DIPLOMARBEIT

Titel der Diplomarbeit

A snorkel trail based on reef condition and visitor perception as a management tool for a threatened shallow water reef in Dahab (South Sinai, Egypt)

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1 Einleitung

Seit jeher üben Korallenriffe mit ihrer Farben- und Formenpracht eine gewisse Faszination auf Menschen aus. Das Wort Koralle selbst ist ein sehr Altes und hat seinen Ursprung bei den Kelten. Besonders von Bewohnern gemäßigter und nördlicher Breiten werden Korallenriffe gerne mit Urlaubsträumen von paradiesischen Palmeninseln inmitten türkisfarbenen Wassers in Verbindung gebracht. Oft bleibt jedoch unklar, was genau ein Korallenriff ist und wie dieses höchst komplexe Ökosystem funktioniert.

Ein Riff ist laut Definition: „ eine maßgeblich von lebenden Organismen aufgebaute, meist bankförmige Struktur, die vom Meeresboden bis zur Wasseroberfläche reicht und so groß ist, dass sie erheblich die physikalischen und ökologischen Eigenschaften ihrer Umgebung beeinflusst. Ihre Konsistenz ist hinreichend fest, den anbrandenden Wasserkräften zu widerstehen und damit einen vieljährigen, charakteristischen Raum für spezifisch angepasste Bewohner zu bilden." (Schuhmacher, 1976)

Korallen besitzen die Fähigkeit Kalzium-Ionen und Kohlendioxid aus dem umgebenden Wasser aufzunehmen und unter Energieaufwand Kalkskelette zu bilden, wodurch es einigen Vertretern ermöglicht ist in weiterer Folge unter passenden Bedingungen massive Riffe wie das Große Barriereriff Australiens aufzubauen, welches sich aus mehreren Einzelriffen zu einer Gesamtfläche von 200 000km² zusammensetzt. Fossile Überreste früherer Korallenriffe bilden heutige Gebirge von mehreren 1000m Höhe wie z.B. Dolomiten und Dachstein. Die meisten hermatypischen (riffbildenden) Korallen gehören der Ordnung Scleractinia (Steinkorallen) an, innerhalb der Klasse Anthozoa (Blumentiere) aus dem Stamm der Cnidaria (Nesseltiere) der Unterabteilung Coelenterata (Hohltiere) aus dem Reich Animalia (Tiere). Generell zeichnen sich hermatypische Korallen durch eine Endosymbiose mit einzelligen Algen der Gattung Symbiodinium/Gymnodinium (Zooxanthellea) aus. Die Photosynthese betreibenden Zooxanthellen leben in den Entodermzellen der Korallen und stehen in regem Stoffaustausch mit diesen wobei die Algen Assimilationsprodukte (Zucker, Glycerin, Aminosäuren) spenden und Kohlendioxid, Phosphat- und Stickstoffhaltige Stoffwechselprodukte der Koralle entziehen (Schuhmacher, 1976). Symbiotisch lebende Korallen haben daher eine zusätzliche Nahrungsquelle in nährstoffarmen Gewässern und die erhöhte Fähigkeit Kalziumkarbonat abzuscheiden (Wilkinson und Buddemeier, 1994). Gegenüber asymbiotischen Korallen ein klarer Vorteil mit bis zu zehnfachen Kalzifikationsraten. Auch andere Riffbewohner wie z.B. die zu der Klasse der Hydrozoa gehörenden Millepora-Arten (Feuerkorallen) besitzen Zooxanthellen und bilden massive Kalkskelette. Das Grundgerüst des Riffs wird also von hermatypischen Korallen gebildet.

Andere kalkbildende oder kalkbindende Organismen, wie Kalkalgen, Foraminiferen, Mollusken, Bryozoen und Polychäten ergänzen dieses Gerüst und verkitten Zwischenräume zu einer stabilen Struktur. Somit wird ein dreidimensionaler vielgestaltiger Lebensraum für unzählige Arten geschaffen (Reaka-Kudla, 1997).

Korallenriffe kommen global innerhalb der 20°C - Isochryme (Linie gleicher winterlicher Temperaturmittelwerte) in nährstoffarmen klaren Meeren vor. Dennoch zählen sie, ähnlich wie die tropischen Regenwälder, zu den artenreichsten und produktivsten Lebensräumen der Erde. Die tatsächliche Artenzahl ist unbekannt, aber Schätzungen sprechen von 3 bis 9 Millionen Arten, die Korallenriffe bewohnen, ungeachtet der unzähligen Mikroorganismen (Reaka-Kudla, 1997). Deutlicher wird die große Diversität wenn man bedenkt, dass Korallenriffe nur 0,2% der Marinen Böden bedecken, jedoch ein Viertel der weltweit bekannten Fischarten beheimaten von welchen viele ausschließlich an Korallenriffen vorkommen (Roberts, 2003). Allein am Golf von Aqaba wurden bisher 47 Gattungen und 120 Arten von riffbildenden Korallen gezählt (Cesar, 2003). Die an Riffe angrenzenden Lebensräume, wie Lagunen und Mangrovenwälder, fungieren als Kinderstube und Futtergründe für Fische und viele andere Organismen (Reaka-Kudla, 1997). Als Grund für eine derartige Mannigfaltigkeit der Arten kann laut „intermediate disturbance hypothesis“ das Auftreten von Störungen in mittleren Zeitabständen und Intensitäten sein (Connell, 1978). Natürliche Störungen gleichen eher pulsierenden Störungen mit einer charakteristischen Magnitude und Frequenz (z.B. Hurrikans, Extremebben und Temperaturschwankungen). Menschliche Aktivitäten neigen dazu chronische Störungen im Hintergrund zu generieren oder jene pulsierenden Störungen in chronische Störungen zu transformieren und erzeugen so zusammengesetzte Störungen. Diese zusätzliche chronische Belastung durch anthropogene Aktivitäten führt zu kontinuierlichen Stress für Korallen und dazu, dass sich das System nach Events wie z.B. Niedrigebben oder Stürmen nicht mehr erholen kann (Nyström et al., 2000). Auch durch den Biodiversitätsverlust in funktionellen Gruppen eines Ökosystems (z.B. durch Überfischung) kommt es zur Degradierung von Ökosystemen, da die Fähigkeiten, sich zu erholen und zu reorganisieren mit der Zahl der Arten innerhalb einer funktionellen Gruppe steigt (Elmqvist et al., 2003). Auf veränderte Umweltbedingungen scheinen Riffe eher zwischen alternierenden stabilen Stadien zu wechseln als auf sanftem kontinuierlichem Weg zu reagieren (Scheffer et al., 2001). So kommt es, dass weltweit letztendlich viele der einst diversen intakten Korallenriffe gänzlich von Makroalgen überwuchert sind. Korallenbleichen, ausgelöst von zu hohen Wassertemperaturen über einen kritischen Zeitraum, sind ausgezeichnet durch den Verlust der symbiotischen Algen, welche Nährstoffe liefern und

Kalzifikationsraten erhöhen. Diese Korallenbleichen treten seit Jahrzehnten in fortlaufend kürzeren Abständen auf und können somit die Erholungsphasen von Riffen nach diesen Events beeinträchtigen (Meesters und Bak, 1993; Grimsditch und Slam, 2006; Schuttenberg, 2001; Westmacott et al., 2000). Durch den Verlust and herbivoren Weidern (durch Überfischung, Verschmutzung und Krankheiten) können sich Makroalgen nach Störungen wie z.B. Korallenbleichen oder Hurrikans ausbreiten und die Korallen überwachsen (Ledlie et al., 2007). Die Makroalgen ihrerseits verhindern das Neuansiedeln von Korallenlarven und sind nach erreichen einer bestimmten Gösse für Herbivore nicht mehr so genießbar. Somit ist dieser degradierte Zustand des Ökosystems relativ stabil (Scheffer et al., 2001).
Bereits 30% der Riffe weltweit sind zerstört und Prognosen sprechen von dem Verschwinden von 60% aller Riffe bis 2030 (Wilkinson, 2002). Zu den größten Anthropogenen Bedrohungen zählen Überfischung, Verschmutzung, Sedimentation, Eutrophierung durch ungeklärte Abwässer und Tourismus (Birkeland, 1997; Westmacott, 2000). Auch die globale Klimaerwärmung, der Anstieg des Meeresspiegels, der Anstieg der Oberflächentemperaturen, Übersäuerung, Korallenkrankheiten und das Massenauftreten von Korallen fressenden Organismen (z.b. *Acanthastar* und *Drupella*) stellen eine Globale Bedrohung für Riffe dar (Westmacott, 2000). Mit stetiger Zunahme an Belastungen und Ausbeutung durch die Menschheit wird ohne prompte und massive Maßnahmen das Ökosystem Korallenriff im Laufe der nächsten Jahrzehnte zu Grunde gehen (Pandolfi et al., 2003).
Für die Menschheit stellen Korallenriffe neben ihrer ökologischen Bedeutung auch eine essentielle Nahrungsquelle dar. In manchen Ländern wird ein Viertel der gesamten Nahrung und 60% des gesamten Proteinbedarfs von Korallenriffen zur Verfügung gestellt. In Ägypten leben mehr als 20% der Bevölkerung an der Küste und fast 40% der industriellen Entwicklungen konzentrieren sich entlang der Küsten (Cesar, 2003). Weiters dienen Korallenriffe als Wellenbrecher der Sicherung von Küstenlinien und stellen wichtige Ressourcen für Umweltbezogenen Tourismus dar. Weltweit wurde dieser ökonomische Wert von Korallenriffen auf 375 Milliarden US$ jährlich geschätzt (Costanza et al., 1997).
Das Rote Meer ist ein langer schmaler Trog, der eine Tiefe von bis zu 2600m erreicht. Es ist über eine relative seichte (c.a.150m) Schwelle an der Strasse von Bab El Mandeb mit dem Indischen Ozean verbunden wodurch es nur in den oberen Schichten zu einem Wasseraustausch kommt. Der Golf von Aqaba, der nordöstliche Nebenarm des Roten Meeres, ist ebenfalls ein tief eingeschnittener Meeresgraben (bis zu 1830m) und ebenfalls durch eine Schwelle bei der Strasse von Tiran vom Roten Meer weitgehend isoliert. Obwohl die meisten Organismen die gleichen wie im Indischen Ozean sind, haben sich eine Vielzahl endemischer

Arten, d.h. nur im Roten Meer bzw. Golf von Aqaba vorkommend, entwickelt. Durch die umliegenden ausgedehnten Wüstengebiete kommt es zu hoher Verdunstung mit geringem Süßwassereintrag, was zu einem erhöhten Salzgehalt von bis zu 42 ‰ führt. Die Saumriffe des Roten Meeres und seines Nebenarmes bilden nach den Bermudariffen im Atlantik und den Ryukuriffen südlich von Japan das nördlichste Korallenriffvorkommen (bis 29°30'N) (Schuhmacher, 1976). Die kontinuierliche windgetriebene Umwälzung der oligotrophen (nährstoffarmen) Wassersäule sorgt für einen stabilen Wärmehaushalt, der die Oberflächentemperatur gegenüber der stark saisonal schwankenden Lufttemperatur ausgleicht (bei ungefähr 28°C in Sommer und 20°C im Winter) (El-Alwany, 2007). Bedingt durch seine besonderen topographischen und hydrographischen Eigenschaften stellt die gesamte Riffprovinz des Roten Meeres ausgesprochen günstige Bedingungen für ein Korallenriffwachstum auch nördlich des Krebs-Wendekreises zur Verfügung (Schuhmacher, 1976).

Die Globale Klimaerwärmung, eine der weltweit größten Bedrohungen der Korallenriffe, hatte bisher aufgrund des stabilisierenden Wärmehaushaltes des Roten Meeres keine massive Korallenbleiche zur Folge (Westmacott et al., 2000). Die größte Bedrohung der Korallenriffe Ägyptens stellt der Tourismus und die Fischerei dar (Cesar, 2003). Trotz des generell guten Zustandes der Riffe Ägyptens wurde in den letzten Jahrzehnten ein signifikanter Rückgang der Korallenbedeckung mit einem Anstieg an Korallenbrüchen im Roten Meer und Golf von Aqaba verzeichnet. Dieser Trend ist eng mit dem schnellen Wachstum des Küstenbezogenen Tourismus korreliert (Maragos et al., 1996). Allein am südlichen Sinai wurde im Zuge einer Marktforschung ein Wachstum des ausländischen Tourismus von 42% pro Jahr verzeichnet, mit besonderer Konzentration der Entwicklung auf Sharm El-Seikh, gefolgt von Dahab und Nuweiba. 30-40% der Wassersportbetreibenden Touristen waren Schnorchler (PERSGA, 2001). Aufgrund dessen und der Einzigartigkeit vieler Organismen dieser Meeresprovinz, sollte besondere Aufmerksamkeit dem Schutz dieser diversen und reichhaltigen Fauna und Flora gewidmet werden (BCCBE, 2007).

Es gibt keine genauen Aufzeichnungen über das Ausmaß der Fischerei und Überfischung in Ägypten, jedoch wird berichtet, dass 44% des marinen Fischfangs Korallenriff-bezogen sind (Pilcher und Abou Zaid, 2000). Weiters gibt es Reporte über eine generelle Abnahme an Körpergrößegröße und Häufigkeit der Fische als auch Berichte von Wilderei in „No-Take"-Zonen (Cesar, 2003). Der Bevölkerungszuwachs und Tourismusboom lässt erwarten, dass die Nachfrage an Fisch weiter ansteigt. Tatsächlich beabsichtigt der „General Authority for Fish Resources Development (GAFRD) des Landwirtschaftsministeriums den gesamten Fischfang

von durchschnittlich 36 tausend Tonnen der 90er Jahre auf 70 tausend Tonnen bis zum Jahr 2017 zu steigern (Pilcher und Abou Zaid, 2000).
Es gibt berichte über Ressourcen vernichtende Fischereimethoden an den Küsten Ägyptens (BCCBE, 2007; Cesar, 2003), wobei z.B. Fischer über das Riffdach trampeln und Ihre Netze über die Korallen ziehen. So können große Schäden, besonders an verzweigten Korallen, entstehen und darüber hinaus Schlüsselarten aus dem Ökosystem Korallenriff entfernt werden (Saila et al., 1993). Durch direkte physikalische Kontakte der Wassersportbetreibenden mit Korallen kommt es zu Bruch und Gewebeschäden und in Folge einer Degradierung der Riffe. Zu solch schädigenden Aktivitäten zählen: Stehen und Gehen am Riffdach; Direkter Kontakt mit Flossen und anderen Ausrüstungsteilen, Aufwirbelung von Sediment und indirekt durch Ankerschäden verursacht von Tagesausflugsbooten (Chabanet et al., 2005; Hawkins und Roberts, 1993; Rogers und Cox, 2003). Das Ausmaß des Schadens ist stark mit der zahl der Taucher bzw. Schnorchler korreliert (Hawkins und Roberts, 1993; Rodgers und Cox, 2003). Der so verursachte anthropogene kontinuierliche Stress führt wie bereits oben erwähnt dazu, dass sich das Ökosystem nach pulsierenden Störungen, wie z.B. Extremebben, Acanthaster-Plagen oder Stürmen nicht erholen kann und zusammenbricht (Nysröm et al., 2000).
Die IUCN definiert Ökotourismus als umweltbewusstes Reisen zu relativ ungestörten natürlichen Arealen mit dem Ziel, die Natur zu genießen, zu studieren und zu erhalten (und alle begleitenden kulturellen Merkmale der Vergangenheit und Gegenwart). Darüber hinaus als Tourismus, der den Naturschutz fördert, geringe negative Auswirkungen durch die Besucher verzeichnet und die örtliche Bevölkerung im Zuge nützlicher sozioökonomischer Projekte einbezieht (BCCBE, 2007).
Zu den nötigen Maßnahmen für einen nachhaltigen riffbezogenen Tourismus am Sinai zählen: Die Limitierung der Besucherzahlen, Schutz von besonders sensiblen Arealen, Verlagerung der Schaden verursachenden Aktivitäten auf weniger störanfällige Gebiete, Förderung von Umweltbewusstsein und Respekt durch Fortbildung im riffökologischen Bereich sowohl für Besucher als auch für Guides und die örtliche Bevölkerung und das Verbot von Ressourcen vernichtenden Fischereimethoden. Eine Möglichkeit diese Maßnahmen umzusetzen ist das errichten von Umweltlehrpfaden (Lang und Stark, 2000; Harriott, 2002; Thorsell und Wells, 1991).
In dieser Studie soll einerseits der aktuelle Zustand (Bruchschäden und partielle Mortalitätsraten) und Charakteristiken (Tiefe, Substrat und Zusammensetzung der Korallengesellschaft) eines durch Schnorcheltourismus und Fischerei bedrohten Seichtwasser-Korallenriffes beschrieben und andererseits die sozioökonomischen Eigenschaften und

Anforderungen der Besucher und Riffnutzer Dahab's mittels standardisierter Fragebögen (nach Heinisch, 2006; Huxham und Tett, 2005) erfasst werden. Dabei werden auch Informationen über die vorherrschende Riffnutzung eingeholt (Art, Frequenz und Ort des Auftretens) (nach Bunce et al., 2000). Ziel ist es, den Plan für einen Unterwasserlehrpfad für Schnorchler als Management-Maßnahme für ein intensiv genutztes Seichtwasserriff nördlich des „Napoleon-Riffs" nahe der „Lagune" in Dahab zu liefern.

