088	0.0251

The algal grazers *Acanthurus nigrofuscus* was the most abundant species from the 50 surveyed with an average 50% of the total abundance over the three years of the study, this small (TL=10cm) algal grazer was used as an indicator for the second effect of the removal of carnivores (Serranidae, Lutjanidae and Lethrinidae), since the removal of such predators increase their abundance. As such it was important to test the density difference of this species and how this correlated to other species. Using GLIMMIX to test the difference in density for *Acanthurus nigrofuscus* showed that there was no significant difference in density between the NTZs and the TZs, but there was a significant difference between the years with 2002 the most abundant and 2012 the least. Additionally there was a significant difference between depths with reef flat three times greater in abundance than the reef edge. All the interaction between the three effects year, fishing status, and depth were significantly (Table 41) (Figure 93&92).

It was observed from the surveys that the abundance of this species is affected the presence of other large bodied species either they compete them on food and space like other Acanthuridae species and Scaridae or prey on them like Serranidae species, as such we used the nonparametric Spearman's rho correlation analysis to test the relationship between *Acanthurus nigrofuscus* and those species in the assemblage, the results showed that there was a highly significant negative correlation between *Acanthurus nigrofuscus* and the large Acanthuridae (*Acanthurus sohal* and *Naso liturstus*), large Scaridae (*Cetoscarus bicolor* and *Scarus gibbus*), and large Serranidae (*Cephalopholis argus*) (Table 42).

Table 41.Results of the Generalized Linear Mixed Model test for the density of Acanthurus nigrofuscus, in Nabq, Gulf of Aqaba, Egypt. Significant results ($p < 0.05$) are indicated with an asterisk.

Effect	Num DF	Den DF	F Value	Pr>F
Year	2	7	777.73	<.0001*
Fishing Status	1	4	0.94	0.3862
Depth	1	4	3307.68	<.0001*
Year*Fishing Status	2	7	22.6	0.0009*
Year*Depth	2	7	329.19	<.0001*
Fishing Status*Depth	1	4	206.22	0.0001*
Year*Fishing Status*Depth	2	7	39.5	0.0002*

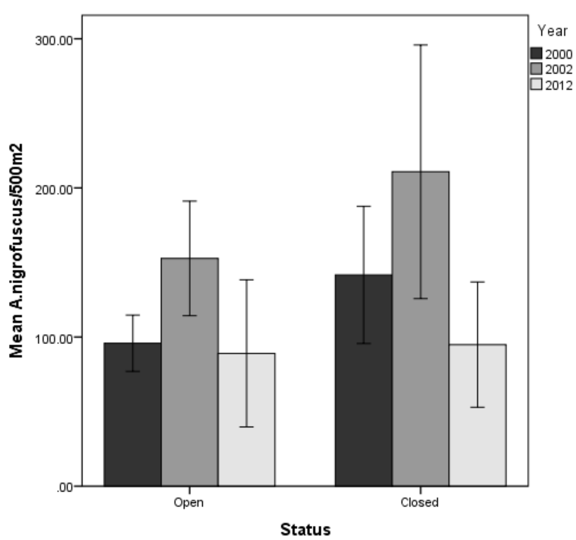

Figure 93. Comparison of mean density for *Acanthurus nigrofuscus* between Take Zones and No Take Zones over the years (2000, 2002, and 2012) in Nabq. Error bars represent +/-1 standard error.

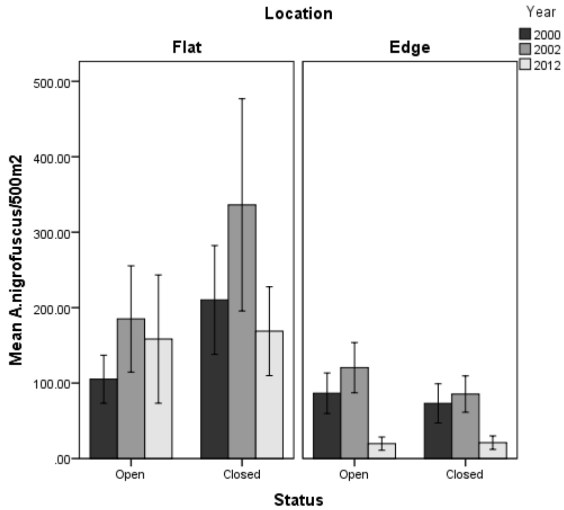

Figure 94. Mean fish density for *Acanthurus nigrofuscus* at reef flat and reef edge in the take and no take zones during summers 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt. Error bars represent +/-1 standard error

Table 42. Results of the non-parametric Spearman's rho correlation analysis for Acanthurus nigrofuscus and other large bodied coral reef fish species from the fish surveyed across the summers 2000, 2002, and 2012 in Nabq, Gulf of Aqaba, Egypt.

Non parametric Spearman's rho		A. nigrofuscus		
Families	Species	Correlation Coefficient	Sig. (2-tailed)	N
Acanthuridae	A. sohal	-.266**	.002	136
Acanthuridae	N. liturstus	-.292**	.001	136
Scaridae	C. bicolor	-.286**	.001	136
Scaridae	S. gibbus	-.263**	.002	136
Serranidae	C. argus	-.259**	.002	136

Correlation is significant at the 0.01 level (2-tailed).

Catch and Fishing Grounds

The total fish catch of Ghargana village fishers was estimated and tested using the GLIMMIX, and it differed significant (P<0.0001) between the surveyed years (Figure 95). Between 1999 and 2008, estimated total catch ranged between 3144Kg. and 5340 Kg. (average 4018 Kg.), total estimated catch increased in 2010 to 8261Kg., while in 2012 it dropped to 4551Kg.

The total fishing effort by the fishers was estimated by numbers of landings/years in order to compare fishing effort between years. As with the catch we find effort to be the highest in 2010 (Figure 96).

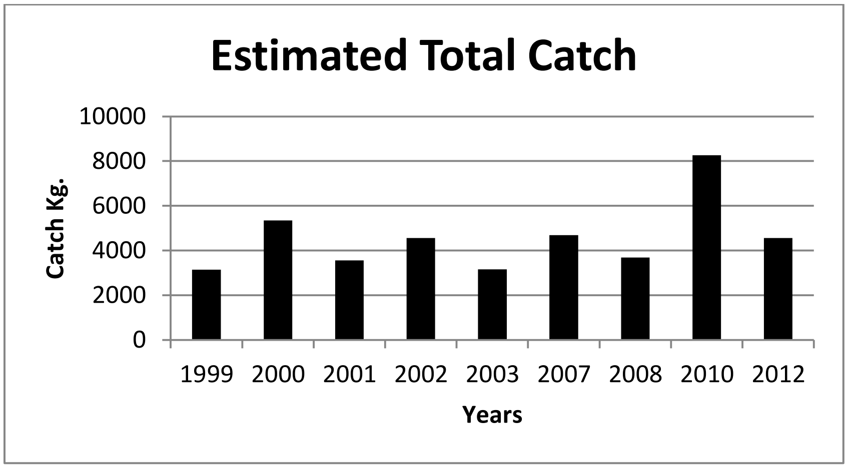

Figure 95. The estimated total Catch for Ghargana Village Fishers over the studied years (1999-2012) in Nabq.

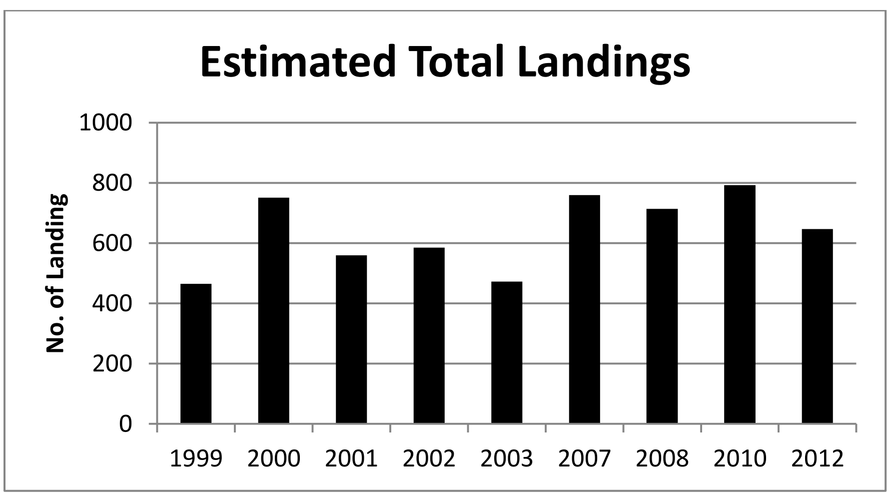

Figure 96. The estimated fishing effort (No. of landings) for Ghargana fishers in Nabq between 1999-2012.

The catch of Ghargana village fishers found to come mainly from 5 main fishing grounds from South to North as follow (Sohop, Ghargana, Qaraneia, Abo Zabad, and Umm Teena) (Figure 56). Ghargana fishing ground where the Bedouin Village was responsible for 51% of the catch in 1999, this percentage decreased over the years representing only 18% of the catch in 2010 and 2012 (Figures 97&98). Consequently other fishing grounds especially South and North of Ghargana (Sohop and Qaraneia), showed increases in contribution in the total catch over years as the local fishers start increasing their fishing effort (number of landing) on these sites (Figure 99). Additionally in 2010 and 2012 fishers start fishing the NTZs mainly north and south of Ghargana (El Tall and Dekeer sites under others in Figure 99 and 100), which greatly increasing the contribution of the catch from these sites representing 24% of the total catch in 2012.(Figure 43).

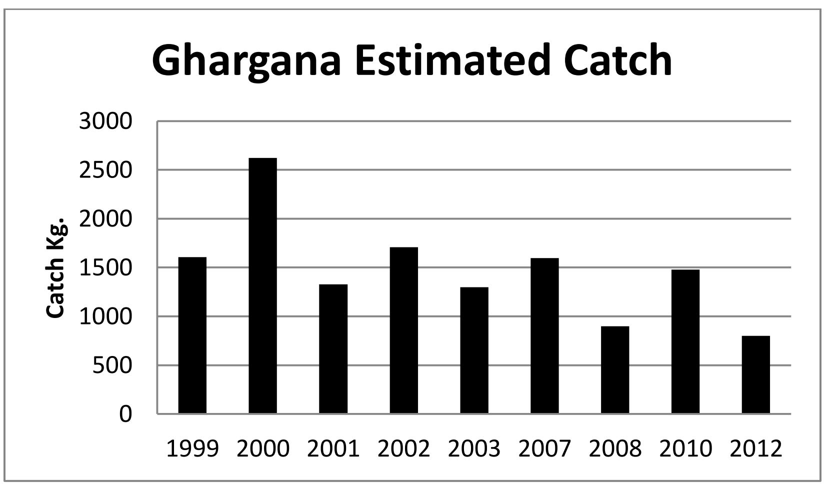

Figure 97. The estimated total catch of Ghargana fishing ground over the studied years(1999-2012).

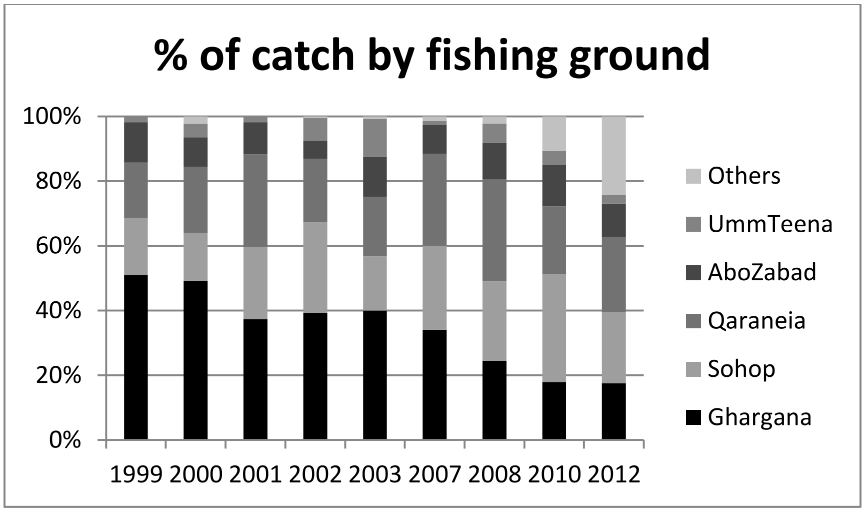

Figure 98. The percentage of the fishing production of Ghargana fishers from the main fishing grounds over the studied years (1999-2012).

