Assessment of the status of coral reefs in the El Quadim Bay, El Quseir, Egypt

by Reef Check e.V.

SUBEX Red Sea Diving Centers
With support from Mövenpick Resort El Quseir

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Acronyms

COTS – Crown-of-Thorns Starfish

EEAA – Egyptian Environmental Affairs Agency

HEPCA – Hurghada Environmental Protection and Conservation Association

NGO – Non-governmental Organisation

RC – Reef Check

SCUBA – Self-Contained Underwater-Breathing Apparatus

SST – Sea Surface Temperature

1. Foreword

When stationed in El Quseir as a medical officer, the German doctor and naturalist Carl Benjamin Klunzinger (1834-1914) spent eights years exploring the region's coral reefs, starting in 1864.

Even today, the publication and results of his investigations in Quseir on corals, crabs, fish and dugongs remain important standard works for taxonomists, ecologists and - above all - marine biologists.

The things this modestly equipped scientist explored, discovered and described in detail paved the way for study of the impact of organisms living together in the coral reef. Klunzinger was the first to address the issue of coral reef ecology from a scientific angle and is thus rightly described as the founder of descriptive reef ecology.

As with all naturalists, Klunzinger was driven by his curiosity to find out more and identify the extensive interrelationships in reef life that would enable him to understand a bit more about this natural wonder.

He observed, sketched, painted and described the diversity, magnificent array of colours and uniqueness of corals and the organisms living in and around them. The only copies of these works in existence can still be seen in many museums in Europe, including the State Museum for Natural History in Stuttgart, Klunzinger's home town and the place where he worked in later life.

As a result of his work, knowledge about coral reef ecology was exported from El Quseir to the rest of the world.

What nobody could possibly have guessed at the time was that today the situation has been reversed: instead of exports of knowledge about coral reefs, in economic terms we are now witnessing imports. The fascinating appeal of coral reefs attracts millions of holidaymakers to the Red Sea. In recent years, beach, snorkelling and diving tourism has become one of Egypt's main sources of income, making coral reefs an important economic factor.

Accordingly, for the resort facilities in El Quadim Bay in El Quseir, investors and operators set themselves the target of permanently maintaining and reconciling economic interests with the ecological value of the coral reef.

When the project was launched in the late 1980s, the three partners (Hotel Serena Beach Company as the investor, Mövenpick Hotels International as the resort manager und Subex as the diving expert) all agreed not only to try and make the project and the resort's operation an economic success, but also to protect and preserve the region's existing natural resources. This aim, shared by all the partners, enabled us at Subex to organise the diving right from the outset in such a way that it helped to preserve the bay and the house reef in El Quadim Bay.

Having run diving operations there for 10 years, we wanted to know whether we had achieved the goal we set ourselves, i.e. using our beach, snorkelling and diving resort to safeguard the coral reefs in El Quadim Bay in the long term.

To that end we commissioned this study to ascertain the current state of 'our' coral reef in El Quadim Bay by scientifically verifiable means and using data that could be compared on a worldwide basis.

In addition to making several extremely interesting observations, the study also tells us whether or not we have managed to reconcile our knowledge about the importance of ecology in the coral reefs with the economic interests of tourism.

The study is aimed at holidaymakers, snorkellers, divers, resort managers, investors, tourism companies, diving organisations, local and national authorities, specialist magazines and national and international environmental organisations, i.e. at anyone interested in the sustainable use of coral reefs their preservation for future generations as pristine ecological habitats.

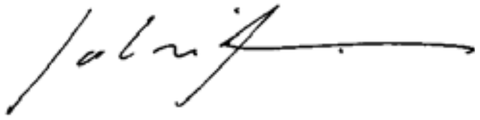
After all, it is true for all of us that what we give to the underwater world, we get back in return.

In that spirit I will sign off. Thank you in advance for paying attention to this study.

El Quseir, December 2005

Johann Vifian

Director / Associate Subex Red Sea Diving Centres



Johann Vifian

Director / Associate SUBEX Red Sea Diving Centers

El Quseir, December 2005

2. Executive Summary

The tourism sector of many countries benefits from the natural beauty of their beaches and coral reefs, which constantly attract an increasing number of visitors. But the steadily growing number of tourists holds dangers for the environment. The coastal development is coupled with the construction of streets, airports and hotels, desalination-, sewage- and wastewater treatment plants, beach replenishment, increasing fishery, as well as the production of trash and pollutants. Also the tourists themselves can be a threat to these delicate ecosystems. Swimmers, snorkellers and divers can cause local damage to reefs by trampling on the reef top or by wilful or unintentional breaking of corals. Heavily dived reefs can, due to a high degree of damage, loose their attractiveness, which then can result in a decrease in tourism. Intact and healthy coral reefs are the foundation of the business of the diving industry, and wise management of the use of this resource is the basis for sustainable and lasting tourism.

This study on the condition of the reefs of the El Quadim Bay, El Quseir, Egypt was commissioned by SUBEX Red Sea Diving Centers and was conducted in October 2005 by Reef Check e.V.. The SUBEX Dive Center in El Quseir is affiliated to the "Green Globe" certified Mövenpick Resort El Quseir, which supported the field work. The assessment of the present state of the reef was divided into two main components: Basic surveys were conducted by means of Reef Check methods, which deliver baseline data on fish and invertebrate indicator species, substrate composition and general reef quality in terms of pollution, damage and diseases. Detailed surveys on the fish and coral fauna were carried out to reveal the diversity and structure of different reef populations and to allow comparisons to other reef sites.

The study was directed to detect and quantify anthropogenic impacts on the reef community, in particular from diving activities. The transects in four deployed sectors will be used as permanent observation stations and the obtained information will serve as baseline for an autonomous monitoring project conducted by members of the dive centre in the future. Based on the data of the study, recommendations and suggestions for the management of the dive centre were developed.

The reefs of the El Quadim Bay are generally in a good ecological condition. The diving tourism does not impose an immediate threat to the coral reefs' health. The recorded data show that the state of the reefs of El Quadim Bay is comparable to reefs in protected areas. The diversity of the fish and coral fauna is high and the population structures are similar to those observed in protected areas.

Between 3 m and 25 m depth, a total of 153 fish species, belonging to 97 genera and 40 families were counted, with the Damselfish (Pomacentridae) being the most abundant fish family. The most abundant Reef Check indicator fish were the Butterflyfish (Chaetodontidae). The fish populations of the northern and southern side of the bay were significantly different, which is not exceptional, but may be due to variable substrate characteristics and hydrodynamic differences. The ban of fishing in the El Quadim Bay seems to have a positive effect on the abundance and diversity of fish. There is no indication that the dive tourism has a major negative impact onto the fish fauna.

From the reef flat to 30 m depth 144 species of stony corals, 4 species of hydrocorals and 15 genera of soft corals were found. The coral communities are heterogeneous, only in the inner part of the bay *Porites nodifera* is dominant. Horizontal as well as vertical zonations could be detected which is a typical feature in reefs generated by depth differences, site characteristica and expositions. The average coral cover was 36.6%, which is relatively high for reefs that grow on steeper slopes. The percentage of recently killed coral was low and the most abundant coral damage was breakage presumably caused by divers, snorkellers and swimmers. Most breakage was observed on the inner southern (right) side of the bay, where diving intensity is highest. It is probable, that part of the responsibility for the breakage lies with the snorkellers who, swimming on the surface, usually move close to the reef crest and are often pushed against the reef by waves.

Coral diseases were not observed in high amounts, but coral predation, mainly by coral feeding snails, was relatively high. Fortunately, only little trash like plastic or fishing gear was found. Some invertebrate indicator species were not observed in the reef, which however, is not necessarily indicating negative impacts. Sewage and pollutants derived from treatment systems or desalination plants do not seem to pose a threat to the reefs of El Quadim Bay due to its isolated location and the sewage treatment and processing systems of the hotel.

However, due to sedimentation, the water inside the bay is frequently turbid. In the scope of this study it was not possible to reveal the source of this sediment causing the turbidity and whether this happens to be a natural or man-made impact.

The reef topography, the exclusion of fishing and the control over numbers and skills of SCUBA-divers by the dive centre staff contribute significantly to the healthy condition of the reefs of the El Quadim Bay. The key to the conservation of intact reefs is given by a sustainable management, the monitoring of diving behaviour, as well as the education and information of staff members of the dive centre and guests. By propagating the knowledge on ecological connections and human impacts to SCUBA-divers and snorkellers and by exemplifying an environmentally friendly and correct behaviour under water, the condition of the El Quadim ecosystem can be preserved for the future.

3. Goals of the study

The goals of this study are to

1) assess the condition of reefs in El Quadim Bay;
2) assess the biodiversity of the fish population and coral fauna;
3) assess the effect of human activities on the reef community,
4) in particular to assess the effect of diving activities;
5) set a baseline for future continuous monitoring;
6) establish long-term monitoring stations that can be used by the dive centre staff to assess a) the effectiveness of management measures and b) changes in reef condition over time;
7) inform the management of our findings and make recommendations.

To attain our goals, we have divided the project into two subcomponents:

1) Reef Check surveys (baseline surveys)
2) Focused surveys on the diversity of the fish and coral fauna

Coral reef survey data from this project will be sent to the Reef Check headquarters where these are used for regular reports on the health of reefs at the global and regional scale (e.g. "The Global Coral Reef Crisis: trends and solutions" (Hodgson & Liebeler, 2002). These reports are promoted and disseminated widely and are also available at the Reef Check website.

At the countrywide scale, Reef Check Egypt will use the results to describe the conditions of reefs in the Red Sea. The data will be housed in the Reef Check database. Over time, as repeat surveys are conducted, data will be used as an early warning detection for large intensity changes.

At the local scale, results will be used to describe the health of the reef, which will assist resource managers to manage tourist activities in the bay.

The long-term objective of this project is to develop a model for public sector involvement in coral reef conservation that can be applied to other areas of the Red Sea.

4. Introduction

4.1. *Value of Reefs*

Coral reefs are one of the most diverse ecosystems in the world. They build islands and atolls, serve as shoreline protection and provide habitats for many fish and invertebrate species. Many of these organisms are exploited by fisheries for direct consumption or other uses, or used as biomedicals. The Red Sea inhabits more than 200 species of stony corals, about 2,000 mollusc species and 1,270 species of fishes (NOAA 1997).

The biological wealth and the astounding beauty of this ecosystem makes it a popular tourism destination, and coral reefs attract an increasing number of divers and snorkelers each year. Tourism to reef areas is a fast growing business and constitutes a major source of income for countries endowed with reefs (Ruppert & Barnes 1994, Wolanski et al. 2003, Barker & Roberts 2004).

4.2. *Threats to Reefs*

However, coral reefs are declining at an alarming rate worldwide. This decline is mostly due to a large variety of human impacts that include local activities to large scale and global changes (ISRS 2004). It is estimated that 20% of the world's coral reefs have been effectively destroyed, 24% are under immediate risk of collapse, and a further 26% are under a longer term threat of collapse (Wilkinson 2004).

4.2.1. Global Climate Change

Global warming increases the frequency and severity of bleaching events (Goldberg & Wilkinson 2004). The 1998 worldwide bleaching event killed approximately 16% of the world's reefs and only a third of them are recovering (Wilkinson 2004). Increasing sea surface temperatures and CO_2 concentrations provide clear evidence of global climate change in the tropics.

4.2.2. Diseases & Plagues

Diseases like white-band disease, black-band disease, "plague" and "plague type II" diminish the number of live corals on a reef. In the Persian/Arabian Gulf, the newly discovered yellow-band disease is affecting up to 75 percent of the coral colonies in local populations (ISRS 2005).

Natural predators of corals include echinoderms such as the Crown-of-thorns-starfish (*Acanthaster planci*), various sea urchins (*Diadema* sp., *Echinotrix* sp., *Echinometra* sp.), as well as corallivorous gastropods (snails) like *Drupella* spp. and *Coralliophila* spp.. Outbreaks of such predators can destroy large areas of reefs for years.

4.2.3. Maritime Transport, Oil and other Hydrocarbons

The Red Sea is part of a major world shipping route which currently carries around 7 percent of the global seaborne trade. Much of the world's crude and refined oil cargoes pass through the Red Sea and Gulf of Aden. About 20,000 ships pass through the Strait of Bab al-Mandab each year (Abduljalil 2005) and an estimated 25,000 to 30,000 ships transit the Red Sea annually (data from 2000). Apart from ship-related pollution risks (e.g. discharges of garbage and oily wastes; bunkering activities), accidents involving tankers together with discharges from unloading operations constitute a serious pollution risk.

The danger from oil pollution comes not only from exploration activities but also from transport, in which millions of tonnes per annum pass through the region. More than 20 oil spills occurred along the Egyptian Red Sea since 1982. The spills involve a number of pollutants, which smother corals and poison them through hydrocarbon absorption. Oil exploration through seismic blasts is also a threat to coral reefs. Small oil spills cause beach contamination and damage to the coastal and marine biota. These occur through the discharge of ballast and bilge water, discharge of waste oil, or bunker oil spill. The lack of reception facilities at the port, inadequate control, and lack of enforcement compound the problem. Potential large oil spills and disasters could cause large-scale destruction of coastal and marine habitats and biota and devastation of beach habitats (Wilkinson 2000).

4.2.4. Coastal Development

4.2.4.1. Construction of Resorts

Since the touristic development in Egypt often takes place in remote areas without any or insufficient infrastructure, hotels need to provide their own sewage treatment, desalination plants and electricity generators. Hot brines from desalination plants and cooling water from generators might cause local damage to coral reefs (Hawkins & Roberts 1994). Not only the number of beach resorts and hotels is continuously increasing, but also the dive tourism sector enjoys greater popularity each year (Shaalan 2005). Therefore, sustainable management regulations for all branches within the tourism sector have to be found and enforced to find a justifiable basis on which the integrity of the coral reef ecosystem is maintained while economic gain is still possible.

4.2.4.2. Nutrients, Sediments, Suspended Matter and Pollutants

Agricultural, industrial and urban run-off carry high loads of suspended matter and pollutants into the nearshore areas. Sediments from beach replenishment or construction sites for roads, ports, airports and buildings turbid the water, reduce light and settle on the coral polyps hence clogging their pores (Goldberg & Wilkinson 2004).

The main direct effects of terrestrial runoff on coral populations are: reduced recruitment, decreased calcification, shallower depth distribution limits, altered species composition (shifting from a more phototrophic to a more heterotrophic fauna), and the loss of biodiversity (ISRS 2004). Nutrient pollution leads to increasing algal growth and turbidity in the water column. Because coral reefs characteristically grow in clear water which is low in nutrient concentrations and produce energy by photosynthesis, these anthropogenic impacts can and often do lead to reef destruction (Cortés & Risk 1985, Guzmán & Jiménez 1992, West & van Woesik 2001).

4.2.4.3. Solid Waste

Solid waste is an increasing problem as tourist centres grow and adequate waste disposal systems are often not implemented. Solid waste litters the coast of many countries and is in particular a problem in centres of population. Plastic bottles and bags are omnipresent litter in the terrestrial and marine environments. Plastic bags can, for instance, be mistaken by turtles for jellyfish, one of their prey, and hence be swallowed; they can also smother corals and damage the coral reef (Hawkins & Roberts 1994).

4.2.5. Impacts of Tourism

4.2.5.1. Fishing

Ever increasing numbers of tourists to coastal and reefal regions consume great quantities of fresh seafood. Species that are high in demand, such as lobster, groupers, emperors and snappers are exploited more and more, and high priced species are at a particular risk of being overfished (Hawkins & Roberts 1994).

4.2.5.2. Direct Impacts of Tourist Activities

Direct Impacts by Swimmers, Snorkelers and Divers

Increasing coral tourism leads to local destruction of frequently dived and snorkelled reefs. Swimming, snorkelling and SCUBA diving can have a direct impact on coral reefs by touching, trampling and breaking of corals and it has been shown that reefs experiencing high rates of diving have a higher percentage of broken corals than non-dived reefs.

On the reef flat, trampling leads to a reduction in number of coral colonies and hard coral cover as well as increased cover of rubble and bare rock. In addition the community structure might change to a reduced abundance of branching coral colonies (Hawkins & Roberts 1992b). This negative effect can be avoided by cross-reef walkways, which give easy access to deeper water in front of the reef edge (Ormond et al. 1997).

In particular snorkellers that are going to explore the underwater life for the first time cause a lot of coral damage, because many of them have poor swimming skills. Once they are exhausted or their mask is flooded, they will trample the corals to take a rest or to bring their gear in order. Even snorkelers with life vests can be observed along the reef edge and it is likely that these non-swimming persons will grab onto anything to get a hold or to keep themselves above the surface. Touching of corals can cause tissue damage that leads to a higher vulnerability, to overgrowth by algae (Riegl & Velimirov 1991), or diseases (Harriott, 1997).

Effects by SCUBA diving are especially distinctive within the first 10 m depth where most recreational scuba diving takes place (Riegl & Velimirov 1991, Hawkins et al. 1999, Tratalos & Austin 2001, Hawkins et al. 2005). In addition to the direct damage of corals, resuspension of sediment by divers also may stress corals (Hawkins & Roberts 1992a). However, none of the studies on the impact of SCUBA divers on coral reefs (Riegl & Velimirov 1991, Hawkins & Roberts 1992a, Harriott et al. 1997, Rouphael & Inglis 1997) was able to prove a major negative impact of diving on the coral reef ecosystem, but this might be due to the lack of long term monitoring studies. Hawkins & Roberts (1992a) even consider the impact of diving on corals in their study more "...an aesthetic than a biological problem". Nevertheless, all studies concluded that the increasing number of dives might lead to a severe damage of coral reefs and that long-term studies and monitoring programmes are needed.

This problem is particularly serious in Egypt, which is today one of the major SCUBA diving destinations in the world, visited mainly by European recreational divers (Bryant et al. 1998).

Curio Trade

Even though prohibited by Egyptian Law 4/1994, the collection and trade of marine curios remained a major problem mainly in the coastal area around Hurghada. Shops sold a wide variety of marine curios such as corals, shells, starfish, sea urchins, dried-out fish, turtles and shark jaws (Hawkins & Roberts 1994). Virtually all of it was collected in the coral reefs of Hurghada, threatening some heavily collected species and the ecosystem in general. Improved implementation of the laws has resulted in the disappearance of this trade.

Boating and Anchoring

The single largest environmental impact from diving was the usage of anchors by dive boats (Tilmant 1987, Harriott et al. 1997). Anchor damage leads to the destruction of the carbonate rock basis of the reef itself and the formation of loose boulders. This creates an unstable substrate unsuitable for the settlement of coral larvae (Riegl & Velimirov 1991). Particularly the reefs in Hurghada suffered from anchor damage in the past. Anchoring within protected areas of Egypt has been prohibited by article 2 of law 102/1983.

4.3. Conservation Efforts in Egypt

4.3.1. Governmental Efforts in Egypt

In June 1997, the responsibility of Egypt's first full time Minister of State for Environmental Affairs was assigned as stated in the Presidential Decree no. 275/1997. From thereon, the new ministry has focused, in close collaboration with the national and international development partners, on defining environmental policies, setting priorities and implementing initiatives within a context of sustainable development. According to the Law 4/1994 for the Protection of the Environment, the Egyptian Environmental Affairs Agency (EEAA) was restructured with the new mandate to substitute the institution initially established in 1982. EEAA represents the executive arm of the Ministry (EEAA 2005, www.eeaa.gov.eg).

Three basic environmental laws are of particular relevance to coral reefs in Egypt. They are law 102 of July 1983, which is concise and specifically aimed at protected areas. Law No. 124/1983 on fishing, aquatic life and the regulation of fish farms prohibits, among other regulations, the use of poisonous and explosive substances in fishing activities. Law 4 of January 1994 is more general in scope and prohibits the collection of corals, shellfish and other marine life in all Egyptian waters.

Most of the regulations that are applicable in the Red Sea nowadays are based on a protocol signed between the Red Sea Governorate, the EEAA and HEPCA. It was stated in a governor's decree of the year 2000 that any violator for the internal regulations of the Red Sea Governorate drafted by the National Parks department will be fined according to the assessment of damage and this assessment will be done by the National Parks (pers. comm. HEPCA).

4.3.2. Non-governmental Activities

Initiated by Johann Vifian, ca. 40 local dive centres established HEPCA – the Hurghada Environmental Protection and Conservation Association in Hurghada and Safaga on September 21, 1992. The charter members decided to respond to the problem of direct anchoring on the reef, with the installation of 100 mooring buoys and lines, to prevent further damage on some of the most popular reefs. In 1995 HEPCA was registered with the Red Sea Governorate and the Ministry of Social Affairs as a Non-Governmental – Non-Profit-Organization.