2 Abstract

Coastal tourism in the South Sinai, especially in Sharm El-Sheikh, followed by Dahab and Nuweiba, has experienced a growth of 42% per year (PERSGA, 2001) whereby an increasing number of visitors are snorkelers (40% in 2003). This study investigated the ecological impact of snorkelers visiting a shallow water reef at the outside of the 'Lagoon' in Dahab. The results are used to frame a plan for an underwater nature snorkelling trail as a reef management tool in this area. Benthic communities, hard coral cover, partial mortality and breakage frequencies of branching hard corals were examined using the point intercept sampling method on the reef flat (0.5m water depth) and back reef (1.0m water depth). In the area where most snorkelers occurred, branching growth forms were in the absolute majority of hard corals with 76.2% of 122 colonies in total. On the back reef, 81% of the broken colonies were branching species. Partial mortality frequency was found in 50% of *Acropora*, 80% of *Millepora* and *Stylophora* and 90% of *Pocillopora* colonies. In addition standardized questionnaires helped to determine visitor's socioeconomic and personal characteristics, requirements and perceptions about further education in reef ecology and skill training related to snorkelling, SCUBA-diving and visiting a reef nature trail in Dahab. 'Nature' (96.5%) was by far the highest motivation for snorkelling and diving. The sorkel- and dive-experience in tropical seas was relative low (48.7% snorkelling beginners, 15.1% novice SCUBA-divers, 27.7% divers at an Open-Water certification level). The interest in further education about reef ecology and skill training was high, and respondents were willing to pay appropriate fees for a guided snorkel trip at an underwater nature trail (62.8% were prepared to pay more than 10€). The less experienced snorkelers and divers who formed the target group for further information and education about reef ecology, threats to the reef and skill training, were also the ones most prepared to financially support such a management project and therefore form an important source of income. The heavy impact on the shallow water reef, mostly caused by snorkelers and local fishermen, and the high interest in nature amongst the respondents, highlight the need for management action. Two strategies include implementing a reef nature trail at the back reef,

restricting the recreational use to the nature trail and less sensitive areas while protecting the shallow reef flat, excluding destructive fishing and recreational use.
The nature trail at the back reef can be used as 'Ecotourism Zone', where access is restricted to small groups of snorkelers led by certified tour guides. Impacts, like physical contact and sediment resuspension, would be minimized by requiring that all guides provide prior briefings and skill training. In addition artificial structures can complete the trail and offer the possibility to switch to deeper areas when the circumstances do not allow snorkelling along the natural back reef (i.e. during low tide).

3 Introduction

Coral reefs are amongst the biologically most productive and diverse ecosystems on earth, supplying millions of people with economic and environmental services (Moberg and Folke, 1999). Coral reefs have been estimated to provide net benefits of US$ 30 billion per year to world economies including tourism, fisheries and coastal protection (Cesar et al., 2003). Yet coral reefs are declining worldwide due to various threats including human activities and global warming (Pandolfi et al., 2003). On a global scale, already 27% of the world's coral reefs are permanently lost; if current trends continue, a further 30% are at risk to disappear (Cesar et al., 2003). In the Caribbean, Mora (2007) reported that human impacts in general (e.g. coastal development and human population density) showed the strongest negative effects on coral reefs at both small and large geographical scales.
According to the Biodiversity Conservation Capacity Building in Egypt (BCCBE, 2007) more than 8 million tourists visit Egypt annually while coastal tourism is the largest sub-sector within the Egyptian tourism market. This massive and fast-growing nature-based coastal tourism industry contributes significantly to national income and depends largely on intact reefs (BCCBE, 2007). Market-demand studies for the South Sinai show that development has concentrated on Sharm El-Sheikh followed by Dahab and Nuweiba: foreign tourism has grown 42% per year (PERSGA, 2001), whereby snorkellers make up 30 - 40% of recreational water sport tourists (Cesar, 2003).
The status of reefs in the Red Sea and Gulf of Aqaba is generally good, with an average of live coral cover of 20 - 50%, a positive ratio of live to dead coral cover, and high species diversity (Kotb et al., 2004). The highest live coral cover is found along reef crests (12 - 82%) and reef slopes, while values in the reef flat areas range from 11 - 35% (Cesar, 2003). Coral

cover in the Egyptian Red Sea has declined by over 30% over the last decades, showing a significant increase of broken and damaged corals (Jameson et al., 1999). This trend is closely related to the rapid growth of the tourism industry along the Red Sea coast and Sinai (Elrafie, 2007; Ibrahim and Ibrahim, 2006). This industry, along with destructive fishing methods and coastal development, appears to be by far the greatest threat to coral reefs in Egypt (BCCBE, 2007; Cesar, 2003). Coral bleaching, on the other hand, which is one of the major global threats to coral reefs, has little effect in this area: the sea surface temperature varies between 26.7°C (July) and 20.8°C (March), well below the temperatures that cause bleaching elsewhere (El Alwany, 2007).

Direct human impacts on coral reefs caused by divers or snorkelers include trampling, fin contact, standing on corals and resuspension of sediment (Chabanet et al., 2005). These cause physical damage and lead to a level of reef degradation that corresponds with the number of visitors (Hawkins and Roberts, 1993; Riegl and Velimirov, 1991; Rodgers and Cox, 2003). Even a low level of such chronic stress can hamper the recovery process after additional natural disturbances such as extreme low tide events (Nyström et al., 2000).

Coral communities differ in their susceptibility to recreational impacts, depending on their growth form (Riegl et al., 1996; Rogers, 1990) and species composition. Communities of the coral genus *Acropora* in shallow water reefs were found to be the most fragile (Riegl and Cook, 1995), and coral species on the outer reef flat are more susceptible to physical damage by trampling than reef crest species.

Diver carrying capacities play an important role in the management of physical damage in coral reefs (Jameson et al., 1999). Recent studies about the ecological carrying capacity of coral reefs report between 4,000 and 15,000 dives per site per year (Jameson et al., 1999; Davies and Tisdell, 1995; Cesar, 2003). Socioeconomic conditions, deduced from user attitudes and perceptions about reef health and crowding turned out to be as important indicators as the actual impacts that diving, snorkelling and other activities have on coral reefs for quantifications and predictions of impacts. Leujak and Ormond (2007) showed that the social carrying capacity – e.g. a level of visitors that avoids a decline in attractiveness of the environment or avoids crowding – provides also a useful tool for sustainable management of coastal tourism. Medio et al. (1997), based on research conducted with divers in Ras Mohammed National Park in the Red Sea, suggested that an “Environmental Briefing” for divers is essential to reduce diver-related damage. The authors urged that more educational strategies should be implemented near dive sites. Other studies in other regions reported similar results (Hawkins and Roberts, 1992; Tratalos and Austin, 2001; Zakai et al., 2002).

Furthermore, improving diver and snorkeler skills and knowledge about potential and actual threats to the reef may be a tool to lead people to environmentally responsible behaviour (Rouphael and Inglis, 2001). Damage caused by snorkelers is considered to be limited to shallow water areas where snorkelers can stand on or kick coral (Plathong et al., 2000; Rogers, 1990). Fewer studies have been performed on snorkelers than on scuba divers, though snorkelling has been reported to be a potential threat especially to shallow water reefs (Allison, 1996; Harriott, 2002; Riegl and Velimirov, 1994).

Snorkelling trails have been proposed as a way to give tourists an understanding of the marine environment and to restrict impacts of snorkelers to defined areas (Harriott, 2002). A main attraction at the U.S. Virgin Islands (Caribbean), for example, is a snorkelling trail established in 1958: nearly 90% of the 50,000 annual visitors use it (Thorsell and Wells, 1991).

Several other studies recommend managing snorkel impacts by protecting more sensitive reef areas dominated by fragile branching coral communities (Harriott, 2002; BCCBE, 2007). This approach involves defining 'Resistant Zones' for intensive use, relatively sensitive 'Ecotourism Zones' for limited use under well-defined circumstances and 'Sensitive Zones' that are closed for recreational use (Roman et al., 2007). Plathong et al. (2000) examined the effects of snorkel trails in the Central Section of the Great Barrier Reef Marine Park. After the initial one-month period, in which coral damage especially around interpretive signs increased, the amount of coral damage stabilised. The authors suggest that short briefings, careful site selection, establishment of floating stations to hold on and rest, floating vests and periodic rotation of trails are useful management strategies. Another recommendation is to restrict snorkelling to clearly defined pathways that are deep enough (> 2m deep) so that snorkelers could not stand on or kick corals (Allison, 1996). Another way to reduce coral damage is environmental interpretation programmes. They provide visitors with information about marine nature and potential threats (Madin and Fenton, 2004). A study in Ras Mohammed National Park and at Sharm El-Sheikh, Red Sea (Leujak and Ormond, 2007), showed that socioeconomic indicators such as user attitudes, nationalities, diving or snorkel experience and skills and knowledge about reef ecology can establish another baseline on reef condition than that determined by biological research. Therefore the perception and satisfaction of visitors about reef condition and health is related to the visitor's previous knowledge, nationality and experience. This research also showed that, in the area of Sharm El-Sheikh, there has been a shift from experienced snorkelers and divers to less or non-experienced visitors with lesser knowledge about reef ecology. This was accompanied by a

shift in the predominant nationalities from German and British to Italian and Russian (Leujak and Ormond, 2007).
In the Gulf of Aqaba, adjacent to the lagoon at Dahab, a well-developed shallow water reef is extensively used by an increasing amount of snorkelers and fishermen. The present study was performed to supply detailed information about the current reef condition. It also yielded a defined plan for an underwater nature trail and provided a basis for further management actions.

4 Material and Methods

4.1 Study area

The field study was conducted between July and October 2007 and in March 2008 at Dahab (28°28' N, 34°30' E), in the southern Gulf of Aqaba, northern Red Sea (Sinai, Egypt). The fieldwork was done in cooperation with master student S. Kompatscher, who investigated the current biological reef condition in a more extensive area. The present study focused on socio-economic surveys and on ecological surveys of the sub-area that appeared to be most intensively used by snorkelers (Fig. 1).
The selected study site, ranging between 400 m and 700 m north of the 'Napoleon Reef', has no common name because it has not previously been used as commercial dive site or snorkel spot. It is, however, now a popular and frequently visited spot amongst snorkel tourists from Dahab and Sharm El-Sheikh, wind surfers and local fishermen.
The fringing reef north of the 'Napoleon Reef' is approximately 200m wide and at its south end it is separated by a small coastal channel from the shore. On the reef flat the coral cover increases towards the wind- and wave-exposed reef edge. The outer reef slope plunges steeply to more than 10 m depth, with high to moderate coral cover (El Alwany, 2007). Compared to the wind- and wave-exposed outer reef edge, the edge bordering the 'Lagoon' is more sheltered and lined with coral pinnacles, followed by a smooth sandy slope towards the 'Lagoon'. Tides are semidiurnal and depths fluctuate at spring tide in a range of 1.0 m and at nip tide in a range of 0.5 m.

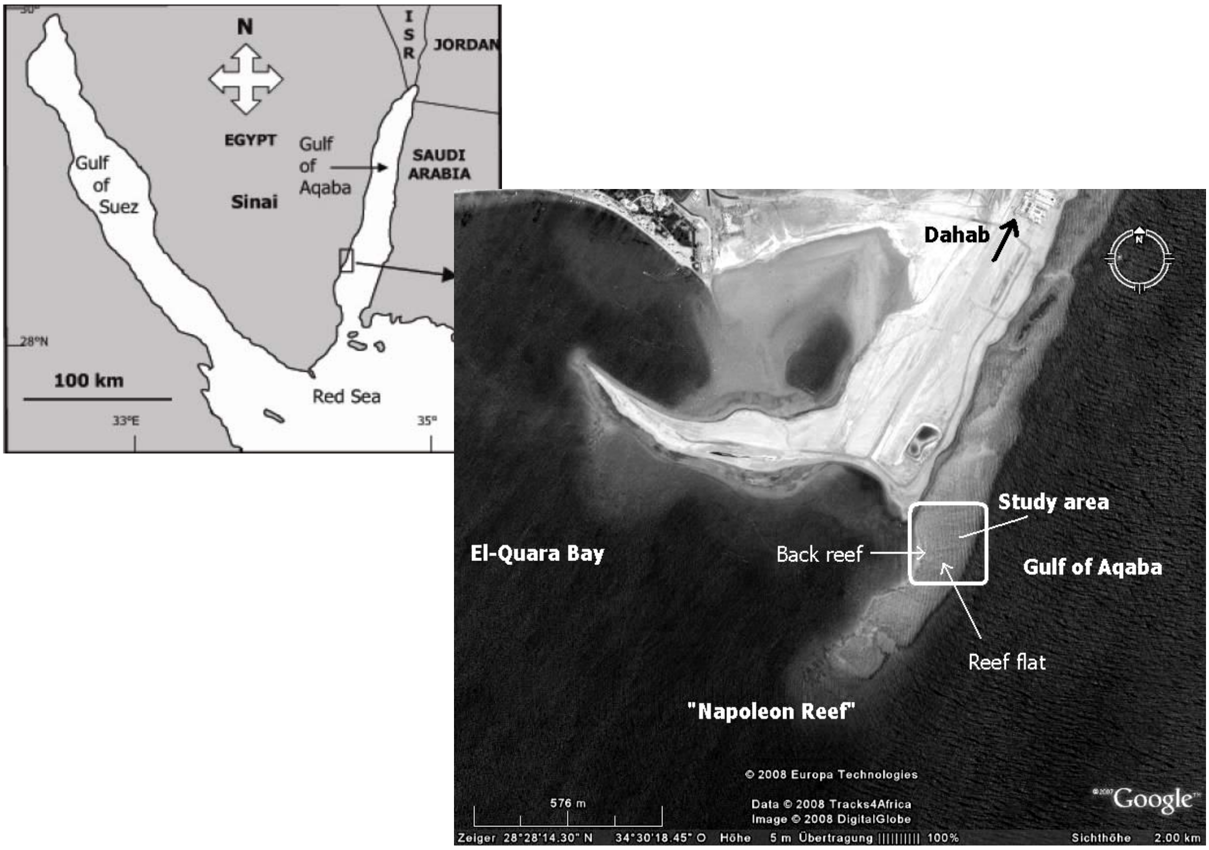

Figure 1. Study area north of the 'Napoleon Reef' in Dahab, Egypt, Gulf of Aqaba (28°28'N, 34°30'E).