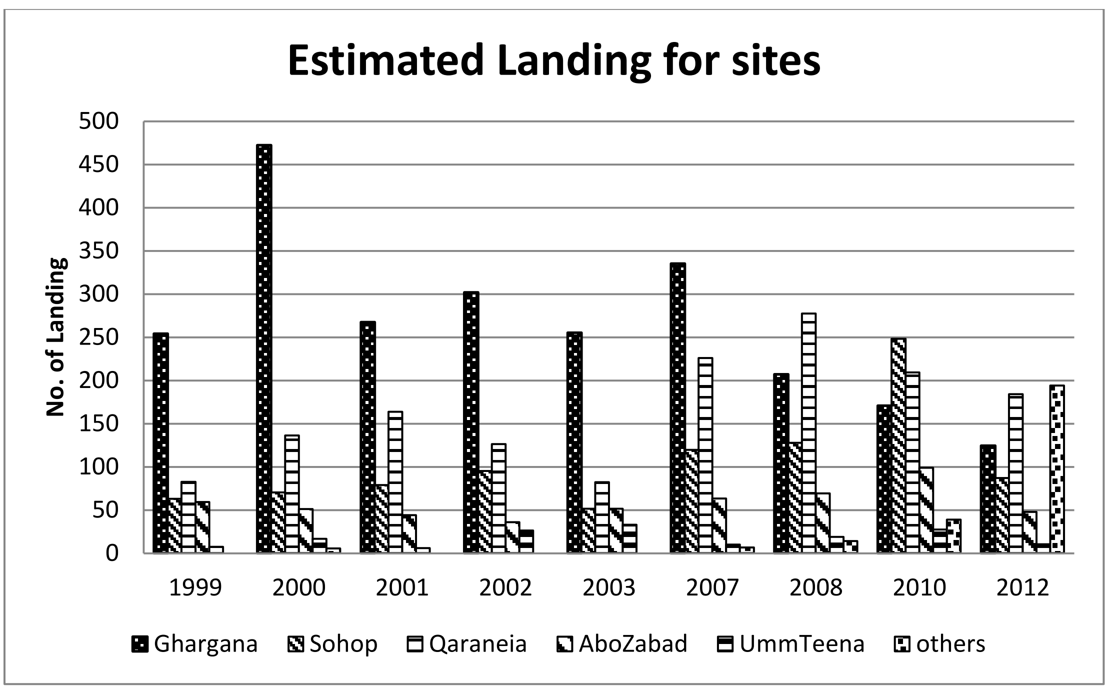

Figure 99. The estimated fishing effort by numbers of landing for the fishing grounds in Nabq over the studied years (1999-2012).

Catch Per Unit Effort CPUE (Kg./Landing) was calculated to compare between fishing grounds over years. We found that Ghargana fishing ground was the least productive of all sites over years, decreasing from 6.6 Kg./Landing in 1999 to 4.6 Kg./Landing in 2008. CPUE increased in 2010 recording 9.2 Kg./Landing due to the expansion of fishing into the NTZs, CPUE dropped to 6.6 kg./Landing in 2012. Fishing sites in the far south and north (Sohop and Umm Teena) of Ghargana provided the largest CPUE in general. CPUE from the NTZs (El Tall and Dekeer) started to appear in the catch in 2010 recording 20.38Kg./landing, which greatly decreased by 2012 to 5.75 Kg./landing (Figure 100).

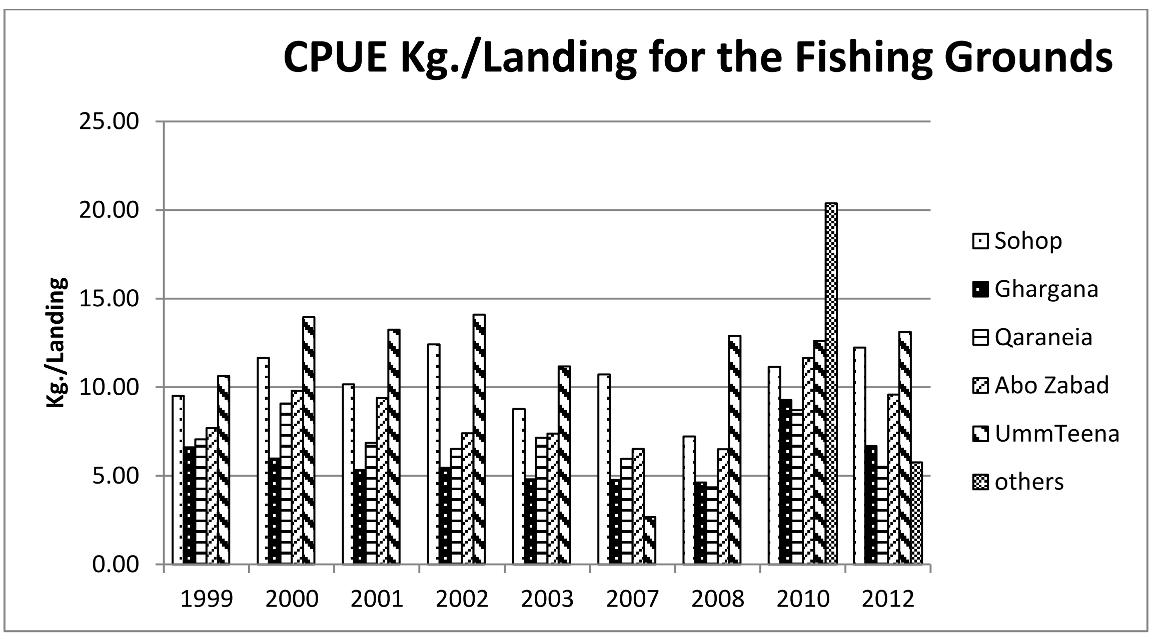

Figure 100. The Catch per Unit Effort (CPUE) kg./Landing for the main fishing grounds in Nabq over the studied years (1999-2012).

Catch and Fishing Techniques

Bedouin fishers use different fishing techniques (Drive Netting, Hook and Line, Closure and Overnight) with different catchability and efficiency in capturing fish. Each technique also had a different effort pattern through the year. Drive netting and hook and line are heavily used from April to September when the weather conditions are favorable for fishing, while in winter (November to April) due to the low sea water temperature and windy weather, the overnight technique was preferred with effort peaking for this technique during this time of the year. We also found that the closure technique was mainly used from September to December due to the seasonal fish aggregation of Muglidae, Gerreidae, and Sparidae. Due to this multi-techniques gear fisheries we calculated the catch for the different technique gear and we find that drive netting was the most often technique used, responsible for 59% of the catch of Ghargana fishers in 1999. This percentage increased to the maximum 70% in 2002, then decreased to 35% by 2012. Other less commonly used techniques such as closure, only responsible for 10% of the catch in 1999 was more used and capturing 34% of the estimated catch in 2012 (Figure 101).

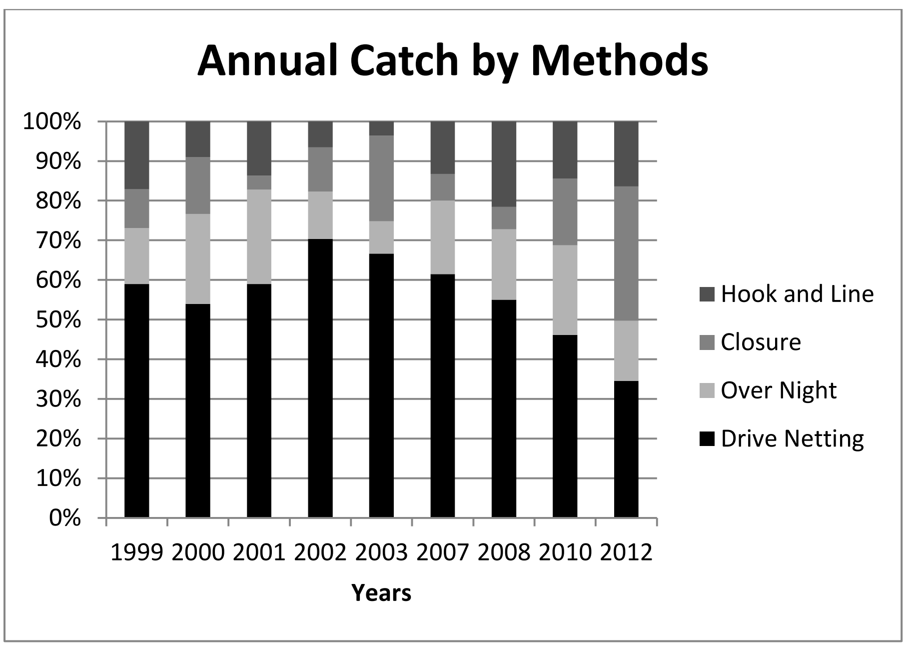

Figure 101. The percentages of the estimated catch from each fishing technique used by Ghargana fishers in Nabq over the studied years (1999-2012).

Catch Per Unit Effort CPUE was calculated for each techniques as Kg./Net*Hrs. for the net using techniques and as Kg./Line*Hrs. for the Hook and Line technique. We found that before 2010 the Catch Per Unit Effort for the Drive Netting (CPUEd) increased from 2.4 Kg./Net*Hrs. in 1999 to 4.14 Kg./Net*Hrs. in 2002, declining gradually to 2.57 Kg./Net*Hrs. by 2008. In 2010 the CPUEd increased to 4.36 Kg./Net*Hrs. and then decreased to 2.42 Kg./Net*Hrs. by 2012 (Figure 102).

The CPUE for the Hook and Line (CPUEh) shows a declining trend over the years studied. CPUEh declined from 1.55 Kg./Line*Hrs. in 1999 to 0.59 Kg./Line*Hrs. by 2012 a decrease of 62% over 13 years . The CPUE for the Closure technique CPUEc did not shows any major change between 1999 and 2008 ranged between 0.11 to 0.26 Kg./Net*Hrs., it increased to 0.7 Kg./Net*Hrs. in 2010 declining to 0.35 Kg./Net*Hrs. by 2012. CPUE for the Overnight technique CPUEo decreased from 0.35 Kg./Net*Hrs. in 1999 to 0.10 Kg./Net*Hrs. in 2003, increasing to 0.42 in 2010 and declining by 2012 to 0.22 Kg./Net*Hrs. (Figure 102).

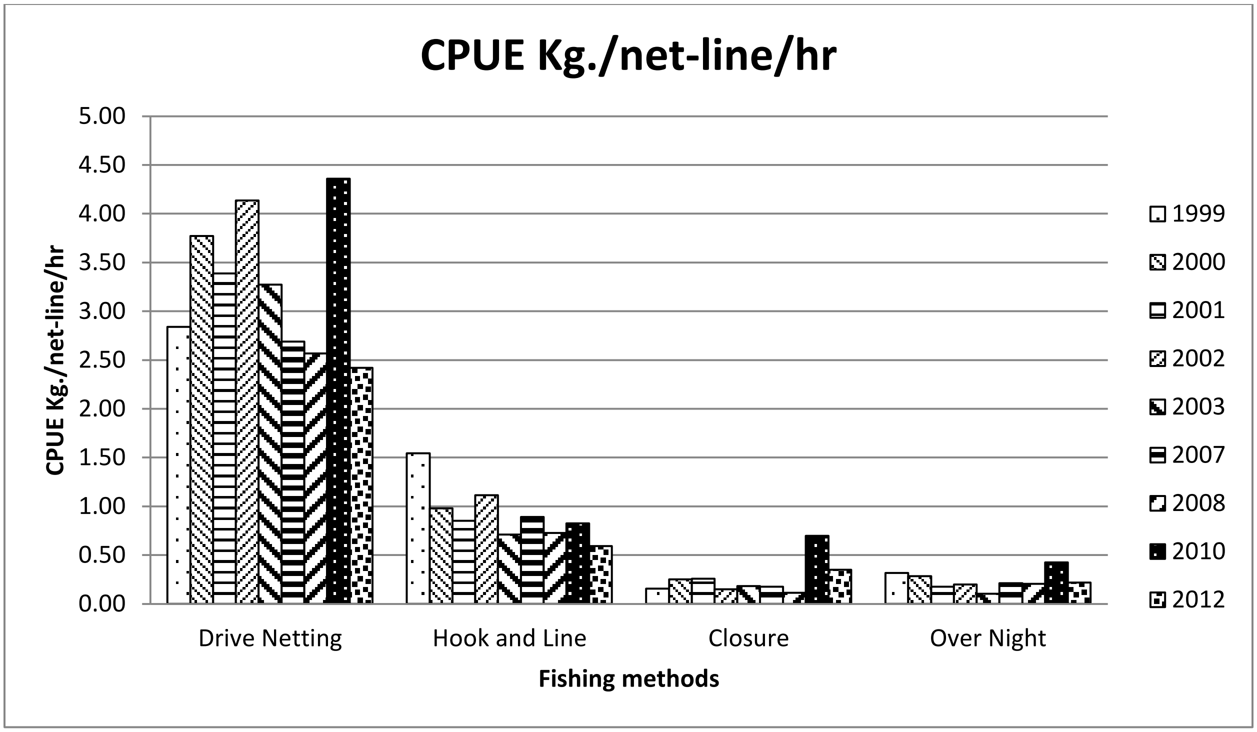

Figure 102. The Catch Per Unit Effort (CPUE) for the different fishing techniques used by Ghargana fishers over the studied years (1999-2012) in Nabq.

Catch Composition

From the analysis of the fish catch data over the studied years (1999-2012) we found that the catch was composed of 85 species representing 26 families (Appendix 4). Ten of these families represented 96-98% of the total catch abundance (Table 43) over the surveyed years, these families represented 4 trophic levels (Herbivores, Omnivores, Invertivores, and Carnivores), with the small (<20cm) herbivores Siganidae being the dominant family throughout the study.