HEPCA is today active in the installation and maintenance of mooring systems, training activities for the boating community and the marine society, production of publications, organisation of awareness activities in schools, as well as cleaning campaigns (beach clean up, reef clean up). HEPCA was recently declared a "Central" NGO, allowing it to operate throughout the whole of Egypt.

4.4. *Survey on the Status of the Reefs in El Quadim Bay*

In summer 2005 Reef Check e.V. was commissioned by SUBEX Red Sea Diving Centers to carry out an audit of the health of a “house-reef” in El Quadim Bay in El Quseir, Egypt. The SUBEX Dive Center is associated with the Green Globe certified Mövenpick Resort El Quseir, which has been designed to minimize its impact on the environment.

4.5. *Research Area*

The Egyptian coastal town of El Quseir is located about 120 km south of the major resort town of Hurghada at the Northern Red Sea coast (Fig. 1), and has so far only limited diving tourism activities. The El Quadim Bay (Fig. 1) is the relict of a fossil riverbed and nowadays the estuary of a wadi (dry river valley), which in irregular time distances discharges water derived from the Eastern Desert Mountains as a result of rare but heavy rainfalls. The study area includes El Quadim Bay and the neighbouring outer fringing reef and extends between N 26°09'40,98"; E 034°14'48,24" and N 26°09'25,32"; E 034°14'58,86".

Fig. 1 Map and satellite image of the Northern Red Sea with the study site El Quseir (satellite image courtesy HEPCA).

The climate in El Quseir is typical for the coast of the Northern Red Sea, it is warm and arid. The average monthly air temperature ranges between 16°C in January and 31.5°C in August (Fig. 2). Rare but heavy rainfalls, which occur in the nearby Eastern Desert Mountains result in rapid runoff events. E.g. in 1994, the wadi in El Quadim Bay was flooded to the extent that the paved road along the bay was flushed away. The last major rainfall is reported from winter 1996/97. There is no regular monitoring of climate data in El Quseir; therefore satellite-derived data are the best available source of information.

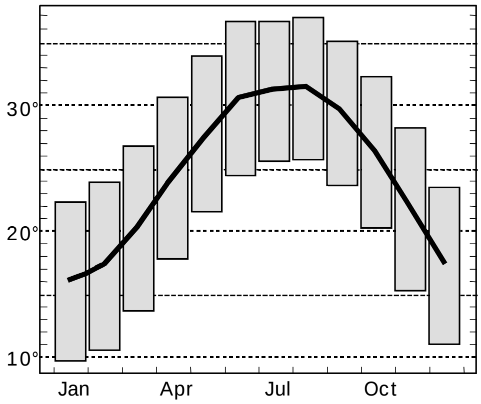


Fig. 2 Average monthly air temperature in El Quseir between 1961-1990. The mean temperature is plotted with a solid line, the diurnal range is indicated by bars; the top (bottom) of each bar indicates the average maximum (minimum) temperature. Data centered at 26.25°N, 34.25°E. Data source: University of East Anglia (0.5 x 0.5 degree 1961-1990 Monthly Climatology), available at http://ingrid.ldeo.columbia.edu/maproom

The temperature of the sea surface reaches its lowest values in February with average monthly temperatures around 21°C, while the annual maximum occurs in August with average temperatures between 28°C and 29°C (Fig. 3). The sea surface temperatures (SST) over the last 23 years exhibit a strong annual periodicity, with relatively cool periods in 1984/85 and 1997/98 (Fig. 4). The general trend suggests an increase in annual mean SST by 0.4°C over this period (Fig. 3, Fig. 4).

SSTs in El Quseir are in the optimum range for coral growth. The devastating worldwide coral bleaching event of 1998, which followed a very strong El Niño, did not reach the Central and Northern Red Sea (Wilkinson 2000).

Fig. 3 Monthly mean sea surface temperature from 1983-2004 in the El Quseir region, calculated from satellite data over an area of 1x1°. Source Reynolds et al. (2002).

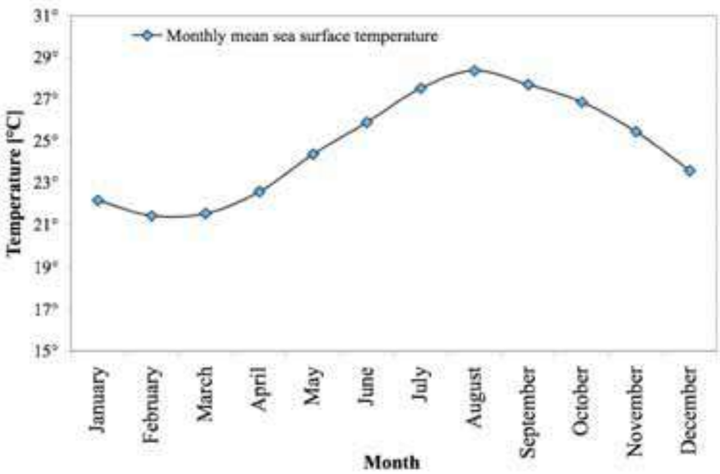
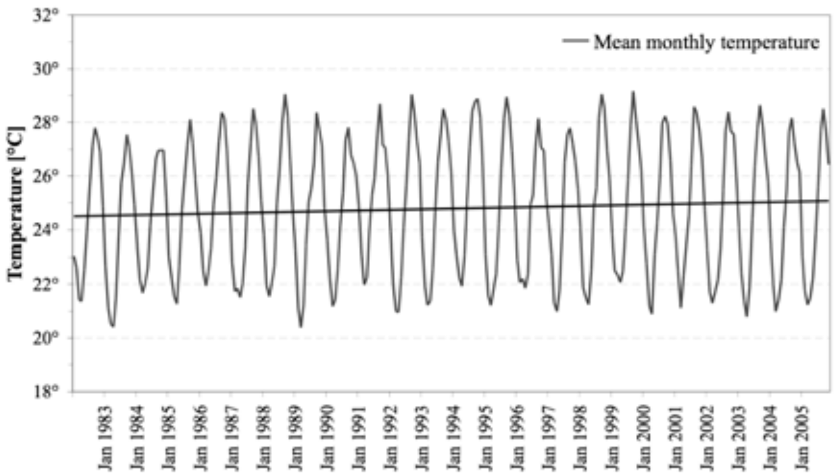


Fig. 4 Monthly mean sea surface temperature from December 1981 to October 2005 in the El Quseir region, calculated from satellite data over an area of 1x1°. Source: Reynolds et al. (2002).



4.6. *Reef Check Surveys*

Four sites were surveyed in the frame of this assessment and compared with respect to human impact, percent cover of several substrate categories, abundance of certain invertebrate and fish species as well as coral damage. Results are listed in Table 5 and the appendix and described in the following chapters.

4.6.1. Methods – Reef Check surveys

This project used Reef Check, a well-tested standardized methodology to characterize reef condition. The Reef Check survey methodology was developed by a group of marine scientists, led by Dr. Gregor Hodgson (Reef Check Foundation), beginning in 1996. It then underwent extensive peer review and has been continuously updated and improved through the annual publication of the Reef Check Survey Manual (Hodgson et al. 2004, www.reefcheck.org). The methodology has been developed with the intention to create a scientifically rigorous, but also easily understandable survey that can be used by non-scientists.

Reef Check surveys focus on the abundance of particular coral reef organisms that best reflect the condition of the ecosystem and that are easily recognisable to non-specialists. Table 1 shows the indicator fish and invertebrate species for the Red Sea region. Pictures of indicator taxa are provided in Plate 1 and 2 in the appendix.

The selection of these organisms was made based on their economic and ecological value, their sensitivity to human impacts (over-fishing/harvesting, aquarium trade), and ease of identification. Sixteen global and eight regional indicator organisms serve as specific measures of human impacts on coral reefs. Some Reef Check indicators are on the species level while others are on a higher taxonomic level. The Reef Check survey begins with a site survey to determine the extent of the reef and the overall coverage of various substrates and live/dead coral. The actual Reef Check survey (Fig. 5) is comprised of four 20-meter transects surveyed at each of two depths, shallow (2-6 m) and mid-reef (6-12 m). Each 20 m transect is sampled for 1) indicator fish species typically targeted by fishers, aquarium collectors and others, 2) indicator invertebrate species typically targeted as food, curios, or aquarium specimens, 3) reef substrate type including live coral, recently killed coral, nutrient indicator algae, and other inert substrate types, and 4) any signs of damage and diseases, including broken corals, bleaching, trash, fishing nets and lines, predators, parasites etc..

Table 1 Reef Check indicator taxa for the Red Sea region.

Fishes

- Butterfly fish (Chaetodontidae)
  - ornamental trade indicator (more than 30 species of Chaetodontidae are collected for aquarium trade)
  - sometimes caught for consumption (mainly Pacific)
- Sweetlips (Haemulidae)
  - fisheries indicator
  - 150 different species that are highly popular food fish
- Snapper (Lutjanidae)
  - fisheries indicator
  - popular food fish
- Broomtail wrasse (*Cheilinus lunulatus*)
  - fisheries indicator
- Humphead wrasse (*Cheilinus undulatus*)
  - live food fish trade
  - due to its size very valuable
  - important predator fish
  - COTS predator
- Bumphead parrotfish (*Bolbometopon muricatum*)
  - fisheries indicator
  - form significant part of reef fish biomass
- Moray eel (Muraenidae)
  - fisheries indicator
  - fished for their size and easy detectability
- Grouper (Serranidae) > 30 cm length
  - fisheries indicator
  - common food fish, easy to catch
- Parrotfish (Scaridae) > 20 cm length
  - fisheries indicator
  - large fish that grazes algae from reef
  - abundance too low → algal overgrowth of reef

Invertebrates

- Banded coral shrimp (*Stenopus hispidus*)
  - ornamental trade indicator
  - collected for aquarium trade
- Long-spined sea urchins (*Diadema* spp., *Echinotrix* spp.)
  - indicator for insufficient predatory fish (bioeroders: while feeding scrape off calcium carbonate from reef and so destabilize it; abundance too high (if - due to overfishing - not sufficient predators are abundant or nutrient concentrations that favour algal growth are high) → net reef erosion)
  - fisheries indicator (decrease algal cover by grazing; abundance too low (due to fisheries or disease) → algal overgrowth of reef)
- Pencil urchins (Heterocentrotus mammilatus)
  - curio trade indicator
  - jewelry, seashell arrangements etc.
- Sea cucumber (*Thelenota* spp., *Stichopus* spp.)
  - fisheries indicator
  - edible, easy to collect
  - digest sand and form compact sediment into pellets → reef formation
- Crown-of-thorns starfish (*Acanthaster planci*)
  - coral predator
  - in high numbers becomes pest → reef destruction
  - COTS outbreaks possibly related to human activities (increased nutrient run-off due to sewage outlets and inappropriate agricultural purposes favours larval growth of COTS)
- Giant clam (*Tridacna* spp.)
  - fisheries indicator
  - curio trade indicator
  - ornamental trade indicator
  - consumption as well as aquarium and curio use
- Triton shell (*Charonia tritonis*)
  - curio trade indicator
  - COTS predator
- Collector urchin (*Tripneustes* spp.)
  - fisheries indicator
- Reef lobster (Malacostraca)
  - fisheries indicator
  - harvested as seafood item
- *Tectus* spp. (*Trochus*) shell
  - curio trade indicator

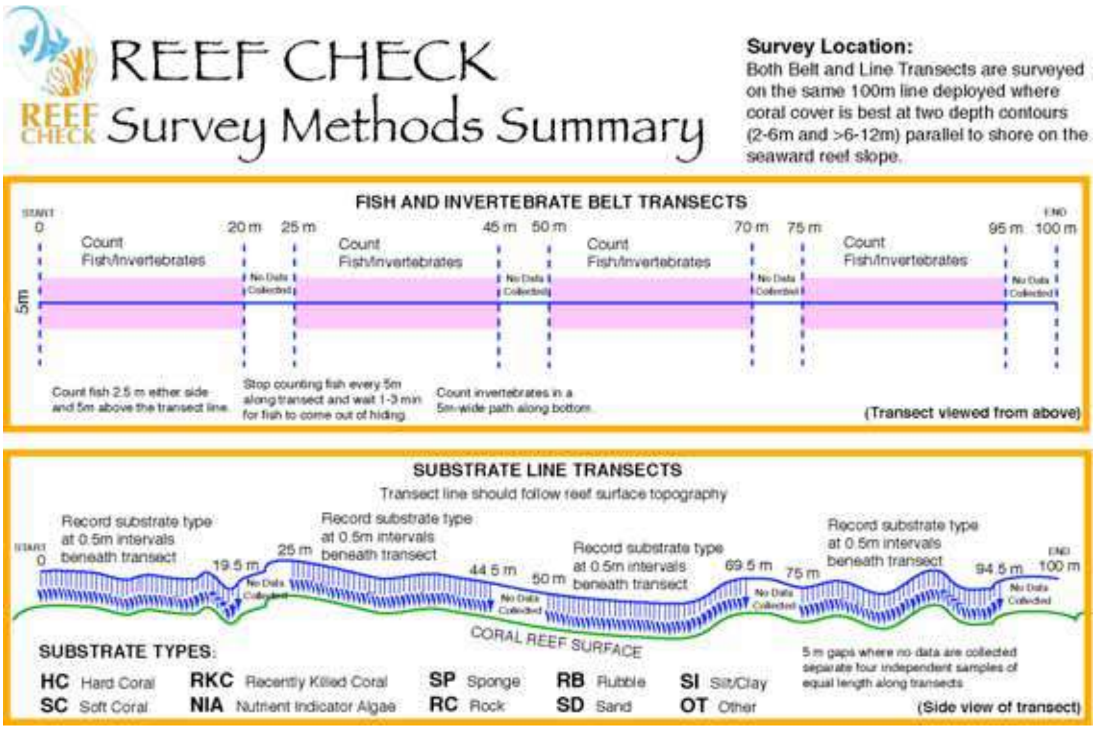


Fig. 5 Reef Check survey method summary.

The sampled fish transects are 5 m wide and 5 m high, and invertebrate and damage transects are 5 m wide, whereas the substrate transect is sampled at 0.5 m intervals (point intercept method). The substrate type along the transect tape is recorded every 50 cm with the help of a small metal weight to avoid biases. The substrate types are differentiated in Table 2.

Table 2 Substrate types used in Reef Check surveys.

Substrate types
➢ Hard coral: includes besides Scleractinia also fire coral (*Millepora*), blue coral (*Heliopora*) and organ pipe coral (*Tubipora*) because these are reefbuilders
➢ Soft coral: include zoanthids, but not sea anemones (the latter go into “Other”)
➢ Recently killed coral: coral that died within the past year. The coral may be standing or broken into pieces, but appears fresh, white with corallite structures still recognisable, only partially overgrown by encrusting algae etc.
➢ Nutrient indicator algae: various blue green algae, *Ulva* and bubble algae to record blooms of algae that might be response to high levels of nutrient input. Algae such as *Sargassum* and *Halimeda* are considered to be part of a healthy reef and are therefore not recorded for this category
➢ Sponge: all sponges (but no tunicates) to discover possible sponge blooms that could be the response to disturbance
➢ Rock: any hard substrate whether it is covered in e.g. turf or encrusting coralline algae, barnacles, oysters etc. and all coral dead for more than one year
➢ Rubble: rocks and coral pieces of the size 0.5 – 15 cm in diameter (if larger, then it is considered rock)
➢ Sand: rocks smaller than 0.5 cm in diameter that falls quickly to the bottom when being dropped
➢ Silt/Clay: sediment that remains in suspension if disturbed
➢ Other: any other sessile organisms including sea anemones, tunicates, gorgonians or non-living substrate

Additionally, a site description records over thirty measures of environmental conditions and expert ratings of human impacts (Hodgson et al. 2004, www.reefcheck.org).

Survey sites were chosen to cover and therefore represent the usually dived sites in El Quadim Bay. The bay has been divided into 5 dive sites by the dive centre management (see Fig. 7). The reefs left (north) and right (south) outside the bay, the reefs left and right inside the bay and one reef in the central part of the bay.

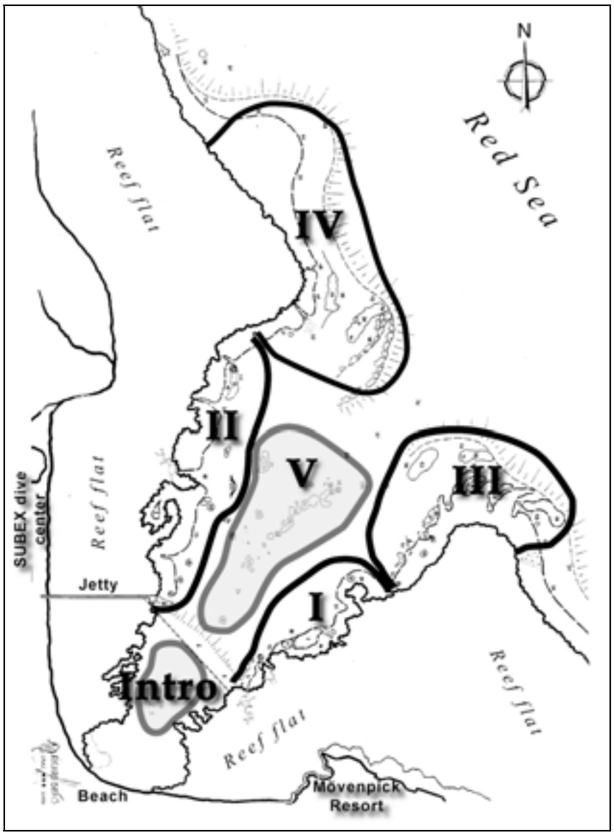


Fig. 6 Map of El Quadim Bay with SUBEX dive sites

Not all types of reef qualify for a Reef Chef Survey. Drop-offs, depth of more than 12 m or areas with high sand coverage are inappropriate and would cause misleading results since they favour some organisms while others can hardly persist. An area mainly covered with sand would for example be expected to have a high abundance of sea cucumbers while the percentage of living coral would be low. A drop-off on the other hand would probably show low numbers of sea cucumbers. Furthermore, drop-offs are not adequate since a survey width of 5 m would already result in great depth differences. Additionally they hold less habitat possibilities for fish and coral cover is less due to its steepness and hence less light availability and attachment possibilities for corals. The surveyed reef parts should therefore best possible represent the total reef, in terms of not only type and physical conditions, but, for the purpose of this study, also dive intensity and usage. Within the scope of this study, four reef sites of the El Quadim Bay were chosen to be surveyed: the two reefs outside the bay (Fig. 7, left outside [QUAE01] and right outside [QUAE04]) with similar hydrodynamic characteristics such as stronger swell and stronger currents and the two reefs inside the bay (Fig. 7, left inside [QUAE02] and right inside [QUAE03]) with likewise similar hydrodynamic characteristics namely less currents, little swell and increased turbidity. The dive site in the middle part of the bay, being more than 17 m deep and without continuous coral cover, was excluded from the survey because of its not suitable characteristics. Since the predominantly dived parts of the El Quadim Bay are the reef slopes (the reef tops are very shallow and therefore only adequate for snorkelling at high tide), parts with less inclination were chosen for the Reef Check Survey. Because especially the reefs inside the bay were partially very cliffy, the usually connected transects (4x20 m with 5 m intersects) were split and randomly set. Also considering dive intensity, the sampled reefs represent the whole bay: while the main proportion of the divers (>60%) only dives the reefs within the bay, the outside reefs are visited by the remaining <30%, who then also return along the inner reefs to the jetty exit.