4.2 Ecological surveys

4.2.1 Sampling design

All field work was done by snorkelling. Six line transects (á 50m) were positioned in the area of the back reef facing the 'Lagoon'. This area appeared to be visited frequently by snorkelers and swimmers and at the same time appeared suitable for implementing a reef nature trail.

4.2.2 Benthic community analysis

Benthic communities were sampled using the linear point intercept method. The substrate was recorded every 100 cm beneath the transect line. Living substrate was classified as hard coral (HC), soft coral (SC) and macroalgae (AL). In addition, living hard coral was identified to species level for the most common genus *Acropora* and to genus level for others via digital macro-photographs made of coral colonies. Hard corals were assigned to different growth-forms (after Veron, 2002) and pooled into four major categories (branching, massive, foliaceous and encrusting (after Hughes, 1987). Branching, tabular and plate-like *Acropora* growth forms were pooled into one category termed branching (after Riegl and Cook, 1995). Partial mortality (PM) and broken coral colonies (BCC) of each colony were estimated in 25% intervals, solely for branching and foliaceous growth forms, as those are the most vulnerable to breakage and trampling. The estimation of PM of other growth forms, like massive, free living or encrusting, showed strong observer-bias and therefore were rejected. This ultimately yielded six classes: No damage (0), ≤ 25% damage (1), ≤ 50% damage (2), ≤ 75% damage (3), ≥ 75% damage (4) and 100% dead (5). Living pieces of branching corals were classified as broken coral fragments (BCF), and dead coral colonies overgrown by algae were designated as DCA. For further analysis of the benthic community, recently killed coral and DCA were pooled to dead coral (DC). Other non-living substrates were classified as coral rock (CR), coral rubble (RB – loose hard coral fragments), sand (SD) and rubbish (RU) (Table 1 and Table 2).

Table 1. Substrate categories used in the benthic community analysis; including abbreviations (Abbr.) used in following tables and graphs.

Living Substrate	Abbr.	Non-living substrate	Abbr.
Hard coral	HC	Dead coral with algae	DCA
Soft coral	SC	Dead coral	DC
Algae	AL	Sand	SD
Partial mortality	PM	Coral rubble	RB
Broken coral colony	BCC	Rubbish	RU
Broken coral fragment	BCF	Coral rock	CR

Table 2. Twelve investigated *Acropora* taxa.

Species	Species
A. acuminata (Verrill, 1864)	*A. samoensis (*Brook, 1891)
A. digitifera (Dana, 1846)	*A. secale* (Struder, 1878)
A. eurystoma (Klunzinger, 1879)	*A. selago* (Struder, 1878)
A. gemmifera (Brook, 1892)	*A. subulata* (Dana, 1846)
A. hyacinthus (Dana, 1846)	*A. variolosa* (Klunzinger, 1879)
A. loripes (Brook, 1892)	*A. pharaonis* (Milne-Edwards&Haime, 1860)

4.2.3 Physical parameters

Depth on the reef flat and the sandy slope towards the lagoon was measured with a diving computer (0.1m accuracy) and the specific coordinates were determined by a hand-held GPS. Measured depth and tidal fluctuations were gauged using WX-Tide32. Temperature was measured every 10 min over a period of seven months (October to April) on two spots on the reef flat (28°28'13.6“N, 34°30'29.8“E; 28°28'11.7”N, 34°30'34.6”E) using ‘HOBO Pro V2 Temperature Loggers’ hidden in hard coral blocks.

4.3 Socioeconomic surveys

Standardised questionnaires and interviews with tourists, local dive leaders and members of the Bedouin community helped to determine socioeconomic and personal characteristics. Respondents were asked about their requirements and perceptions about further education in reef ecology and skill training, related to snorkelling, SCUBA-diving and visiting a reef nature trail in Dahab, Egypt. Between July and October 2007, 365 self-administered questionnaires were collected from 318 visitors and 47 staff-members of 29 dive centres in Dahab. Questionnaires were available in 7 different languages (English, German, Dutch, Italian, Spanish, French and Russian). Translations were provided by native speakers. Back translations were not necessary as respondents communicated their viewpoint through marking appropriate boxes. Questionnaires were either handed out on a one-to-one basis, with the interviewer waiting for the respondents to fill out the five pages, or they were given to the manager or staff of the dive centre, who informed the involved persons about the matter and procedure of distribution, and collected later.

4.3.1 Questionnaire construction

Respondents were asked 64 questions (Annex 4) subdivided into four sections on the following topics (after Huxham, 2005, Heinisch, 2006):

The first section consisted of 10 general questions about demographic characteristics (age, sex and nationality), snorkel proficiency (beginner or advanced) and diver-certification level: Open Water Diver (OWD), Advanced/Rescue Diver (AOWD) and Dive Master/Instructor.

The second and third sections contained 28 Likert-scaled questions with first-person statements depicting differing viewpoints on a four-point scale (totally agree, agree, disagree or fully disagree). Respondents were asked to indicate the number on the scale which best represented their own viewpoint.

Questions of the second section helped to distinguish the respondent's motivation for snorkelling/diving (sporting experience, natural experience, recreation, adventure, social contact i.e. family and friends or meeting people), perceptions about further environmental education, skill training and briefings in proper behaviour related to visiting a reef nature trail. Furthermore, respondents were asked to depict the role of environmental education during their diver education on a three point-scale (major, minor or irrelevant).

In the third section, respondents were asked about their desire for each of 10 different facilities at a snorkel site (sanitary, sunshades, snack bar, rental of snorkel equipment, snorkelling lessons, bar, children's playground, sunbathing, lifeguard and first aid). Moreover,

respondents were asked to choose one out of five price categories they would consider paying for a guided trip on a reef nature trail (<10€, 11-20€, 21-30€, 31-40€, >40€).
The fourth and last part contained questions about the respondent's source of previous knowledge about reef ecology (university, diver education, technical literature, conversations with other snorkelers/divers or no previous knowledge at all). Finally, 24 statements about reef ecology with a bi-polar answer scale (true, false) were put forward. Statements were randomly repeated to avoid response-set bias.

4.4 Statistical analysis

All statistical analyses were processed using SPSS.15 (after Eckstein, 2006). Frequencies included median and range for ordinal-scaled data and mode for nominal-scaled data. For interval-scaled data, mean scores, median, range and standard error were calculated for each question (age, snorkel- and SCUBA-dives, number of correct ecology answers). Normal distribution was tested using the Kolmogorov-Smirnov-Test. Ordinal-scaled data were compared using the Kruskal-Wallis-Test. Associations between variables were investigated using Spearman rank-order correlations. Differences of nominal-scaled variables were determined using non-parametric Chi^2-Goodness-of-fit and associations were calculated using Chi^2-Independence related to crosstabs.

5 Results

5.1 Biological surveys

5.1.1 Substrate composition

In the area that most snorkelers visit, six point intercept transects (300 data points) yielded 122 (40.7%) hard coral colonies of 6 families, 10 genera and 9 species of *Acropora* (Annex 1). The total live hard coral cover (HC) amounted to 33.6% (101 colonies). The area was divided into 'back reef' and 'reef flat'. Significantly higher mean frequencies of living unbroken hard coral colonies were found on the reef flat – 20.3 ± 3.9 SE (40.6%) – than on the back reef, 13.3 ± 0.3 SE (26.6%) ($Chi^2 = 5.14$; $p < 0.05$). In contrast the coverage by sand was significantly higher on the back reef than on the reef flat: 25.7 ± 3.7 SE (51.3%) versus 12.0 ± 1.7 SE (24.0%) ($Chi^2 = 14.88$; $p < 0.001$; n=3, 150 data points). Coral rock, dead coral and soft coral occurred more often on the reef flat. Coral rubble was more frequent on the back reef (2.3 mean ± 0.67 SE) than on the reef flat (1.7 mean ± 0.67 SE). The percentage of coral rubble was 4.7% on the back reef and 3.3% on the reef flat. The values for live broken coral colonies were 0.7 ± 0.3 SE (1.3%) on the back reef and 1.0 ± 0.6 SE (2.0%) on the reef flat. Living broken coral fragments were recorded on the back reef (2.0 ± 0.7 SE; 1.3%) but not on the reef flat (Fig. 2). Among all living hard corals the percentage of broken colonies amounted to 4.5% for both the reef flat and back reef.

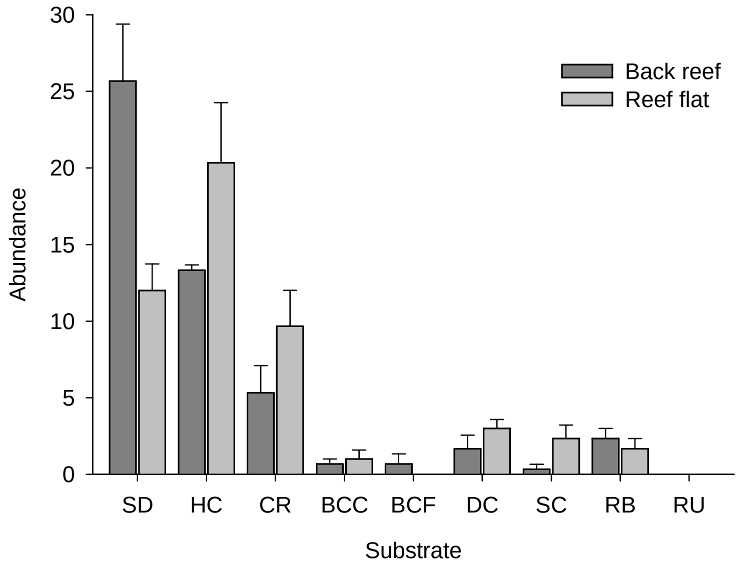

Figure 2. Mean abundance and standard error of nine different substrate categories; Abbrev.: Sand (SD), live hard coral (HC) coral rock (CR), live broken coral colony (BCC), live broken coral fragment (BCF), soft coral (SC), rubble (RB), rubbish (RU), and dead coral (DC); Average abundances between reef flat and back reef differ significantly for HC ($p \leq 0.05$) and SD ($p \leq 0.01$) (n = 3 transects, 150 data points).

5.1.2 Growth form

In the area where most snorkelers occurred, branching growth forms formed the vast majority of hard corals, with 93 (76.2%) of 122 colonies in total. The rest was formed by 13 encrusting, 12 massive and 4 foliaceous colonies. All living broken coral colonies, broken coral fragments, recently killed corals and nine of ten dead, algae-overgrown corals were also of branching growth form. Regarding the two areas separately, on the back reef, 40 of 49 hard coral colonies (81.6%) were of branching growth form, 4 (8.2%) were foliaceous, 3 (6.1%) massive and 2 (4.1%) encrusting. On the reef flat, out of 73 hard coral colonies, the corresponding values were 53 (72.6%) branching, 11 (15.1%) encrusting and 9 (12.3%) massive (Table 3).

Table 3. Abundance and percentage of four growth form categories of all hard coral colonies (live and dead) on the back reef, reef flat and in total; percentage related to the number of hard coral colonies in each area (n=6 transects, 300 data points).

Growth form	Back reef		Reef flat		Total	
	Abundance	Percent of HC	Abundance	Percent of HC	Abundance	Percent of HC
branching	40	81.6%	53	72.6%	93	76.2%

foliaceous	4	8.2%	0	0.0%	4	3.3%
massive	3	6.1%	9	12.3%	12	9.8%
encrusting	2	4.1%	11	15.1%	13	10.7%
Gesamt	49	100.0%	73	100.0%	122	100.0%

The genera categorized as branching were *Acropora*, *Pocillopora* and *Stylophora*. *Millepora* showed branching and foliaceous growth forms. The mean Frequencies of branching coral genera in the two reef zones, back reef and reef flat, differed significantly only for *Millepora* spp. (Chi² = 7.14; $p < 0.01$): *Millepora* almost exclusively occurred on the back reef (4 mean ± 1.16 SE) and was rare on the reef flat (0.7 mean ± 0.67 SE). This contrasts with *Acropora* spp., when showed a trend toward a higher frequency on the reef flat (10 mean ± 1.67 SE) than on the back reef (7 mean ± 1.53 SE). Pocilloporids also tended to have a higher mean abundance on the reef flat (4 mean ± 0.58 SE) than on the back reef (2 mean ± 2.00 SE) (Fig. 3).

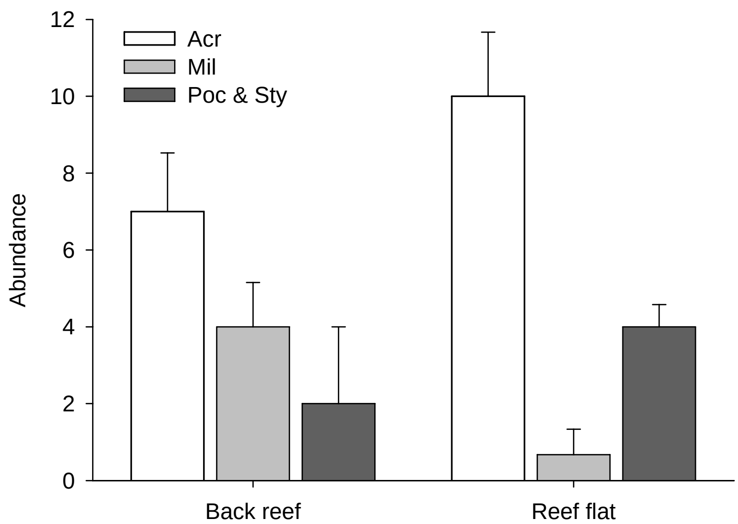

Figure 3. Mean abundance and standard error of branching and foliaceous coral genera in the two examined reef zones, back reef and reef flat. The difference is significant for *Millepora* spp. (Chi²=7.14; $p \leq 0.01$); Abbrev.: *Acropora* (Acr), *Millepora* (Mil), *Pocillopora* (Poc), *Stylophora* (Sty) (n = 3 transects; 92 data points).