In 1999 herbivores represented 65.3% of the total catch with Siganidae the dominant family (47%) of the total fish abundance followed by large bodied herbivore Scaridae (16.5%), while carnivores contributed 16.2% of the total catch abundance with Lethrinidae the dominant family (12%) (Figure 102 & Table 43). Herbivores increased in percentage in the total catch over the years (2000 to 2003) with Siganidae be more abundant in favor of the other large bodied herbivores as Scaridae, meanwhile the Carnivores families contribution to the total catch decreased dramatically over the same time period. The contribution of the herbivores in the total catch decreased gradually over the years 2007-2012, this decreased was associated with an increase in the target carnivores contribution in the catch, reached its highest record 21.8% in 2010. Additionally the omnivores and invertivores families increased in abundance by 2012 represented 28.8% of the total catch in 2012.

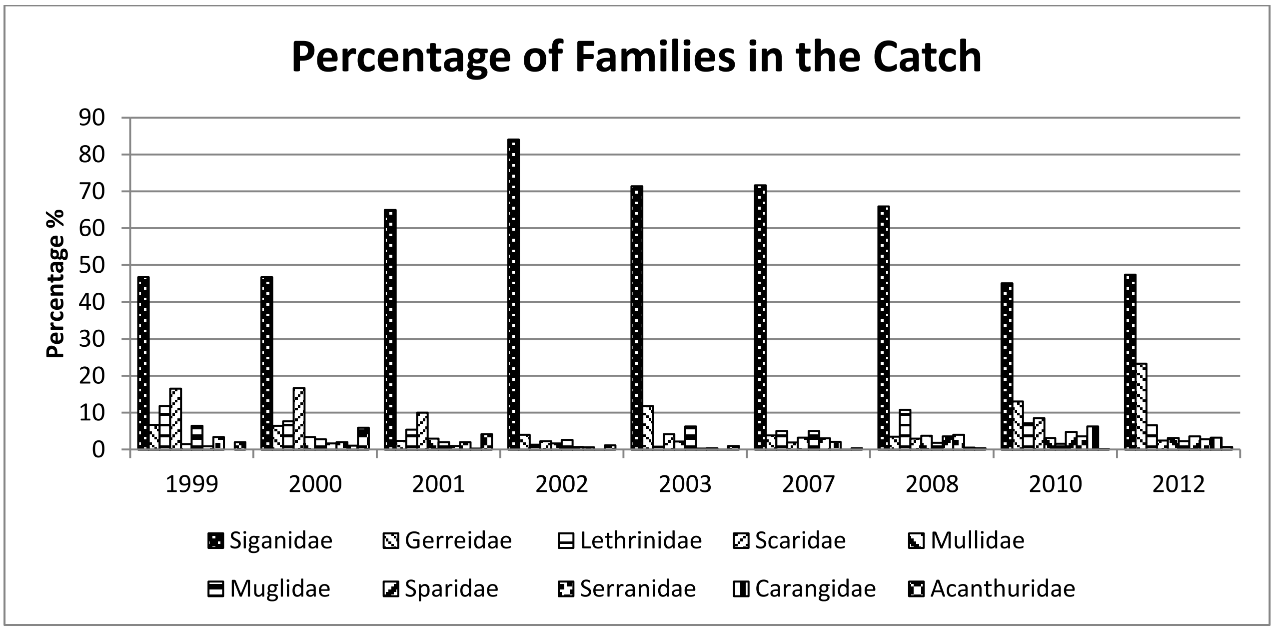

Figure 103. The catch composition of Ghargana fishers over the surveyed years (1999-2012) in Nabq.

Table 43. The percentages of fish trophic levels and their families caught by Ghargana fishers in the total catch of Ghargana over the studied years 1999-2012.

Trophic level	**Families**	**1999 %**	**2000 %**	**2001 %**	**2002 %**	**2003 %**	**2007 %**	**2008 %**	**2010 %**	**2012 %**
Herbivores	**Siganidae**	46.8	46.7	65.0	84.1	71.4	71.7	66.0	45.0	47.4
	Scaridae	16.5	16.7	10.0	2.3	4.2	1.9	2.9	8.6	2.5
	Acanthuridae	2.1	5.9	4.2	1.2	1.0	0.3	0.4	0.2	0.7
Subtotal		**65.3**	**69.3**	**79.2**	**87.5**	**76.6**	**73.9**	**69.3**	**53.9**	**50.6**
Omnivores	**Muglidae**	6.4	2.8	2.0	2.6	6.3	5.1	1.9	1.6	2.3
Invertivores	**Gerreidae**	6.7	6.4	2.4	4.0	11.9	3.9	3.5	13.1	23.3
	Mullidae	1.5	3.4	3.0	1.7	2.2	3.2	3.8	3.2	3.2
Subtotal		**14.6**	**12.7**	**7.4**	**8.3**	**20.4**	**12.2**	**9.1**	**17.9**	**28.8**
Carnivores	**Lethrinidae**	11.9	7.6	5.4	1.3	0.8	5.1	10.8	7.1	6.6
	Serranidae	3.4	2.0	2.0	0.7	0.3	2.1	4.1	3.6	2.8
	Sparidae	0.9	1.7	1.0	0.7	0.3	3.0	3.6	4.8	3.6
	Carangidae	0.0	1.1	0.3	0.1	0.0	0.1	0.6	6.3	3.2
Subtotal		**16.2**	**12.5**	**8.8**	**2.8**	**1.4**	**10.4**	**19.1**	**21.8**	**16.3**
	Total %	**96.1**	**94.5**	**95.4**	**98.7**	**98.5**	**96.5**	**97.5**	**93.5**	**95.6**

Discussion

Total Species and Diversity of the Fish Assemblage

There was no significant difference between NTZs and TZs in total number of species in the fish assemblage, indicating that fishing pressure was not significantly changing the total species composition between NTZs and TZs. This may be due to the proximity of these site to each other which enables the movement of species between fished and un-fished sites. The year effect however was significantly different with 2012 having the least number of species. Pair wise comparison between the years indicated that total species had significantly decreased in Nabq 2012 compared to 2000 and 2002, likely due to the worsen fishing activities over this time period in addition to fishing in the NTZs due to the non-compliance of the fishers.

Comparing the six surveyed sites showed that they were significant difference with Ghargana having the least number of species. This could be due to the direct impact from increased fishing effort at Ghargana where the fishermen live having it the most heavily fished site in Nabq (Galal

1999, Galal et al. 2002, Ashworth & Ormond 2005). In addition, this change in number of fish species could be due to the change in the habitat (Algal shift at the reef flat) due to net fishing over the reef flat where fishers walk over the reef trampling the life coral (Mabrouk 2003 unpublished).

The GLIMMIX test revealed that the reef edge has significantly more fish species and diversity H` (Shannon-Wiener index) than the reef flat, which was expected as the reef edge is the highest coral cover and divers zone on the reef providing a good habitat for different fish species and as a results the associated fishes species were higher than any other zone on the reef (Williams 1991). Additionally the reef flat was the zone where most of the fishing activities occurred and so it was heavily fished (Galal 1999, Ashworth 2004) and this negatively impacted the total species, having the reef edge (less fished) zone with more fish species and fish diversity.

While there was no change in fish diversity over years or between the NTZs and the TZs, or any of the interactions. Comparing sites shows a significant difference and Ghargana was the lowest diversity index. This indicate that heavily fishing pressure at Ghargana could be responsible for this decline.

<u>Changes in the Assemblage Abundance</u>

Comparing the fish density for the fish assemblage of the 50 species (9 families) showed a significant increase in 2002 and a significant decline by 2012 to be the least in mean fish density, indicating that fishing activities between 2002 to 2012 had a negative impact on the total abundance of the fish assemblage.

There was no significant difference in fish abundance between NTZs and TZs, while there was a significant interaction between the fishing status, depth and year. Fish density was significantly higher in the NTZs than the TZs at the reef flat (the heavily fished zone over the reef) in 2000 and 2002, while in 2012 there was no significant difference, as the NTZs was also fished. Depth was shown to be a significant factor in determining the distribution of the fish assemblage over the reef, with reef flat significantly higher in fish density than the reef edge in the three years of the study, since the wide reef flat in Nabq provide a good habitat for the algal grazers families (Acanthuridae, Scaridae and Siganidae). That explain why the later were found to be the dominant families in the fish assemblage with an average 89% over the three years, similar results were found in Galal (1999) and Ashworth (2004).

The commercially targeted families (Scaridae, Serranidae, and Lutjanidae) and the non-target families (Chaetodontidae and Pomacanthidae) were significantly different in abundance between sites and Ghargana village was the least abundant . This could be due to the difference in fishing effort between the sites, and due to the heavily fishing activities at Ghargana, which did not just extremely decreased the abundance of the target commercial families like Serranidae and Lutjanidae which are first to be decline (Russ 1985, Roberts & Polunin 1991), but it also decreased the abundance of the non-target families (Chaetodontidae and Pomacanthidae) too, as it entangled in the nets and discarded as by catch (Galal 1999).

Changes in Families Abundance

All families were significantly different in abundance over years, increasing from 2000 to 2002 and then declining by 2012. Pairwise comparison between 2002 and 2012 indicate that the commercial top trophic level (carnivores) families (Lutjanidae, Serranidae and Lethrinidae) were significantly decreased by (51%,75% and 84% respectively), that could be due to the continues illegal fishing activities mainly by line in the NTZs which reduce the total abundance of these families by 2012, and this explain why the Catch Per Unit Effort for Hook and Line (CPUEh) was declining to be the least by 2012. Earlier study only on the NTZs in Nabq showed that there was a significant increase in the abundance of these families from 1995 to 2000 (Galal et al. 2002). The commercial mid trophic level (herbivores) families Acanthuridae, Siganidae and Scaridae also significantly decreased by 47%,60% and 70% respectively from 2002 to 2012, This indicated that heavily and illegal fishing in Nabq did not just effect the abundance of the top trophic level of high value commercial fish families but it impacted fishes lower in the food web which has lower commercial value, similar results was found by Helpern (2003). The commercially targeted family Mullidae and the non-target family Chaetodontidae were the least impacted families from fishing activities. These relatively small species showed a weak responses to fishing (Molloy et al. 2009), as both are small in size which enabled them to escape capture or were discarded live after capture as they were not of interest to fishers as in the case of the Chaetodontidae family. Unlike these small fishes the larger size non-target family Pomacanthidae was highly impacted decreasing by 60% between 2002-2012.

Acanthuridae the dominant family in the assemblage over the reef flat and edge in Nabq (68%) was significantly increased in abundance in 2002 and decreased significantly by 2012. The interaction between the year and fishing status was significantly different with NTZs having higher abundances of fish than TZs in 2000 and 2002. Similar results were found by Ashworth (2004) from the heavily fished Dahab area north of Nabq, were increased fishing intensity not just decreased the top predators but also decreased their prey herbivores. Contrary to earlier studies on South Sinai by Roberts and Polunin 1992 who found that the herbivores families especially Acanthuridae increased significantly in the fished areas as a second effect to the fishing of their carnivore predators families Serranidae, we believe that at that time of the later study fishing intensity was not high to have an effect of the lower commercial value

Acanthuridae, and there was still Serranidae to catch. Additionally the interaction between the three factors year, fishing status and depth showed that the NTZs were significantly more abundant in Acanthuridae than TZs in 2000 and 2002 at the reef flat, the heavily fished part of the reef. By 2012 the abundance of Acanthuridae was dramatically decreased in both NTZs and TZs and there was no significant difference between them at the reef flat. This could be due to the continues net fishing over the reef flat, add to that fishing the NTZs which started in 2009 (Galal 2012), decreasing Acanthuridae in both zone.

Changes in Species Abundance

The artisanal fisheries did not just impact the abundance of highly valued commercial species over the years surveyed, but 8 species were extirpated by 2012, 6 of them were commercially target species while the other two were non-target coral health indicators species. 22 species out of the 50 were significantly different in abundance between the years, with 2012 being less abundant by 2012. We found that all the large body (>30cm) top (carnivores) and the mid (herbivores) trophic levels increased in abundance in 2002, but then sharply declined by 2012. Additionally the large bodied non-target species *Chaetodon semilarvatus, Pomacanthus maculosus* and *Pomacanthus imperator* declined drastically by 2012 with the first two disappeared from the surveyed sites.

Acanthurus nigrofuscus (*A. nigrofuscus*) the dominant species in the assemblage (50% of the total abundance of the 50 surveyed species) increased by 47% in mean density from 2000 to 2002, and decreased by 49% by 2012, indicating that this small body low commercial species could be negatively impacted from artisanal fisheries in Nabq as a result of the illegal netting fishing in the NTZs and as the high commercial value species by line were dramatically declined. Additionally *A. nigrofuscus* was negatively correlated with large bodied species, either because they preyed on them as in the case of *Cephalopholis argus* (Serranidae) (Russ, 1985; Ashworth and Ormond, 2005), or they competed with them on food and space as the case with *Acanthurus sohal* and *Naso liturstus* (Acanthuridae), or *Cetoscarus bicolor* and *Scarus gibbus* (Scaridae) (Roberts and Polumin 1991, 1992, King 1995).

Catch and Fishing Grounds

The total estimated catch of Ghargana village fishers showed a remarkable increase in 2010, when fishers were fishing both TZs and NTZs (Galal et al. 2012 and E. El-Aaydi, personal communication, June 15, 2012). However by 2012 the catch production returned back to the same level before 2010, although fishers kept fishing both zones. This indicate that fishing the NTZs did not sustain the increase in the fish catch for a long period of time.