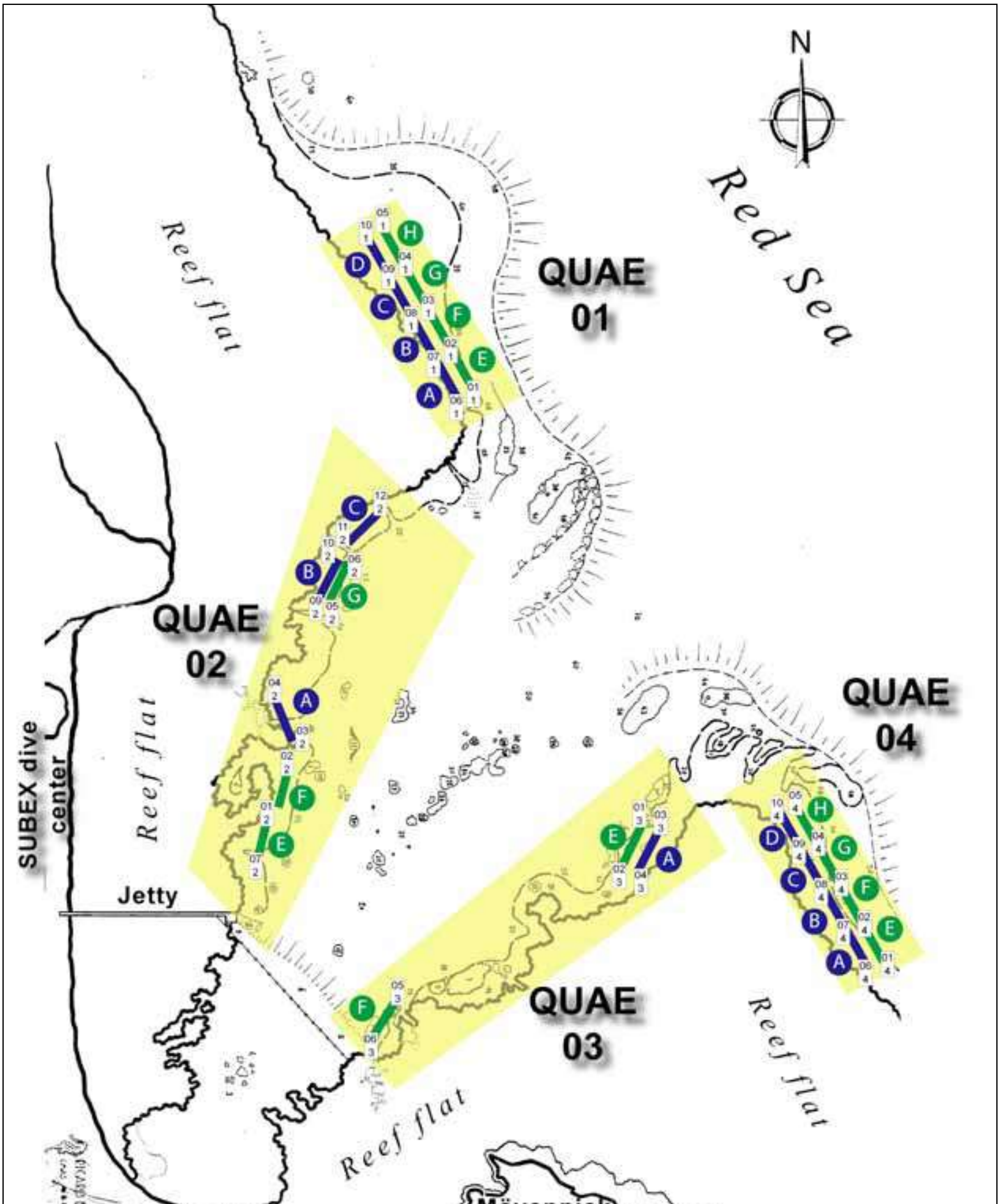


Fig. 7 Map of El Quadim Bay with position of Reef Check transects

4.6.2. Results – Reef Check surveys

4.6.2.1. Fish

The fish counts according to the RC-protocol showed that the most abundant of the RC indicators were butterfly fish with an average abundance of 12.8 individuals per 100m^2 (Table 5, Fig. 10A). The abundance of butterfly fish is slightly higher than in the Egyptian Red Sea average, whereas the abundance of parrotfish, groupers, sweetlips, and snappers is similar to other Red Sea reefs. Numbers of moray eels, bumphead parrotfish and humphead wrasse (Napoleon wrasse) were too low to allow any comparison.

The cluster analysis of fish communities shows two main clusters that group the transects regarding depth (Fig. 8). The cluster representing 10 m depth also contains almost exclusively transects that are exposed to the predominant northerly winds and waves. Even though there is no clear group that represent the protected transects inside the bay, an ANOSIM significance test gives evidence for a significant difference between exposed and protected transects. The difference of fish assemblages at 5 m and 10 m depth is also confirmed by the ANOSIM test (Table 3).

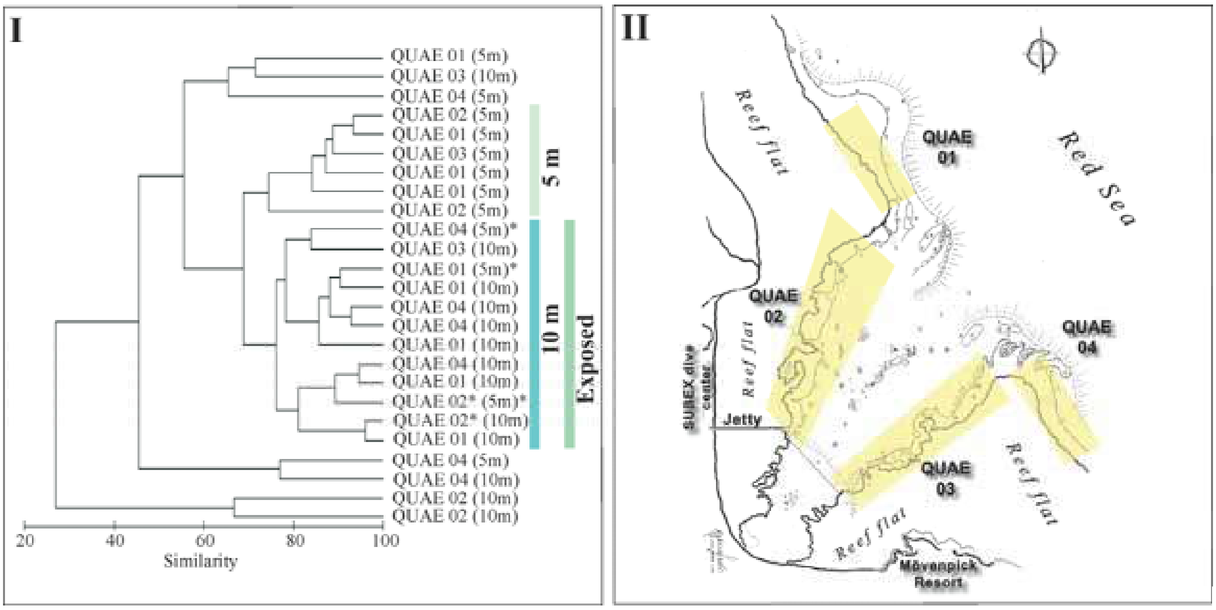


Fig. 8 (**I**) Dendrogramme of relationships between fish assemblages (Bray-Curtis similarity) and (**II**) map of El Quadim Bay, El Quseir, Egyptian Red Sea coast with location of the transects

Table 3 ANOSIM significance test with a two-way crossed layout on Bray-Curtis similarities of relationships between fish assemblages at different depth and sites (protected and exposed) at El Quadim Bay, El Quseir, Egyptian Red Sea coast (*$0.05\geq p\geq 0.01$**$0.01>p\geq 0001$, ***$p<0.001$)

	5 m *vs* 10 m	exposed *vs* protected
Global *R*	0.364	0.350
P	0.001	0.028
Significance level	**	*

A more detailed analysis of fish abundances is provided in chapter 4.7.3.1.

4.6.2.2. Substrate

Live hard coral cover (HC) ranged from 34% to over 40%, with an average of 37% at the surveyed sites. Recently killed coral (RKC) was negligible (average 0.5%) on the surveyed reefs, but almost half of the reef surface falls into the category rock (RC, mostly old reef carbonate, average 49%). This is very likely a natural effect of the topography, as the fore-reef in El Quadim Bay is relatively steeply inclined and thus a large part of the reef surface is not covered by living organisms. Soft corals (SC) cover about 9% of the reef, very little sponges (SP, 0.1%) were found.

The dendrogramme based on Bray-Curtis similarities shows a clustering of the transects into several groups that represent areas which are protected and exposed to the predominant northerly winds and waves. These main clusters either represent transects from one of the two depth or contain distinct sub-clusters regarding depth (Fig. 9). This pattern of differentiation of the benthic habitat between 5 m and 10 m depth as well as exposure to wave action is also confirmed by an ANOSIM significance test (Table 4).

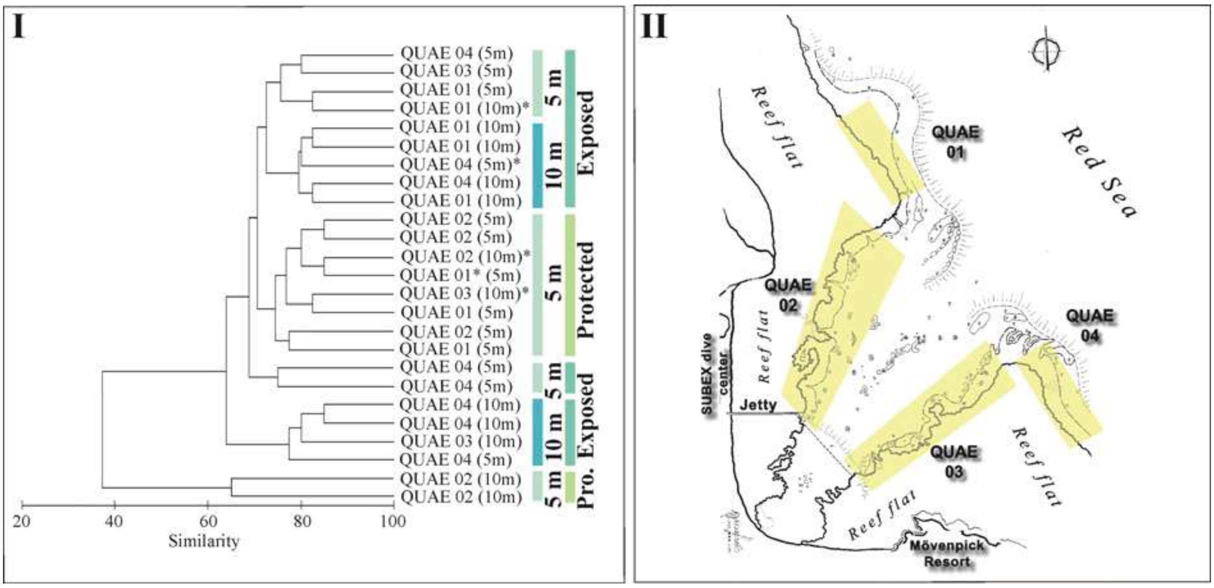


Fig. 9 (**I**) Dendrogramme of relationships between benthic cover (Bray-Curtis similarity) at different transects, and (**II**) map of El Quadim Bay, El Quseir, Egyptian Red Sea coast with location of the transects; mismatches regarding exposure to waves and depth are marked with *, respectively.

Table 4 ANOSIM significance test with a two-way crossed layout on Bray-Curtis similarities of relationships between benthic cover at different depths and sites (protected and exposed) at El Quadim Bay, El Quseir, Egyptian Red Sea coast (*$0.05 \geq p \geq 0.01$, **$0.01 > p \geq 0.001$, ***$p < 0.001$).

	5 m *vs* 10 m	protected *vs* exposed
Global *R*	0.269	0.494
P	0.004	0.001
Significance level	**	**

A more detailed analysis of the coral population is provided in chapter 4.8.

4.6.2.3. Invertebrates

The bioeroding long-spined sea urchins *Diadema* and *Echinotrix* averaged 1.7 individuals per 100 m^2, a relatively low value for the Red Sea (average for 190 sites in the Egyptian Red Sea is 5.6). Numbers were higher in the shallow transects.

Sea urchins are nocturnal feeders. Therefore, it is difficult to detect the total number during daylight when they tend to hide in crevices and caves. It can be expected that the actual number of sea urchins present in the reef is much higher than observed during the surveys. This is also supported by observations during a night dive where high numbers of sea urchins were observed.

Neither edible sea cucumbers, Triton shells, nor COTS were found at any of the sites. The numbers of pencil urchins were slightly higher than in the average Red Sea reefs, while the numbers of *Tridacna* clams were lower (5.9 vs. 8.4).

No lobsters could be observed, even though some empty carapaces were found. This leads to the assumption that they occur in El Quadim Bay, however, due to the fact that they are nocturnal feeders and typically stay in caves and crevices throughout daytime, lobsters could not be observed during the survey. Anecdotal information from old fishermen in El Quseir tells us that some decades ago the number of large lobsters was very high, so that they could take a good catch in a few hours on the reef flat.

Also coral shrimps hide in cracks and holes during the day when Reef Check surveys are carried out. Therefore the lack of observed coral shrimps does not necessarily mean that they are not abundant in the El Quadim Bay. This is supported by the fact that during a night dive some individuals were seen.

As the Reef Check protocol requires that all surveys are carried out by daylight, between 8 and 17 h, this error for nocturnal species is systematic and comparisons to other Reef Check sites are possible.

4.6.2.4. Damage

Most transects showed some degree of coral breakage, mainly attributed to divers and snorkelers. Little garbage was recorded at the transects, and the total amount of direct human damage is considered to be low. The corallivorous gastropods (*Drupella* sp. and *Coralliophila* sp.) occurred on most transects. Bleaching was not observed.

Table 5 Mean values of Reef Check indicators in El Quadim Bay, El Quseir (SD – Standard deviation, HC – hard coral, SC – soft coral, RKC – recently killed coral, NIA – nutrient indicating algae, SP – sponge, RC – rock, RB – rubble, SD – sand, SI – silt, OT – other.).

Indicator	Mean	SD	Indicator	Mean	SD	Indicator	Mean	SD
Fishes			**Invertebrates**			**Substrate**		
Butterfly fish	12.8	0.9	Banded coral shrimp	0.0	0.0	HC	37.3	3.2
Haemulidae	0.0	0.1	Long-spined sea urchin	1.7	1.1	SC	9.2	3.4
Broomtail wrasse	0.7	0.4	Pencil urchin	2.1	2.2	RKC	0.5	0.2
Grouper	1.0	0.6	Sea cucumber	0.0	0.0	NIA	0.0	0.0
Bumphead parrot	0.0	0.0	Crown-of-thorns starfish	0.0	0.0	SP	0.1	0.2
Humphead wrasse	0.0	0.0	Giant clam	5.9	3.4	RC	48.6	11.8
Parrotfish	4.6	3.3	Triton	0.0	0.0	RB	0.5	0.9
Snapper	1.2	1.4	Collector urchin	0.0	0.0	SD	3.3	6.7
Moray eel	0.0	0.1	Lobster	0.0	0.0	SI	0.0	0.0
			Trochus	0.2	0.1	OT	0.5	0.6

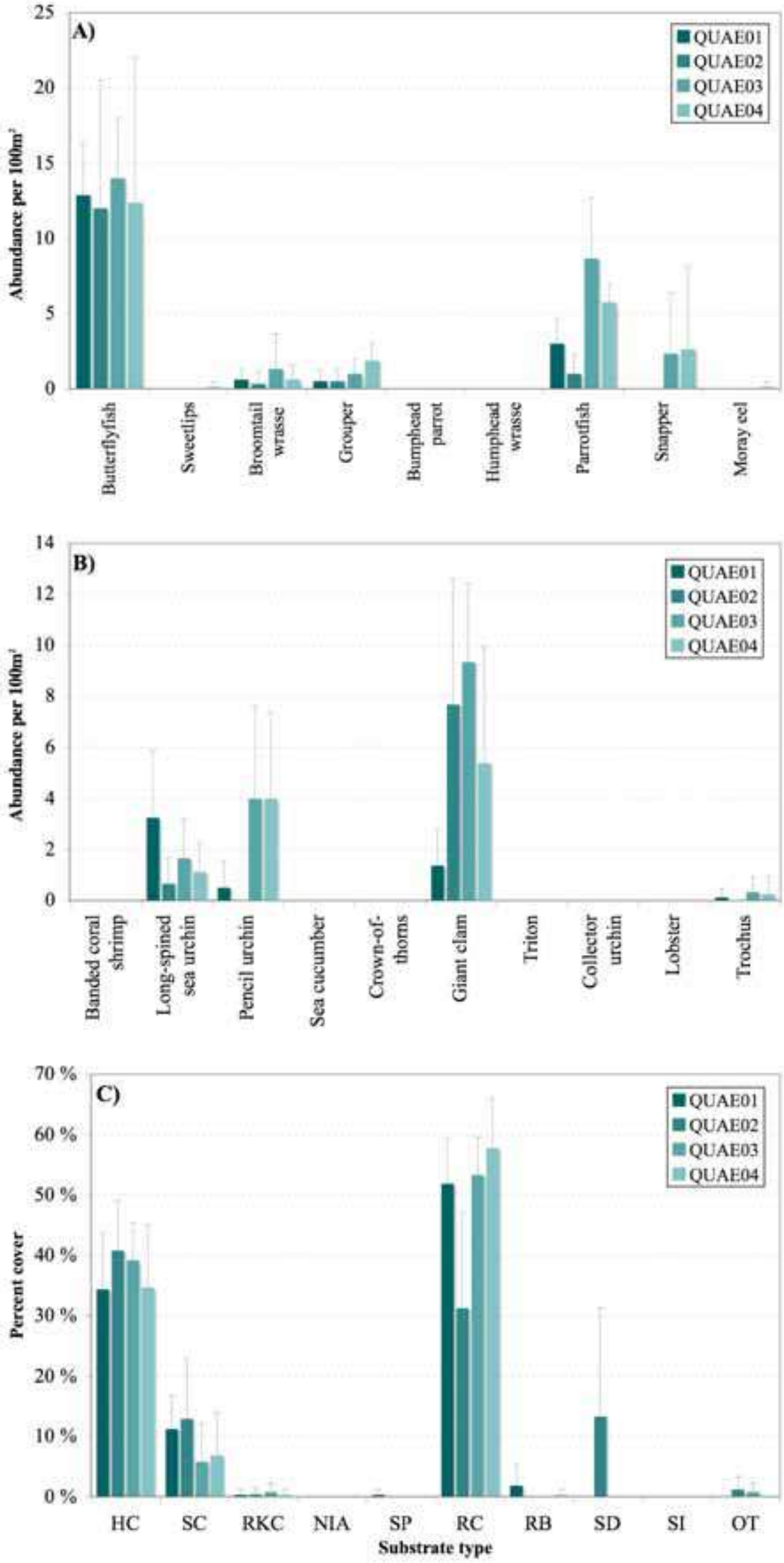


Fig. 10 Results of Reef Check – Surveys in the four sites of El Quadim Bay. A) abundance of fish indicators, B) abundance of invertebrate indicators, C) Benthic cover. (HC – hard coral, SC – soft coral, RKC – recently killed coral, NIA – nutrient indicating algae, SP – sponge, RC – rock, RB – rubble, SD – sand, SI – silt, OT – other.)

4.7. *Diversity of the Fish Population*

This part of the study investigates the community structure of fishes on the coral reef in El Quadim Bay to evaluate whether the current management practice of the recreational SCUBA diving is sufficient to prevent a negative impact on the fish fauna. The main objectives of the study are: 1) to describe the community structure of fishes, 2) to compare this structure with other fish communities of the Red Sea in order to estimate the impact of recreational SCUBA diving, and 3) to provide baseline data for a regular monitoring in the future.

4.7.1. Methods – Visual Census

The fish community was surveyed by the visual census technique using SCUBA as described in English et al. (1994). Transects of 50 m length and 5 m width (=250 m^2) were marked at the study site (Fig. 13 II). At each site visual censuses were conducted along three transects at the shallow slope (5 m) and deep slope (10 m), respectively. The distance between transects at each site was about 10 m. The observer waited five minutes after laying the transect line to allow fishes to resume their normal behaviour. Subsequently the diver swam along the transect and recorded all fishes encountered 2.5 m on each site of the line and 5 m above the transect. All observed fishes were identified and recorded on a plastic slate. The duration for the count of each transect was 40-45 minutes. The visual census technique is widely applied and accepted for fish ecological studies on coral reefs (English et al. 1994). However, all our conclusions are restricted to day active and non-cryptic species (Brock 1982).

4.7.2. Statistical Analyses

Abundance of fishes was described by relative abundance (RA) and frequency of appearance (FA).

$$\text{RA} = \frac{\text{average abundance of species i from each depth and site}}{\text{average abundance of all species from each depth and site}} \times 100$$

$$\text{FA} = \frac{\text{number of transects in which species i was present}}{\text{total number of all transects}} \times 100$$

RA describes the percentage of each species of the total abundance of all fishes. FA gives the information, on how many percent of the transects a species is observed.