5.1.3 Partial mortality

The surveyed partial mortality of branching and foliaceous growth forms yielded 106 colonies, of which 52 were *Acropora* spp., 14 *Millepora* spp., 9 *Pocillopora* spp., 9 *Stylophora* spp., and 14 dead, algae-overgrown colonies that could not be identified (N.i. in Fig. 4). All *Acropora*, *Pocillopora* and *Stylophora* colonies and 10 of 14 *Millepora* colonies were of branching growth form. The other 4 *Millepora* colonies and 1 dead, algae-overgrown colony were foliaceous. Partial mortality was found in 50% of *Acropora*, 80% *Millepora* and

Stylophora, and 90% *Pocillopora*. About 40% of *Acropora* showed partial mortality up to 25%. Other growth forms, like massive, encrusting or free living, were not taken into consideration for partial mortality (Fig. 4).

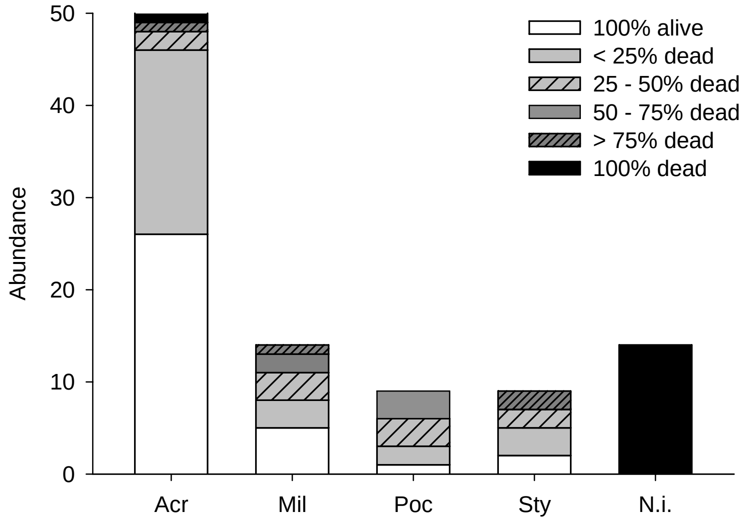

Fig 4. Absolute abundance and partial mortality of four branching or foliaceous genera (n = 98); *Acropora* (Acr), *Millepora* (Mil), *Pocillopora* (Poc), Stylophora (Sty), dead and algae-overgrown colonies listed as not identified (N.i.).

5.1.4 Coral community

Three hundred data points yielded 107 identified hard coral colonies of 6 families and 10 genera (Annex 1). Amongst the ten identified genera the highest absolute abundance was found for *Acropora* with 52 colonies (49.1%) followed by *Millepora*, 14 colonies (13.2%), *Pocillopora* and *Stylophora* with 9 colonies each (8.5%) and *Montipora* with 8 colonies (7.5%). The other five genera – *Porites* (5), *Favites* (3) *Platigyra* (3), *Galaxea* (2) and *Favia* (1) – made up the remaining 13.2%. The most conspicuous difference in the composition of *Acropora* communities between back reef and reef flat was found for frequencies of *Acropora selago*, *A. loripes* and *A. gemmifera*. In general, the back reef community contained more species. *A. selago* contributed the biggest proportion of 21 *Acropora* colonies on the back reef (47.6%), followed by *A. loripes* (14.3%), *A. eurystoma* (9.5%) and *A. secale* (9.5%). The remaining 19.2% were represented by *A. gemmifera*, *A. hyacinthus*, *A. variolosa* and *A. pharaonis* (all ≤ 5%). Among the Acroporidae, *A. loripes*, *A. secale* and *A. pharaonis* were exclusively found on the back reef. By contrast, on the reef flat, *A. gemmifera* made up almost half (48%) of the total 31 colonies. *A. selago* (22.6%), *A. eurystoma* (16.1%), *A. variolosa* (6.5%) and *A. hyacinthus* (3.2%) formed the rest of the *Acropora* community on the reef flat. *A. digitifera* was rare and exclusively found on the reef flat (3.2%) (Fig. 5).

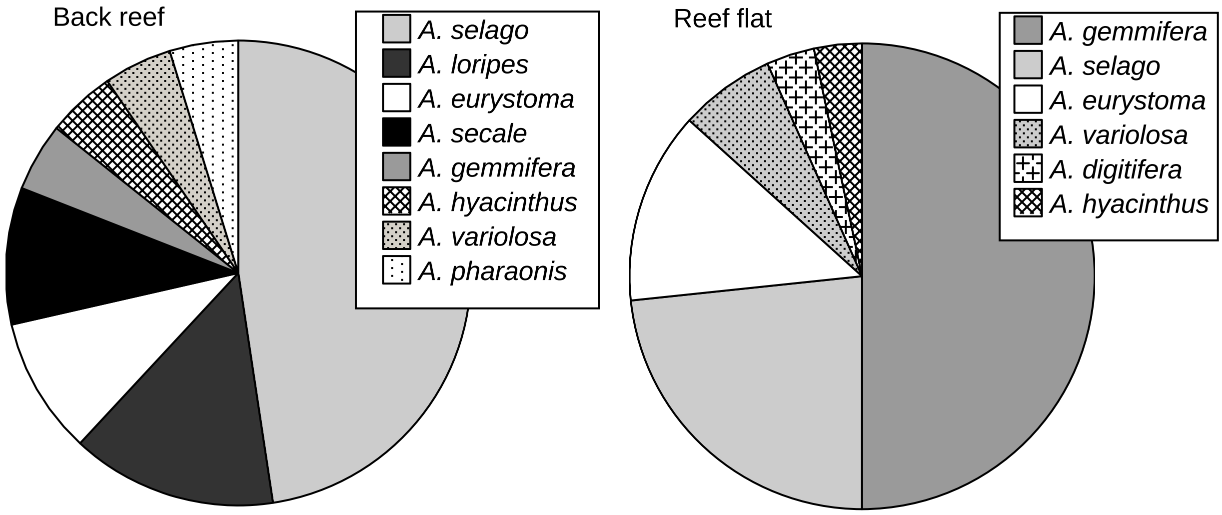

Figure 5. Absolute abundance of *Acropora* colonies on the back reef (left; n = 21); and on the reef flat (right; n = 31); Clockwise order of taxa relating to descending values (150 data points each).

5.2 Socioeconomic surveys

5.2.1 Demographic characteristics

Of the 318 respondents, 57% (182) were male and 43% (136) female. Age ranged from 14 to 65 years with a median of 30. Half of the respondents were between 25 and 36 years old. The largest age-class ranged from 25 to 30 years, followed by 30 to 35-year-old visitors (Fig. 6A). Most visitors participating in the survey were from Western Europe (80.5%). The biggest number were German (115; 36%), followed by Dutch (62; 20%), Austrian (33; 10%), British (28; 9%), Swiss (18; 6%) and Hungarian (13; 4%). Furthermore, 52 respondents of 20 nationalities, each amounting to a percentage < 3%, were categorised as ‘Others’ (Fig. 6B).

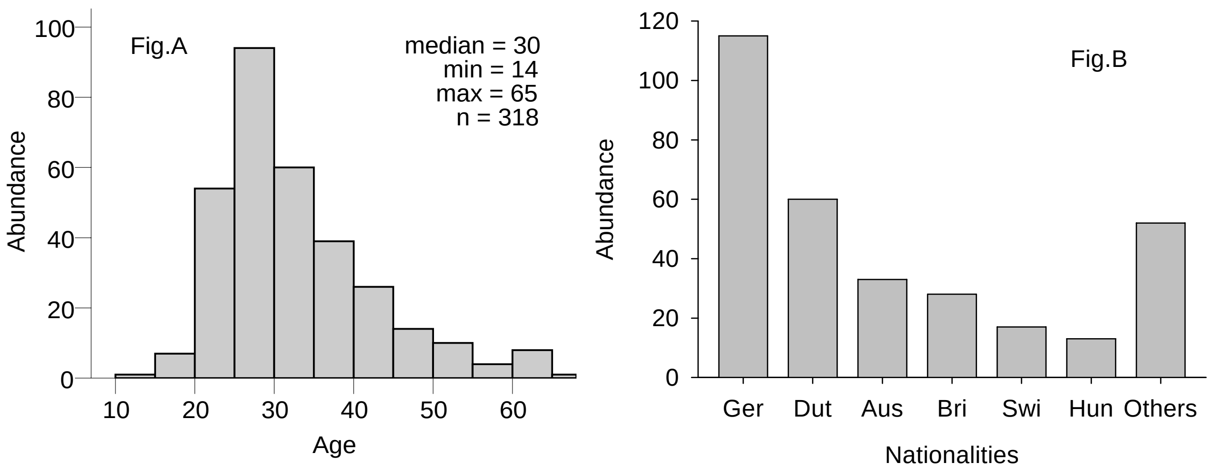

Fig 6. A: Absolute abundance of age classes of respondents (left); each class covers 5 years (Skegness=1.212; Kurtosis=1.325; n=318). B: Absolute abundance of 26 nationalities (right); German (Ger), Dutch (Dut), Austrian (Aus), British (Bri), Swiss (Swi), Hungarian (Hun) and 20 nationalities with a proportion < 3% each marked as ‘ (Others; viewed in Annex 2). Represented data can differ from actual proportions of visitor’s nationalities in Dahab (n=318).

5.2.2 Snorkel- and SCUBA-dive frequencies and experience

In total, 71.1% (226) were snorkelers, whereof almost half (48.7%) rated themselves as beginners, the other 51.3% as advanced. However, the stated numbers of snorkel dives in tropical seas showed a median of 20 with a range from 0 to 1000. Amongst the 226 snorkelers, 44.0% had dived 0 to 10 times in tropical seas and 81.9% were also SCUBA divers with a median of 20 dives in tropical seas (Fig. 7A). Of the respondents, 84.3% (268) were SCUBA-divers: 41.5% (132) had an advanced- or rescue-diver certification level, followed by 27.7% (88) divers with an Open Water brevet (the lowest certification level). Furthermore, 15.7% (50) of the SCUBA-divers were novice divers taking their first dive lessons and another 15.1% (48) were on a level of dive-leaders or dive-instructors. The amount of SCUBA dives in tropical seas per person ranged from 0 to 3000 with a median of 31.5. Amongst the 268 SCUBA-divers, 26.9% had dived 0 to 10 times in tropical seas and 69.0% rated themselves also as snorkelers with a median of 10 snorkel dives in tropical seas (Fig. 7B). There is a moderate positive correlation between snorkel proficiency and diver certification, i.e. highly certified SCUBA-divers tended to rate themselves as advanced snorkelers (Spearman's Rho = 0.29; $p < 0.001$).

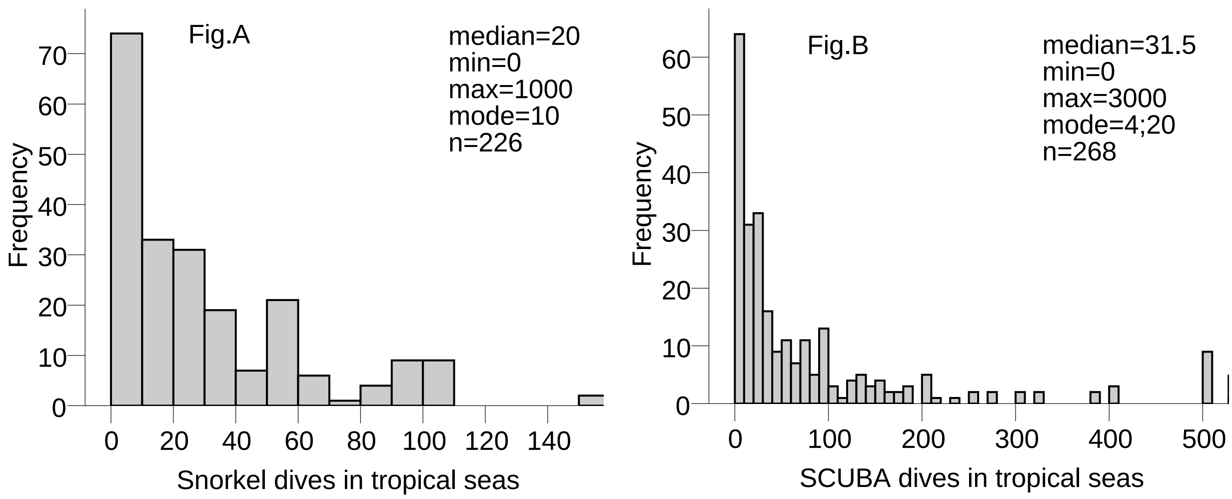

Fig 7. Absolute abundance of snorkel dives (A) and SCUBA-dives (B) in tropical seas; interval width of each class is 10; graph scales presented from 0 to 95-percentiles (150; 500); Note that maxima lie outside the graph scales (descriptive statistics listed in Annex 3).

5.2.3 Motivation for snorkelling/diving

Nature (96.5%) and recreation (86.2%) were by far the highest motivations for snorkelling or SCUBA-diving. In comparison, other motivations such as sport (65.1%), adventure (61.0%), social contacts, i.e. friends or family (61.6%), and meeting people (57.5%) have been agreed on by more than half of the respondents (comprising the categories 'agree' and 'fully agree'; Fig 8.). Related to the variable 'gender', men tended to rate the motivation 'adventure' higher than women (Chi² = 12.4; df = 1; p < 0.01).

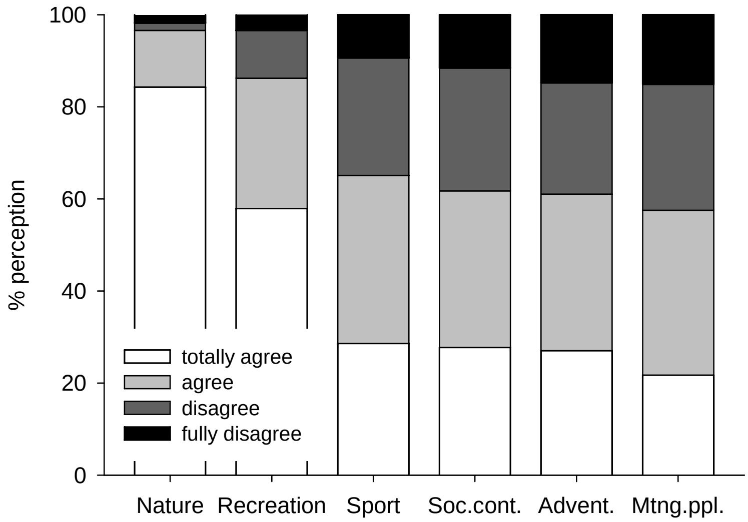

Figure 8. Percentage of rated motivations for snorkel- and SCUBA-dives; Social contacts (Soc. cont.), Meeting people (Mtng. ppl.) (n=318).