There were mainly five fishing grounds (Sohop, Ghargana, Qaraneia, Abo Zabad, and Umm Teena) for Ghargana village fishers until 2010 (Figure 1), with Ghargana the main fishing ground responsible for 51% of the total catch in 1999. This catch decreased over the surveyed years to only 18% of the catch by 2012. There are three possible explanations for this, the first is the decrease in the CPUE (number of Kg./landing) for Ghargana fishing ground over years from 6.6 Kg./landing in 1999 to 4.62 Kg./landing in 2008, leading the fishers to extend their effort north and south of Ghargana where the CPUE was higher. The second explanation is that the low abundance of the higher value commercial species, mainly the carnivores (Figure 5), which declined by 85 % from 2002 to 20012. The last explanation is that the change in the fish habitat at Ghargana due to intensive fishing which affect negatively the fish stock. Hawkin and Rebort (2004) reported that intensive artisanal fishing transformed the Caribbean reefs to low coral cover. At Ghargana, intensive fishing did not just decreased the fish population, but it also significantly decreased the coral cover at the reef flat (Mabrouk 2003) leading to a shift to algae as a result of the trampling effect from the fishers. Ghargana village fishers also fished the NTZs mainly El Tall and Dekeer north and south Ghargana, causing the CPUE for this sites to decrease from 20.38 Kg./landing in 2010 at the beginning of the non-compliance to 5.75 Kg./landing by 2012. The catch from these sites represented 24% of the total catch in 2012 and they became from the main fishing grounds for Ghargana fishers.

Catch and Fishing Techniques

Catch Per Unite Effort for drive netting (CPUEd) was increasing in the time period 1999-2002, and this can be due to the increase in fish abundance in the TZs as a results of the spillover effect from the NTZs as explained in earlier studies (Galal 2002, Ashworth and Ormond 2005). After 2002 there was a declining trend for the CPUEd as a results of overfishing, only year 2010 was the remarkably higher as a result of fishing the NTZs which start in 2009 (Galal 2012) and confirmed by Nabq' rangers (Figure 22).

Drive netting was the main fishing technique the fishers used, responsible for 70% of the total catch in 2002, and it decreased to 35% by 2012, meanwhile other alternative techniques especially the closure increased responsible for 34% of the catch. This change in fishing gear and techniques was mainly due to the decrease in the CPUEd.

The hook and line technique showed a continuous decline over the surveyed years from CPUEh 1.55 Kg./line*hr. in 1999 to 0.59 Kg./line*hr. in 2012. Which could be due to the increase in fishing intensity. It was observed in this study that the number of these boats increased from 2 motor boats in 2002 to 15 boats by 2012 harbor at Ghargana, some of these boats were also used for a weekly fishing trips Tiran Islands south of Nabq where fish catch is better (E. Abdelazeem, personal communication, April 23, 2013).

Catch Composition

Siganidae was the dominant family in the catch over the years, with *Siganus rivulatus* the dominant species. The extensive Seagrass based ecosystem in Nabq provided a very good meadow habitat for *Siganus rivulatus* (Gab-Alla 1996) and also as spawning area recorded from interviews with the Ghargana fishers (Mabrouk et al. under review). The percentage of Siganidae in the catch increased from 48% in 1999 to reach its highest abundance 84% in 2002, meanwhile the other target commercial families specially carnivores were decreasing gradually reaching its lowest abundance 1.4% of the catch in 2003 (table). Siganidae contribution in the catch started to decreased gradually after 2002 while the carnivore families started to appeared again in the catch with a considerable amount as the fishers increased their effort on the healthy sites north and south Ghargana. In 2010, by fishing the NTZs Siganidae reach its minimum contribution in the catch 45% of the total abundance and we started to see a larger bodied herbivore Scaridae again representing 8.6%, and the carnivores increased to 21.8% of the total catch. This improve in the catch quality did not continue and by 2012 Scaridae decreased to 2.5% and the Carnivores families decreased to 16.3% while the lower commercial small body Gerreidae (*Gerres oyena*) increased to 23.3% with the increase of using the Closure technique at this year.

Conclusion

Establishing NTZs in Nabq showed promising results at the beginning of the establishment (1995-2002), resulting in increased fish abundance in the NTZs and CPUE in the TZs (Galal 1999 and 2002, Ashworth 2004, and Ashworth and Ormond 2005). However, it could not stop the decline in fish population, catch and CPUE at Ghargana (the main fishing ground for Nabq fishers and where they live) due to the heavy fishing activities there, an impact which could be shifted to other sites in Nabq. Over the past years (2009-2012) noncompliance to the NTZs has been recorded and fishing the NTZs increased the amount and the quality of the annual catch, but this was for a limited time period and was not sustainable. Due to the decline in the CPUE for the main fishing techniques, fisher increasingly used other alternative fishing technique, which twisted the catch to smaller lower value commercial species.

The three main surveyed fish groups (top trophic carnivores, mid trophic herbivores and the coral health indicator species) used in this study decreased significantly from 2002 to 2012. Generally we found that the high value commercial fish species especially from families Serranidae and Lethrinidae were severely reduced or removed from the surveyed reef. We believe that law enforcement coupled with the support of the local community are the key factors in having a successful marine reserve (Gell and Robert 2002, Graham et al. 2011). Additionally we also believe that the size of the NTZs and TZs is important to the success of the system being used in Nabq, and combination of smaller size and high fishing intensity could be responsible for the deterioration of both the fish community and the habitat as in the case of Ghargana resulting in low fish density and diversity.

Recommendation

- Inform and involve fishers and local community about the unsustainable nature of the artisanal fishing in Nabq PA and how this affect them now and the consequences of these nature on the future of their fisheries.
- Establishing a council for fisheries from the fishers and local community, sharing in taking the decisions, involve in monitoring and enforcing the fisheries in Nabq.

- Strict the enforcement of the No Take Zones and increase the presence and the number of the ranger in the protected area.
- Redesign the size and the locations of the NTZs and the TZs in coordination with the fishers and local community.
- Seasonal closure for line fishing to enhance the stock of the high commercial value fishes.
- Establishing a monitoring system as part of the fisheries management plan in Nabq, where monitoring for fishing activities, catch, fish community and habitat are regularly conducted, and commented to the council.

APPENDICES

Appendix 1

List of the target surveyed fish species (50 species), their families and trophic levels

Table 44. List of the target surveyed fish species (50 species), their families and trophic levels.

Trophic Level	Families	Species
Herbivores	Acanthuridae	*Acanthurus gahhm*
		Acanthurus nigrofuscus
		Acanthurus sohal
		Ctenochaetus striatus
		Zebrasoma desjardinii
		Zebrasoma xanthurum
		Naso liturstus
		Naso unicornis
	Siganidae	*Siganus luridus*
		Siganus rivulatus
		Siganus stellatus
	Scaridae	*Cetoscarus bicolor*
		Scarus gibbus
		Scarus fuscopurpureus
		Scarus ghobban
		Scarus sordidus
		Scarus frenatus
		Scarus ferrugineus
		Scarus niger
		Scarus psittacus
		Hipposcarus harid
Invertivores	Mullidae	*Parupeneus forsskali*
		Parupeneus cyclostomus
		Mulloides flavolineatus
		Mulloides vanicolensis
Carnivores	Serranidae	*Cephalopholis argus*
		Cephalopholis miniata
		Epinephelus fasciatus
		Epinephelus tauvina
		Ploctropomus pessuliferus
		Variola louti
	Lutjanidae	*Lutjanus ehrenbergii*
		Lutjanus monostigma
		Lutjanus bohar
		Macolor niger
	Lethrinidae	*Lethrinus mohsena*
		Lethrinus nebulosus
		Monotaxis grandoculis

Table 44 (cont'd)

Trophic Level	Families	*Species*
Corallivores & Invertivores	Chaetodontidae	*Chaetodon fasciatus*
		Chaetodon paucifasiatus
		Chaetodon austriacus
Corallivores & Invertivores	Chaetodontidae	*Chaetodon auriga*
		Chaetodon trifascialis
		Chaetodon melannotus
		Chaetodon lineolatus
		Chaetodon semilarvatus
		Heniochus intermedius
	Pomacanthidae	*Pomacanthus imperator*
		Pomacanthus maculosus
		Pygoplites diacanthus

Appendix 2

List of the fish catch species from Nabq fishers

Table 45. List of the fish catch species from Nabq fishers.

Families	**Scientific Name**	**English Name**	**Local Name**
Acanthuridae	*Zebrasoma desjardinii*	Desjardin's Sailfin Surgeonfish	Fahah
Acanthuridae	*Acanthurus nigrofuscus*	Brown Surgeonfish	Genah
Acanthuridae	*Naso unicornis*	Bluespine Unicornfish	Raho
Acanthuridae	*Acanthurus Sohal*	Sohal Surgeonfish	Sohal
Balistidae	*Rhinecanthus assasi*	Picasso Triggerfish	Hokb
Balistidae	*Pseudobalistes fuscus*	Blue Triggerfish	Shoaram
Belonidae	*Tylosurus choram*	Red Sea Hound fish	khirman or khorm
Carangidae	4 common species	Jacks and Trevally	Bayad
Chanidae	*Chanos Chanos*	Milkfish	Khanya
Chirocentridae	*Chirocentrus dorab*	Wolf Herring	Abo Saif
Fistulariidae	*Fistularia commersonii*	Bluespotted cornetfish	Kasbaa
Gerreidae	*Gerres oyena*	Slenderspin Mojarra	Kasa
Haemulidae	*Plectrorhynchus gaterinus*	Blackspotted Grunt	Qatran
Haemulidae	*Diagramma picta*	Painted Grunt Sweetlips	Shataf
Hemiramphidae	*Hyporhamphus far and Hyporhamphus gambarour*	Blackbarred Halfbeak and Red Sea Halfbeak	Gambarour
Holocentridae	*at least 2 species*	Squirrelfish	Balool
Holocentridae	*Sargocentrom spiniferum*	Sabre Squirrelfish	Kehaa
Kyphosidae	*Kyphosus vaigiensis & cinerascens*	Bressy Chup & snubnose Chup	Tahmal
Labridae	*Coris aygula*	Clown Coris	Hogm
Labridae	*Cheilinus lunulatus*	Broomtail Wrasse	Rabady
Lethrinidae	*Monotaxis grandoculis*	Big Eye Emperor	Abo Ain
Lethrinidae	*Lethrinus obsoletus*	Yellow strip emperor	Bongoz
Lethrinidae	*Lethrinus elongates*	Longnose Emperor	Khermia
Lethrinidae	*Lethrinus mahsena*	Mahsena	Mehsena
Lethrinidae	*Lethrinus nebulosus*	Spangled Emperor	Shoor
Lutjanidae	*Aphareus rutilans*	Rusty Jobfish	Aysamon or Fares
Lutjanidae	*Lutjanus bohar*	Twinspot Snapper	Bohar
Lutjanidae	*Lutjanus sp.*	Dory Snappers	Hebria
Muglidae	*Oedalechilus labiasus & Crenimugil crenilabis*	Thicklip Mullet & Fringlip Mullet	Bory or Arabi
Mullidae	4 species	Goatfishes	Ammor & Parpony

Table 45 (cont'd)

Families	**Scientific Name**	**English Name**	**Local Name**
Mullidae	*Parupeneus cyclostomus*	Yellowsaddle Goatfish	Sablawy
Platycephalidae	*Papiloculiceps longiceps*	Flatheadfish	Rhakad
Priacanthidae	*Priacanthus hamrur*	Goggle Eye fish	Sharrany
Scaridae	*Scarus ghobban*	Bluebarred Parrotfish	Ghobban
Scaridae	10 Species according to color	Parrotfish	Harid
Scaridae	*Hipposcarus harid*	longnose Parrotfish	Harid Abiad & Wargaa
Scombridae	*Euthynnus affinis* & other	Kawakawa	Balameta & Tuna
Scombridae	*Scomberomorus commerson*	Narrowbarred Spanish Mackerel	Darak
Scombridae and Carangidae	*Rasterelleger kanagurta& Trochurus indicus, Alepes djedaba*	Indian Mackerel and Arabian Scad	Baghah
Serranidae	*Variola louti*	Lunertail grouper	Bosa & Sherifa
Serranidae	*Epinephelus fasciatus*	Blacktip Grouper	Daghmaa
Serranidae	*Plectropomus pessuliferus & Plectropomus areolatus*	Roving Grouper & Squaretail Grouper	Nagel
Serranidae	*Epinephelus tauvina & E. Sp.*	Greasy Grouper	Tuina or Kosher dreasy
Serranidae	6 species	Grouper	kosher
Siganidae	*Siganus stellatus*	Forktail Rabitfish	Ahmady
Siganidae	*Siganus luridus*	Squaretail Rabbitfish	Harafy
Siganidae	*Siganus argenteus*	Stellate Rabbitfish	Shepeh
Siganidae	*Siganus rivulatus*	Rivulated Rabbitfish	Sigan
Soleidae	*Pardachirus marmoratus*		Mosa
Sparidae	*Diplodus noct*	Arabian Pinfish	Abo Nocta
Sparidae	*Rhabdosaragus sarba & R. haffara*	Yellowfin Bream & haffara Seabream	Denis
Sparidae	*Argyrops spinifer & A. filmentosus*	Kingsoldier Bream and Soldier Bream	Morgan
Sparidae	*Acanthopagarus bifasciatus*	Twobar Bream	Rabag
Sphraenidae	4 common species	Baracudas	Barracuda
Terapontidae	*Terapon jarbua*	Jarbua Terapon	Henwa