Community indices such as Shannon-Wiener diversity (H’; ln basis), species richness (number of species), and fish abundance were compared among sites and depths. Multivariate analyses of the data such as MDS (multi-dimensional scaling) and ANOSIM (analysis of similarities) significance tests were performed with PRIMER-5 software (Primer-E 2000). MDS was based on Bray–Curtis similarities of abundance data. Highly abundant species in contrast to species with very low abundance can disturb the analysis. Therefore, a log(1+x) transformation of data was conducted. MDS is a 3-dimensional ordination of samples brought down to a 2-dimensional plot. The quality of the MDS plot is indicated by the stress value. Values <0.2 give a potentially useful 2-dimensional picture, stress <0.1 corresponds to a good ordination and stress <0.05 gives an excellent representation.

The ANOSIM significance test compares similarities of species compositions between the samples and can give evidence for differences. A two-way crossed layout of ANOSIM was performed with the transformed data. Two terms are important in an ANOSIM significance test: *p* (significance level) and Global R. Global R indicates the degree of similarity between the tested groups with values between –1 and 1. If all replicates within sites are more similar to each other than any replicate from different sites, the value of R is 1. Values close to zero indicate that the similarity between sites is very high, showing a low difference between them (Clarke & Warwick 1994).

4.7.3. Results – Fish Population

4.7.3.1. Fish Assemblages and Community Indices

In this part of the study a total of 16,683 fishes were counted on 12 visual census transects at 5 m and 10 m depth, representing 111 shallow-water species belonging to 47 genera and 31 families. Additional observations between 3 m and 25 m depth compiled a total of 153 species belonging to 97 genera and 40 families (Appendix 3). Most individuals observed on the visual census transects belonged to the families Pomacentridae (Damselfishes; 56.6%, 15 species), Anthiinae (Anthias; 32.5%, 1 species, subfamily of Serranidae), Acanthuridae (Surgeonfishes; 2.3%, 9 species), Labridae (Wrasses; 2.3%, 27 species), Chaetodontidae (Butterflyfishes; 1.3%, 8 species), Scaridae (Parrotfishes; 0.7%, 8 species), and Serranidae (Grouper; 0.6%, 14 species) (Fig. 11).

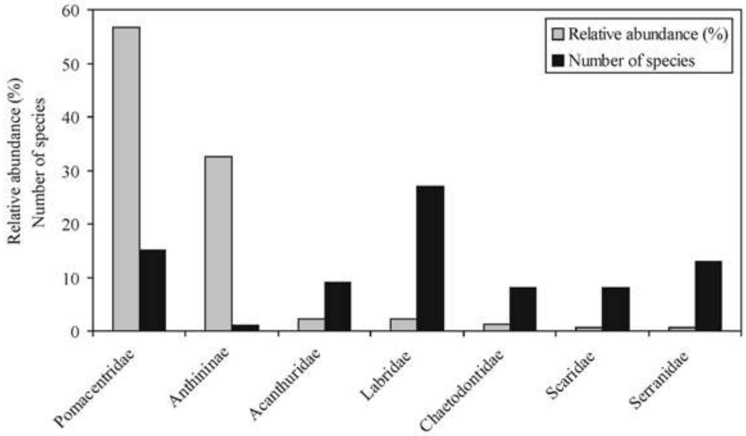


Fig. 11 Dominant families of the ichthyofauna on visual census transects (250 m^2) at El Quadim Bay, El Quseir, Egyptian Red Sea coast.

In terms of species richness per family the ichthyofauna showed the following ranking: Labridae (Wrasses; 17.5%), Pomacentridae (Damselfishes; 9.7%), Serranidae (Grouper; 9.1%), Acanthuridae (Surgeonfishes; 5.8%), Chaetodontidae (Butterflyfishes; 5.2%), and Scaridae (Parrotfishes; 5.2%) (Table 6).

Table 6 Percentage of species of the most abundant fish families at El Quadim Bay, El Quseir, Egyptian Red Sea coast in comparison to other fish assemblages on Red Sea coral reefs. [1]this study (VC), [2]Khalaf and Kochzius (2002, VC), [3]Rilov and Benayahu (2000, VC), [4]Zajonz et al. (unpubl. report, VC), [5]Schraut (1995, VC), [6]Krupp et al. (1993, VC+F). *VC* visual census, *F* fishing.

Location	Labridae	Poma-centridae	Serranidae	Acanthuridae	Chaeto-dontidae	Scaridae
El Quadim Bay[1] (Egypt)	17.5	9.7	9.1	5.8	5.2	5.2
Aqaba[2] (Jordan)	19.2	9.1	3.5	3.0	4.0	5.1
Eilat[3] (Israel)	20.4	12.7	6.3	4.1	4.9	5.6
Dahab[4] (Egypt)	13.7	11.9	7.7		5.4	3.6
Sharm El Sheikh[5] (Egypt)	14.8	10.2	6.3		5.1	4.0
Sanganeb Atoll[6] (Sudan)	12.4	9.6	5.2	4.0	4.8	3.6

Table 7 Relative abundance of the most abundant fish species at El Quadim Bay, El Quseir, Egyptian Red Sea coast in comparison to other fish assemblages of marine reserves in the Red Sea. [1]this study (VC), [2]Khalaf and Kochzius (2002, VC), [3]Krupp et al. (1993, VC+F). *VC* visual census, *F* fishing.

Species	El Quadim Bay[1] (El Quseir, Egypt)	Marine Science Station[2] (Aqaba, Jordan)	Sanganeb Atoll[3] (Sudan)
Chromis dimidiata	44.9	5.6	19.5
Pseudanthias squamipinnis	32.5	24.1	43.6
Chromis ternatensis	5.8	4.0	5.2
Chromis viridis	3.6	1.6	2.6
Amblyglyphidodon flavilatus	0.8	1.0	1.1

The most abundant species were *Chromis dimidiata* (Half-and-half Chromis; 44.9%), *Pseudanthias squamipinnis* (Scalefin anthias; 32.5%), *Chromis ternatensis* (Ternate Chromis; 5.8%), *Chromis viridis* (Blue-green Chromis; 3.6%), and *Amblyglyphidodon flavilatus* (Yellowflank Damselfish; 0.8%), representing 87.6% of all individuals (Table 7). In terms of frequency of appearance the most common species were *Chromis dimidiata* (Half-and-half Chromis), *Pseudanthias squamipinnis* (Scalefin Anthias), *Chromis ternatensis* (Ternate Chromis), *Ctenochaetus striatus* (Lined Bristletoot), *Chaetodon austriacus* (Exquisite Butterflyfish), *Siganus luridus* (Squaretail Rabbitfish), and *Zebrasoma xanthurum* (Yellowtail Surgeonfish) (all 100%; for pictures see Plate 4).

Shannon-Wiener diversity (ln basis) ranged from 1.3 to 1.8, species richness from 33 to 49 species, and total abundance from 701 to 2,029, but no significant difference was obvious between different depths or sites (Fig. 12).

4.7.3.2. Multivariate Analysis of the Fish Community

MDS analysis based on Bray-Curtis similarity of log(1+x) transformed data showed two main groups (Fig. 13): left (transects 1-6) and right (transects 7-12) sites at El Quadim Bay with subgroups at 5 m and 10 m depth for sites on the right of the bay. Transect number 4 did not match the groups of the MDS plot and for the sites on the left side subgroups regarding depth cannot be distinguished. However, an ANOSIM significance test with a two-way crossed layout confirmed the difference between sites on the left and right of El Quadim Bay (p=0.01) as well as 5 m and 10 m depth (p=0.05) (Table 8).

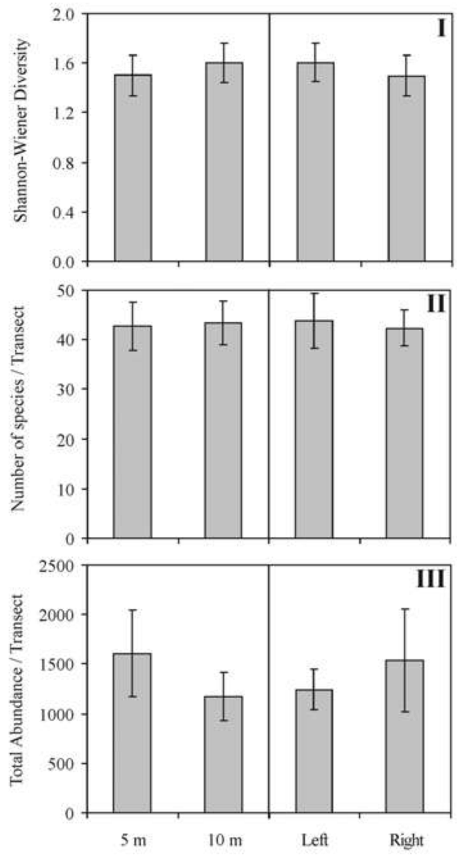


Fig. 12 Shannon-Wiener Diversity (I), species richness (II), and total abundance (III) at different depth and sites (Left: transects 1-6; Right: transects 7-12) (average ± SD) at El Quadim Bay, El Quseir, Egyptian Red Sea coast.

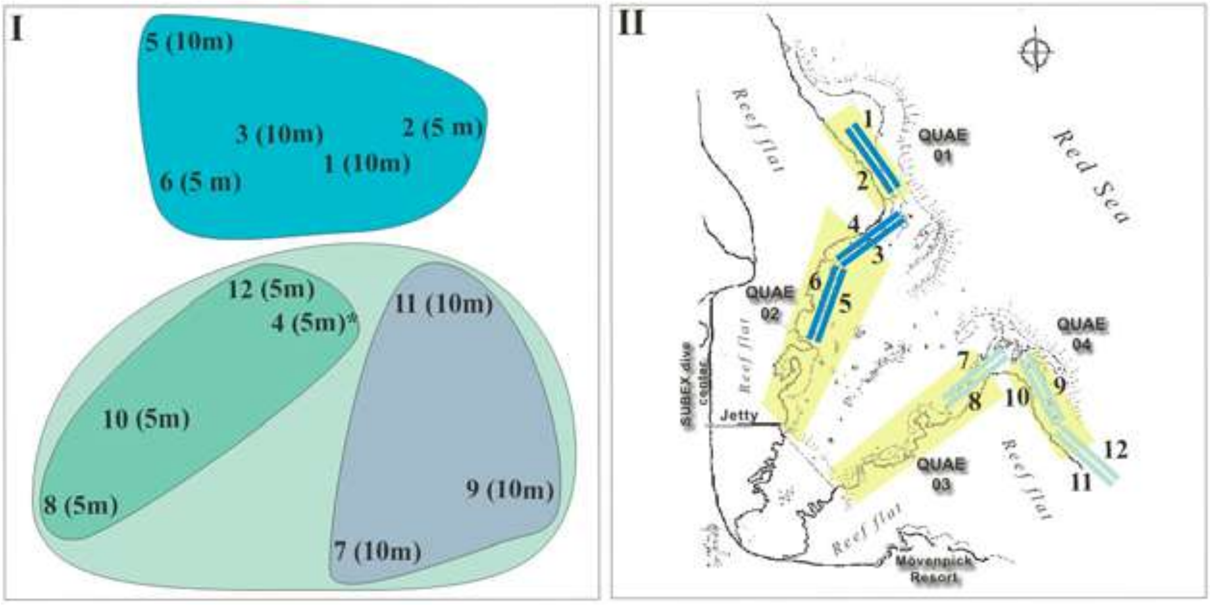


Fig. 13 (I) MDS plot of relationships between fish assemblages (Bray-Curtis similarity, log(1+x) transformation of data, group average, stress = 0.05). (II) map of El Quadim Bay, El Quseir, Egyptian Red Sea coast with location of the 12 transects (even transect numbers: 5 m depth; odd transect numbers: 10 m depth)

Table 8 ANOSIM significance test with a two-way crossed layout on Bray-Curtis similarities of relationships between fish assemblages at different depth and sites at El Quadim Bay, El Quseir, Egyptian Red Sea coast (*$0.05 \geq p \geq 0.01$**$0.01 > p \geq 0001$, ***$p < 0.001$).

	Left sites *vs* right sites	5 m *vs* 10 m
Global *R*	0.500	0.426
P	0.01	0.05
Significance level	*	*

4.7.4. Discussion – fish population

4.7.4.1. Dominant Taxa and Fish Community Parameters

Chromis dimidiata (Half-and-half Chromis) and *Pseudanthias squamipinnis* (Scalefin Anthias) are the most abundant species in El Quadim Bay. In reserves at the Marine Science Station in Aqaba, Jordan (Khalaf & Kochzius 2002b) and Sanganeb atoll in Sudan (Krupp et al. 1993) (Table 7), as well as at the Japanese gardens off Eilat (Israel, Rilov & Benayahu 2000) and at Nuweiba (Egypt, Ben-Tuvia et al. 1983) *P. squamipinnis* (Scalefin Anthias) is the most abundant species. At Sanganeb atoll *C. dimidiata* (Half-and-half Chromis) is the second most abundant species (Table 7) and is also found in high numbers at the Marine Science Station, Japanese gardens, and Nuweiba (Ben-Tuvia et al. 1983, Krupp et al. 1993, Rilov & Benayahu 2000, Khalaf & Kochzius 2002a). The comparison of the relative abundance of the most common species at El Quadim Bay with the reserves at the Marine Science Station in Jordan and at Sanganeb atoll in Sudan shows a high similarity. The only exception is the very high abundance of *C. dimidiata* (Half-and-half Chromis) at El Quadim Bay.

On Red Sea coral reefs, labrid and pomacentrid species are the dominant fishes. Labridae (Wrasses) contribute the highest percentage of species, followed by Pomacentridae (Damselfishes). Compared to other coral reefs, El Quadim Bay shows a very high number of Serranids (Groupers). The number of

Acanthurids (Surgeon fishes), Chaetodontids (Butterfly fishes) and Scarids (Parrotfishes) at El Quadim Bay is within the same range of other fish assemblages in the Red Sea (Table 6).

In terms of relative abundance of families, the ichthyofauna at El Quadim Bay is dominated by Pomacentridae (Damselfishes), followed by Anthiinae (Anthias; subfamily of Serranidae), Acanthuridae (Surgeonfishes) and Labridae (Wrasses). Almost the same pattern is found along the Jordanian coast in the Gulf of Aqaba, with the only difference that Labridae are more abundant than Acanthuridae (Khalaf & Kochzius 2002b). The dominance of Pomacentridae was also revealed by visual censuses of fish assemblages on coral reefs in New Caledonia (Rossier & Kulbicki 2000) and on the Great Barrier Reef (Ackerman & Bellwood 2000).

Shannon-Wiener diversity (H') did not differ between sites and depths (Fig. 12). Regarding depth, the influence on diversity (H') is not clear: Khalaf & Kochzius (2002b) as well as Öhman & Rajasuriya (1998) did not find a significant correlation between diversity (H') and depth in Jordan and Sri Lanka, respectively. However, Friedlander & Parrish (1998) pointed out a weak positive correlation in Hawaii, resulting in a higher diversity at larger depth. It seems that changes in diversity with depth are caused by environmental factors that differ between reefs. Therefore, a general trend of increasing diversity with depth is not evident.

Species richness was rather similar in the two depths, which is in contrast to the general trend of species richness increasing with depth, which has been shown for the Red Sea (Edwards & Rosewell 1981, Roberts & Ormond 1987), in Hawaii (Friedlander & Parrish 1998), and Sri Lanka (Öhman & Rajasuriya 1998). However, this trend is most pronounced between 1 m and 6 m depth, with a smaller or no difference between 6 m and 12 m depth (Roberts & Ormond 1987). Since this study did not record fishes in the shallow water on the reef flat, this trend could not be detected.

The overall picture shows a higher abundance of fishes at 5 m depth than at 10 m depth (Fig. 12). This finding is in contrast to the study of Khalaf & Kochzius (2002b) in the Gulf of Aqaba which shows the opposite pattern. A study on herbivorous fishes, such as Acanthuridae (Surgeonfishes), Scaridae (Parrotfishes), and Siganidae (Rabbitfishes) in the Gulf of Aqaba also suggest a higher abundance in 10 m depth than in 5 m depth (Bouchon-Navaro & Harmelin-Vivien 1981). However, these differences might be due to regional differences, such as reef morphology and coral cover. In Hawaii, Friedlander & Parrish (1998) did not reveal a connection of total fish abundance to depth.

The analysis of the dominant taxa and fish community parameters revealed the following pattern: 1) Labridae (Wrasses) and Pomacentridae (Damselfishes) were the dominant families in terms of species richness of the ichthyofauna at El Quadim Bay as well as on other Red Sea coral reefs, 2) in terms of relative abundance damselfishes (Pomacentridae) were the dominant family, 3) fish diversity and species richness at El Quadim Bay were not correlated to depth in the observed range of 5 m and 10 m, and 4) abundance of fishes was higher at 5 m depth than at 10 m depth.

4.7.4.2. Multivariate Analysis of the Fish Community

Multi-dimensional scaling (MDS) as well as ANOSIM analysis indicate significant differences between the fish communities of the two different sites (left side and right side of bay) and depths (Fig. 13, Table 8). Such habitat and depth specific differences in fish communities of coral reefs are supported by other studies in Jordan (Khalaf & Kochzius 2002b), Sri Lanka (Öhman & Rajasuriya 1998), and Hawaii (Friedlander & Parrish 1998). These differences can be due to changes in the benthic coral cover, current pattern and wave action. Since the benthic habitat at the transects was not investigated, it is not possible to correlate benthic cover and pattern in the fish community. However, the differences between the left and right side of El Quadim Bay might be due to different exposure to wave action. At the left side, transects 3-6 are protected from the northerly winds and waves, whereas all transects on the right side are completely exposed.

4.7.4.3. The Impact of recreational SCUBA Diving on the Fish community

Since data of the fish community in El Quadim Bay prior to the diving activities are not available, the possible impact of recreational SCUBA divers on the fish community can only be estimated by comparison to other sites in the Red Sea that are not impacted. Data that allow a direct comparison are only available from coral reefs at the Jordanian coast in the Gulf of Aqaba (Khalaf & Kochzius 2002b, a). A comparison of the total abundance of fishes at El Quadim Bay and undisturbed reefs in Jordan shows almost the same average values of about 1,400 fishes/transect (250m^2) (Khalaf & Kochzius 2002a). A study by Hawkins et al. (1999) could not detect an influence of recreational SCUBA diving at sites with about 5,000 dives per year in the Caribbean, which is comparable to the average diving pressure in El Quadim Bay (Table 15).

Comparison of the dominant taxa and fish community parameters did not show major differences to other coral reef fish assemblages in the Red Sea. The percentage of species of the most abundant families was very similar to other reefs in the Red Sea and the percentage of serranid species (Grouper) was remarkably high in El Quadim Bay (Table 6). Since groupers are valuable food fishes, the high number of grouper species present might be due to the exclusion of fishing in El Quadim Bay. The relative abundance of the most abundant species at El Quadim Bay was also quite similar to marine reserves in Jordan and Sudan (Table 7).

It can be concluded that fish communities of El Quadim Bay are comparable with undisturbed reefs in marine reserves of the Red Sea. The current diving frequency does not show a negative impact on the fish community at El Quadim Bay.

4.8. Diversity of the Coral Population

4.8.1. Coral Communities

Coral communities are generally defined as a product of the species abundance, diversity and identity of the dominant forms. The community is named after its dominant species, which is usually the most conspicuous but not necessarily the most abundant (Sheppard, 1992). In contrast to non-colonial organisms, the dominance in coral communities depends on bottom coverage. So the dominant species cover(s) a greater part of the ground than the other species growing at the same stand. Thus, the dominant species largely determine(s) the physiognomy of a coral community. Different coral communities, with the same dominant species, externally may possess a great similarity, but they are not always closely related in their species composition and their ecological claims. The boundary of the settlement of a coral community can be recognized by the appearance of new species, and often by the disappearance of others. The species, by which coral communities differ, are called differential species (Scheer 1978). In terms of total coverage, spatial organization, diversity, dominance and size class distribution, the community structure varies between zones in response to a combination of physical controls and biological interactions. Components of biological stress in coral communities are predation by coral-feeding fish and molluscs, bioerosion by boring fauna and diseases caused by microorganism (Sorokin 1993). Physical stress dominates shallow turbulent zones of the reef, while in calm or deeper zones the biological stress prevails (Sheppard 1981). Exposure to hydrodynamics, resuspension of sediments, changes in salinity and temperature and excess of light seem to be the most important among the factors of physical stress, whereby intensive hydrodynamics is a rather positive factor for the corals (cited in Sorokin 1993). In the Arabian region Sheppard & Salm (1988) and Sheppard & Sheppard (1991) analysed coral data of nearly 200 sites from both northern Gulfs and the Arabian mainland to the Yemen border. They showed the existence of 13 principle coral communities. Several communities could be subdivided into smaller units. These simply reflect different depth divisions on one reef type in most cases. The extended level encloses 22 groups. The distribution of the communities shows a clear north-south trend with most communities showing considerable localisation. Eight of the 13 communities are limited to either the northern, central, or southern areas of the Red Sea. Four communities span two areas and just one is spread throughout the Red Sea. After Sheppard & Sheppard (1991), the northern Red Sea comprises 5 different coral communities.