5.2.4 Knowledge and perception about reef ecology and threats to the reef

Respondents, asked about the source of their knowledge about reef ecology, indicated that they gained information mostly from conversations with other snorkelers or SCUBA-divers (73.6%). This source was followed by technical literature such as books and magazines (66.4%), information provided during their diver education (53.8%), or at a university as part of their studies (28.9%); 10.4% indicated having no previous knowledge whatsoever about reef ecology. Amongst the SCUBA-divers, 59.4% considered that environmental protection played a major role in their diver-education, 31.1% divers rated the role as minor and 9.4% as irrelevant. Related to the variable 'diver-certification', respondents with a lower certification level (Open Water Diver) tended to rate the role of environmental protection during their diver-education as minor, those with a higher certification level (Dive master or Instructor) tended to rate it as major (Spearman's Rho = −2.1; p < 0.01; Chi² = 14.0; df = 2; p < 0.01).

However, the vast majority of respondents showed awareness of potential threats to the reef, e.g. global warming (87.1%), slow coral recovery after breakage (94.3%), physical contact with corals (96.9%), feeding of marine animals (92.1%), sedimentation (89.0%), nutrient contamination (88.4%). They further agreed that snorkelling has an effect on the condition of coral reefs (94.0%) and can become a decisive factor for reef quality (82.1%). Finally, 95.6% of the respondents agreed that implementing protected areas, i.e. excluding tourism and fishing from threatened areas, would be an effective method of reef protection (n=318).

5.2.5 Interest in further education and training relating to an underwater nature trail

Most respondents agreed that sensible approaches included offering environmental education courses for snorkelers/divers (89.9%), briefings in snorkel skills (89.6%) briefings in proper behaviour (95.6%) and a well-trained guide leading a snorkel trip on a reef nature trail (85.8%). Furthermore, the majority stated that a reef nature trail would be one reason for them to choose a snorkel site (71.7%) or to choose a dive center (66.4%). Lastly, 78.3% of the respondents agreed that offering environmental education courses for snorkelers and divers would promote business for dive centres (Fig. 9). The results show a weak, highly significant, positive correlation between age-class and the perceptions about a briefing in snorkel skills before visiting a reef nature trail. Accordingly, the lower the age-class the more respondents agreed that such briefings would be sensible before visiting a reef nature trail. Those findings are also confirmed by the Kruskal-Wallis-Test, which showed highly significant differences between the mean ranks of the group relating to the age-class ($Chi^2 = 12.6$; $df = 3$; $p \leq 0.01$). Related to the variable ‘gender’, women tended to agree more on skill-briefings than men ($Chi^2 = 7.2$; $df = 1$; $p < 0.01$).

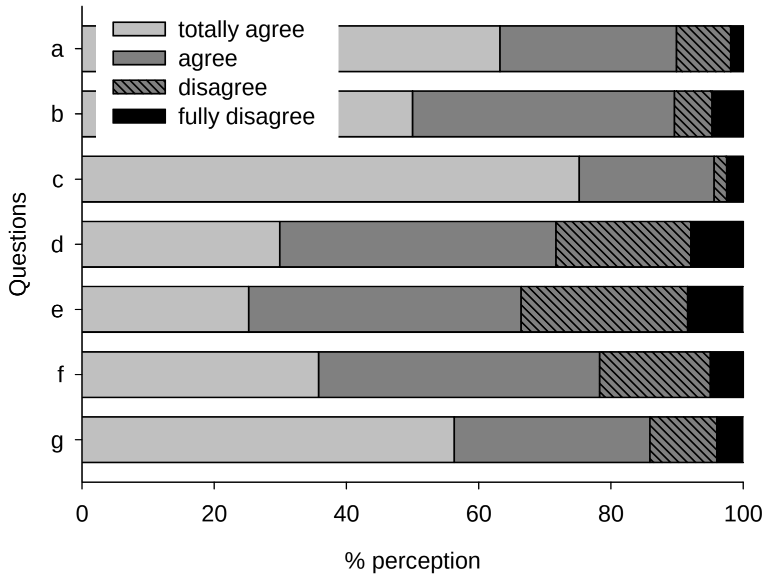

Figure 9. Interest in further education and training relating to an underwater nature trail (n=318); Posed questions (a-f): (a) Offering environmental education courses for snorkelers/divers is sensible; (b) A briefing in snorkel skills before visiting a reef nature trail is sensible; (c) A briefing in proper behaviour before snorkel/dive trips for reef protection is sensible; (d) A reef nature trail is one reason for me to choose a snorkel site; (e) Offering environmental education courses for snorkelers/divers is one reason for me to choose a dive centre; (f) A well-trained guide leading a snorkel trip on a reef nature trail is sensible.

5.2.6 Willingness to pay for visiting a snorkel trail

The majority of the 312 respondents stated that they were willing to pay fees for a guided trip or for renting a guide-book when visiting a reef nature trail. For a guided trip, 44.2% of the visitors were prepared to pay 11 to 20 €, followed by 37.2% who would pay up to 10 €. Moreover, 16.0% were ready to pay 21 to 30 € and a minority of 2.2% even 31 to 40 €. One visitor stated a willingness to spend more than 40 €, and six respondents did not answer the question. The responses for rated expenditures for a guide book lending fee showed a similar ratio: 43.8% of respondents were prepared to pay 11 to 21€, followed by 34.6% who would pay up to 10 €, 16.0% were ready to pay 21-30€ , 3.2% would even pay 31-40€ and six respondents stated a willingness to pay more than 40€ (Fig. 10). There was a highly significant, weak negative relationship between snorkel proficiency and the willingness to pay for visiting a reef nature trail, guided or with a guide book (Spearman's Rho = −0.24; $p < 0.01$). Accordingly, beginners tended to agree to pay a higher fee than advanced snorkelers. Within SCUBA-divers, the same trend was found related to diver-certification level (Spearman's Rho = −0.33; $p < 0.01$; $Chi^2 = 11.0$; df = 2; $p < 0.01$).

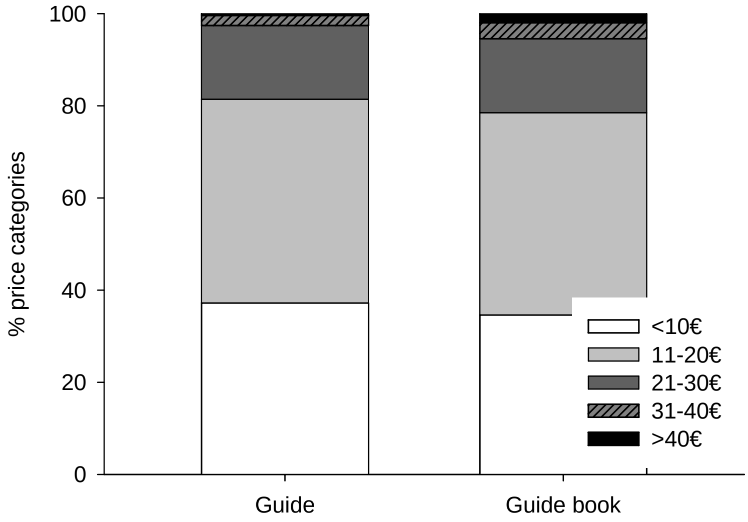

Figure 10. Willingness to pay (€) for a guided snorkel trip on a reef nature trail (left) or for visiting such a nature trail including a guide book lending fee (right) (n=312; 6 missing responses).

5.2.7 Desired facilities at a snorkel site

Out of ten different potential facilities, the most desired ones were first aid (85.6%), sunshades (79.6%) and sanitary (73.0%). Less important but still required by more than half of the respondents were floating aids to hold on to and rest (67.3%), a life guard (64.5%), the possibility to rent snorkel equipment (58.5%) and snorkel lessons (50.6%). Least required were a snack bar (44.3%), sun bathing (31.4%), a bar providing soft-drinks and alcohol (28.9%), and a children's playground (19.5%) (Fig. 11). A moderate positive relationship on a highly significant level was found between the desire for snorkel equipment as well as for snorkel lessons and the respondents' snorkel proficiency or diver certification level. Beginners had a greater interest in snorkel lessons and rental opportunities than advanced snorkel- or SCUBA-divers (Spearman's Rho = 0.22 to 0.27; $p < 0.001$). A life guard was also desired more by beginners (Spearman's Rho = 0.21; $p < 0.001$). Related to the variable 'gender', a bar at a snorkel site was rated higher by men than by women ($Chi^2 = 7.5$; df = 1; $p < 0.01$).

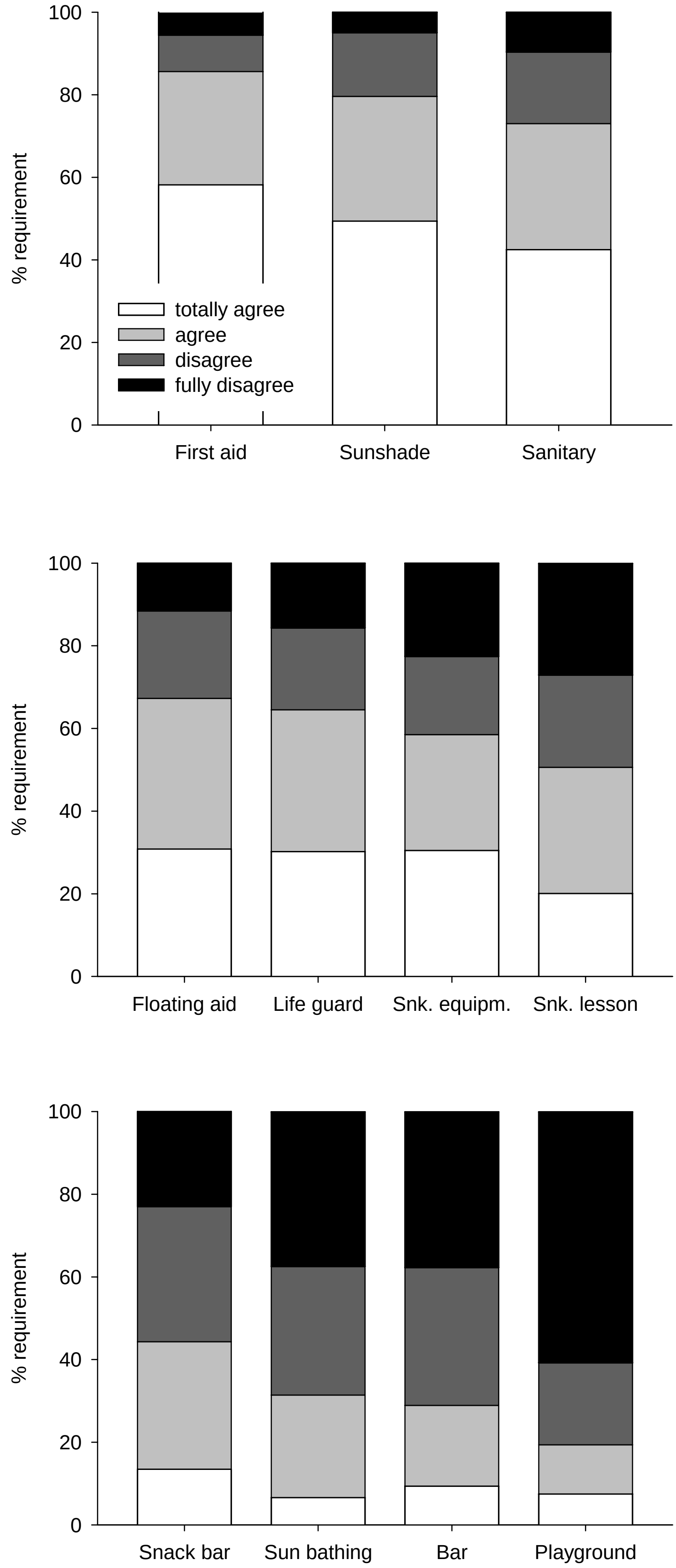

Figure 11. Eleven desired facilities at a snorkel (Skn.) site; facilities required by more than 70% (left), more than half (middle), less than half (right) of the respondents; Children's playground (Playground) (n=318).

5.3 Observations and photo documentation (Fig. 12)

All following observations and documentations were conducted in the course of the present study. The back reef area north of the 'Napoleon Reef' is visited daily by snorkelers and swimmers coming from Dahab and Sharm El Sheikh. Visitor peaks occur in the afternoon, with more than ten 'Landcruisers' each carrying about eight people mostly from Sharm El Sheikh. Snorkelers have been documented to swim over the reef flat at high and low tide, re-suspending sediment, kicking live coral and standing on corals. Furthermore, wind-surfers, kite-surfers and kayaks have been documented to pass over the reef flat even at low tide. Every day, fishermen have been observed walking over the reef flat in groups of two to five people, pulling fishing nets (3m times 20m and more over the reef flat, damaging the reef. The amount of fish catch was typically very small in the huge, mostly empty nets. Additionally, children used lines with hooks to catch fish off the beach. This led to lost fishing gear being wrapped around coral on a regular basis. Moreover, rubbish – i.e. plastic bags covering live coral, bottles, cans, iron rods, car tires, batteries, clothes, etc. – was continuously documented and collected during the survey.

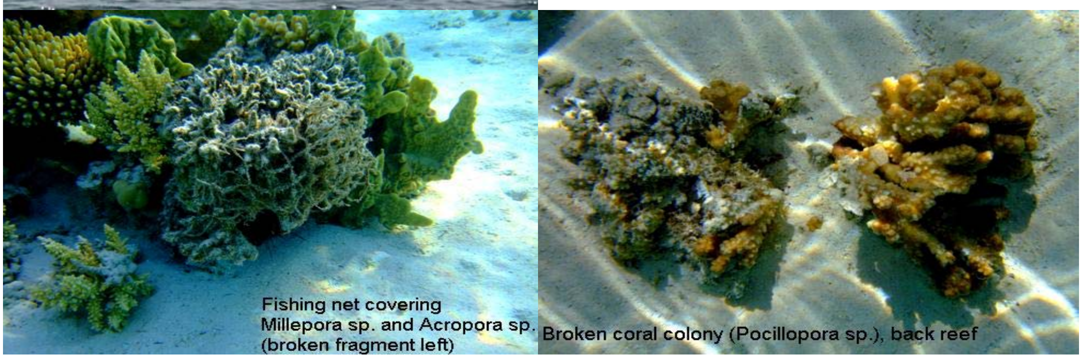

Fig 12. Photo documentation; Human impacts on the reef flat and back reef at the 'Lagoon' in Dahab, Egypt.

6 Discussion

6.1 Ecological surveys

Substrate composition

The pooled coral cover (CC) of 33.6% agrees with the results of Kotb et al. (2004), who reported a mean CC of 35% for the Gulf of Aqaba. The relatively high live coral cover of 40.6% found on the reef flat in the present study approximates the value of 43.1% found by Hasler and Ott (2008) for sites like the adjoining ‘Napoleon Reef’. This points to a coral reef in generally good condition and underlines the need for protection and management in an area of rapidly and massively growing coastal tourism.