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CHAPTER 4: RESOURCE DEPENDENCY AND COMPLIANCE TO ARTISANAL FISHERIES REGULATION IN NABQ PROTECTED AREA, GULF OF AQABA, EGYPT

Abstract

Fisheries in Nabq Managed Resource Protected Area MRPA is a Bedouin tradition, and as part of the conservation policies for Nabq, the management authority established in 1995 five No Take Zones (NTZs) in coordination with the local community (Bedouin). The objectives was to sustain artisanal fisheries for the Bedouin and to reduce the potential conflict between fisheries and touristic activities (diving, snorkeling and camping). The NTZs was enforced by both Nabq rangers and the local community in a high degree of compliance from the fishers. As a results fish population and catch per unit effort CPUE were observed to increase between 2000 and 2002. Over the next decade, the attitude of the fishers toward the NTZs changed, and fishers started fishing the NTZs in 2009, which led to decline in the CPUE and fish abundance of many of the target species. In this study we investigated the relationship between the fishers in Nabq, their fisheries resources and the compliance of the fishers to the conservation measures in particularly the No Take Zones. We conducted a face to face interview in Nabq in 2013 of 24 fishers representing 75% of the permanent fishers. A questionnaire was developed to; 1) assess the resource dependency of the fishermen in Nabq. 2) evaluate fishers attitude to marine conservation and causes to their attitude. 3) assess fishers perception to the changes in the fisheries resources and the causes to those changes and 4) identify fishers attitude to change in their livelihood. We found that 54% of the fishers are fished daily, and fishing represented a source of income and subsistence for 92% of the fishers. Fishers were aware of the regulation of the protected area and generally support conservation measures. However the majority of fishers

(87.5%) disagreed on the way Nabq authority mange fisheries, mainly due to the lack of enforcement which was a key issue for the several noncompliance in the NTZs. Fishers were aware of the degradation in fish abundance, size and diversity and they relate this to illegal fishing and to the fishers from outside Nabq. Although Bedouin fishers were highly dependent on the fisheries resources, (66.7%) were interested in changing their livelihood to work in tourism which is more profit and secure. Robust enforcement and participatory approach in management and taking decision with the local community are critical for fishers compliance. Using opportunities from tourism to create alternative job opportunities for the fishers can reduce resource dependency and help achieving sustainable fisheries.

Introduction

Fish is a primary source of protein for 17 percent of the world's population and nearly a quarter in low-income food-deficit countries (FAO 2012). It is estimated that 90% of the world's fishers are small-scale fishers, with most residing in developing countries (FAO 2005). Globally artisanal fisheries catch approximately 30 million tons of fish annually for human consumption (approximately the same amount of edible fish as large scale fisheries) (Jacquet & Pauly 2008). According to FAO's Glossary, artisanal, or small-scale fisheries, are traditional fisheries involving fishing households, using relatively small amount of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, and mainly for local consumption. Artisanal fisheries are important as source of nutrition, employment and income (Béné et al. 2007). However, despite its importance in providing food security and livelihoods in coastal communities, small-scale fisheries are largely ignored and marginalized throughout the world (Berkes et al. 2001).

Artisanal fisheries, although they are based on low level of technology, they have the capacity to significantly alter marine ecosystems through overfishing and habitat damage (Magni & Robert 2006). In order to counter this threat, Marine Protected Areas (MPAs) have been used as a successful management approaches. MPAs are a central strategy of management approaches that aim to protect biodiversity, as well as support the social and economic well-being of human societies (Mascia 2003, IUCN-WCPA 2008). MPAs that restrict fishing and other human activities conserve fish habitats and populations which may sustain or increase yields of nearby fisheries (Pauly et al. 2002). Although MPAs are a popular conservation strategy, their impacts on human welfare are poorly understood (Mascia et al. 2010), often leading to conflict with the local community and non-compliance, negatively impact the effectiveness of the MPAs. As a result full participation of the affected human community is a must for successful implementation of MPAs (Bray 2011). Additionally, effective enforcement, persistence management and high compliance are important for MPAs to be successful and achieve the decided conservation objectives (Graham et al. 2011, Edger et al. 2014).

In Egypt 7 MPAs have been established since 1983, six of them are in the Red Sea and the Gulf of Aqaba, and only one (El-Salum MPA) in the Mediterranean. Ras Mohammed National Park is the only protected area which does not allow any kind of fishing activities even for the local community (Bedouin), while all the other do under different circumstances. One of the main objectives of MPAs which allow fishing, is to ensure sustainability of the artisanal fisheries that occurring there through proper regulation. For example restricting fishing access only to the local community, gear restrictions and establishment of No Take Zones (NTZs). In this study we analyzed the scene of Nabq Managed Resource Protected Area MRPA; the largest MPA on the Gulf of Aqaba and the only MPA to implement No Take Zones (NTZs) alternating with the Take

Zones (TZs). Although the establishment of the NTZs in 1995 involved the local community (The Bedouin), and it was effectively enforced and managed by the MPA staff and the Bedouin intensively, we noted that over the years there has been a decline in fish due to noncompliance in the NTZs from the Bedouin (chapter 3). It is important to identify whether the changes in the fishers attitude caused due to the lack of environmental awareness of younger fishers as Galal et al. claimed in (2012) or not and if not what are the causes. Additionally the dependency of Nabq fishers on the fisheries resources should be clearly understood, as strong resource dependency could act as a barrier to compliance in coral reef fisheries (Marshall et al. 2007). Understanding and evaluating the resource dependency of the fishers is important for MPAs success and can minimize the negative impacts of protected areas on resource users through strategies that reduce their dependency and increase their resilience to changes in resource access policy (Bailey & Pomeroy 1996, Ban et al. 2009, Marshall et al. 2009& 2010).

In order to better unrevealed the values and motivation of the fishers we conducted a survey in the Gulf of Aqaba, Nabq. A questionnaire was developed for this interview based on methods of Marshall et al. (2010) who conducted similar study in Egypt for Gabal Elba Protected Area in the south of the Red Sea. The questionnaire we used in this social survey was to specifically assess the fishers relationship and dependency on the fisheries resources, their perception to the changes of the marine environment and causes of these changes in order to better identify the fishers attitudes to marine conservation, and their perception to the changes in resource policy and livelihood (social resilience). The results from this study should help managers and decision makers take the appropriate actions to return compliance to the fisheries in Nabq, maintaining this traditional activity and conserving fisheries resources.

Background

Study Location

Nabq is one of a network of five protected areas established with the assistance of a European Union Donation to Egypt. This network of protected areas constitutes one third (11,000 Km^2) of the total area of South Sinai Governorate. Nabq was declared by the Egyptian government in 1992 as a Managed Resource Protected Area (MRPA), IUCN Category VI, (Protected Area (PA) managed mainly for the sustainable use of natural ecosystems). This defines the PA as an area of land, with coast and seas as appropriate, where the interaction of people (Bedouin) and nature over time has produced an area of distinct character with significant aesthetic, cultural and ecological value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area. Nabq is the largest PA on the Gulf of Aqaba, a total area of 736 km^2, of which 421 km^2 land and 315km^2 sea, including the marine sector of Dahab city north of Nabq (Figure 1), with a coast of 74Km of which 24Km is located in Dahab. Nabq characterized by a great diversity of habitats and ecosystems, where the three main marine ecosystems coral reef, sea grass, and mangrove are interacting together in a uniquely setting on Gulf of Aqaba coast (Mabrouk, 2007). The coral reefs in Nabq are among the best and most diverse in the Egyptian Red Sea, 208 species of hard coral and 438 coral reef fishes were recorded (Veron Pers. Comm. & Mabrouk 2007). Due to the diversity in habitats and ecosystems, Nabq is one of the most attractive touristic site in South Sinai and thus receives an average of 3000 tourists per month. On the coastal safaris, tourist visit the mangrove stands, snorkeling, diving or camping at the designated areas. While in the wadies inland they go for camel safaris and Bedouin dinner. Most of the Bedouin in Nabq are involved in tourism activities, in a one way or another. They provide traditional Bedouin dinner to the tourists at El Ghargana cafeteria or at the shelters of the protected area on the coast in addition to organized camel safaris and Bedouin dinners in Nabq wadies, which make tourism an important source of income to the Bedouin.

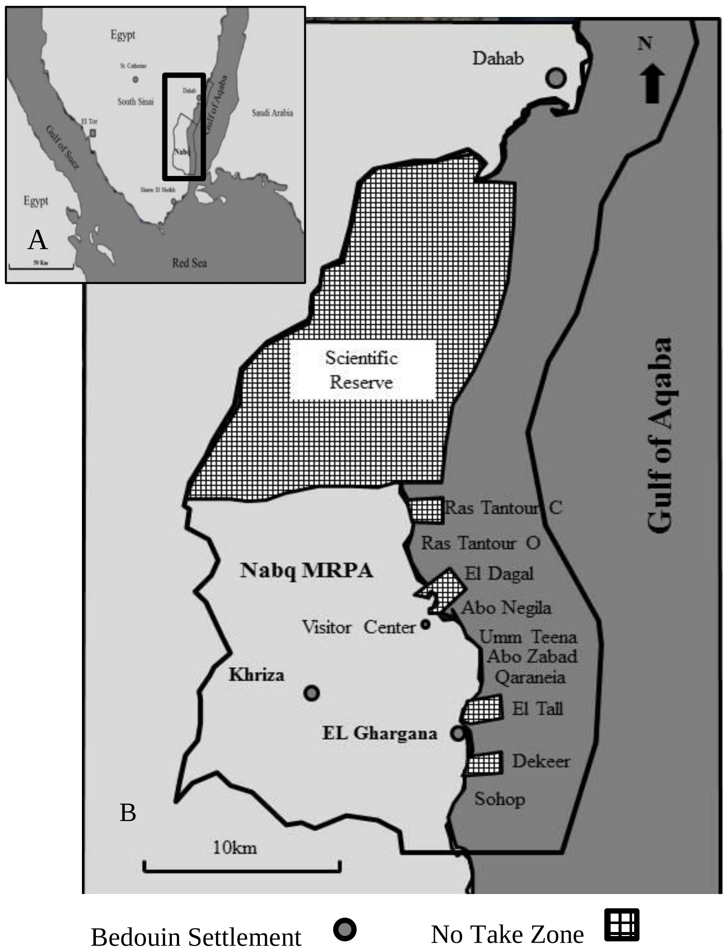

Figure 104. A. The location of Nabq Managed Resource Protected Area (MRPA) on the Gulf of Aqaba, B. The Bedouin settlements, No Take Zones and fishing grounds in the Nabq.

Nabq is inhabited only by Bedouin mainly from El Mezina tribe with a total population of 452 inhabitants in 2006 (Mabrouk, 2007), with an increase of 2.9% per year. More than half (241 inhabitant with 49 households) of this population still have a nomadic life style moving between two main settlements, Ghargana village (The fishermen village) on the coast and Khriza village at the interior of Nabq (Figure 104). In summer 43 families (227 persons) settled at Ghargana Village on the coast where it is cooler and has calm sea condition for fishing.

Artisanal Fishing and its Management in Nabq

Fishing in Nabq is a Bedouin tradition, the catch is mainly for subsistence but also serves as a source of income, as they sell it fresh for the Bedouin cafeteria and restaurant at Ghargana village or dry it and sell it to other Bedouin's remote communities. Artisanal fisheries by the Bedouin in Nabq is a typical Red Sea coral reef fisheries, using multi-gear and for multi-species (Ormond & Douglas 1996, Spalding et al. 2001, Ashworth et al 2004). The fishers applied traditional fishing techniques using different types of gear. Four main traditional fishing techniques the Bedouin are used in Nabq (Mabrouk 2007): hand line fishing, drive net fishing, overnight net fishing and closure net fishing.

In 1995 the Management authority of Nabq established an alternating NTZs and Take Zones (TZs) along the coast of Nabq in coordination with the Bedouin fishermen society to maintain the traditional fisheries activities and ensure its ecologically sustainability (Pearson & Shehata 1998); the first and only MRPA in Egypt to have such system. The management authority established 5 NTZs (Figure 104), with total reef area of 3.56 km^2 constituting 30% of the reef in Nabq. The network of NTZs was selected to encourage spillover of fish from NTZs into fished areas, and the fished areas to be accessible to fishermen living in Nabq (Galal 1999). The NTZs were visibly marked and enforced by the local ranger and regulations was respected by the fishermen (Galal et al 2002).

Fisheries Compliance in Nabq (1995-2009)

are mainly influenced by three main factors: (a) fisheries industry structure. (b) control and enforcement and (c) internal societal obligations (legitimacy and norms) (Nielsen, 2003).

Fisheries Structure

The structure of Nabq fisheries in 1995 was characterized by small number of fishers, 15 permanent fishers at Ghargana village and 2 small motorized boats (6m length). The fish catch was mainly for subsistence. The fishers had a leader (Sheikh) and his "word" was respected by the Bedouin. He and the fishers were involved in decision related to the establishment the NTZs in Nabq. Such structure facilitated the establishment of the NTZs with strong compliance from the fishers.