4.8.2. Methods – Coral Population

4.8.2.1. Diversity

For the identification of the scleractinian corals the software keys Coral ID Version 1.1 – A key to the Scleractinian Corals of the World (©Australian Institute of Marine Science and CRR Qld Pty Ltd) and Staghorn Corals of the World – A Key to the Species of Acropora (©CSIRO Publishing 1999) were used. For further support the publications of Ditlev (1980), Scheer & Pillai (1983), Sheppard & Sheppard (1991), Wallace (1999) and Veron (2000) were consulted. The identification of non-scleractinian corals is based on Ditlev (1980). The publication of Fabricius & Alderslade (2001) served as support for the soft corals (Alcyoniina group). The analysis of coral diversity was non-invasive, no samples were taken. All corals were documented photographically and identified by their features visible *in situ*. Finally, a collection of more than 500 digital photos arose.

4.8.2.2. Community Analysis

Transects

For the qualitative assessment of the coral communities visual surveys (Kenchington 1978) of 2 x 30 minutes were conducted at each site (QUAE 01-04) from a depth of 20 m to the reef flat.

Indices

Stirling & Wilsey (2001) tested the "Empirical Relationships between Species Richness, Evenness, and Proportional Diversity" on various samples and yielded that they may not be significant if the number falls below 10 individuals. Thus the calculation of these indices for each replicate ($n \geq 10$) was carried out to detect possible inequalities, transitions or tendencies. Further the diversity index of Shannon & Wiener (1948) as used in Loya (1976) was calculated. The common species of each transect were tested on dominance.

Species Richness (cited in Stirling & Wilsey 2001):

$$[S] = \text{the number of species present (in a sample)}$$

To acquire the species richness per row, species that could only be identified by genus were only included, if they were the only specimen of the particular genus in that row.

Shannon-Wiener index H’ (cited in Loya 1976):

$$H' = -\sum_{i=1}^{S}(Pi - \ln Pi)$$

n_i = the number of colonies in each species i (i=1,2,3, ….)
N = the number of colonies present in the entire sample.
P_i = The proportion of the individual species to the total: n_i / N (=relative abundance)

The diversity index (H’) converges to zero if all individuals (colonies) belong to one species and reaches its peak (H'_{max}) if all species have a similar amount of individuals (colonies) (Müller 1984).

Dominance (Scheer 1978):

$$D = \frac{ci}{C} x100$$

c_i = coverage of species i (i=1,2,3, …)

C = total coverage of all species

Evenness or equitability (cited Stirling & Wilsey 2001):

$$J' = \frac{H'}{\ln(S)}$$

H’ = Shannon-Wiener index
S = Species Richness

This index typically is on a scale ranging from 0, which indicates low evenness or high single-species dominance, to 1, which indicates equal abundance of all species or maximum evenness.

Margalef’s Index (Magguran 1988):

$$D' = \frac{(S-1)}{\ln(N)}$$

N = number of individuals (colonies)
S = number of species

4.8.3. Results – Coral Population

4.8.3.1. Diversity

According to Veron (2000) 303 scleractinian species (Class: Anthozoa, Subclass: Hexacorallia, Order: Scleractinia) do occur in the Red Sea, with 35 endemics. In this study a total of 144 species were identified including 9 endemics. The highest number of species was found within the family Faviidae with 44 species, followed by the Acroporidae with 28 species and the Agariciidae with 14 species. A complete species list is given in Appendix 5. Further, 5 non-scleractinian species, considered as hermatypes, comprising 4 hydrocorals (Class: Hydrozoa, Subclass: Anthoathecatae, Order: Leptolida) and the organ pipe coral *Tubipora musica,* were identified. Together with the identified soft coral genera (Class: Anthozoa, Subclass: Octocorallia, Order: Alcyonacea, Alcyoniina group) they are listed in Appendix 4.

4.8.3.2. Coral Communities

Qualitative Assessment

QUAE 01

Reef slope

The lower reef slope between 10 and 20 metres is very heterogeneous. Both, coral cover and diversity are high. However, none of the coral species dominate this area. With its inclination of around 45° a diverse arrangement of different faviids as well as the typical species for this area, *Acropora valida, Acropora variolosa, Porites nodifera, Porites lutea* and *Pocillopora damicornis* have the highest share of coral cover. The results of the QUAE 01m (10 m) transect confirm this result. Here *Pocillopora damicornis* had the highest part of the coral cover with 14.3%, followed by *Acropora valida* and *Acropora variolosa* with 9.5% each. The share of the different genera and families of coral cover for each transect is shown in Fig. 14 and their absolute cover in Table 10. Obviously, the two important genera of *Acropora* (27%) and *Pocillopora* (21%) together constitute almost half of the coral cover in 10 m depth.

Around 10 m the inclination of the reef slope changes to approx. 90°. At this steep wall the coral cover is lower than in the area below 10 m and above 5 m. At the upper reef slope and reef edge the cover increases and the species composition changes. Here, *Acropora acuminata* and *Acropora gemmifera* occur, which were not encountered in the deeper area, while *Acropora valida* and *Acropora variolosa* are occurring only sporadically here. Two more species appear to dominate the reef surface, the fire coral *Millepora dichotoma*, with a share of 14.7% of the coral cover in the 5 m transect, and *Pocillopora verrucosa* with 11.8%. The average coral cover was significantly higher in the 5 m transect (QUAE 01s) with 42.5% than in 10 m (QUAE 01m) with 26.3%. The soft corals covered 9.4% and 13% respectively. The cover in 10 m consisted mainly of Xeniids and the cover in 5 m of *Sinularia* sp. The share of coral cover for various coral genera and groups is shown in Fig. 14.

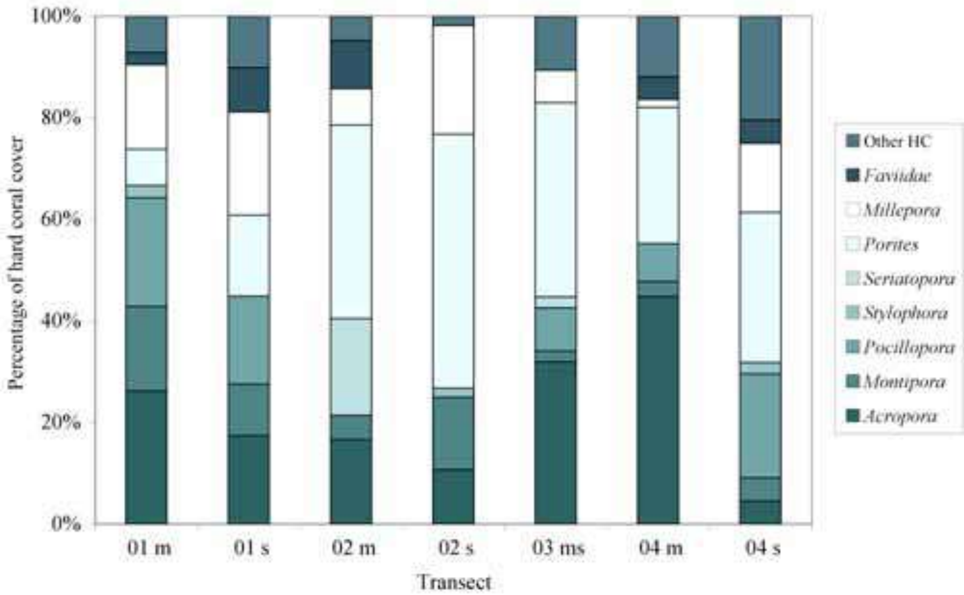


Fig. 14 Share of different coral groups on coral cover (HC= Hermatypic Coral, m=medium=10 m; s=shallow=5 m).

Reef edge / reef crest

The reef edge in QUAE 01 is rounded and does not show the typical shape of the reef crest. The predominant part of this reef section consists of small to medium-sized, bush-shaped branching corals of the species *Pocillopora verrucosa*, *Acropora acuminata* (growth form: corymbose) and *Acropora gemmifera* (growth form: digitate). Some massive Faviids like *Echinopora gemmacea* and *Favia rotumana* occur, also incrusting *Montipora* spp..

Reef flat

The reef flat of QUAE 01 shows a broad zone (rear zone) with medium coral cover clearly dominated by *Stylophora pistillata*. The diversity decreases strongly. Individual small colonies of different species (e.g. *Porites* spp.) occur scattered, but only the fire coral *Millepora platyphylla* occupies a noticeable part.

QUAE 02

Reef slope

The reef slope in QUAE 02 consists over large areas of blocks and pinnacles of the columnar *Porites nodifera* and *Porites rus*. The dominance is highest in the seaward part of the bay. On the more sheltered, landward part of the bay, *Millepora dichotoma, Seriatopora hystrix* and *Goniopora* spp. prevail. These species can deal better than others with the increased sedimentation in his area, caused by run-offs from the reef flat. The coral cover decreases landwards and soft corals, mainly Xeniids, abound. These cover 16.7% of the 10 m transect, which represents the highest value of all samples. The coral cover of genera and families of stony corals and soft corals for each transect is given in Table 10.

Acropora valida, Acropora variolosa, Porites lutea and various Faviids occur at the lower reef slope, but to a far lower extent than in QUAE 01. At the upper reef slope *Millepora dichotoma, Acropora acuminata* and *Porites lobata* are important species. Surprisingly, *Pocillopora verrucosa* and *Pocillopora damicornis* were encountered in QUAE 02 far less frequently than in the other sectors. In the two transects QUAE 02m and QUAE 02s they do not occur at all.

Reef edge/Reef flat

The reef edge in QUAE 02 shows a clear curve with overhangs. A spur-and-groove-system is partly developed. The diversity and the coral cover are high. *Acropora hyacinthus, Acropora gemmifera* and *Porites lobata* are frequently found species. High coral cover and diversity and various Faviids, mainly *Platygyra lamellina* and *Platygyra daedalea* characterize the subsequent zone. Further abundant species are *Porites lobata*, *Millepora platyphylla* and incrusting *Montipora* spp.

QUAE 03

Reef slope

The reef slope in QUAE 03 is similar to QUAE 02, with prevailing dominance of *Porites* spp. and *Millepora dichotoma, Seriatopora hystrix* and *Goniopora* spp. landwards. The reef structure in the inner part is even more complex with many incisions, gorges and caves than the northern part. Especially the Agariciids are more abundant than in QUAE 02 and other sites. Among them are *Leptoseris explanata, Leptoseris mycetoseroides, Leptoseris scabra* and *Pachyseris speciosa,* which were defined as scyophilic ("shade loving") by Sorokin (1993).

Reef edge - Reef flat

The inner area of the bay is similar in structure and species composition to QUAE 02, but with a lower cover of Faviids. The external field in turn resembles QUAE 01. The main part of the reef flat consists of consolidated coral rock. A narrow zone with normal coral cover was observed.

QUAE 04

Reef slope

The inclination of the reef slope in QUAE 04 is more regular than in QUAE 01 and it lacks the steep walls. It shows common characteristics with QUAE 01, despite an obviously higher contribution of *Acropora* spp.. In 10 m *Acropora variolosa* and *Acropora secale* showed their highest cover of all transects with 4.5% and 8.8%.

The share of coral cover of the 17 most important species for each transect is given in Fig. 15 and the corresponding values are listed in Table 11.

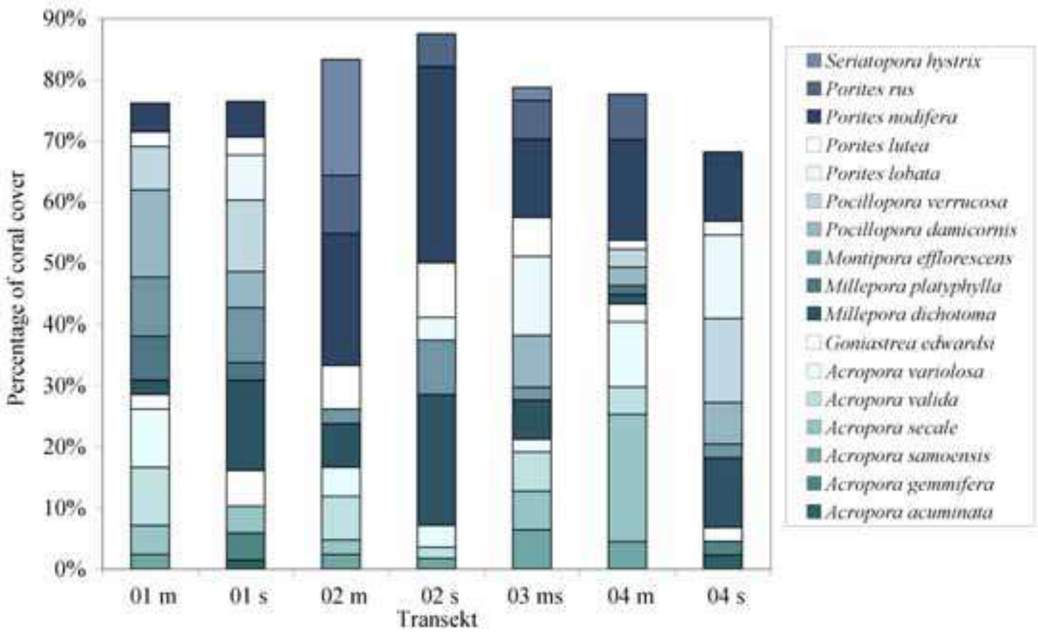


Fig. 15 Share of different coral species on coral cover (m=medium=10 m; s=shallow=5 m).

Dominance

The share of coral cover of the individual species or coral group differs considerably regarding depth, sites or exposure (Fig. 14, Fig. 15). For example, *Acropora acuminata* and *Acropora gemmifera* occur only in the external shallow transects QUAE 01s and QUAE 04s. *Goniastrea edwardsi*, a representative of the family Faviids, the plate fire coral *Millepora platyphylla* and *Pocillopora verrucosa* appear only in the transects outside of the bay (QUAE 01 and QUAE 04).

Acropora gemmifera is frequently encountered also in the inner area, however, almost exclusively at the reef edge. *Seriatopora hystrix* occur only in the transects inside the bay. The values for the dominance of the 17 most important species for each transect are given in Table 11. Only three species occur in all of the 7 transects. These are *Porites nodifera, Porites lutea* and *Millepora dichotoma*. The highest value for dominance of the 7 transects ranges from 12.8% to 32.1%. The highest value is reached by *Porites nodifera* in transect QUAE 02s and QUAE 02m. The two species with the highest dominance for each transect are presented in Fig. 16.

The columnar *Porites nodifera* has a mean dominance over all transects of nearly 15% and *Millepora dichotoma* of approximately 10%. This shows the importance of these species for the coral communities and the general appearance of El Quadim Bay. A comparison of the more sheltered areas (QUAE 02 + QUAE

03) with the more exposed transects (QUAE 01 + QUAE 04) shows differences for some of the coral groups (Fig. 17). The differences are particular obvious in the cover of the genus *Porites* and the soft corals of the family Xeniidae. Their coverage is in each case more than double in the sheltered area. Faviids and *Acropora* show a higher coverage on the outside. The cover of *Pocillopora* sp. is five times higher on the outside than on the inside.

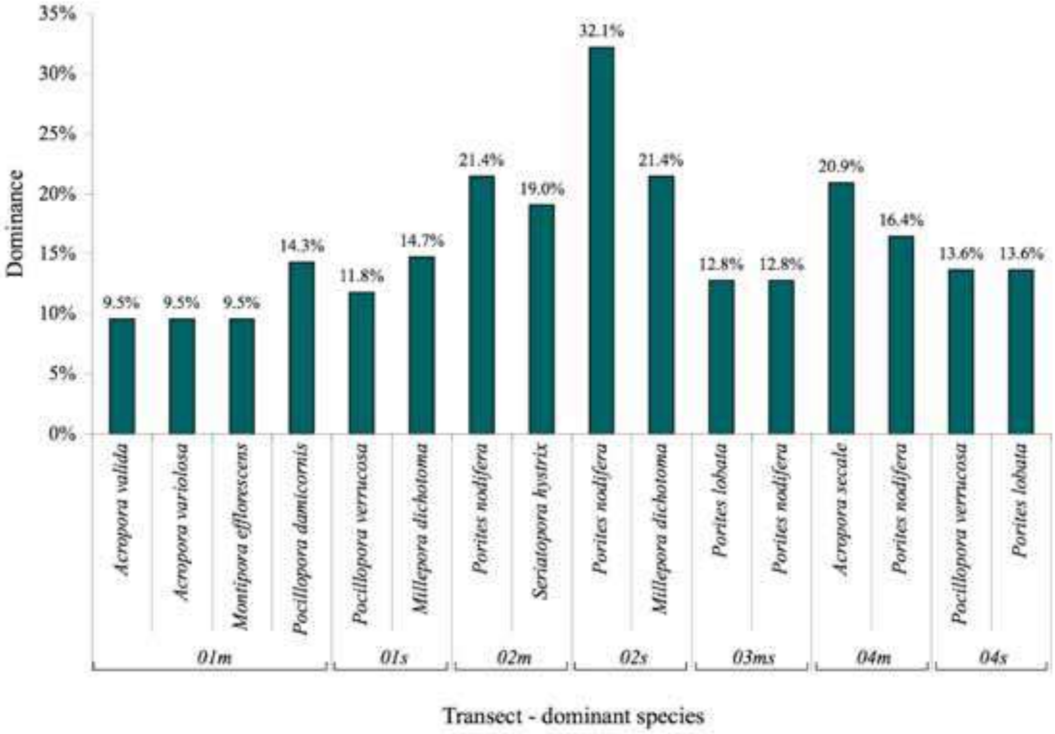


Fig. 16 Transect QUAE 01-04 with dominating species (m = medium = 10 m; s = shallow = 5 m).

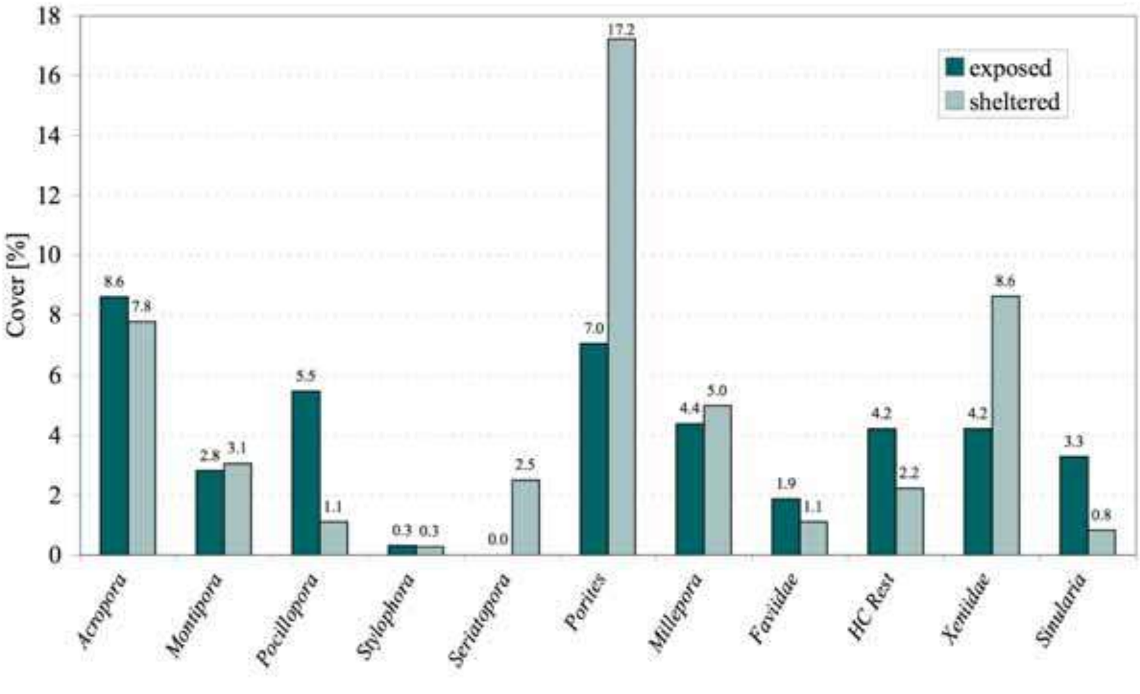


Fig. 17 Cover comparison between the inner, sheltered sites and the outer, more exposed sites for different coral groups.