Coral breakage

In a study on the Red Sea in 1999, Jameson et al. characterized sites as ‘hot spots’ based on a coral damage index to provide coral reef managers with information about the extent of physical coral damage. They denoted a ‘hot spot’ when the percent of broken coral colonies is ≥ 4% or the percent cover of coral rubble is ≥ 3%. In the present study, the total percentage of live broken coral colonies was 2.0% on the reef flat and 1.3% on the back reef, where the same amount of live broken coral fragments was found (1.3%). Although the amount of broken coral colonies did not reach 4% of the total substrate, it exceeded this value when regarding only live hard coral substrate (up to 4.5% of the colonies were broken on both the reef flat and back reef). Importantly, the percentage of coral rubble exceeded the criteria (3%) of Jameson et al. (1999), totalling 4.7% on the back reef and 3.3% on the reef flat. Consequently the entire reef north of the ‘Napoleon Reef’ has to be designated as a ‘hot spot’. These findings and the observations of numerous daily visitors from Sharm El-Sheikh (mentioned in ‘observations and photo documentation’) suggest a strong relation between visitor frequency and coral breakage as pointed out in some other studies on coral reefs (Jameson et al. 1999; Marshall 2000, Riegl and Velimirov, 1991; Rodgers and Cox, 2003). Living broken coral fragments (BCF), which were found here solely on loose sandy substrate on the back reef (1.3%), have less chance to survive here than on hard substratum (Dizon and Yap, 2006). Due to wave action and currents, broken fragments can be washed away and land on sandy patches of the reef flat and back reef. Additionally, coral fragmentation has been reported to lead to reduced sexual reproductive output within the damaged colony (Zakai et al., 2000).

Growth form

The proportion of branching colonies (81.6% on the back reef and 72.6% on the reef flat) agrees with the values (80%) reported by Hasler and Ott (2008) and is much higher than the percentage Hawkins and Roberts found in 1992 for the South Sinai (21.7%). All living broken coral colonies, broken coral fragments, recently killed corals and nine of ten dead, algae-overgrown corals were also of branching growth form. This reflects the fact that branching colonies are most vulnerable to breakage caused by direct human impacts, i.e. trampling, fin contact and standing on living coral (Kay and Liddle, 1987, 1989). Branching growth forms are known to be most vulnerable to breakage (Riegl and Riegl, 1996; Riegl and Cook, 1995; Marshall, 2000). Due to increased coral mortality, coral diseases, algal overgrowth and a loss of fitness (colony size, energy reserves and fecundity), coral fragmentation by trampling has become a chronic background stress degrading coral cover (Nyström et al. 2000; Rodgers and Cox, 2003) rather than a one-time storm event, making it a threat to reefs (Dizon and Yap, 2006; Plathong, 2000; Richmond and Hunter, 1990).

Partial mortality

Partial mortality was found in 50% of Acropora sp., 80% of *Millepora* sp. and *Stylophora* sp., and in 90% of *Pocillopora* sp. (n=97 branching colonies; Fig. 4). One reason for such a relatively high partial mortality could be extreme low tide events (personal observation). However, the additional anthropogenic chronic stress caused by trampling and sediment resuspension should be taken into consideration in any management effort in this area: such stress could be the crucial factor for reef recovery or reef degradation (Nyström et al., 2000). Furthermore, algal overgrowth, affecting not only dead coral but also living coral during low tide events, could be exacerbated by damage due to breakage as reported by Riegl and Velimirov (1991) who found in the Red Sea a high correlation between the frequency of coral breakage and algal overgrowth.

The relatively high abundance of dead and algae-overgrown hard coral colonies in the present study (13.2%) could be explained as corals that died longer ago and have not yet been overgrown by other corals. Once dead and overgrown by algae, corals seem to remain in that state for lengthier periods. According to a study by Schiemer et al. (2008) on the influence of colony size and coral health on the occupation by coral-associated gobies, corals that showed no or little partial mortality were more frequently inhabited by breeding gobies than colonies in worse condition. They also found especially larger coral colonies to be in worse condition than smaller ones. The findings of Schiemer et al. (2008) demonstrate the effects of coral health on other reef associated organism, in this case, gobies.

Coral community

In the present study, *Acropora* (49.1%) followed by *Millepora* (13.2%) had the highest abundance amongst the nine identified genera. In another study on breakage in Red Sea reefs, Riegl and Velimirov (1991) reported *Acropora* to be most affected genus and *Millepora dichotoma* to be the most affected species. According to Riegl and Cook (1995), *Acropora* communities of shallow water reefs, especially on the outer reef flat, were the most fragile ones. Riegl and Velimirov (1991) also reported *Acropora* to be the most affected genus and *Millepora dichotoma* to be the most affected species related to trampling. This means that the reef area of the present study, with its relatively high abundance of *Acropora* and *Millepora,* is vulnerable to breakage: it is a shallow water reef with less than 50 cm water above the corals at low tide. The *Acropora* community in the back reef is dominated by *Acropora selago* (47.6%), followed by *A. loripes*, *A. secale* and *A. eurystoma. A. gemmifera* (48.0%) dominates the reef flat. This difference leads to a difference in sensitivity between the two areas, the reef flat being exposed and the back reef being semi-exposed to wind and waves. In the northern Red Sea, Riegl and Piller (2000) found *A. gemmifera* with an average cover of 43% on the wind- and wave-exposed reef crest, *A. secale* (48%) on semi-exposed locations, and *Millepora dichotoma* on areas that were current exposed but sheltered from direct storm swell impacts. This agrees with the findings in the present study. Rogers et al. (2003) stated that corals adapted to low-energy environments were most vulnerable, but, ultimately, their in situ experiments showed that no corals were entirely resistant to trampling.

In summary, this shallow water reef is covered by less than half a meter of water at low tide, and about 70% of the coral colonies are branching and therefore vulnerable to breakage. Accordingly, snorkelling should be shifted to pinnacles in the lagoon with a minimum depth of 2 to 3m, and destructive fishing methods should be banned completely.

6.2 Socioeconomic surveys

Demographic characteristics

The questionnaires were distributed mostly at dive centres all over Dahab. Therefore, the proportions of demographic characteristics like nationality, age and the proportion of SCUBA-divers and snorkelers represent a selective data acquisition.

Most of the 318 respondents were from Western Europe (80.5%), successively comprising Germans (36%), followed by Dutch (20%), Austrians (10%), British (9%) and Swiss (6%). The remaining 19.5% were divided into 20 nationalities each amounting to less than 5 %. Leujak and Ormond (2007) reported for Ras Mohammed National Park and Sharm El-Sheikh, South Sinai, that 60% of the visitors came from Italy, 12% from Russia, 11% from Egypt and 15% from Western Europe. They also mentioned a shift in the nationalities of visitors in the last ten to twenty years from German and British, through Italian, to Russian. Furthermore, they found the more recent visitor groups to be less experienced snorkelers with poorer knowledge of reef ecology; such guests were also more satisfied with reef health at heavily impacted sites as well as with the current visitor numbers than experienced visitors.

Although the above proportions of nationalities reflect selective data acquisition, one interpretation of the findings of Leujak and Ormond (2007) is that the Western European visitors that formerly came to Sharm El-Sheikh have switched to Dahab, a recently fast-growing but still smaller and less crowded location. A faster growth of Russian and Italian visitor numbers compared to the number of Western and Northern Europeans have been reported for Egypt since 2000 (Ibrahim and Ibrahim, 2006). Therefore the changes in proportions of nationalities could affect visitor centres like Sharm El-sheikh earlier than more remote areas like Dahab.

In the present study the interest in further education and training amongst the respondents is high. For some visitor groups at the Sharm El-Sheikh area different results were found. As reported by Leujak and Ormond (2007) little experience, poor knowledge about reef ecology and unsatisfactory snorkel skills mean that National Park rules are broken (i.e. standing and walking on the reef flat, collecting shells, feeding of marine animals, etc.). According to the observations in the present study numerous visitors are coming daily from Sharm El-Sheikh to the ‘Lagoon’ in Dahab for snorkelling and swimming. This, combined with low interest in further education amongst some of those visitor groups, as reported by Leujak and Ormond (2007), points out that the characteristics and perceptions not only of visitors staying in Dahab but also of those coming from Sharm El-Sheikh need to be taken in consideration for further management actions to protect the shallow water reef at the ‘Lagoon’.

Snorkel- and SCUBA-dive frequencies and experience

Amongst the 226 snorkelers, almost half (48.7%) rated themselves as beginners, with 44% having snorkelled only 0 to 10 times in tropical seas. Amongst the snorkelers the majority (81.9%) were also SCUBA-divers with a median of 20 dives in tropical seas. Of the total 268

SCUBA-divers, 27.7% were Open Water Divers (lowest certification level) and 15.1% were novice divers, 69.0% rated themselves also as snorkelers and 26.9% had dived only 0 to 10 times in tropical seas. Therefore, the experience and proficiency of snorkelers and divers can be rated as low. Accordingly, skill training, briefings on proper behaviour and information about reef ecology are sensible tools to reduce the impact of physical damage caused by snorkelers and divers (Medio et al., 1997). In the South Sinai a shift in activities from active divers to snorkelers and to less experienced visitors in general has been reported in relation to nature-based tourism (Leujak and Ormond, 2007).

Motivation for snorkelling/diving

Nature (96.5%) and recreation (86.2%) were by far the highest motivations for snorkelling or diving compared to other motivations such as sport, adventure or meeting people. Importantly, the perception about reef health is connected to the knowledge and experience of the visitors (Leujak and Ormond, 2007). This means that further education and information not only affects the behaviour of snorkelers and divers (Medio et al., 1997), but can also enhance the pressure on the fast-growing tourism to meet the demand for a healthy reef.

Knowledge and perception about reef ecology and threats to the reef

Most respondents (73.6%) gained their knowledge about reef ecology from conversations with other divers and snorkelers, followed by reading of technical literature and magazines (66.4%), information provided during diver education (53.8%) and at a university as part of their studies (28.9%). The latter means that almost one third of the respondents were on an academic educational level. About forty students of University groups participated in the survey and could cause a bias. Excluding those students, respondents with an academic education would amount in 19.1%, still a relative high proportion. It remains unclear if that relative high percentage of academics represents the actual proportion of visitors in Dahab. 10.4% indicated having no previous knowledge about reef ecology at all, which agrees with the 15.1% reported by Leujak and Ormond (2007). Regardless of which source respondents quoted, the vast majority were aware of potential threats to the reef, i.e. global warming, physical contact with corals, feeding of marine animals, sedimentation. This agrees with the highly rated motivation ‘nature’ (96.5%), underlining that the marine environment was part of the motivation to take up snorkeling or diving in first place. Amongst the SCUBA-divers more than 40% rated the role of environmental protection during their diver education as minor or irrelevant. That shows that diver education could and should pay more attention on informing students about environmental protection and potential threats to the reef before divers practise their activities in a vulnerable environment like the coral reef. Guides, in general, play a crucial role in informing people about national park rules (Leujak and Ormond, 2007). In some cases, guides have been reported to inadequately perform their role in providing environmental information: 37.5% of respondents who were on guided tours to the Ras Mohammed National Park did not know that corals were animals (Leujak and Ormond, 2007). The tour leaders bringing groups from Sharm El-Sheikh could play an important role in informing visitors about national park rules and restrictions. Such information needs to be combined with skill checks and skill training. Thus, further education and training is advisable for both guides and visitors.

Interest in further education and training relating to an underwater nature trail

Several authors reported that briefings positively influenced the quantity of diver-related damage (Hawkins and Roberts, 1993; Medio et al., 1997; Tratalos and Austin, 2001; Zakai et al., 2002). This contrasts with Rouphael and Inglis (2001), who suggested focusing more on skill training conducted by professionals than on pre-dive briefings. In a study about the effectiveness of environmental interpretation programs in the Great Barrier Reef Marine Park, Madin and Fenton (2004) reported that participants in an interpretive program gained more knowledge and understanding about the reef environment and a greater understanding of actual and potential anthropogenic impacts on the reef than non-participants. The authors also reported greater environmental awareness and knowledge amongst visitors who participated in more interpretive activities. In the present study the vast majority of respondents agreed that sensible approaches included offering environmental education courses for snorkelers/divers, briefings in proper behaviour and a well-trained guide leading a snorkel trip on a reef nature trail. Furthermore, most stated that a reef nature trail would be one reason for them to choose a snorkel site and that they were willing to pay fees for such a guided trip or a guide-book. Based on this high interest in nature, the door is open for further education as one tool for minimising the negative impacts and enhancing the positive impacts associated with growing nature-based tourism in a relatively undamaged but threatened natural area. This further creates the possibility to indirectly increase the carrying capacity of an area by providing further information and training (Hawkins and Roberts, 1992; Davies and Tisdell, 1995).

Willingness to pay for visiting a snorkel trail

Most (62.8%) of the 312 respondents were willing to pay more than 10 € for a guided trip or for renting a guide-book at a reef nature trail. The cost category 11 to 20 € had the highest number of responses (44.2%), followed by 0 to 10 € (37.2%). In the latter category, it remained uncertain how many of those respondents were unwilling to spend any money. Less experienced snorkelers and divers tended to be prepared to pay a higher fee than experienced ones. Therefore, the less experienced snorkelers and divers who formed the target group for further information and education about reef ecology, threats to the reef and skill training, were also the ones most prepared to financially support such a management project. This result, however, contrasts with the findings of Leujak and Ormond (2007) in the Sharm El-Sheikh area, where those respondents with poorest knowledge about reef ecology tended to be least interested in further education, i.e. slideshows. The lower interest was also correlated with the visitor's nationalities (Italian, Russian). The fact that numerous visitors come from Sharm El-Sheikh to the 'Lagoon' in Dahab points out that also the socioeconomic characteristics of those visitors need to be taken in consideration for management actions. One possible solution for visitors would be to separate the groups based on their interest. 'Sun-tourists' on one hand, who show little interest in further information about reefs, could spend their time bathing in an area apart from the reef. On the other hand, 'snorkel-groups' could be directed to a reef nature trail complete with briefings, skill training and a guided trip.

The report on Biodiversity Conservation Capacity Building in Egypt (2007) pointed out that the challenge for reef-associated tourism in Egypt is to generate economic benefits while maintaining the coral reef ecosystem on which it depends. The annual recreational value of Egypt's coral reefs has been estimated – using the 'zonal travel cost method' (ZTCM), including a vector for the socioeconomic characteristics of the zone from which visitors come, to be USD 142 million. Results from the 'individual travel cost method' (ITCM), including a vector for the individual characteristics of the visitor, yielded a value of USD 191 million per year. The willingness of visitors to pay (WTP) for coral reef conservation, was estimated to be about USD 1.5 million per year (BCCBE, 2007). Those numbers of recreational valuation highlight the importance of management and protection of Egypt's coral reefs from both an economic and ecological point of view.