Control and Enforcement

Increased enforcement activities can reduce or even prevent non-compliance behavior among fishers (Nielsen 2003). It is mainly based on the deterrence model by Becker (1968), which assume that the compliance and noncompliance behavior depend on the economic gain to obtained from bypassing the regulation compared to the likelihood of detection and the severity of the sanction. It is the same idea of the utilitarian calculus (by philosopher Jeremy Bentham), and based on this theory most of the fisheries managers increase monitoring, control and enforcement (MCE) activities, and increase the severity of the sanctions to deterring noncompliance.

In Nabq, most of the fishing activities were from land, and the rangers were accommodated in Nabq 1995-2007 having a daily routine of land patrol by day and night. Action against the violators was taken, starting with confiscating all the equipment used in the violation to being arrested and paying a penalty which ranged from $300 to $2,000 US Dollars. Additionally a damage evaluation fee based on the damage caused to the environment were assessed and individuals could be sentenced to up to one year in jail. The Bedouin in Nabq were involved in the control and sharing the responsibility of the enforcement of the NTZs and PA regulations. Four community guards including the Ghargana village Bedouin leader and two assistant rangers (all from Nabq Bedouin) were hired by Nabq management authority. These actions were very important to deterred noncompliance behavior by the fishers and to gain the respect and trust of the Bedouin community to the rangers.

Legitimacy and Bedouin Norms

Compliance appears to be higher in fisheries where co-management institutions are in place (Kuperan et al 1998 OECD 1996), and the more the fishermen are involved in designing and enforcing the regulation, the more the regulation will be accepted as legitimate (Jentoft 1998). Legitimacy is here perceived as a normative phenomenon, and differs from moral in the sense that legitimacy is linked to a political authority system. This was realized in Nabq as the management authority involved the Bedouin in taking the decision of establishing the NTZs as mention earlier, and making them aware of the problem and the impact of unsustainable fishery on their livelihood. It was also important to involve them in the management, and enforcement of the PA regulation as community guards and assistant rangers.

Norms are often defined as the typical actions; attitudes and expectations among fishers concerning the behavior and attitude of peers. Furthermore, norms are seen as social pressure that creates both positive and negative sanctions (Gidden 1984). In Nabq it was important to use the Bedouin social norms. Bedouin have their own norms and even their own laws and regulations. For instant, when they have a conflict they don't report to the police or go to court, they have their own social court, and it is governed by the tribal or community leader, who plays the role of the judge which was respected by the tribe and the community. This Bedouin norms facilitate compliance of the NTZs, once the Bedouin leaders agreed on the establishment of the NTZs it became a Bedouin norm and every one had to respect it in Nabq.

Fisheries Noncompliance to the NTZs in Nabq

Noncompliance to the NTZs from Nabq fishers was recorded in 2009 and the role of the NTZs benefits was negated (Galal et al. 2012). Fishers at this time started fishing the NTZs especially the one close to their main settlement on Nabq coast (Ghargana village). Therefore mean fish abundance of the target families (Serranidae, Lethrinidae, and Lutjanidae), and the catch per unit effort CPUE decreased in Nabq (Galal et al. 2012), and as a result the fishers couldn't catch enough fish to sustain their livelihood as recorded by Nabq ranger (Abdelazeem I. Pers. Comm.).

Methods

designed using an interview instrument with the fishermen in Nabq to:

- Assess the resource dependency of the fishermen of Nabq.
- Assess fishers perception to the changes in the fisheries resources and causes for those changes.
- Evaluate fishers attitude to marine conservation and reasons for that attitude. and
- Identify fishers attitude to change their livelihood.

Survey Technique and Sample

Interviews with the fishers were conducted from April through May 2013 by a trained ranger from Nabq while doing his daily patrol along the coast. Fishers were approached while they were still at the fishing ground after or before the fishing operation, which mainly dependent on the weather and sea condition. Twenty four fishers were interviewed, which represented 100% of Nabq permanent fishers who were living at Ghargana village (15 fishers). The rest of the fishers that interviewed were from outside Nabq, mainly from Dahab city and represented 37% of the interviewers. Fishers were invited to participate in the survey anonymously, and they agreed to voluntarily be interviewed. The questionnaire (Appendix 1) was translated in to Arabic and each interview with the fishers lasted for approximately one hour and was conducted in Arabic.

Data Analysis

All questionnaire responses were entered into a database using Microsoft Excel, Data were tabulated and evaluated with mean, standard deviation and standard error. Categorical, and ordinal responses were coded and evaluated using frequency of occurrence. Additionally statistical software package (IBM SPSS, version 20), used to analyze correlation between different variables (Appendix 2).

Assessing Resource Dependency of Nabq Fishers

Resource dependency is a key concept for describing and understanding the nature and strength of the relationship between resource users and a resources they depend upon (Force et al. 1993, Bailey and Pomeroy 1996, Krannich and Zollinger 1997, Jacob et al. 2001, Marshall et al. 2009& 2010). Communities that are predominately fishing dependent are a typical example of resource dependent communities (Bailey and Pomeroy 1996) and Ghargana village in Nabq is considered one of these communities. Understanding the level of dependency on a resource can assist the resource users to survive and adapt to changes (social resilience) in the user-resource relationship (Albrecht and Thompson1988, Canan and Hennessey 1983, King 1998). This can also assist resource managers and decision makers to design and implement resource-protection policies that not only protect ecological values but also the social systems dependent upon them (Marshall et al. 2007).

According to previous studies by Marshall et al. (2007, 2009 & 2010) resource dependency can be conceptualized and measured using three main characteristics features; social, economic and environmental characteristics:

- Social characteristics include the level of attachment to the occupation and place, employability, family characteristics and perceptions of change.
- Economic characteristics include business characteristics, approach and income.
- Environmental characteristics include nature of the interaction with the resource, level of specialization, local skills and knowledge, and perceptions of environmental change and condition.

In this study we assess the resource dependency for Nabq fishers using responses to survey questions reflecting the three major characteristics of the resource dependency (social, economic and environmental). Due to the important of the fishers perception of change we separate it from the social characters for resource dependency. Survey questions were modified from those used by Marshall et al. (2007, 2009 &2010) to be suitable for the Bedouin fishers to understand and answer as Nabq ranger advised.

Assessing Fishers Perception to the Change in the Marine Resources

Questions to evaluate the perception of the fishers to the changes in the quality of Nabq fisheries and the coral reef habitat in the last 10 years (2002-2012) was included in the questionnaire, It was important to determine the fishermen perception to the changes of the marine resources mainly the fish populations and coral reef habitat, and what in their opinion caused these changes . Questions were asked of the fishermen about their perception of the change in fish abundance, fish size, fish diversity, and coral reef habitat. The fishermen were also asked to evaluate the causes for the degradation in the marine resources, if they thought there was change.

Evaluating Fishers Attitude to Marine Conservation and Causes to that Attitude

Fishers attitude to marine conservation were used as indication of how likely fishers were to support and comply with conservation policy such as marine protected areas and no take zones (Marshall et al. 2010).

Fishers were questioned to evaluate their awareness and attitude about the Nabq protected area regulation and conservation policies. They were asked if they are aware that their village and coastal waters are in Nabq protected area, if they support or oppose the establishment of the MPA and why. We also asked the fishers if they agree or disagree that Nabq fisheries is effectively managed and why. We used the last question as the main indicator for their compliance to the NTZs and Nabq PA regulation.

Identifying Fishers Attitude to Change (Social Resilience)

Social resilience is the ability of individual to have resilience and flexibility in order to cope and adapt to the changes in resource policy over time (Marshall et al. 2007). According to Marshall et al. (2009) social resilience has four elements; 1) the perception of risk associated with change, 2) the perception of the ability to plan, learn, and reorganize, 3) the perception of the proximity to the threshold of coping, and 4) the level of interest in change. Due to the differences of Nabq artisanal fisheries than those cases studied by Marchall (2007 and 2009) (Queensland, Australia and Salum, Egypt) we assessed social resilience of the fishers in Nabq using two main elements, their interest in new job other than fishing and their perception of their ability to cope with changes.

Fishers were asked 1) If they are interest of in a job other than fishing and what would this job be, 2) If they think that they could withstand the physical, social and economic difficulties of fishing, 3) If they have other options available if they decided to no longer be a fishermen, and what these options were.

Results

Assess Resource Dependency of Nabq Fishers

1- Social Characteristics

Attachment to fishing and place

We found that (63%) of the fishers were always living in Nabq, while (25%) were from Dahab city (100 Km. north of Nabq), the remaining fishers were from Sharm El-Sheikh (8%) and El-Tur (4%); cities 35 and 150 Km. south of Nabq respectively. Additionally of the fishers interviewed (83%) had always fished in Nabq. The majority of fishers in this study (75%) had always been fishermen, and (45.8%) of them also had experience with other professions, such as tourism (29.2%), working for Nabq protected area (16.7%) or working in herding (sheep, goats and camels) (8.3%). Additionally 41.6% of the fishers had no other options for employment. When we asked the fishers why they were fishing, we found that 67% of the fishers fish for subsistence, 63% as source of income and 25% as a hobby. Only 13% fished to pass the traditional fishing knowledge to the next generation. The range of ages at entering the fishing industry was between 8–45 years old with the mean age being 18 years of ages (s.e. = 1.8). The range of number of years the fishers spent in this industry ranged between 10-50 years, with the mean being 23.9 (s.e. = 2.4).

Family dependency

Almost all the fishers (95.8%) were married, owned their own home and had relatives or family members fishing. We found that 33% of the fishermen's wives were also involved in the fishing industry. The average number of fishers' relatives involved in fishing was 8.9 (s.e. 1.6). All fishers who were married had children and household size ranged from 1- 15 child per fisher with mean being 4.4 children per fisher (s.e. 0.67).

Employability

Age, education and attitude to working elsewhere were used as indicators for employability. Older and lower educated resource users where found to be always less willing to leave their homes to work elsewhere (Marshall et al. 2010). In this study we found that 54 % of the fishers have had other profession, while the rest have no other experience than fishing. The mean age of the fishers in this study was 42 years of age (s.e. 3.12) and ranged from 23 to 70 years old (Figure 105). We found that (29%) of the fishers interviewed were illiterate, and only 21% had obtained any high school education (Figure 106).

2- Economic Characteristic

All the fishers in this study were self-employed, and they own their own fishing business. Of the fishers surveyed 42% stated that fishing does not contribute to the family's income as it is mainly for subsistence or as a hobby, while 50% of the fishers said that fishing contributed between 25-75% of the family's income (Figure 107). Fishers in Nabq were found to have an average income of $11.17/fisher/day (s.e. 0.86) in 2012. Fishers in this regimes do not pursue fishing throughout the year due to the rough weather conditions, especially in winter. The estimated average catch of the fishers in Ghargana Village in Nabq was 4548 Kg. (s.e. 528) with an average income of $13645 (s.e.1584) (Mabrouk & Taylor under review).

Figure 105. Fishers age classes in Nabq from the social survey through April and May 2013

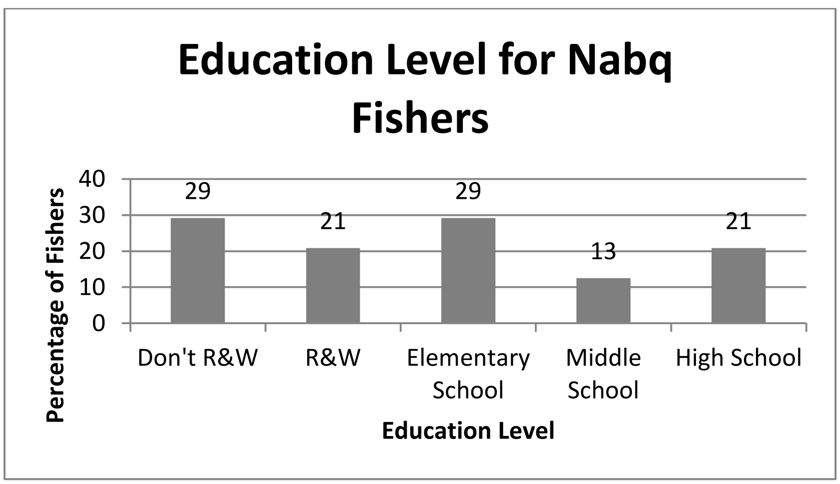

Figure 106. Fishers education level in Nabq from the social survey through April and May 2013

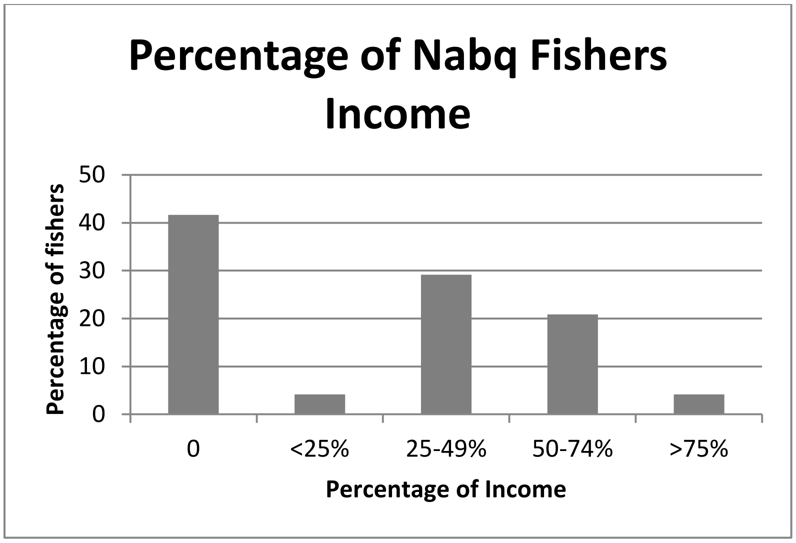

Figure 107. Percentage of Nabq fishers income from fishing contributed to the family's income from the social survey in April and May 2013.