Cover and Species Richness

The mean coral cover of the studied sites resulted in 36.6%. This cover does not differ significantly from the 35.7% found by Riegl & Velimirov (1991) for fringing reefs around Hurghada. The lowest cover had QUAE 01m with 26.3% and the highest QUAE 04s with 46.5%. The average cover in 5 m with 38.3% was higher than in 10 m with 34.8%.

The sheltered sites (QUAE 02 + 03) have a higher coral cover (40.3%) than the exposed sites (QUAE 01 + 04) with 34.5%. In summary, the analysis of transects comprises 50 species (=[S], Species Richness) with an average Species Richness of 9.0 species per segment or replicate (20 m, 40 test points). QUAE 01s (n=4) bear the highest mean value (11) and QUAE 04s (n=4) with 7.25 the lowest. The segments on 5 m have a higher Species Richness with a mean value of 9.3 species (n=12) than on 10 m with 8.6 (n=13). The sheltered sites (QUAE 02 + 03) showed an average of 8.4 (n=9) species and the exposed sites (QUAE 01 + 04) 9.3 (n=16). Thus, the Species Richness indicates a structure of higher diversity in the exposed areas and in shallower areas. A summary of coral cover and Species Richness for each transect is listed in Table 12.

Shannon-Wiener Index and Evenness

The Shannon-Wiener index H' has a cumulative mean value of 2.02 over all segments (n=25). In 5 m and 10 m the corresponding values are 1.94 and 2.10, but only the segments of QUAE 01 m ($p<0.05$) and QUAE 01s ($p<0.1$) show a high similarity. The sheltered sites (QUAE 02 + 03) have a lower value (1.90) than the exposed sites (QUAE 01 + 04; 2.09). For the individual transects the values range from 2.14 for QUAE 02s to 2.87 for QUAE 01s. The lowest values at QUAE 02m and QUAE 02s indicate a low diversity or unbalanced abundances here.

The index J' (Evenness) for the segments shows values between 0.78 and 1 with a significance $p<0.05$ for J' within transects. The mean values are 0.94 (n=25) per segment, 0.95 for the 5 m segments and 0.91 for 10 m. The exposed sites (QUAE 01 and QUAE 04) show a mean value of 0.95 compared to 0.90 for the sheltered sites (QUAE 02 and 03). The high values reflect the balanced abundances and thus support community structures without clear dominance. Lower values at the transects QUAE 02 m, QUAE 02s and QUAE 04 m indicate a possible dominance for these sites.

Bray-Curtis Similarity

The cluster analysis with the Bray-Curtis similarity (50 species) among the study sites QUAE 02 is mostly uniform. The segments of the 5 m and 10 m transects are grouped together in each case (Fig. 18, Table 9). Matching features of segments of QUAE 02s (5 m) are a high cover of *Porites nodifera* and *Millepora dichotoma*. For the 3 segments of QUAE 02 m (10 m), these are the occurrence of *Porites nodifera*, *Porites rus* and *Seriatopora hystrix*. This grouping reflects an overlapping of coral communities 3 and 6 (Table 14). The two main branches of the cluster analysis reverberate the two basic differences of the segments and/or coral communities, one with high contribution of *Porites* spp. (below) and one without (above). Generally, coral communities can overlap and a vertical as well as a horizontal zonation has been found in El Quadim Bay.

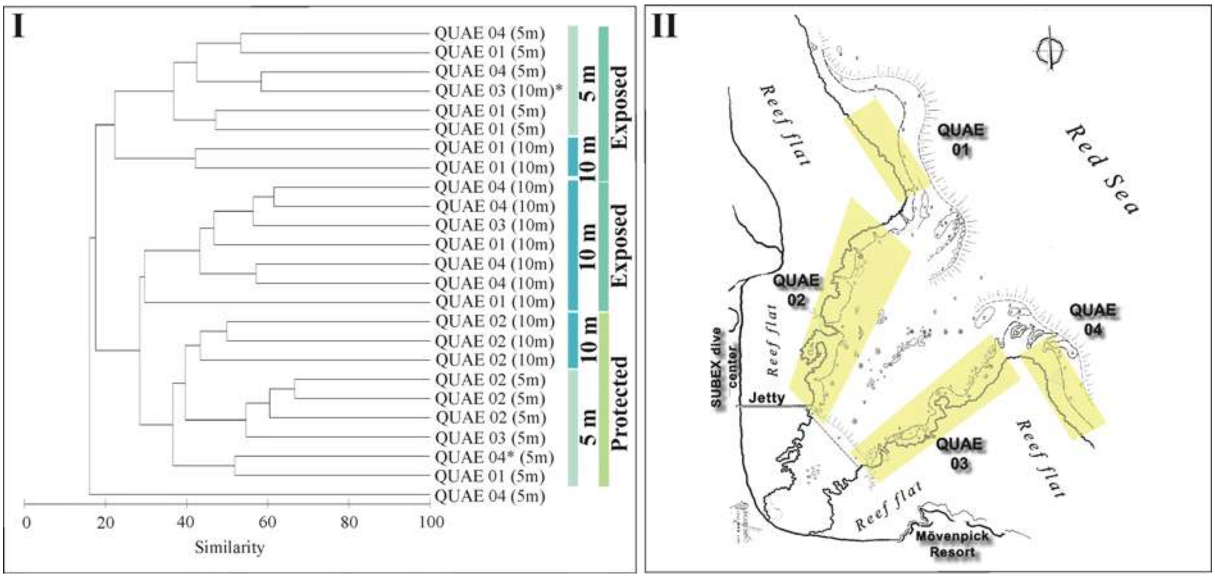


Fig. 18 (**I**) Dendrogramme of relationships between coral assemblages (Bray-Curtis similarity) at different transects. (**II**) Map of El Quadim Bay, Quseir, Egyptian Red Sea coast with location of the transects; mismatches regarding exposure to waves and depth are marked with *, respectively.

Table 9 ANOSIM significance test with a two-way crossed layout on Bray-Curtis similarities of relationships between coral assemblages at different depths and sites (protected and exposed) at El Quadim Bay, El Quseir, Egyptian Red Sea coast (*$0.05 \geq p \geq 0.01$, **$0.01 > p \geq 0.001$, ***$p < 0.001$).

	5 m *vs* 10 m	protected *vs* exposed
Global R	0.573	0.351
P	0.001	0.003
Significance level	**	**

Coral Communities

In the El Quadim Bay and its surrounding area primarily 7 different coral communities were found. Three of these communities are qualitatively estimated and 4 are statistically supported by the transect assessments. It has to be noted that the quantitative data are not sufficient to prove all coral communities statistically. The dominant species and key features of the 7 coral communities of the El Quadim Bay are presented in Table 14.

Table 10 Cover of genera and families of hermatypic corals (=HC) and soft corals (bottom) for each transect (m= 10m, s= 5m). Zero values are not shown.

Site QUAE	01 m	01 s	02 m	02 s	03 ms	04 m	04 s
Acropora	6.9%	7.5%	5.8%	5.0%	12.5%	18.8%	1.3%
Montipora	4.4%	4.4%	1.7%	6.7%	0.8%	1.3%	1.3%
Pocillopora	5.6%	7.5%			3.3%	3.1%	5.6%
Stylophora	0.6%			0.8%			0.6%
Seriatopora			6.7%		0.8%		8.1%
Porites	1.9%	6.9%	13.3%	23.3%	15.0%	11.3%	3.8%
Millepora	4.4%	8.8%	2.5%	10.0%	2.5%	0.6%	1.3%
Faviidae	0.6%	3.8%	3.3%			1.9%	6.3%
Other HC		4.4%	1.7%	0.8%	4.2%	6.3%	
Xeniidae	9.4%	0.6%	16.7%	7.5%	1.7%	1.3%	5.6%
Sinularia	3.1%	8.1%	1.7%		0.8%	1.9%	
Rhytisma	0.6%	0.6%					3.8%
Klyxum					3.3%		
Lithophyton						0.6%	0.6%

Table 11 Dominance of the 17 most important species for each transect. Zero values are not shown.

Species	01 m	01 s	02 m	02 s	03 ms	04 m	04 s
Acropora acuminata		1.5%					2.3%
Acropora gemmifera		4.4%					2.3%
Acropora samoensis	2.4%		2.4%	1.8%	6.4%	4.5%	
Acropora secale	4.8%	4.4%	2.4%		6.4%	20.9%	
Acropora valida	9.5%		7.1%	1.8%	6.4%	4.5%	
Acropora variolosa	9.5%		4.8%	3.6%	2.1%	10.4%	
Goniastrea edwardsi	2.4%	5.9%				3.0%	2.3%
Millepora dichotoma	2.4%	14.7%	7.1%	21.4%	6.4%	1.5%	11.4%
Millepora platyphylla	7.1%	2.9%				1.5%	
Montipora efflorescens	9.5%	8.8%	2.4%	8.9%	2.1%		2.3%
Pocillopora damicornis	14.3%	5.9%			8.5%	3.0%	6.8%
Pocillopora verrucosa	7.1%	11.8%				3.0%	13.6%
Porites lobata		7.4%		3.6%	12.8%		13.6%
Porites lutea	2.4%	2.9%	7.1%	8.9%	6.4%	1.5%	2.3%
Porites nodifera	4.8%	5.9%	21.4%	32.1%	12.8%	16.4%	11.4%
Porites rus			9.5%	5.4%	6.4%	7.5%	
Seriatopora hystrix			19.0%		2.1%		
Other	23.8%	23.5%	16.7%	12.5%	21.3%	22.4%	31.8%

Table 12 Coral cover, Species Richness S, Shannon-Wiener index H', Evenness J' and Margalef's Index for all transects. The lower part of the table shows the mean values for the indices per segment.

Site	01m	01s	02m	02s	03ms	04m	04s
Colonies (n=)	42	68	42	56	47	67	44
Coverage [%]	26.3	42.5	35.0	46.7	39.2	41.9	27.5
Species Richness [S]	18	23	16	15	19	23	19
$H' = -\Sigma$ pi ln pi	2.75	2.87	2.44	2.14	2.67	2.69	2.70
$J' = H'/\ln S$	0.95	0.91	0.88	0.79	0.91	0.86	0.92
Margalef's Index	4.55	5.21	4.01	3.48	4.68	5.23	4.76
Mean	(n=4)	(n=4)	(n=3)	(n=3)	(n=3)	(n=4)	(n=4)
$H' = -\Sigma$ pi ln pi	2.09	2.26	1.96	1.75	1.99	2.17	1.84
Species Richness [S]	8.5	11	8.7	8	8.7	10.3	7.3
Eveness $J' = H'/\ln S$	0.98	0.95	0.92	0.84	0.93	0.94	0.94
Margalef's index	3.22	3.54	2.89	2.40	2.76	3.27	2.61

Table 13 Coral cover, Species Richness S, Shannon-Wiener index H', Evenness J' and Margalef's Index separated by depth and exposure. The lower part of the table shows the mean values over the replicates.

	10 m	5 m	exposed	sheltered
Coverage [%]	35.6	37.7	34.5	40.3
Species Richness [S]	36	37	44	28
Mean	(n=13)	(n=12)	(n=16)	(n=9)
Species Richness [S]	9.3	8.6	9.3	8.4
Evenness J'	0.95	0.91	0.95	0.90
Margalef's index	3.15	2.81	3.16	2.68
$H' = -\Sigma$ pi ln pi	2.10	1.94	2.09	1.90

Table 14 Summary of key features of the 7 coral communities of the El Quadim Bay.

Nr.	Dominant species	Characters	Habitat
1	*Stylophora pistillata*	Low diversity. *Millepora platyphylla* abundant	Reef flat
2	*Acropora gemmifera, Acropora hyacinthus*	*Echinopora gemmacea* und *Porites lobata* abundant	Reef edge / reef crest
3	*Millepora dichotoma*	*Seriatopora hystrix* and *Goniopora* spp. in deeper areas abundant	Sheltered reef slope or fore reef areas, high sedimentation(?)
4	-	High diversity with medium coral cover, balanced abundances, many Faviids	Exposed, gentle reef slope
5	*Acropora acuminata, Pocillopora verrucosa*	Partly with *Millepora dichotoma* abundant - dominant, high coral cover	Upper reef slope <5m
6	*Porites nodifera*	*Porites lutea* and *Porites rus* abundant, high coral cover	Protected reef slope areas
7	*Acropora variolosa, Acropora valida, Acropora secale*	*Pocillopora damicornis* abundant, high coral cover	semi-exposed, gentle reef slope >5m

4.8.4. Discussion – Coral Population

4.8.4.1. Diversity

For the entire Red Sea Sheppard & Sheppard (1991) summarized 220 scleractinian species with a part of 158 species for the northern Red Sea. Abou Zaid (2000) reported 128 species in 45 genera for the northern Red Sea. Compared to the latter the results of this study showed a higher coral diversity (Order: Scleractinia) with 144 species in 45 genera. However, Veron (2000) listed 303 species with descriptions of some new species. Further Sheppard & Sheppard (1991) synonymised some species (genera *Stylophora* and *Psammocora*), which were again split by Veron (2000).

A comparison of the coral diversity on the genus level between the El Quadim Bay and the entire Red Sea (based on Veron 2000) is given in Appendix 6.

91% of the scleractinian species of the northern Red Sea would thrive in the area around the El Quadim Bay, if compared to Sheppard & Sheppard (1991). Referring to the number of species listed by Veron (2000), 48% of all species of the entire Red Sea do occur in El Quadim Bay. Unfortunately, detailed information and literature on the biogeography and local occurrence of scleractinian corals is scarce. Riegl & Velimirov (1994) listed 96 species of hard corals (92 scleractinian corals, 137 transects) for the region around Hurghada and Loya & Slobodkin (1971) 97 (95 scleractinian corals) species for Eilat in the Gulf of Aqaba. However, rare and cryptic species most likely are underrepresented in these approaches. In summary, the results show that the El Quadim Bay has a high coral diversity.

5. Discussion

5.1. Natural Impacts

5.1.1. Sediment Input

Since the establishment of the Mövenpick resort and the SUBEX Dive Center, the area was flooded in November 1994 and the winter of 1996/97 to the extent that in 1994 even the paved road along the bay was flushed away. High loads of sediment were discharged into the bay and onto the reef, staying in the water column for over a week and preventing all dive tourism.

Sedimentation can also be caused by the prevailing hydrodynamic characteristics of the reef surrounding. High swell and strong currents can disperse sediment from the seafloor and transport it into the reef, which slows down the water velocity and causes the sediment to settle.

Sediment production within the reef is caused by mechanical erosion such as wave action and by bioerosion. Bioeroding organisms such as sea urchins, parrotfish, boring sponges and bivalves degrade corals and rocks into sediment particles.

5.1.2. Natural Predators

In the El Quadim Bay *Drupella* was present with a varying degree of abundance most commonly on compact branching forms of *Acropora* and *Pocillopora*, while *Coralliophila* was found to feed intensely on *Porites* sp. at several sites. It is well-known, that branching corals, mainly *Acropora* spp. are preferred by *Drupella* while *Porites* is a main food source for *Coralliophila* (Fujioka & Yamazato 1983, Chen et al. 2004).

Generally damage was at a sub-lethal level, with most infected corals showing partial mortality ranging from 10% to 70% of the colony.

COTS plagues significantly damaged reefs in the Red Sea during the late nineties. During the Reef Check survey no COTS were observed. According to reports of the dive centre staff, COTS can occasionally be found in low numbers in the El Quadim Bay.

5.2. Effects of Human Activities

5.2.1. Coastal Development

5.2.1.1. Construction and Beach Replenishment

During the Reef Check survey no negative effects or long-term consequences of construction works could be detected. Construction rubble was not observed in the hotel area or the adjacent reef.

During the establishment of the hotel in 1994 parts of the beach between the high tide line and the street were artificially heaped up with sand and gravel to make place for deck chairs. The (fine) sand is mobilised by wind and footsteps and transported slowly towards the sea where it is suspended by waves and swimmers. With currents and tides it is then distributed within the bay and partly into the reef. To our knowledge another 500 m^3 of sand were added in summer 2005. However, staff members of the dive centre observed no increase in turbidity after the recent replenishment.

There is a regular increase in turbidity (co-occurring with the tides), which is a natural process in wadi-estuaries due to the suspension of terrigenous material as well as carbonate particles, which are mobilised by currents and transported from the reef flat.

In the framework of this study it is not possible to determine whether the turbidity in the bay increased as a result of beach replenishment, or actually even declined after the construction of the road in the 70s, because there is no historical information available.

5.2.1.2. Garbage, Nets etc.

The impact of garbage and abandoned fishing gear is relatively low, however, plastic bags blown from land to the reefs and smothering corals have been observed, as well as plastic trash from the hotel.

5.2.1.3. Desalination

The Mövenpick Resort is producing parts of the freshwater with a desalination plant (R/O Plant), situated about 1.5 km from the resort. An amount of 900 m^3 of seawater is pumped daily through the system, ca. 300 m^3 fresh water are produced. The remaining 600 m^3 are enriched in salt, and are pumped onto the beach and eventually enter the sea. This avoids the direct pumping of concentrated and hot brines into the seawater.

5.2.1.4. Sediment Input from Phosphate Loading

Phosphate ore washing and sewage discharge are principal nutrient enrichment forces along the Egyptian coastline. There is a phosphate loading harbour in El Hamrawein, ca. 20 km north of El Quadim Bay. During loading of phosphate ore great amounts of phosphate dust are blown away and transported by the predominantly coastline parallel NNW winds onto the coastal strip and the fringing reef. It has not been subject of this study to determine the fate of this phosphate dust, but it cannot be excluded that a part of it is transported by winds parallel to the coastline and coastal currents and eventually reaches El Quadim Bay, thus contributing to the turbidity in the bay.

5.2.1.5. Sewage

Sewage, high in coliform bacteria and suspended solids, has often been, even though illegal, left untreated and discharged into the intertidal zones. Additional wastes in the form of plastics are discharged to the sea from urban areas and shipping.

Apparently sewage does not impose a big problem in the bay, because the hotel is linked to a sufficiently effective sewage treatment plant. This treatment system is situated about 1.5 km from the hotel, close to the desalination plant. All sewage is pumped to this plant, filtered and disinfected, and is then used for irrigation of plants in the hotel gardens. The solid residual waste is removed from the treatment plant and deposited in a garbage dump in the desert (pers. comm. SUBEX).

Seepage from lawn irrigation does occur in low amounts to the reef flat, but does not seem to have significant effects on the reef.

5.2.2. Fishing

Fishing is not allowed in the El Quadim Bay, but sometimes fisher boats try to poach into the area. When spotted, they are immediately sent out of the bay.

5.2.3. Anchoring

Anchoring is presently no reason for concern in El Quadim Bay, as the boats used by SUBEX Dive Center are moored on fixed buoys. To our knowledge the dive centre takes care that foreign fishing or diving boats do no enter the bay.

5.2.4. Direct Impacts of Tourist Activities

5.2.4.1. Recreational SCUBA Diving and Snorkeling

Most broken corals observed during our surveys were of the species *Millepora*. Due to their predominant presence in shallower depths and their delicate structure, species like *Acropora* and *Millepora* are known to be broken and damaged easily by divers (Riegl & Velimirov 1991). However, they are also known to be faster growing species that can tolerate frequent breakage and the broken tips are often able to reattach and regenerate (Riegl & Velimirov 1991).