7 Conclusions and recommendations

Ecologically, the diverse, shallow water reef north of the ‘Lagoon’ in Dahab is at risk. The reef flat is covered by less than 50cm of water at low tide and is threatened by current reef users such as snorkelers, fishermen and surfers. Caused by the minor depth of the reef and the high frequencies of branching hard corals the entire reef has to be seen as very sensitive and vulnerable to breakage. Further management actions should take topics like social and economic carrying capacity, establishment of no-use and multi-use areas, protection of hot-spot areas and development of sustainable uses into consideration. Furthermore local communities, NGOs and private sectors should be involved. Implementing public awareness programmes and promoting research and teaching on marine nature as important tools need to be part of management actions as well (BCCBE, 2007; Harris, 2006; Roman et al., 2007)To reduce the damage and lead to a sustainable use within the criteria of ‘eco-tourism’, I propose the following management actions relating to a reef nature trail (Fig 13):

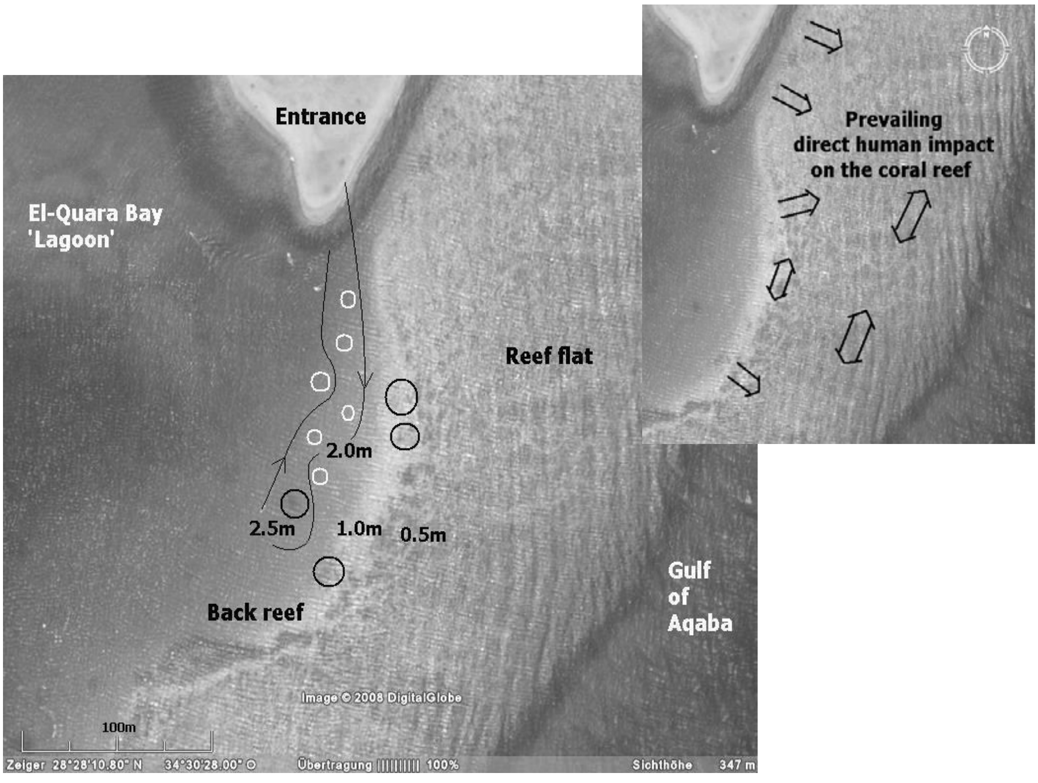

Figure 13. Prevailing direct human impact (right) and proposed reef nature trail for snorkelers (left) at El-Quara Bay (‘Lagoon’) north of the ‘Napoleon Reef’, Dahab, Egypt. Right image: directions and areas of frequent direct human impact caused mainly by snorkelers, fishermen and surfers (black double arrows). Left image: natural pinnacles (black circles), proposed artificial structures (white circles) and an example for a snorkel trip along the underwater nature trail (black single arrows). Trail length measures about 150 m one way; depths refer to mean tide level; Tidal range ± 0.5m (nip tide) ± 1.2m (spring tide).

(1) To manage snorkelling and other recreational activities at this shallow water coral reef, I propose the following zoning plan (terminology after Roman et al., 2007): The reef flat, categorized as a ‘Sensitive Zone’, dominated by branching *Acropora* communities in shallow water, should be closed for recreational activities and fishery. The back reef, categorized as a ‘relatively sensitive’ habitat, is dominated by shallow hard coral communities and can be used as an ‘Ecotourism Zone’. Here, access is restricted to small groups of snorkelers led by certified tour guides. Impacts would be minimized by requiring that all guides provide prior briefings and skill training. This area offers possibilities to implement a reef nature trail. In addition a snorkel trail based on artificial structures should complete the nature trail to provide snorkelling trips during low tide, when the back reef is to shallow to snorkel without causing heavy impacts. Because the reef flat, as a ‘Sensitive Zone’, is too shallow and vulnerable for snorkelling, the nature trail is limited to a small stripe along the back reef. Here, additional trail stations based on artificial structures, as mentioned above, open the way for a rotating snorkel trail system providing recover periods for impacted parts of the trail (Plathong et al., 2000). The extensive beach area, bordering western margin of the ‘Ecotourism Zone’, can be identified as a ‘Very Resistant Zone’: depths of more than 3m with sandy substrate and sporadic coral and sea grass patches make snorkeler contacts with corals negligible.

(2) Keep surfers a safe distance away from the swimming and snorkelling area.

(3) Submerge artificial structures in different sizes and shapes. This would provide environmental enhancement by forming additional three-dimensional habitat for benthic and pelagic flora and fauna (Armono and Hall, 2006; Cabaitan et al., 2008; Harris, 2006). The proposed reef nature trail (Fig. 13) extends over a strip of about 150 m length in a minimum depth of 2 m to avoid fin contact with the bottom and to minimize resuspension of sediment (Harriott, 2002; Rogers, 1990). Such structures offer the possibility to switch from the back reef to a deeper area and provide an insight in benthic and fish communities when the circumstances do not allow snorkelling along the shallow back reef (i.e. at low tide).

(4) The present study reports numerous living broken coral fragments that landed on sandy substrate. Transplanting such living coral fragments to artificial structures increases their chances of survival (Dizon and Yap, 2006). This would require considering suitable material, transportation, fixation, location characteristics and seasonal fluctuations (Edwards and Gomez, 2007; Fujiwara et al., 2004). The

proposed material for such artificial structures would be concrete. It combines several advantages such as relatively high persistence in salt water, low costs and a relative suitable substrate for the attachment of coral fragments compared to other materials like iron, unglazed tiles or natural coral rock (Fujiwara et al., 2004). Hence, artificial structures can be matter of environmental interpretation programmes (Madin and Fenton, 2004), reef restoration and scientific research at the same time.

(5) Professionally trained guides and water-proof guide books providing an insight into reef biology and ecology on several levels, for visitors with poor previous knowledge about the reef nature as well as for university groups (Hasler and Ott, 2008; Leujak and Ormond, 2007; Medio et al., 1997).

(6) Implement facilities providing snorkel lessons, rental snorkel equipment, sanitary, sunshades, a life guard and fist aid (Fig 11.).

(7) Involve the local community in course of socio-economic management actions by giving them real tangible responsibility throughout the process so that they develop a sense of ownership for coral reefs, and are motivated to observe the regulations that they helped to establish (Crosby et al., 2002) e.g. professional training of current local fisherman for the maintenance of equipment and facility in substitution to restricting destructive fishing in the area. Furthermore traditional knowledge of local fishermen can contribute to the scientific understanding of reef ecosystems e.g. local fishermen may advise on reef fish behaviour, habitat and migration patterns (Bunce et al., 2000).

(8) Entrance fees and fees for rental equipment, guided tours, largely paid by foreign visitors, form a potential source to finance coral reef conservation (Arin and Kramer, 2002). In addition advertising surfaces used by tour operators and other companies can contribute to provide a self-sustaining system. As mentioned above, the less experienced snorkelers and divers who formed the target group for further information and education about reef ecology, threats to the reef and skill training, were also the ones most prepared to financially support such a management project. Hence those groups form an important source of income.

(9) Open the reef for further research. Regular monitoring on the nature trail and the nearby natural reef is an important supply of information about status and changes in community structure, coral damage and ecosystem health (Hawthorne, 2005; Wilkinson et al., 2003). Artificial pinnacles provide information about reef biology on all levels, for tourists with poor or rich previous knowledge, for school-classes and biology students, for SCUBA-divers with deeper interest in marine biology and for

scientific studies, i.e. observations of recruiting patterns and growth rates of juvenile coral colonies or the effects on fish communities. Therefore visitors get the chance to have a closer look into coral reef dynamics and the process of marine biology research further reducing the gap between environmental protection and tourism.

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9 Zusammenfassung

Der Tourismus Boom an den Küsten Ägyptens der letzten Jahre und Jahrzehnte und die damit verbundene Verbauung der Küsten, Überfischung und Explosion an Wassersportaktivitäten alarmieren zu sofortigen Schutz- und Managementmaßnahmen zum Erhalt der Korallenriffe am Roten Meer und Golf von Aqaba. Schnorchelaktivitäten können Korallen vor allem durch physischen Kontakt und Aufwirbelung von Sediment schädigen (Chabanet et al., 2005; Riegl und Velimirov 1991). Besonders gefährdet sind dabei verzweigt wachsende Korallen (Riegl et al. 1996), von denen sich die Gattung *Acropora* als besonders fragil erwies (Riegl und Cook, 1995). Demnach ist es sinnvoll Schnorchel-Aktivitäten auf Bereiche zu beschränken, welche tief genug sind (mind. 2m) um Bodenkontakt zu vermeiden (Allison, 1996). Eine weitere Möglichkeit, Schäden and Riffen zu minimieren, wird in Umweltbildungsprogrammen gesehen. Dabei werden die Besucher über die Funktion und Mögliche Bedrohungen der Riffe informiert und in Folge dessen zu umsichtigerem Verhalten animiert (Madin und Fenton, 2004). Dies kann mit Hilfe von Schnorchel-Lehrpfaden vermittelt werden, wodurch zusätzlich die Auswirkungen auf ausgewählte Areale beschränkt werden (Harriott, 2002). Im Zuge einer Studie über die Auswirkungen der Nutzung eines Schnorchel-Lehrpfads am Großen Barriere Riff, wiesen die Autoren darauf hin, dass eine bedachte Auswahl des Platzes, einführende Briefings, Auftriebshilfen und regelmäßige Rotation der Pfade hilfreich für das Management eines Lehrpfades seien (Plathong et al., 2000). Auch die Fertigkeiten im Schnorcheln stehen in Beziehung mit dem Ausmaß an verursachten Schäden (Leujak und Ormond, 2007). Daher ist es besonders für Anfänger und unerfahrene Schnorchler sinnvoll, vor dem besuch eines Lehrpfades oder anderen Riffabschnitts an einem Schnorchelkurs teilzunehmen um den einfachsten, sichersten und umweltschonendsten Umgang mit der Ausrüstung zu üben. Unabhängig von Fertigkeit und Erfahrung sollte jeder Riffbesucher über grundlegende ökologische Inhalte und mögliche Bedrohungen für Korallenriffe informiert werden.

Die bedeutendsten Ergebnisse dieser Studie lassen sich in 5 Ökologische und 6 Sozioökonomische Punkte zusammenfassen:

1. Bei Ebbe ist der gesamte Riffbereich weniger als einen halben Meter tief.
2. Die Lebendbedeckung von Hartkorallen ist relativ hoch mit 26,6% am Rückriff und 40,6% am Riffdach.
3. Der Großteil der lebenden Korallen war verzweigt wachsend (81,6% am Rückriff und 72.6% am Riffdach). Wobei fast die Hälfte der lebenden Korallen (49,1%) der Gattung *Acropora* angehörten.

4. Die Hälfte und mehr der verzweigt wachsenden Korallen waren geschädigt (50% von *Acropora* spp., 80% von *Milleproa* spp. und *Stylophora* spp., und 90% von *Pocillopora* spp.).
5. Am Rückriff überstieg die Zahl an Korallenbruchstücken (4.7%) die von Jameson et al. 1999 angegebene Schwelle von 4,0% und zeichnet demnach dieses Gebiet als „Hot Spot“ aus.
6. Der Grossteil an Schnorchlern und Tauchern in Dahab hat geringe Erfahrung bezüglich ihrer Aktivitäten an tropischen Riffen. Von den Schnorchlern sind 44,0% 10mal oder weniger in tropischen Meeren geschnorchelt und 42,8% der Gerätetaucher waren Anfänger oder besaßen eine Zertifizierung auf dem „Open-Water“ Niveau.
7. Eine Überwältigende Mehrheit der Befragten (96,5%) gab als Motivation „Naturerlebnis“ für ihre Schnorchel- oder Tauchaktivitäten an. Für 86.2% der Befragten war „Erholung“ ebenfalls eine große Motivation.
8. Die Mehrheit der Befragten gab an, Ihr bisheriges Wissen über Riffökologie schöpfte die Mehrheit aus Gesprächen mit anderen Schnorchlern und Tauchern (73,6%) und Fachliteratur (66,4%).
9. Die absolute Mehrheit schätzte folgende vorgeschlagene Maßnahmen bezüglich Fortbildung und Training im Zuge eines Rifflehrpfadbesuches als sinnvoll ein: Ein Angebot von Umweltbildungskursen für Schnorchler und Taucher generell (89,9%); Eine Einführung in praktische Fertigkeiten des Schnorcheltauchens (89,6%); Die Begleitung und Betreuung durch einen ausgebildeten Guide (85,8%).
10. Darüber hinaus gaben 71,7% der Befragten an, so ein Rifflehrpfad wäre für sie ein Grund, einen Schnorchelplatz auszuwählen. 78,3% schätzten das Angebot Rifflehrpfadbesuchen als Geschäfts fördernd für Tauchbasen ein.
11. Eine große Mehrheit der Befragten erklärte sich bereit, eine angemessene Eintrittsgebühr für einen geführten Schnorcheltrip an einem Rifflehrpfad zu zahlen wobei die Preiskategorie von 11 bis 20 € am häufigsten angegeben wurde (44,2%).

Aus den Ergebnissen wird ersichtlich, dass es sich um ein fragiles bedrohtes Korallenriff handelt welches in seinem gesamten Ausmaß zu seicht für Schnorchelaktivitäten ist. Laut Biodiversity Conversation Capacity Building in Egypt (2007) besteht die Herausforderung für Riff-Assoziierten Tourismus in Ägypten darin, wirtschaftliche Profite zu generieren und gleichzeitig das Ökosystem Korallenriff zu erhalten von dem die Tourismus-Industrie abhängt.