3- Environmental Characteristic

We found that 54% of the fishers interviewed fish daily if the weather permitted, while 25% fished weekly and 21% fished monthly. The average duration of a fishing trip was 7 days, and they all stop fishing during bad weather. The main fishing techniques the fishers used were drive netting (96%), hook and line (67%) and passive (overnight and closure) netting (25%). Hook and line was conduct by boats or at low tide at the reef edge. We found that 58% of the fishers used boats for line fishing, whose length ranged from 3 meter with paddles to 12 meter with an 80 HP motor. Fishers stated that they caught 85 different species of fish (Appendix 4) depending on the season and technique used (Mabrouk and Taylor under review). Bedouin women were also participating in the fishing activities in Nabq with 33% of the fishermen's wives were fishing (12.5% daily, 16.5% weekly and 4% monthly). Wives were reported to fish at the low tide using line at the reef edge or gleaning the reef shells and octopus over the reef flat. Almost all the fishers (91%) in this survey were aware of the areas where and the timing when fish aggregated for spawning or feeding.

Assess Fishers Perception to the Change in the Fisheries Resources

Most of the fishers (91.7%) in the study perceived that the fish abundance in Nabq had degraded over the past 10 years and 62.5% of them realized that fish size had decreased. Additionally 58.3% of the fishers were aware that fish diversity had also declined, while 41.7% think that there had been no change in fish diversity. Fishers perceptions to the quality of the coral reef habitat split with 41.7% of the fishers perceiving that there had been degradation in coral while 54.2% had stated no change in coral habitat quality had been seen in the last 10 years (Table 46). Almost all the fishers (95.8%) stated that the cause of the degradation in the fisheries resources in Nabq was due to the high impact of the illegal fishing and to the increase in the number of fishermen from outside Nabq, while 50% of the fishers reported that this degradation was due to too many fishermen in Nabq. Most of the fishers (91.7%) did not report any impact form tourist activities such as snorkeling and diving (Table 47).

Table 46. Fishers perception to the quality of fisheries resources in Nabq by percentage of fishers supporting each category, 2013.

Resource Type	Improved %	No change %	Worsened %	I don’t know %
Coral reef	0.0	54.2	41.7	4.2
Fish abundance	4.2	4.2	91.7	0.0
Fish size	4.2	33.3	62.5	0.0
Fish diversity	0.0	41.7	58.3	0.0

Table 47. Fishers perception to causes to the fisheries resources degradation in Nabq by percentage of fishers supporting each category, 2013.

Causes for marine environmental degradation	no impact %	low impact %	moderate impact %	high impact %
Too many fishermen	8.3	12.5	29.2	50.0
Improved fishing technology and techniques (e.g., nylon nets, masks)	62.5	33.3	4.2	0.0
Improper fishing techniques (e.g., active netting on reef flat)	66.7	12.5	12.5	8.3
Too many visitors (e.g., divers and snorkelers)	91.7	4.2	4.2	0.0
Illegal fishing (e.g., using harpoons, mesh size)	0.0	0.0	4.2	95.8
Fishermen from outside Nabq	0.0	0.0	4.2	95.8
Pollution	75.0	4.2	0.0	20.8
Others (Plastics)	0.0	0.0	0.0	8.3

<u>Evaluating Attitude to Marine Conservation</u>

We found that all the fishers (100%) were aware that they were conducting fishing inside Nabq protected area, and (91%) of the fishers were supportive of the establishment of Nabq PA. When they were asked why it was established, 91.7% said to protect coral reef habitat and coral reef fishes. Additionally, 70.8% said that the PA also to protect mangrove and wildlife. Only two fishers (8.3%) stated that they were not supportive of the establishment of Nabq PA because they didn't benefit from it. Almost all the fishers (96%) were aware about the regulation of the protected area. We found that (87.5%) of the fishers were supportive of closing areas to fishing in order to protect fish stock and their breeding ground, and all the fishers supported seasonal closure to protect fish spawning and recruiting. Finally 87.5% of the fishers disagreed that Nabq fisheries is currently being effectively managed by the current protected area management program. The main reason for this belief was due to the lack of law enforcement, and reduction of personal level of shared management as they were no longer engaged in the management of the area and did not benefits (job) from this program.

Identifying Fishers Attitude to Change

We found that 66.7% of the fishers in this study were interested in other jobs (e.g. tourism; governmental) than fishing while the rest (33.3%) of the fishers were not willing to leave fishing and find other job. However (71%) of the fishers have no other alternative than fishing at the time of the survey, while the reminder (29%) reported that they already had other jobs, working mainly for tourism or Nabq protected area. Many of the fishers (79%) believe that they could withstand the difficulties of fishing, and all of them believed that they could adapt and cope with seasonal closure while 87.5 believe that they can adapt with spatial closure.

Discussion

The aim of this study was to determine the reasons behind the change in the conservation attitude of the fishers in Nabq protected area which resulted in noncompliance with the No Take Zones (Galal et al., 2012; Mabrouk and Taylor under review). Identify fishers attitude to change their livelihood.

Nabq fishers were strongly depending on fishing for subsistence and as a source of income (67% and 63% respectively). Although fishers were found to have a strong attachment to fishing in Nabq (83%) a growing number already have other job mostly related to tourism. Meanwhile (33.3%) were not welling to leave fishing for any other job since many Bedouin like to be self-employed. Family dependency on Nabq fisheries was also relatively high. The 24 fishers interviewed represented 23 household with a 148 people. Additionally the Bedouin women were found to share the fishermen in fishing and played an important role in the artisanal fisheries in Nabq. Nabq fishers were found to use different fishing techniques using different gears targeting a variety of coral reef fishes and that was critical to have them cope, adapt and support conservation policies and accept change. They were also generally aware of the degradation in the fish abundance, size and diversity in Nabq. They support measures to conserve fisheries and enhance enforcement. Almost all Nabq fishers were aware of the protected area regulations, and its benefits to the fisheries, contrary to what was assumed by Galal et al. (2012) on the lack of awareness, or what was reported in Marshall et all (2010) in Gabal Elba National Park south in the Red Sea.

Although the fishers in Nabq were aware of the protected area regulations and they supported the establishment of the protected area, the area and seasonal closure policies, they disagree on the way the current fisheries are managed and the way the protected area is managed in general. We believe this to be the main reason for the non-compliance to the NTZs and other PA regulation. The fishers mention many reasons for this disagreement such as the lack of law enforcement (fishers from outside Nabq is fishing illegally in the NTZs and no action from the rangers), lack of management (only one ranger and no staff resident in Nabq any more), lack of coordination between the management and the fishers and finally lack of services provided by the PA management such as road maintenance, job opportunities, veterinary services and health services which were provided by the protected area in the past and was funded by the European Union (1992-2003). It was interesting to determine that although there was strong dependency from the fishers on the fisheries resource in Nabq, many of them (66.7%) were interested in changing their livelihood and asking to work mainly in tourism, contrary to Gabal Elba fishers who were limited to their social flexibility and livelihood options (Marshall et al. 2010). The primary reason for this is the large tourism industry in the Sharm El Sheikh area and the use of Nabq as a main touristic destination.

Younger fishers, with less years in fishing industry and less income from fishing were found to be most interested in job other than fishing.

Conclusion

Understanding the dependency relationship between fishers and marine resources is essential for effective management of these resources. Better understanding of this relationship and how to influence it can be a cost effective approach to improve conservation effectiveness (Marshall, 2010). Managing Nabq fisheries started in 1995 by establishing the no take zones (NTZs), involving the local fishers in the decision making process and in the responsibility of enforcing and managing these zones to ensure compliance. As a result CPUE increased in the take zones and target fish species increased in the closed sites (Galal et al., 1999&2002). Over the years non-compliance from the fishers to the NTZs has occurred and CPUE declined and target species declines greatly (Galal et al. 2012, Ashworth et al. 2005, Mabrouk and Taylor under review). Bedouin fishers from Nabq and Dahab depended on Nabq fisheries to a great extent, fishing for many of them is a form of subsistence and source of income. However many of the fishers were willing to change their livelihood for more profit and secured jobs like working in tourism or for the government. Although the fishers were aware about the regulation of the protected area and support conservation measures they disagreed on the way that Nabq fisheries were managed, mainly due to the lack of enforcement which was the key issue for the noncompliance for the NTZs.

Nabq management authority need to gain the trust and respect of the fishers and local community which has seemingly been lost over the years in order to have compliance to the fisheries and protected area regulations. This can be achieved by strictly enforcing the fisheries and protected area regulations and using the participatory approach in involving the local community in the responsibility and management of this valuable resources area. Additionally there is a need to provide opportunities for the local people to be involved in tourism, to reduce the dependency of the local community on the fisheries resource. Having projects to involve fishers in environmentally friendly tourism activities (Ecotourism), will reduce the dependency and negative impact of fishers on the fisheries resource and the coral reef of Nabq and provide a chance for fish habitats and fisheries to recover.

APPENDICES

Appendix 1

Social Bedouin Fishers Questionnaire

NABQ- 2013

A. Describing your relationship and dependency on the fisheries resources

1. Do you live in the Nabq?
☐ no
☐ yes

1.1. In which town do you live? ________________________________

1.2. Have you always lived in Nabq?
☐ no ☐ yes

2. Have you always been a fisherman?
☐ no
☐ yes

2.1. What other professions have you had ____________________

2.2. Have you ever had any additional professions __________________

3. Age and when you started fishing ? ____,____

4. Why you are fishing, you can choose more than one reason?
☐ Pass the traditional knowledge.
☐ Subsistence.
☐ Source of income.
☐ Hobby .
☐ All of the above.

5. Are you married?
☐ no
☐ yes →
is your spouse fishing too? how many days a week ?
____

6. How many children do you have? _________ children , Ages__________

7. How many relatives or family members do you have are fishermen?
____

8. Approximately what percentage of your family's income comes from fishing?

□ For subsistence only 0% □ < 25% □ 25-49% □ 50% - 74% □ > 75%

9.How often you go fishing?
□ Every day □ Weekly (no. of days) ( ) □ Monthly (no. of trips/months and which months)

10. What did you do for the days or months that you did not fish?
____

11. Why did you not fish every month?
□ bad weather
□ fish are seasonal
□ family reasons
□ other: ____

12. How many days are you away on a typical fishing trip? __________ days

13. Do you always go fishing in Nabq ?
□Yes ⟶ Where?
□ No ⟶ Where?
Please refer to map of the area on the back of this survey and 'color in' the areas that are most important to you as a fisherman. If it doesn't have a name?

14. What gear and technique do you use to catch these fish?
□ net (gill or trammel)
□ net (active or passive netting)
□ hand line
□ other

15. What fish do you target? Please list the species names as good as you can.
____
____

16. How often do you fish from a boat?
□ never
□ only some of the time
□ most of the time
□ every time

17. How big is the boat that you mostly fish from? __________ meters and ______________ HP

18. Do you know areas where fish aggregate (spawning or feeding areas)?
□ no
□ yes ⟶ Where and which species?

19. what level of education you have?
□ Don't R&W
□ R&W
□ Elementary
□ Middle

□ University

B. Your attitudes to change

Please answer the following questions with “no,” “yes,” or “I don’t know.”

1. Are you interested in a job other than fishing?
□ no
□ yes

2. Do you think that you can with stand the difficulties of fishing?
□ no
□ yes

3. Do you have other options available if you decided to no longer be a fisherman, specify?
□ no
□ yes

4. Do you think that you can survive if you were asked to change where or when or how to fish?
□ no
□ yes

C. Method for evaluating attitudes to marine conservation

1. Are you aware that your village and coastal waters are in Nabq protected area?
□ no
□ yes

2. Did you support or oppose the establishment of Nabq as a protected area?
□ support
□ oppose
□ I can’t remember

3. Why did you support or oppose the establishment of Nabq as a protected area?
____
____

4. Why do you think Nabq was declared as a protected area?
□ To protect the coral reef
□ To protect the fish
□ To protect the mangrove
□ To protect the wild life
□ Others
□ I don’t know

5. What do you know about the regulation of Nabq PA (what to do and what not to)?
____
____

6. Would you support or oppose closing some areas of your fishing grounds to help protect fish stocks from overfishing?

☐ support
☐ oppose
☐ I’m not sure

7. Why support or oppose closing some areas to help protect fish stocks from over fishing?
____
____

8. Would you support or oppose seasonal closure of fishing (spawning season)?
☐ support
☐ oppose
☐ I’m not sure

9. Why support or oppose seasonal closure of fishing (spawning season)?
____
____

10. Do you agree or disagree that Nabq fisheries is effectively managed?
☐ agree
☐ disagree
☐ I’m not sure

11. What do you think can be done to be effectively managed?
____
____

D. Perception to the change of the marine environment and causes of that change

1- What is your perception to each of the marine resource?