Carrying Capacity

The concept of carrying capacity can be a useful tool for the management of recreational SCUBA diving in coral reefs. Salm (1986b, 1986a) introduced the concept of diver carrying capacity. The carrying capacity assumes that there is a certain level of disturbance which an ecosystem can cope with, before degradation takes place (Hawkins & Roberts 1997). Carrying capacity in coral reefs is usually expressed as the number of dives per site per year, and is a measure of the number of divers a reef can tolerate without becoming significantly degraded (Jameson et al. 1999). Studies in the Caribbean (Dixon et al. 1993) and Red Sea (Hawkins & Roberts 1997) indicate a carrying capacity of 4,000 to 6,000 and 5,000 to 6,000 dives per site and year, respectively.

The management of the SUBEX Dive Center in El Quadim Bay has implemented relatively strict regulations to avoid damage to the reef. Presently the dive intensity is restricted to 120 accepted divers at a time. A regular day is divided into five time slots each two hours long. Within each time slot not more than 20 independent divers plus three guided tours (each max. five divers) are allowed in the bay. Buoyancy skills of divers are checked before divers are allowed to dive independently. Night dives take place three times a week with a maximum of 20 participants. Most diving courses are conducted in the shallow water areas and are limited to 20 dives a day. These dives are not taken into account in the following analysis.

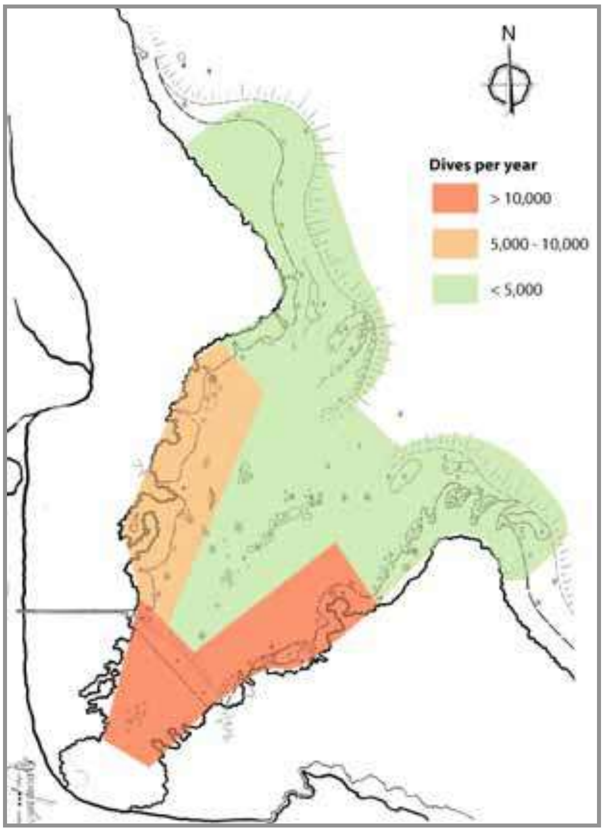


Fig. 19 Distribution of diving intensity in El Quadim Bay.

The dive sites inside and outside the bay are not dived in equal intensity: Almost three quarters of all dives are done in the inner sectors of the bay, while about one quarter of the dives starts at the outside. All divers brought to the outer reefs by zodiacs make their way back along the inner parts of the reef, further increasing the numbers of divers passing these areas.

Also, the distribution between right and left side is skewed: two thirds of the divers prefer the right (southern) side of the bay, while one-third dive along the left (northern) side. The middle part of the bay is dived by less than 10% of all divers (Fig. 19).

The calculation of the real frequency of passing divers is shown in Table 15. The calculation is based on the statistics from 2001 through 2004 provided by the dive centre.

Based on this calculation, the sector with the highest diving pressure is clearly the inner right side of the bay (SUBEX sector I, or QUAE 03), which experiences approximately 11,000 dives per year, while the least affected sector is the outer left side of the reef (SUBEX sector IV, or QUAE 01) with less than 1,000 dives per year.

Table 15 Distribution of dives per sector. Average of registered dives from 2001-2004, including night dives, but excluding dive courses.

Total number of dives per year and sector	
Outside R (South)	1832
Outside L (North)	916
Inside R (South)	10907
Inside L (North)	5454
Center	1513
Total	**20622**

Additionally, there are about 1,100 registered snorkelers per year, which are not counted within these dive numbers. The real number is certainly higher, as many snorkelers bring their own gear and go for snorkelling on their own. Snorkelers start in the bay, especially along the reef crest and over the reef flat where the water can be very shallow. It is very likely that these snorkelers are in large part responsible for the observed breakage of corals at the reef crest, since divers are less affected by waves and usually keep a greater distance to the reef.

The diving pressure of 11,000 divers/year at sector I exceeds the number of 5,000 to 6,000 dives per site and year, which was recommended by Hawkins and Roberts (Hawkins & Roberts 1997) for a coral reef in the Red Sea, and which is generally accepted as the upper limit before serious degradation takes place. However, our data do not show significant effects on the ecosystem. There are several factors which might cause this result: a) The topography of the reef at the right inner side is relatively steep, and in large parts builds a drop-off of 10 to 20m. This reduces the risk of coral breakage by fins caused by divers with buoyancy problems. Also, wave exposure is relatively low inside the bay, which reduces the risk that divers are pushed onto the reef by waves. b) The reefs in the area are protected from fishing, which very likely has a positive effect on the fish community, which is by far greater than disturbance by divers would have. c) The behaviour of divers in El Quadim Bay is, because of the regulations of the dive centre, probably less damaging than in other areas. In the frame of this study this cannot be substantiated by data, but would be interesting to verify in a future study.

The fact that El Quadim Bay is exclusively used by a single dive centre allows a proper management of the diving activities. A positive side effect of the exclusive utilisation of El Quadim Bay for recreational SCUBA diving is the exclusion of fishermen.

The results of this study show, that the concept of carrying capacity has its values, but can not be applied straightforward to each diving area. It is of great importance to take the natural context into account, like topography, but of equal or even higher importance is a well-planned and implemented management scheme.

It is not subject of this study to assess the economic sustainability of such “environmentally-friendly” management approaches, but in the long term it is in the interest of any investment based on the integrity of its natural resources to do the utmost to conserve these resources in order to maintain the foundation of the enterprise.

6. Recommendations

It has been shown that unexperienced divers and underwater photographers pose a greater risk of damage for the reef than other divers (Barker & Roberts 2004). It was not the goal of this study to check on diver behaviour, but it would be interesting to observe diver behaviour and then take appropriate measures to minimise the risk of damage, e.g. by further improving training and education of divers, or offering special courses for underwater photographers. It should be considered to make the presence of a dive guide mandatory when using underwater cameras.

The results of our studies show that neither the fish population nor coral or invertebrate populations in El Quadim Bay are affected by diving activities. However, there are indications that the carrying capacity of the inner parts of the bay has reached its limit. The particular local conditions, including the steep topography of the reef, the easy access to the dive sectors over the jetty, and the management of diving activities, like briefing of new guests and the limitation of the size of dive groups contribute to the fact, that the high diving pressure has not yet resulted in significant ecological damage. Another important factor is probably the effective exclusion of fishing activities, which even in national parks like Ras Mohammed in Sinai occurs regularly, even though it is illegal. We assume that the positive effects of protection from fishing outweigh the potentially negative effects of diving, snorkelling and boating.

The key to a successful and sustainable management of El Quadim Bay lies in the training of dive guides and instructors. These are in a key position pass on their knowledge and skills to the recreational divers. It has been shown that a detailed briefing before the dive, where in addition to information about the dive site, also information on ecology, threats to reefs and guidelines for responsible diving are given, significantly reduces damage to the reef (Barker & Roberts 2004). Divers tend to try to act like their instructors, which gives them a great opportunity to act as role models for environmentally-friendly diving.

The relatively low diving pressure at the outer sectors leaves space for a moderate increase of diving frequency on these reefs. However, it should be noted that divers are brought to the start of their dive with a dinghy equipped with an outboard engine, thus increasing the noise pollution for sea life. Marine mammals like dolphins, which frequently visit the bay, may as a result avoid the area.

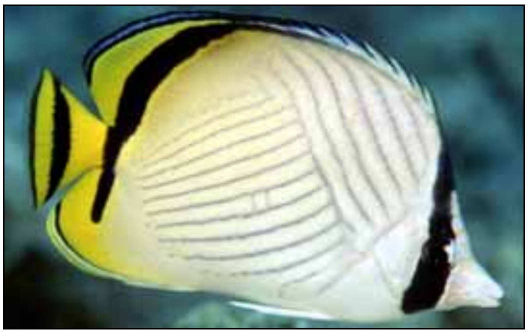
7. Appendix

7.1. Plates

Plate 1 Reef Check indicator fish Red Sea

Common Name	Family Name	Indicator of
Butterflyfish (all species)	Chaetodontidae	Overfishing, Aquarium Collection
Grouper (any over 30 cm)	Serranidae	Overfishing, Live fish trade (Indo-Pacific)
Grunts/Sweetlips/Margates	Haemulidae	Overfishing
Moray Eel (all species)	Muraenidae	Overfishing
Parrotfish (over 20 cm)	Scaridae	Overfishing
Snapper	Lutjanidae	Overfishing
Broomtail wrasse	*Cheilinus lunulatus*	Overfishing
Bumphead Parrotfish	*Bolbometopon muricatum*	Overfishing
Humphead (Napoleon) Wrasse	*Cheilinus undulatus*	Overfishing

Butterflyfish (all species)
Chaetodontidae
Example: Vagabond butterflyfish (*Chaetodon vagabundus*)



Robert A. Patzner

Grouper (any over 30 cm)
Serranidae
Example: Coral hind (*Cephalopolis miniata*)

Marc Kochzius

Grunts/Sweetlips
Haemulidae
Example: Blackspotted sweetlip (*Plectorhinchus gaterinus*)

Georg Heiss

Moray Eel (all species)
Muraenidae
Example: Yellow-margined moray (*Gymnothorax flavimarginatus*)

Robert A. Patzner

Snapper
Lutjanidae
Example: Bluelined snapper, *Lutjanus kasmira*

Robert A. Patzner

Snapper
Lutjanidae
Example: Onespot snapper (*Lutjanus monostigma*)

Marc Kochzius

Parrotfish (any over 20cm)
Scaridae
Example: Ember parrotfish

John E. Randall

Bumphead Parrotfish

Bolbometopon muricatum

John E. Randall

Broomtail wrasse
Cheilinus lunulatus

Marc Kochzius

Humphead (Napoleon) Wrasse
Cheilinus undulatus

Marc Kochzius

Plate 2 Reef Check indicator invertebrates Red Sea

Common Name	Species/Class Name	Indicator of
Banded Coral Shrimp	*Stenopus hispidus*	Aquarium collection
Lobster (all edible species)	*Malacostraca (Decapoda)*	Overfishing
Long-spined Black Sea Urchin	*Diadema* spp.	Overfishing
Pencil Urchin	*Eucidaris* spp.	Curio trade
Sea Egg/Collector Urchin	*Tripneustes* spp.	Overfishing
Triton	*Charonia* spp.	Curio trade
Crown-of-thorns Starfish	*Acanthaster planci*	Population outbreaks
Edible Sea Cucumber (2 species)		Beche-de-mer fishing
Prickly Redfish	*Thelenota ananas*	
Greenfish	*Stichopus chloronotus*	
Giant Clam (give size/species)	*Tridacna* spp.	Overharvesting

Banded Coral Shrimp
Stenopus hispidus

Jeff Jeffords

Lobster (all edible species)
Malacostraca (Decapoda)

Long-spined Black Sea Urchin
Diadema savignyi, Diadema setosum, Echinotrix diadema

William Kiene

Pencil Urchin
Heterocentrotus mammillatus

Georg Heiss

Collector Urchin
Tripneustes spp.

Georg Heiss

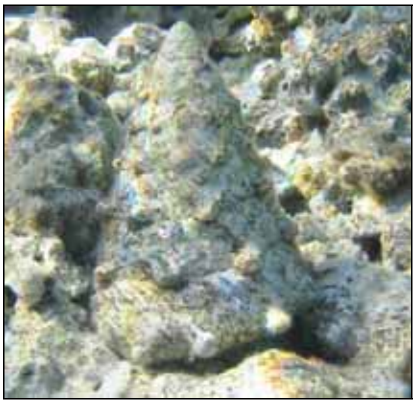
Crown-of-thorns Starfish
Acanthaster planci

Marc Kochzius

Triton
Charonia tritonis

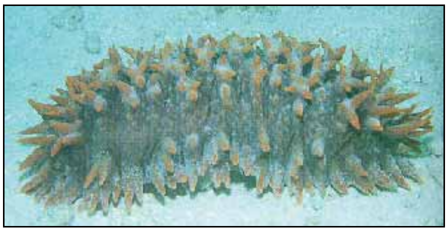
Karenne Tun

Tectus
Example: *Tectus dentatus*.



Georg Heiss

Edible Sea Cucumbers
Example: Prickly Redfish *Thelenota ananas*



Edible Sea Cucumbers
Example: Greenfish *Stichopus chloronotus*

Karenne Tun

Giant Clam
Tridacna spp. Example: *T. maxima*

Marc Kochzius

Plate 3 Examples for Reef Check substrate categories (all photos Christian Alter).

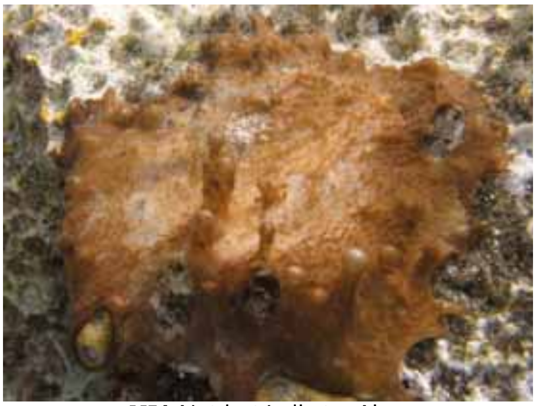
HC Hard Coral

SC Soft Coral

RC Rock

RCK Recently Killed Coral

SD Sand



NIA Nutrient Indicator Algae

SP Sponge

OT Other

Plate 4 Common fish species in El Quadim Bay (all photos Marc Kochzius).

Scalefin anthias (male)
Pseudanthias squamipinnis (Peters, 1855)

Scalefin anthias (female)
Pseudanthias squamipinnis (Peters, 1855)

Exquisite butterflyfish
Chaetodon austriacus Rüppell, 1836

Yellowflank damselfish
Amblyglyphiodon flavilatus Allen and Randall 1980

Half-and-half chromis
Chromis dimidiata (Klunzinger, 1871)

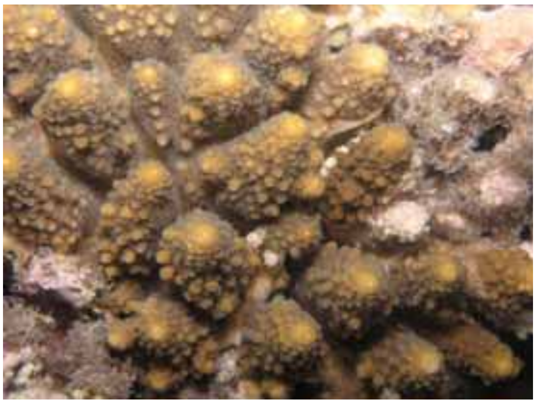
Blue-green chromis
Chromis viridis (Cuvier, 1830)

Lined bristletooth
Ctenochaetus striatus (Quoy and Giamard), 1825

Yellowtail surgeonfish
Zebrasoma xanthurum (Blyth), 1852

Plate 5 Common coral species in El Quadim Bay (all photos Christian Alter).


Acropora acuminata (Dana, 1846)


Acropora gemmifera (Brook, 1892)


Acropora hyacinthus (Dana, 1846)


Acropora samoensis (Brook, 1892)


Acropora secale (Studer, 1878)


Acropora selago (Studer, 1878)


Acropora valida (Dana, 1846)


Acropora variolosa (Klunzinger, 1879)


Montipora efflorescens (Bernard, 1897)


Montipora tuberculosa (Lamarck, 1816)

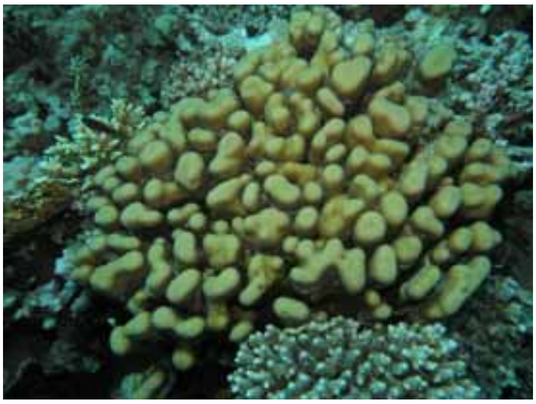

Cyphastrea microphthalma (Lamarck, 1816)

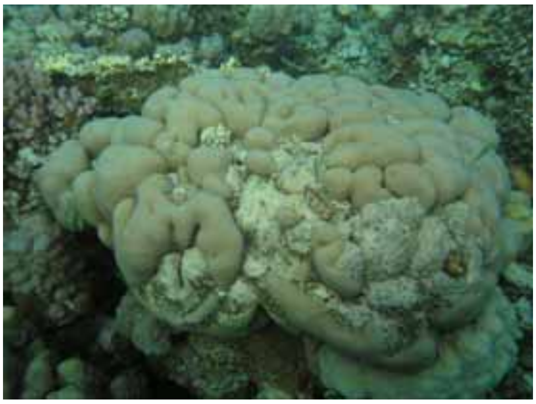

Echinopora forskaliana (Milne Edwards & Haime, 1850)


Echinopora gemmacea (Lamarck, 1816)

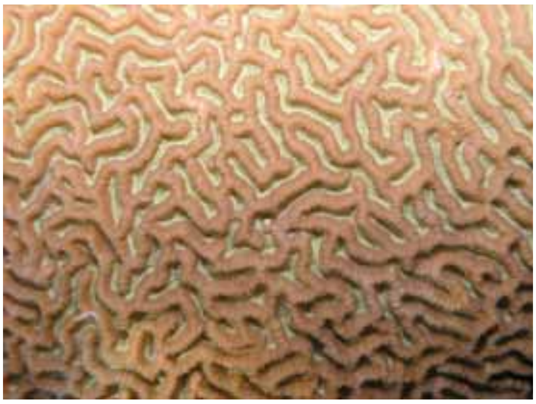

Favia favus (Forskål, 1775)


Favia rotumana (Gardiner, 1899)


Favia stelligera (Dana, 1846)



Goniastrea edwardsi (Chevalier, 1971)



Platygyra daedalea (Ellis and Solander, 1786)

Platygyra lamellina (Ehrenberg, 1834)

Acanthastrea echinata (Dana, 1846)

Pocillopora damicornis (Linnaeus, 1758)

Pocillopora verrucosa (Ellis and Solander, 1786)

Seriatopora hystrix (Dana, 1846)

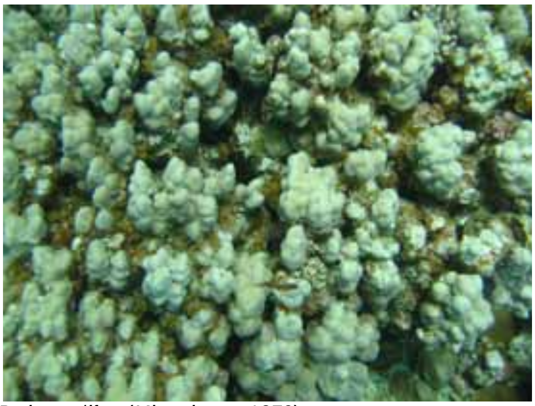
Stylophora pistillata (Esper, 1797)


Goniopora columna (Dana, 1846)


Porites columnaris (Klunzinger, 1879)


Porites lobata (Dana, 1846)


Porites lutea (Milne Edwards & Haime, 1851)


Porites nodifera (Klunzinger, 1879)


Porites nodifera (Klunzinger, 1879)


Porites rus (Forskål, 1775)


Coscinarea monile (Forskål, 1775)

7.2. Tables

Appendix 1 Results of Reef Check surveys in El Quadim Bay.