Um die schädlichen Auswirkungen von Wassersport- und Badetourismus und destruktiver Fischerei auf das Seichtwasser-Korallenriff angrenzend an die „Lagune" in Dahab zu minimieren schlage ich folgende Management-Maßnahmen bezogen auf einen Unterwasser-Schnorchellehrpfad vor:

1) Ich schlage folgenden Zonierungsplan vor (nach Roman et al., 2007): Das Riffdach, die „Sensitive Zone", dominiert von zerbrechlichen *Acropora*-Kolonien in seichtem Wasser, sollte für touristische Aktivitäten und Fischerei gesperrt werden. Das Rückriff, die „Relativ Sensitive Zone", dominiert von Hardkorallen-Gesellschaften im seichten Wasser, kann als „Ökotourismus-Zone" genutzt werden, wobei der Zugang auf kleine Schnorchel-Gruppen beschränkt bleibt, die von speziell ausgebildeten Guides geführt werden, welche zusätzliche Briefings und Schnorchelschulungen abhalten. Diese „Ökotourismus-Zone" ist nun ideal geeignet für die Errichtung eines Rifflehrpfades. Der Pfad ist gut zugänglich, relativ geschützt durch das vor gelagerte Riff, leicht und schnell vom Strand aus zu erreichen, nahe dem Areal, wo sich derzeit die Aktivitäten konzentrieren und dennoch in sicherem Abstand zum natürlichen Riff (Fig. 13). Der ausgedehnte Strandbereich, westlich an die „Ökotourismus-Zone" angrenzend, kann als „Sehr Resistente Zone" bezeichnet werden, wo ein sandiger Abhang in einen über 3m tiefen sandigen Bereich mit vereinzelten Korallenblöcken und Seegrasflächen übergeht. Hier können sich Badegäste und jene Schnorcheltouristen, die nicht an einem Lehrpfadbesuch interessiert sind vergnügen.
2) Da die Nutzbare Fläche des Schnorchellehrpfades innerhalb der „Ökotourismus-Zone" auf einen schmalen Streifen des Rückriffs beschränkt ist, welches bei Niedrigwasser ebenfalls zu seicht für Schnorchelaktivitäten ist, könnten künstliche Strukturen die Basis für zusätzliche Lehrpfadstationen bilden. Somit gäbe es Ausweichmöglichkeiten bei Ebbe oder wenn Teile des Pfades im Sinne eines „Rotierenden Systems" zur Erholung gesperrt werden (Plathong et al., 2000). Für die Errichtung von künstlichen Lehrpfadstationen eignet sich jener Bereich, der parallel zum Rückriff verläuft und aus einem sanft abfallenden, sandigen Hang von 2 bis 3m Tiefe besteht (Fig. 13). Als künstliches Substrat eignet sich Beton. Er ist günstig, haltbar und einfach zu produzierenden. Auch Korallen zeigten eine relativ gute Anheftungsfähigkeit auf Beton (Fujiwara et al., 2004). In Folge der momentanen Aktivitäten ist eine Menge an lebenden Korallenbruchstücken angefallen welche oft auf sandigem Substrat zu liegen kamen und so wenige Überlebenschancen haben Dizon und Yap, 2006). Transplantiert

man diese Bruchstücke auf die Lehrpfadstrukturen, werden sie am Leben erhalten und bilden die Basis für das künstliche Riff. Künstliche Strukturen in verschiedenen Größen und Formen mit einer vielgestaltigen Oberfläche bereichern die Umwelt indem sie zusätzliche dreidimensionale Habitate für benthische und pelagische Flora und Fauna schaffen (Armono und Hall, 2006; Cabaitan, 2008; Harris, 2006).

3) Professionell ausgebildete Guides und wasserfeste Interpretationsbroschüren in verschiedenen Sprachen sollen dem Besucher einen tieferen Einblick in die Riffökologie bieten, über Mögliche Bedrohungen für die Riffe informieren und auf entsprechendes achtsames Verhalten hinweisen. Die Fortbildung findet auf allen Ebenen statt: Für Kinder und Erwachsene; Für jene mit geringem Vorwissen ebenso, wie für Studentengruppen (Leujak und Ormond, 2007; Medio et al., 1997).
4) Einrichtungen welche im Zuge eines Lehrpfadbesuches Leihausrüstung, Schnorchel- und Umweltkurse, Sanitäre Anlagen, Schattenspender und Erste Hilfe zur Verfügung stellen.
5) Gerade die weniger erfahrenen Schnorchler und Taucher die an der Umfrage dieser Studie teilnahmen bekundeten das größte Interesse an Fortbildung und Training. Weiters waren eben dieselben bereit, einen größeren finanziellen Beitrag für den geführten Besuch eines Rifflehrpfades zu leisten. Somit stellt die eigentliche Zielgruppe (Anfänger und Unerfahrene) eine essenzielle Einnahmequelle für das Projekt „Lehrpfad als Management-Tool“ dar. Eintritts- und Leihgebühren sowie die Vermietung von Werbeflächen ermöglichen somit ein selbstfinanzierendes System. Sowohl die örtliche Bevölkerung als auch NGOs (Non Governmental Organisations) sollten hierbei einbezogen werden um die Instandhaltung, einen professionellen Ablauf und die vertrauensvolle Verwaltung der Einnahmen zu gewährleisten.
6) Das Riff und der Lehrpfad sollten weiteren wissenschaftlichen Studien zur Verfügung stehen, um wichtige Informationen über Zustände und Veränderungen für ein nachhaltiges Management zu liefern und um in zukünftigen Studien noch ungelüftete Geheimnisse über Gegebenheiten und Funktionsmechanismen des Korallenriffs zu erforschen.

10 Literature

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11 Annex

Annex 1. Frequency, percentage and cumulative percentage of 6 families, 10 genera and 9 *Acropora* taxa on the back reef (n=21) and reef flat (n=31).

Family		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Acroporida	61	20.3	57.0	57.0
	Faviidae	7	2.3	6.5	63.6
	Milleporidae	14	4.7	13.1	76.6
	Pocilloporidae	18	6.0	16.8	93.5
	Poritidae	5	1.7	4.7	98.1
	Oculinidae	2	0.7	1.9	100.0
	Total	107	35.7	100.0	
Missing	System	193	64.3		
Total		300	100.0		

Genera		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	*Acropora*	52	17.3	48.6	48.6
	Montipora	9	3.0	8.4	57.0
	Favia	1	0.3	0.9	57.9
	Favites	3	1.0	2.8	60.7
	Platigyra	3	1.0	2.8	63.6
	Millepora	14	4.7	13.1	76.6
	Pocillopora	9	3.0	8.4	85.0
	Stylophora	9	3.0	8.4	93.5
	Porites	5	1.7	4.7	98.1
	Galaxea	2	0.7	1.9	100.0
	Total	107	35.7	100.0	
Missing	System	193	64.3		
Total		300	100.0		

Aroporora taxa				*Aroporora* taxa			
Back reef	Abundance	Percent	cumulative percent	Reef flat	Abundance	Percent	cumulative percent
A. selago	10	47.6%	47.6%	*A. gemmifera*	15	48.4%	48.4%
A. loripes	3	14.3%	61.9%	*A. selago*	7	22.6%	71.0%
A. eurystoma	2	9.5%	71.4%	*A. eurystoma*	5	16.1%	87.1%
A. secale	2	9.5%	81.0%	*A. variolosa*	2	6.5%	93.6%
A. gemmifera	1	4.8%	85.7%	*A. digitifera*	1	3.2%	96.8%
A. hyacinthus	1	4.8%	90.5%	*A. hyacinthus*	1	3.2%	100.0%
A. variolosa	1	4.8%	95.2%	total	31	100.0%	
A. pharaonis	1	4.8%	100.0%				
total	21	100.0%					

Annex 2. Abundance and percentage of 26 nationalities of 318 respondents; Represented data can differ from actual visitor population rates of Dahab.

Nationality	Frequency	Percent	Cumulative Percent
German	115	36.2	36.2
Dutch	62	19.5	55.7
Austrian	33	10.4	66.0
British	28	8.8	74.8
Swiss	18	5.7	80.5
Hungarian	13	4.1	84.6
Egyptian	7	2.2	86.8
Polish	5	1.6	88.4
Canadian	4	1.3	89.6
Russian	4	1.3	90.9
American	4	1.3	92.1
Belgian	3	0.9	93.1
Denmark	3	0.9	94.0
France	3	0.9	95.0
Israeli	3	0.9	95.9
Slovakian	3	0.9	96.9
Norwegian	2	0.6	97.5
South African	2	0.6	98.1
Spanish	2	0.6	98.7
Bosnian	1	0.3	99.1
Czech	1	0.3	99.4
Italian	1	0.3	99.7
Ukrainian	1	0.3	100.0
Total	318	100.0	

Annex 3. Descriptive statistics of snorkel- and SCUBA-dives in tropical seas

Cases		Snorkeler	SCUBA-diver
N	Valid	226	268
	Missing	0	0
Dives in tropical seas		Snorkel	SCUBA
Mean		44.35	132.84
Std. Error of Mean		6.55	19.38
Median		20.00	31.50
Mode		10	4; 20
Std. Deviation		98.46	317.30
Variance		9,693.70	100,679.53
Skewness		6.02	5.57
Std. Error of Skewness		0.16	0.15
Kurtosis		46.21	39.18
Std. Error of Kurtosis		0.32	0.30
Range		1,000	3,000
Minimum		0	0
Maximum		1,000	3,000
Percentiles	25	3	10
	50	20	31.5
	75	50	100
	95	150	500

Annex 4. Questionnaire structure; 64 questions in four sections (A-D).

A. General questions

1. Nationality: [ ]

2. Language(s): [ ]

3. Age: [|]

4. Sex: male ☐ female ☐

5. Snorkeler: Yes ☐ No ☐

6. Snorkel proficiency:

☐ Non-swimmer
☐ Beginner
☐ Advanced

7. Number of snorkel trips in tropic seas: [|]

8. SCUBA-Diver: Yes ☐ No ☐

9. Dive certification: OWD ☐ AOWD ☐ Dive Master / Instructor ☐

10. Number of SCUBA dives in tropical seas: [|]

Please mark the following assertions with 1 (I totally agree) to 4 (I fully disagree)!

B. Motivation for snorkeling /diving:

	(I agree – disagree) 1	2	3	4
11. Sporting experience	☐	☐	☐	☐
12. Natural experience (fish, corals)	☐	☐	☐	☐
13. Recreation	☐	☐	☐	☐
14. Adventure (sharks, currents)	☐	☐	☐	☐
15. Social contacts (friends, family)	☐	☐	☐	☐
16. Get to know people	☐	☐	☐	☐
17. Offering environmental education courses (ecology courses, reef nature trail) for snorkelers/divers is sensible.	☐	☐	☐	☐
	1	2	3	4

	1	2	3	4
18. I think offering environmental education courses for snorkelers/divers promotes business for dive centres.	□	□	□	□
19. Offering environmental education courses for snorkelers/divers is one reason for me to choose a dive centre.	□	□	□	□
20. A reef nature trail is one reason for me to choose a snorkel site.	□	□	□	□
21. A briefing in snorkel skills before visiting a reef nature trail is sensible.	□	□	□	□
22. A well-trained guide leading a snorkel trip on a reef nature trail is sensible.	□	□	□	□
23. A briefing in proper behaviour before snorkel / dive trips for reef protection is sensible.	□	□	□	□
24. Resting platforms for snorkelers are sensible.	□	□	□	□
25. Snorkel activities can become a decisive factor for the quality of coral reefs.	□	□	□	□

26. During my previous snorkel/diving education, environmental protection

played a major role	□ 1
played a minor role	□ 2
was irrelevant	□ 3

Please mark the following assertions with 1 (very important for me) to 4 (absolutely not important for me)
C. On a snorkel trip I would like to have the following facilities:

	(important – not important) 1	2	3	4
27. Sanitary facilities (toilet, shower)	□	□	□	□
28. Sunshades	□	□	□	□
29. Kiosk (snacks, cool drinks, ice cream)	□	□	□	□
30. Bar (cool drinks, alcoholic drinks)	□	□	□	□
31. Rental of snorkel-equipment	□	□	□	□
32. Snorkelling lesson	□	□	□	□
33. Children's playground	□	□	□	□
34. Sunbathing (sun bed, etc.)	□	□	□	□
35. Lifeguard	□	□	□	□
36. First aid	□	□	□	□

37. For me a guided snorkel trip on a reef nature trail can cost:

< 10 €	11-20 €	21-30 €	31-40 €	> 40 €
☐	☐	☐	☐	☐

38. For me a snorkel trip on a reef nature trail including a guide-book-lending fee can cost:

< 10 €	11-20 €	21-30 €	31-40 €	> 40 €
☐	☐	☐	☐	☐

D. Ecology questions

39. Are you involved with biology or ecology on a private or professional level?

	Yes	No
Professional:	☐	☐
Hobby:	☐	☐

40. My previous knowledge of reef ecology comes from following sources:

	Yes	No
Education (university, etc.)	☐	☐
Diver education (specialty naturalist etc.)	☐	☐
Technical literature (books, magazines)	☐	☐
Conversation with other snorkelers / divers	☐	☐
No previous knowledge	☐	☐

41. Coral reefs are species-rich habitats. true ☐ false ☐

42. Coral reefs are mainly found in tropical seas. true ☐ false ☐

43. A dense cover of algae is a sign for a healthy coral reef. true ☐ false ☐

44. Empty shells of mussels and snails are ecologically important. true ☐ false ☐

45. Many juvenile fish find hiding space in the caves and channels of the reef. true ☐ false ☐

46. Corals are sessile animals. true ☐ false ☐

47. Coral reefs are also present in freshwaters. true ☐ false ☐

48. Hermit crabs live in empty shells. true ☐

false ☐

49. Single-celled algae live in symbiosis with corals. true ☐ false ☐

50. Clownfish change their sex during their life. true ☐ false ☐

51. The name “surgeonfish” comes from their ingredients used by Egyptians for healing. true ☐ false ☐

52. Parrotfish mainly feed on algae. true ☐ false ☐

53. Juvenile Emperor-Angelfish look different than adult individuals. true ☐ false ☐

54. Sea urchins feed on plants. true ☐ false ☐

55. Sea stars feed on plants. true ☐ false ☐

56. Crown-of-thorns starfish feed on corals. true ☐ false ☐

57. Corals recover fast when broken. true ☐ false ☐

58. Feeding marine animals (e.g. sharks, morays, etc.) is an effective method of reef protection. true ☐ false ☐

59. Global warming is a major threat to coral reefs. true ☐ false ☐

60. Corals can easily be damaged and die when touched. true ☐ false ☐

61. Applying fertilizers to threatened reefs is an effective method of reef protection. true ☐ false ☐

62. Implementing protected areas, excluding tourism and fishing from threatened areas, is an effective method of reef protection. true ☐ false ☐

63. Sedimentation (sand dispersal, etc.) can threaten tropical reefs. true ☐ false ☐

64. Dive / snorkel activities have no effects on the condition of coral reefs. true ☐ false ☐ false ☐

Danksagung

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CURRICULUM VITAE

Name: Judith Sabine Hannak
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Education

- 1983-1987: Primary School, Vienna
- 1987-1991: Junior High School, Vienna
- 1991-1995: Senior High School, Vienna
- 1995-1998: Medicine, University of Vienna
- 1997-2006: Biology, University of Vienna
- 2006-2008: Zoology, University of Vienna

Research visits

- 2003: Field study on Sea Turtles, Calis/Turkey
- 2003: Field course: Marine environments, Rovinj/Croatia
- 2003: Field course: Coral reef ecology, SEC Sinai Environmental Center, Dahab/Egypt
- 2005: Shark project volunteer, Los Roques/Venezuela
- 2006: Field course: Marine ecology, Calvi/Corsica/France
- 2007: Field course: Coastal environments, California/USA
- 2007: Field study: DAED (Dahab Association for Environmental Development), Dahab/Egypt

Skills

- Underwater fieldwork methods (including Pulse Amplitude Modulated Fluorometry, Diving PAM)
- Reef-check course (University of Vienna, Dahab/Egypt)
- Digital underwater macro-photography
- Microscopy techniques (light microscopic methods, fluorescence microscopy, laser scanning microscopy and computer enhanced video- and UV-microscopy)
- Dissection skills (Medical University of Vienna)
- MS-Office
- Image processing (Adobe Creative Suit)
- Statistical methods (SPSS 15)
- SSI Diving Instructor

Languages

- German
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Vienna, 03.11.2008

Judith S. Hannak