Resource type	Improved	No change	Worsened	I don't know
Coral reef				
Fish abundance				
Fish size				
Fish diversity				
others				

2- How strong is the impact of the following factors in degrading the marine environment?

Causes for marine environmental degradation	no impact	low impact	moderate impact	high impact
Too many fishermen				
Improved fishing technology and techniques (e.g., nylon nets, masks)				
Improper fishing techniques (e.g., active netting on reef flat)				
Too many visitors (e.g., divers and snorkelers)				
Illegal fishing (e.g., using harpoons, mesh size)				
Fishermen from outside Nabq				
Pollution				
Others (sold waste, plastics)				

Appendix 2

The different variables for the fishers questionnaire and their indicators

Table 48. The different variables for the fishers questionnaire and their indicators.

	Variables	
A	**Describing your relationship and dependency on the fisheries resources**	
I	**Attachment to place and fishing**	
1	Do you live in the Nabq?	In which town do you live?
2	Have you always lived in Nabq?	
3	Have you always been a fisherman?	
4	Do you always go fishing in Nabq ?	
5	What did you do for the days or months that you did not fish? Nothing 0, Tourism 1, NP official 2, NP casual 3, Herding 4, Other 5.	
6	when you started fishing ?	
7	Fishing years	
8	Why you are fishing?	Pass the traditional knowledge
		Subsistence
		Source of income
		Hobby
II	**Family dependency**	
9	Fishermen Women	Are you married?
10		Is your women fishing?
11		How often? Daily 3, weekly 2, Monthly 1, Never 0
12	How many children do you have?	
13	How many relatives or family members are fishermen?	
III	**Employability**	
14	Age	
15	what is your level of education? Don't R&W 0, R&W 1, Elementary 2, Middle 3, High 4, Diploma 5, University 6	
16	What other professions have you had? Nothing 0, Tourism 1, NP official 2, NP casual 3, Herding 4, Other 5	
IV	**Economic dependency**	
17	Do you own your fishing business?	
18	Approximately what percentage of your family's income comes from fishing? 0% 0, <25% 1, 25-49% 2, 50-74% 3, >75% 4	

Table 48 (cont'd)

V	**Environmental dependency**	
19	How often you go fishing? Monthly 1, Weekly 2, Every day 3	
20	Why did you not fish every month?	bad weather
		fish are seasonal
		family reasons
21	How many days are you away on a typical fishing trip?	
22	What gear you use ?	Trammel net
		Gill net
		Line
23	What technique do you use ?	Active net
		Passive net
		Hand Line
24	How often do you fish from a boat? Never 0, Monthly 1, Weekly 2, Daily 3.	
25	How big is the boat?	Length in meter
		Horse Power
26	Do you know areas where fish aggregate?	
B	**Perception to the change of the marine environment and causes of that change**	
27	What is your perception to each of the marine resource? Improved1, No change 0, Degraded -1	Coral reef
		Fish abundance
		Fish size
		Fish diversity
28	How strong is the impact of the following factors in degrading the marine environment? No impact 0, Low Impact 1, Moderate Impact 2, High Impact 3.	Too many fishermen
		Improved fishing technology and techniques (e.g., nylon nets, masks)
		Improper fishing techniques (e.g., active netting on reef flat)
		Too many visitors (e.g., divers and snorkelers)
		Illegal fishing (e.g., using harpoons, mesh size)
		Fishermen from outside Nabq
		water Pollution
		Solid waste (Plastic)
C	**Method for evaluating attitudes to marine conservation**	
29	Are you aware that your village and coastal waters are in Nabq protected area? Yes 1, No 0.	
30	Did you support or oppose the establishment of Nabq as a protected area? Support 1, Oppose 0	

Table 48 (cont'd)

31	Why do you think Nabq was declared as a protected area?	To protect the coral reef
		To protect the fish
		To protect the mangrove
		To protect the wild life
		I don't know
32	What do you know about the regulation of Nabq PA ? Know 1, Don't Know 0.	
33	Would you support or oppose closing some areas of your fishing grounds? Support 1, Oppose 0	
34	Would you support or oppose seasonal closure? Support 1, Oppose 0	
35	Do you agree or disagree that Nabq fisheries is effectively managed? Agree 1, Disagree 0, not sure 0.5.	
D	**Fishers attitudes to change**	
36	Are you interested in a job other than fishing? Yes 1, No 0.	
37	Do you think that you can withstand the difficulty of fishing ? Yes 1, No 0.	
38	Do you have other options available if you decided to no longer be a fisherman? Yes 1, No 0.	
39	What other professions have you had? Nothing 0, Tourism 1, NP official 2, NP casual 3, Herding 4, Other 5	
40	Do you think that you can survive if you were asked to change where or when or how to fish? Yes 1, No 0.	

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CHAPTER 5: CONCLUSION

The Egyptian Environmental Affairs Agency established a network of three Protected Areas on the Gulf of Aqaba, Ras Mohamed National park, Nabq Managed Resource Protected Area and Abu Gallum Manage Resource Protected Area. The main objective of these Protected Areas was to conserve the biodiversity of the coral reef system and yet allow a sustainable traditional fisheries by the local community (Bedouin) in selected regions of the network. As a result, different conservation measures were used, in Ras Mohamed and Sharm El Sheikh where all types of fishing were prohibited, while in Nabq, fishing was permitted only for the Bedouin and an alternative No Take Zones and Take Zones management program was used to protect the overall fisheries while allowing the Bedouins fishing rights for food security and livelihoods. Fishing was allowed in Dahab and the rest of the Gulf of Aqaba but reserved solely for the Bedouin with little regulation by the government. The effectiveness of the MPAs in conserving fish population and sustaining the fisheries has always been a controversial issue and has been of great interest of many fisheries and marine scientists all over the world, especially for coral reef fisheries where the MPAs is commonly used as a primary management tool for protection of biodiversity. Although many studies have demonstrated the effectiveness of this tool around the world, others have equally shown that it has been ineffective in many part of the world. The reasons for this dichotomy of viewpoints is that for a MPA to be effective many conditions and terms need to be met, starting from the designing and planning till the implementation, monitoring and enforcement components of the management programs (Taylor et al. 1995).

This dissertation was designed to assess the effectiveness of the MPAs in the Gulf of Aqaba to answer one main question: whether the MPAs positively affecting the coral reef fish community over the last decade. Earlier studies by Roberts and Polunin (1992), Galal (1999) and (2002), Ashworth (2004) and Ashworth and Ormond (2005) shown that the MPAs in the Gulf of Aqaba and the NTZs in Nabq were effective in conserving the fish populations, at the beginning of their establishment. This dissertation research attempts to look at the longer range view and assess if they are still providing wished for benefits after two decades from Roberts and Polunin 1992 seminal work and given the changes in governance in Egypt. The information that I collected will hopefully help increase the sustainability of the coral reef fisheries ecosystems while protecting the abilities of the local people to fish for sustenance and livelihoods.

I found that the MPAs in the Gulf of Aqaba were effective in conserving the fish population to some extent. Species richness and diversity were higher in the unfished regions Ras Mohamed and Sharm than in the fished areas of Nabq and Dahab. Additionally Nabq fisheries showed a significant decrease in species richness by 2012 where fishing had increased in recent years. Contrary to this finding, I noted that the fish community in Dahab increased in both species richness and diversity where fishing pressure had been reduced, public awareness had increased, and some enforcement had been implemented with the assistance of the Non-Governmental organization (NGOs) and the Bedouin.

By 2012 Ras Mohamed, the unfished region, was shown to have a noticeable decrease in the abundance of the fish assemblage including fishes from the highly commercial target family Serranidae and the low target families Acanthuridae and Scaridae. Nabq the fished region decreased in the abundance of the fish assemblage, and in the abundances of 8 of the 9 families evaluated. While Dahab, the fished region, increased in the abundance of the fish assemblage and all the commercially target families. Additionally size of the target herbivore and carnivores decreased in 2012 in the fished region Nabq and Dahab While fish located near Sharm, the unfished region and where the biggest resort in Egypt (over 50,000 room), did not show any significant change in species richness, diversity, assemblage abundance or the abundance of the fish assemblage studied. Generally by 2012 the MPAs in the Gulf of Aqaba decreased in the abundance of the fish assemblage and the target herbivores (Acanthuridae, Siganidae, and Scaridae) and carnivores (Serranidae, Lutjanidae, and Lethrinidae), while the non-target families Chaetodontidae and Pomacanthidae increased in abundance. The fish assemblage was different between regions at the beginning of the study while at the end the fish assemblage at all sites became more similar. Likewise the difference noted in the fish assemblage at the beginning of the study and the end were no longer as apparent at the end, with reef flat and reef slope fish much more similar in 2012 compared to 2002 because of non-compliance and overfishing.

My study focused more on Nabq in order to investigate the effectiveness of using the NTZs in conserving the fish population and the fisheries. I found that the use of NTZs couldn’t stop the decline of the fish populations nor the fish catch at Ghargana site and there is a possibility that this impact was extended to the nearby sites. Unfortunately I found that fishers started fishing the NTZs by 2009 and did not respect the no take regulations anymore. I found that the CPUE decreased for the main fishing technique used and to adapt, fishers increasingly used other alternative techniques targeting lower value commercial species. Additionally some highly valued commercially target species from families Serranidae and Lutjanidae had disappeared from the surveyed sites in 2012 due to lack of enforcement which allowed non-compliance and fishing the NTZs.

It was important to understand the relationship between the Bedouin fishers and the fisheries resources in Nabq to assess their dependency on these resources, their attitude toward conservation, their perception toward the changes in these resources and toward the possibilities of changing their livelihood. Many of the fishers in Nabq and Dahab were dependent on Nabq fisheries to a great extent, mainly for subsistence and as a source of income. However they said they would be willing to change their career and work in tourism or other governmental secured job. Fishers were aware about the decline in the fisheries and confirmed the disappearance of some of the target species which they related to the increase in the number of fishers and illegal fishing from outside Nabq. Although fishers were aware, of the regulation and generally support the conservation measures, they were in conflict with the management authorities due to the lack of enforcement resulting in noncompliance in the NTZs.

As a ranger, I was part of the management of these protected area as manager of Nabq and the Gulf of Aqaba protectorates (1995-2009) and based on the results from the earlier studies and this study, I believe that the MPAs in the Gulf of Aqaba initially played an important role in conserving the fish population in the area. However, this role has diminished over time and as a result fish populations have declined in Ras Mohamed and Nabq. It is my opinion that this is mainly to the change in the fishers behavior where they now fished Ras Mohamed and the NTZs in Nabq, as a result of lack of enforcement and management resources. While in Dahab, I believe participation from the local fishers in the fisheries management, enforcement and education increased their awareness and support of the MPA's, result in higher voluntary compliance and thus increasing fish diversity, fish population demonstrating that the reef fishes were starting to recover. Also Sharm where the resorts prevent fishers from access and hotel managers are enforcing the law since they are aware about the important of the coral reef and coral reef fishes for their tourists, no changes in the fish population metrics were observed.

Implications for Fisheries Management and Future Research

It is important that the MPAs managers, policy makers and stakeholders are aware of the present situation of the fish population and fisheries in the studied regions, and that loosing these valuable and vulnerable resource could be just a matter of time if we continue to manage the same old way. One way to improve the management of these resources is through involvement in the local citizenry which will require programs that increase the awareness of the stakeholders. Currently, the Gulf of Aqaba Protectorates authority is facing a lack in human and financial of resources (Sowers 2007, Samy 2011) especially after the European Commission finished their projects in 2002. A new fisheries management plan for the Gulf of Aqaba protectorates should be established, where the participatory approach of the stakeholders is included.

Beside the No take zones other fisheries management measures should be implemented in order to recover the depleted stocks from the regions studied where fishing were allowed, especially the highly valuable carnivorous target families (Serranidae, Lutjanidae, and Lethrinidae). Restrictions on such things as size limit, bag limit per fisher, and seasonal closure at the spawning season need to be implemented. A new more effective system in law enforcement should be applied where the local Bedouins are involved and sharing the responsibility. This was successfully applied earlier and funded by the EU project but was terminated due to lack of fund. The successful experience in Dahab working with the local community and NGOs, sharing knowledge and authority to the community in managing the fisheries resources and enforcing it by the Bedouin fishers resulted in increased compliance with fisheries regulations resulting in increases in the fish diversity and density.

The No Take Zones and Take Zones should be redesigned in Nabq and increased in size in order to relieve the fishing pressure in some regions of relatively high human populations centers such as the case in Ghargana. When designing the size and location of NTZ one must be cognizant of such ecological factors of where fishes nursery ground habitats are and the home range of the target fish.

This study shown the important of monitoring and research in management the fisheries resources. As such, I believe that one should develop a long term monitoring plan for the fish population abundance and diversity and coupled with an assessment of fish catch and habitats quality including coral reef, sea grass and mangrove for this region. Volunteers from the local communities and from the diving communities should be involved in monitoring and enforcement as in the case of Dahab. A study on the reef connectivity and the transportation of fish larvae should be conducted to identify the location and size of donor reefs for further protection in order to adjust the size and numbers of NTZ in the Gulf of Aqaba for improved fisheries resource management of the coral reef fisheries in this region.

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