Mean percent substrate cover

	QUAE01			QUAE02			QUAE03			QUAE04		
Substrate type	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*
HC	34.4	9.4	45.0	40.8	8.2	50.0	39.2	6.3	45.0	34.7	10.5	50.0
SC	11.3	5.5	20.0	12.9	9.9	30.0	5.8	6.3	12.5	6.9	7.0	17.5
RKC	0.3	0.9	2.5	0.4	1.0	2.5	0.8	1.4	2.5	0.3	0.9	2.5
NIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SP	0.3	0.9	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RC	51.9	7.6	67.5	31.3	16.0	47.5	53.3	6.3	60.0	57.8	8.1	75.0
RB	1.9	3.5	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	2.5
SD	0.0	0.0	0.0	13.3	18.0	45.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OT	0.0	0.0	0.0	1.3	2.1	5.0	0.8	1.4	2.5	0.0	0.0	0.0

Mean abundance of indicator species of fish (no. of individuals / 100m^2)

	QUAE01			QUAE02			QUAE03			QUAE04		
Indicator Fish	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*
Butterflyfish	12.9	3.4	19	12.0	8.5	24	14.0	4.0	18	12.4	9.6	32
Haemulidae	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.1	0.4	1
Broomtail wrasse	0.6	0.7	2	0.3	0.8	2	1.3	2.3	4	0.6	0.9	2
Grouper	0.5	0.8	2	0.5	0.8	2	1.0	1.0	2	1.9	1.1	3
Bumphead parrot	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Humphead wrasse	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Parrotfish	3.0	1.6	5	1.0	1.3	3	8.7	4.0	13	5.8	1.3	7
Snapper	0.0	0.0	0	0.0	0.0	0	2.3	4.0	7	2.6	5.5	16
Moray eel	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.1	0.4	1

Mean abundance of indicator species of invertebrates (no. of individuals / 100m^2)

	QUAE01			QUAE02			QUAE03			QUAE04		
Indicator Invertebrates	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*	*Mean*	*SD*	*Max*
Banded coral shrimp	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Long-spined sea-urchin	3.3	2.6	9	0.7	1.0	2	1.7	1.5	3	1.1	1.1	3
Pencil urchin	0.5	1.1	3	0.0	0.0	0	4.0	3.6	7	4.0	3.3	10
Sea cucumber	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Crown-of-thorns	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Giant clam	1.4	1.4	3	7.7	4.9	16	9.3	3.1	12	5.4	4.5	14
Triton	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Collector urchin	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Lobster	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Trochus	0.1	0.4	1	0.0	0.0	0	0.3	0.6	1	0.3	0.7	2

Appendix 2 Average fish abundance per transect (250 m^2) at El Quadim Bay, El Quseir, Egyptian Red Sea coast. For details regarding location of transects see Fig. 1. Nomenclature is according to FishBase (FishBase 1999).

Transect number Depth	1+3+5 10 m	2+4+6 5 m	7+9+11 10 m	8+10+12 5 m	**Total**
Dasyatididae					
Taeniura lymma	0.7	0.3			**0.3**
Synodontidae					
Synodontidae spp.	0.3	0.7			**0.3**
Holocentridae					
Holocentridae spp.	0.3		0.3		**0.2**
Myripristis murdjan	0.7		0.3		**0.3**
Neoniphon sammara	2.3	2.0	1.7	0.3	**1.6**
Sargocentron caudimaculatum	1.0	0.3	0.3	0.3	**0.5**
Fistulariidae					
Fistularia commersonii	0.3				**0.1**
Scorpaenidae					
Pterois miles		0.3	0.3		**0.2**
Pterois radiata				0.3	**0.1**
Serranidae					
Aethaloperca rogaa				0.3	**0.1**
Cephalopholis argus	3.3	1.0	0.7	2.3	**1.8**
Cephalopholis hemistiktos	1.3	1.3			**0.7**
Cephalopholis miniata	1.0	0.7	3.3	8.0	**3.3**
Cephalopholis sexmaculata	0.3		0.3	0.3	**0.3**
Diploprion drachi	1.3	1.0	0.7		**0.8**
Grammistes sexlineatus		0.3	0.3		**0.2**
Plectropomus sp.				0.7	**0.2**
Pseudanthias squamipinnis	200.3	210.3	181.7	1217.3	**452.4**
Serranidae spp.			2.3		**0.6**
Variola louti			0.7	0.3	**0.3**
Cirrhithidae					
Paracirrhites forsteri	4.7	6.0	4.7	8.0	**5.8**
Pseudochromidae					
Pseudochromis fridmani	2.0	0.3			**0.6**
Priacanthidae					
Priacanthus hamrur	6.0	1.3	5.3		**3.2**
Apogonidae					
Apogon quinquelineatus	0.7				**0.2**
Apogonidae sp.	1.0				**0.3**
Carangidae					
Carangidae spp.		0.7	0.3	1.0	**0.5**
Carangoides bajad	0.3	1.0	0.7	1.0	**0.8**
Lutjanidae					
Lutjanus ehrenbergi			0.3	3.0	**0.8**
Macolor niger			20.0	0.3	**5.1**
Caesionodae					
Caesio lunaris			0.7	10.0	**2.7**
Caesio striatus				5.7	**1.4**
Caesio suevicus			0.3	10.0	**2.6**
Haemulidae					
Plectorhynchus gaterinus				0.3	**0.1**
Lethrinidae					
Lethrinus spp.	0.3	2.3	0.7	0.3	**0.9**
Monotaxis grandoculis		0.3	1.3	2.0	**0.9**
Khyphosidae					
Kyphosus spp.			6.3		**1.6**
Mullidae					
Mullidae spp.		0.3			**0.1**
Mulloidichthys vanicolensis		7.3	9.7		**4.3**
Parupeneus macronema			0.3		**0.1**
Chaetodontidae					
Chaetodon auriga	1.7	0.7	1.0	2.0	**1.3**
Chaetodon austriacus	9.0	10.0	9.7	8.3	**9.3**
Chaetodon fasciatus	0.7	2.0	0.7	2.0	**1.3**
Chaetodon lineolatus	0.3				**0.1**
Chaetodon melannotus		0.7	1.0	1.0	**0.7**
Chaetodon paucifasciatus	4.0	1.3	3.3	1.7	**2.6**
Chaetodon semilarvatus		1.3		1.3	**0.7**

Transect number Depth	1+3+5 10 m	2+4+6 5 m	7+9+11 10 m	8+10+12 5 m	**Total**
Heniochus intermedius	1.3	1.7	1.0	2.0	**1.5**
Pomacanthidae					
Centropyge multispinis	1.3		0.3	2.3	**1.0**
Pomacanthus imperator				0.3	**0.1**
Pygoplites diacanthus	1.0	3.0	0.7	2.0	**1.7**
Pomacentridae					
Abudefduf vaigiensis			6.7	17.7	**6.1**
Amblyglyphidodon flavilatus	15.3	17.0	12.7	1.0	**11.5**
Amphiprion bicinctus		0.7			**0.2**
Chromis dimidiata	734.0	728.7	650.7	381.0	**623.6**
Chromis ternatensis	63.7	50.7	106.0	104.7	**81.3**
Chromis viridis	23.0	103.7	25.0	47.0	**49.7**
Neopomacentrus miryae	2.3			0.3	**0.7**
Pomacentridae spp.	19.3	0.3		2.0	**5.4**
Pomacentrus sulfureus	12.7	5.7	6.0	8.0	**8.1**
Pomacentrus trichourus	2.3				**0.6**
Labridae					
Anampses lineatus		1.0			**0.3**
Anampses meleagrides				1.7	**0.4**
Anampses twistii	1.0			0.3	**0.3**
Bodianus anthioides	0.7				**0.2**
Cheilinus diagrammus	2.7	1.3	0.7	2.7	**1.8**
Cheilinus fasciatus	0.3				**0.1**
Cheilinus lunulatus	0.3	1.3	0.3	0.3	**0.6**
Cheilinus sp.	1.3	1.0	0.3	1.0	**0.9**
Cheilinus trilobatus		0.7			**0.2**
Coris aygula	0.3		0.3	1.7	**0.6**
Epibulus insidiator	0.3		0.3		**0.2**
Gomphosus caeruleus klunzingeri	3.0	3.0	3.0	2.7	**2.9**
Halichoeres sp.			0.3	1.3	**0.4**
Hologymnus annulatus	0.3				**0.1**
Labridae spp.	14.3	9.0	1.7	9.0	**8.5**
Labroides dimidiatus	4.7	2.0		2.0	**2.2**
Larabicus quadrilineatus	8.0	2.0	2.7	2.0	**3.7**
Pseudocheilinus octotaenia	3.3	1.0	3.7		**2.0**
Pseudodax moluccanus	0.3			0.7	**0.3**
Thalassoma rueppellii	1.0	2.0	1.0	19.0	**5.8**
Scaridae					
Cetoscarus bicolor	0.3			0.3	**0.2**
Chlorurus sordidus		0.3			**0.1**
Hipposcarus harid		0.7		0.7	**0.3**
Scaridae spp.	4.7	11.7	1.3	10.7	**7.1**
Scarus niger	1.0	3.0	1.3	0.7	**1.5**
Scarus sordidus	0.3				**0.1**
Blenniidae					
Blenniidae spp.	1.0		2.0	1.7	**1.2**
Meiacanthus sp.			1.3	1.0	**0.6**
Plagiotremus sp.	0.3	0.3		0.3	**0.3**
Acanthuridae					
Acanthuridae spp.	3.0	2.0		8.7	**3.4**
Acanthurus nigricans			0.7	1.7	**0.6**
Acanthurus sohal	0.3	1.3		0.3	**0.5**
Ctenochaetus striatus	15.3	13.3	6.3	5.3	**10.1**
Naso lituratus	2.0	2.7	1.3	3.3	**2.3**
Naso unicornis	0.7	0.7		0.3	**0.4**
Zebrasoma veliferum	19.7	7.7	4.0	10.3	**10.4**
Zebrasoma xanthurum	3.0	8.3	4.3	2.0	**4.4**
Siganidae					
Siganus luridus	10.7	8.3	2.3	6.3	**6.9**
Scombridae					
Rastrelliger kanagurta			5.3		**1.3**
Balistidae					
Balistapus undulatus	1.3	1.0	0.3	1.0	**0.9**
Balistidae spp.	0.3				**0.1**
Balistoides viridescens	0.3				**0.1**
Pseudobalistes fuscus	0.7				**0.2**

Transect number Depth	1+3+5 10 m	2+4+6 5 m	7+9+11 10 m	8+10+12 5 m	**Total**
Rhinecanthus assasi	0.7	1.0	1.7	1.0	**1.1**
Sufflamen albicaudatus	0.3				**0.1**
Monacanthidae					
Aluterus scriptus	0.7				**0.2**
Amanses scopas	0.7	1.7	1.7	2.3	**1.6**
Cantherhines pardalis	0.7				**0.2**
Monacanthidae		0.3			**0.1**
Ostraciidae					
Ostracion cyanurus	0.3				**0.1**
Tetraodontidae					
Arothron diadematus	0.3	0.3			**0.2**
Total	1231.0	1254.3	1116.7	1959.0	**1390.3**

Appendix 3 Additional fish species observed outside the transects

Torpedinidae (Electric Rays)
Torpedo panthera
Muraenidae (Moray Eels)
Gymnothorax flavimarginatus
Ophichthidae (Snake Eels)
Callechelys marmorata
Synodontidae (Lizardfishes)
Saurida sp.
Synodus sp.
Holocentridae (Squirrelfishes)
Sargocentron spinifer
Syngnathidae (Pipefishes)
Corythoichthys flavofasciatus
Corythoichthys nigripectus
Corythoichthys schultzi
Trachyrhamphus bicoarctatus
Platycephalidae (Flatheads)
Papilloculiceps longiceps
Scorpaenidae (Scorpionfishes)
Scorpaenopsis oxycephalus
Serranidae (Groupers, Anthiases)
Epinephelus fasciatus
Epinephelus fuscoguttatus
Epinephelus tauvina
Cirrhitidae (Hawkfishes)
Cirrhites pinnulatus
Pseudochromidae (Dottybacks)
Peudochromis springeri
Carangidae (Jacks)
Caranx sexfasciatus
Lutjanidae (Snappers)
Lutjanus fulviflamma
Lutjanus monostigma
Sparidae (Seabreams, Porgies)
Acanthopagrus bifasciatus
Kyphosidae (Sea Chubs)
Kyphosus cinerascens
Lethrinidae (Emperors)
Lethrinus borbonicus
Lethrinus mashena
Lethrinus olivaceus
Mullidae (Goatfishes)
Parupeneus cyclostomus
Parupeneus forsskali
Sphyraenidae (Barracudas)
Sphyraena barracuda
Sphyraena flavicauda
Pomacanthidae (Anglefishes)
Pomacanthus asfur
Pomacanthus maculosus
Pomacentridae (Damselfishes)
Dascyllus aruanus
Dascyllus marginatus
Dascyllus trimaculatus
Plectroglyphidodon lacrymatus
Pomacentrus aquilus
Labridae (Wrasses)
Bodianus axillaris
Bodianus diana
Cheilinus mentalis
Cheilinus undulatus
Coris gaimard gaimard
Halichoeres hortulanus
Halichoeres marginatus
Novaculichthys taeniourus
Scaridae (Parrotfishes)
Scarus collana
Scarus ferrugineus
Scarus ghobban
Pinguipedidae (Sandperches)
Parapercis hexophthalma
Blenniidae (Blennies)
Meiacanthus rhinorhynchus
Petroscirtes mitratus
Gobiidae (Gobies)
Bryaninops yongi
Gobiodon citrinus
Acanthuridae (Surgeonfishes)
Acanthurus nigrofuscus
Siganidae (Rabbitfishes)
Siganus stellatus
Ostraciidea (Boxfishes)
Ostracion cubicus
Tetraodontidae (Pufferfishes)
Arothron hispidus
Arothron stellatus
Diodontidae (Porcupinefishes)
Chilomycterus spilostylus
Diodon hystrix

Appendix 4 Soft corals (Alcyoniina group, Stolonifera group) and Hydrozoa (Order: Leptolida) in El Quadim Bay.

Alcyoniina group	Stolonifera group	Leptolida
Alcyoniidae	**Tubiporidae**	**Milleporidae**
Cladiella sp.	*Tubipora musica*	*Millepora dichotoma*
Klyxum sp.		*Millepora exesa*
Rhytisma sp.		*Millepora platyphylla*
Sarcophyton sp.		**Stylasteridae**
Sinularia sp.		*Distichopora violacea*
Nephtheidae		
Dendronephthya sp.		
Lemnalia sp.		
Lithophyton sp.		
Paralemnalia sp.		
Scleronephthya sp.		
Stereonephthya sp.		
Xeniidae		
Anthelia sp.		
Heteroxenia sp.		
Sympodium sp.		
Xenia sp.		

Appendix 5 Scleractinian species of El Quadim Bay (144 total).

Acroporidae
Acropora abrotanoides
Acropora acuminata
Acropora digitifera
Acropora eurystoma
Acropora gemmifera
Acropora grandis
Acropora hyacinthus
Acropora pharaonis
Acropora samoensis
Acropora secale
Acropora selago
Acropora squarrosa
Acropora subulata
Acropora valida
Acropora variolosa
Astreopora gracilis
Astreopora myriophthalma
Astreopora suggesta
Montipora calcarea
Montipora cocosensis
Montipora cryptus
Montipora efflorescens
Montipora informis
Montipora nodosa
Montipora stilosa
Montipora tuberculosa
Montipora turgescens
Montipora verrucosa

Agariciidae
Gardineroseris planulata
Leptoseris explanata
Leptoseris foliosa
Leptoseris incrustans
Leptoseris mycetoseroides
Leptoseris scabra
Leptoseris yabei
Pachyseris speciosa
Pavona danai
Pavona diffluens
Pavona explanulata
Pavona frondifera
Pavona maldivensis
Pavona varians

Astrocoeniidae
Stylocoeniella guentheri

Dendrophyllidae
Turbinaria reniformis

Euphyllidae
Plerogyra sinuosa

Faviidae
Cyphastrea chalcidicum
Cyphastrea microphthalma
Cyphastrea serailia
Echinopora forskaliana
Echinopora fruticulosa
Echinopora gemmacea
Echinopora hirsutissima
Echinopora lamellosa
Erythrastrea flabellata
Favia albidus
Favia danae
Favia favus
Favia lacuna
Favia laxa
Favia maritima
Favia matthai
Favia speciosa
Favia pallida
Favia rotumana
Favia stelligera
Favia veroni
Favites abdita
Favites halicora
Favites paraflexuosa
Favites pentagona
Favites spinosa
Favites vasta
Goniastrea edwardsi
Goniastrea pectinata
Goniastrea peresi
Goniastrea retiformis
Leptastrea bottae
Leptastrea pruinosa
Leptastrea purpurea
Leptastrea transversa
Leptoria phrygia
Montastrea curtas
Oulophyllia crispa
Platygyra acuta
Platygyra carnosus
Platygyra crosslandi
Platygyra daedalea
Platygyra lamellina
Plesiastrea versipora

Fungiidae
Ctenactis crassa
Ctenactis echinata
Fungia fungites
Fungia granulosa
Fungia horrida
Fungia scruposa
Fungie scutaria
Herpolitha limax
Podabacia crustacea

Merulinidae
Hydnophora exesa
Hydnophora microconos
Merulina scheeri

Mussidae
Acanthastrea echinata
Acanthastrea faviaformis
Acanthastrea ishigakiensis
Acanthastrea lordhowensis
Acanthastrea rotundoflora
Blastomussa wellsi
Lobophyllia corymbosa
Lobophyllia hataii
Lobophyllia hemprichii
Symphyllia erythraea

Oculinidae
Galaxea fascicularis

Pectiniidae
Echinophyllia aspera
Echinophyllia orpheensis
Mycedium elephantotus
Oxypora convoluta
Oxypora crassispinosa
Oxypora lacera

Pocilloporidae
Pocillopora damicornis
Pocillopora eydouxi
Pocillopora verrucosa
Seriatopora caliendrum
Seriatopora hystrix
Stylophora danae
Stylophora mamillata
Stylophora pistillata
Stylophora subseriata
Stylophora wellsi

Poritidae
Alveopora viridis
Goniopora ciliatus
Goniopora columna
Goniopora savignyi
Goniopora somaliensis
Porites columnaris
Porites harrisoni
Porites lobata
Porites lutea
Porites nodifera
Porites rus
Porites solida

Siderastreiidae
Coscinerea columna
Coscinarea monile
Psammocora haimeana
Siderastrea savignyana

Appendix 6 Diversity of scleractinian corals, sorted by genera, of the El Quadim Bay in comparison to the entire Red Sea (after Veron, 2000).

Family	Genus	Diversity of scleractinia for the Red Sea	Diversity of scleractinia for El Quadim Bay
Acroporidae	*Acropora*	47	15
	Anacropora	2	0
	Astreopora	5	3
	Montipora	29	10
Agariciidae	*Gardineroseris*	1	1
	Leptoseris	7	6
	Pachyseris	2	1
	Pavona	12	6
Astrocoeniidae	*Stylocoeniella*	2	1
Dendrophyllidae	*Heteropsammia*	1	0
	Turbinaria	6	1
Euphyllidae	*Euphyllia*	1	0
	Plerogyra	1	1
	Physogyra	1	0
Faviidae	*Barabattoia*	1	0
	Caulastrea	2	0
	Cyphastrea	4	3
	Diploastrea	1	0
	Echinopora	7	5
	Erythrastrea	1	1
	Favia	15	12
	Favites	10	6
	Goniastrea	7	4
	Leptastrea	5	4
	Leptoria	1	1
	Montastrea	3	1
	Oulophyllia	1	1
	Platygyra	6	5
	Plesiastrea	1	1
Fungiidae	*Cantharellus*	2	0
	Ctenactis	2	2
	Cycloseris	7	0
	Diaseris	2	0
	Fungia	12	5
	Herpolitha	2	1
	Podabacia	2	1
	Sandolitha	1	0
Meandrinidae	*Gyrosmillia*	1	0
Merulinidae	*Hydnophora*	2	2
	Merulina	2	1
Mussidae	*Acanthastrea*	6	5
	Blastomussa	2	1
	Cynarina	1	0
	Lobophyllia	4	3
	Symphyllia	4	1
Oculinidae	*Galaxea*	2	1
Pectiniidae	*Echinophyllia*	3	2
	Mycedium	2	1
	Oxypora	4	3
Pocilloporidae	*Pocillopora*	3	3
	Seriatopora	2	2
	Stylophora	6	5
Poritidae	*Alveopora*	8	1
	Goniopora	13	4
	Porites	14	7
Siderastreidae	*Coscinarea*	3	2
	Psammocora	6	1
	Pseudosiderastrea	1	0
	Siderastrea	1	1
Trachyphyllidae	*Trachyphyllia*	1	0
Scleractinian coral diversity (total)		303	144

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