DIPLOMARBEIT

Titel der Diplomarbeit

Evaluation of reef condition of a potentially threatened shallow-water reef in the Red Sea (Sinai, Egypt)

Zur Erlangung des akademischen Grades

MAGISTRA DER NATURWISSENSCHAFTEN (Mag. rer. nat)

Verfasser/in:	Sarah Kompatscher
Matrikel-Nummer:	0107224
Studienrichtung (lt. Studienblatt):	Biologie/Zoologie
Betreuer:	Prof. Dr. Jörg A. Ott
Wien am, 15.01.2009	

Danksagung

Zu allererst möchte ich mich bei meinen Betreuern Dr. Jürgen Herler und Dr. Michael Stachowitsch für die großartige Unterstützung bedanken; nicht nur fachliche Gespräche, vor allem auch aufmunternde Worte während der Feldarbeit und danach trugen wesentlich zum gelingen dieser Arbeit bei.

Großer Dank geht auch an Prof. Dr. Jörg Ott, der mir die Möglichkeit zur Durchführung dieser Arbeit gab, für die Betreuung und Korrektur.

Bedanken möchte ich mich auch bei der Arbeitsgruppe Phykologie, welche mir während der Diplomarbeit stets mit Rat zur Seite stand, meinen Gefährten im Studium, meinen langjährigen Arbeitskollegen und Chefs und natürlich meinen Freunden.

Nicht zuletzt möchte ich mich bei meinen Eltern bedanken, die mich meinen Weg gehen ließen und mich dabei immer unterstützt haben.

CONTENTS

1 Einleitung

Korallenriffe zählen mitunter zu den schönsten, produktivsten und artenreichsten Ökosystemen der Erde (Birkeland 1997; Bryant et al. 1998). 8% der Weltbevölkerung leben innerhalb 100 km Entfernung von der Küste (Bryant et al. 1998) und sind somit vom Meer in Form von Fischereierträgen (Birkeland 1997), Erholungs- und Freizeitangeboten (Bryant et al. 1998), wobei Küstenschutz eine enorme Bedeutung hat, abhängig. Schätzungen zufolge sind 600 000 km^2 des Meeresbodens von seicht lebenden Korallen bedeckt (Birkeland 1997), welche ein Sechstel der Küstenlinien der Welt säumen (Birkeland 1997) und ein Viertel der marinen Fischarten beherbergen (Wilkinson 2004).

Im Roten Meer ist die Fauna äußerst vielfältig, welche sich in der Artenanzahl von Korallen (ca. 300 riffbildende) und Fischen (über 1400) widerspiegelt (Wilkinson 2004) und zudem viele endemische Arten aufweist (Schuhmacher 1988; Bryant et al. 1998; Wilkinson 2004). Das Rote Meer, im Speziellen der Golf von Aqaba, stellt einen weitgehend abgegrenzten Wasserkörper dar, welcher die nördlichste Ausbreitung von Korallenriffen (29.5° N) bildet (Al-Rousan et al. 2003). Die Region des nördlichen roten Meeres weist ein arides Klima mit einer mittleren Verdunstung von $1m^3$ pro Tag auf (Loya 2004), welche durch Nordwinde begünstigt wird. Dadurch ist die Salinität erhöht (40 – 41.5‰) (Loya 2004) und die Wassertemperaturen schwanken im Jahresverlauf zwischen 20 und 28°C (Schuhmacher 1988; Loya und Klein 1997; Loya 2004). Die Gezeiten im Golf von Aqaba haben einen maximalen Hub von 1m, wobei extreme Springtiden eher selten auftreten (Loya 2004). In manchen Fällen können diese jedoch zur Austrocknung ganzer Riffdachabschnitte führen (Loya 2004). Der steile Küstenstreifen entlang des Roten Meeres ist beinahe ausschließlich von Saumriffen (erstrecken sich entlang der Küste) geprägt (Schuhmacher 1988). Die Längserstreckung kann dabei ohne Unterbrechung mehrere Kilometer betragen, die laterale Ausdehnung, je nach Abschüssigkeit des Meeresbodens, bis zu 100 m (Schuhmacher 1988).

Vor allem durch das relativ langsame Wachstum von riffbildenden Steinkorallen ist das weltweite Riffwachstum durch Faktoren wie Meeresspiegelschwankungen (Kennedy und Woodroffe 2002), Korallenbleiche und -krankheiten (Wilkinson 2004) bedroht. Zudem befinden sich die meisten Korallenriffe in gefährlichem Rückgang (Wilkinson 2004). Ursachen sind Küstenverbauung, anthropogene Verschmutzung wie Nährstoff- und Sedimenteintrag (Nyström et al. 2000), destruktive, nicht nachhaltige Fischereimethoden (Wilkinson 2004), unkontrollierter Tourismus und die weltweite Klimaveränderung (Nyström et al. 2000; Hughes et al. 2003; Wilkinson 2004). Letztere wird durch Erhöhung der

Oberflächentemperatur (Hoegh-Guldberg 1999), verstärkte UV-Strahlung (Anthony und Kerswell 2007) und den Meersspiegelanstieg deutlich (reviewed in Nyström et al. 2000). Davon ist vor allem die Gezeitenzone, die produktivste Zone eines Korallenriffs (Anthony und Kerswell 2007), betroffen. Die globale Klimaerwärmung stellt wohl eine der stärksten Bedrohungen der letzten Jahre dar und wird als Hauptursache für vermehrtes Auftreten von Korallenbleichen, sowie die Veränderung des Meerwasser-Chemismus angesehen (Hughes et al. 2003; Kleypas et al. 2006). Korallenbleiche, der Farbverlust der Koralle, ist die Folge von stressbedingtem Ausstoß der symbiotischen Algen oder Verlust der Photosynthesepigmente (zusammengefasst von Brown 1997 und Rosenberg und Ben-Haim 2002), wodurch die Koralle schlussendlich stirbt. Der Klimawandel und das Zusammenwirken mehrerer Stressfaktoren (Hughes et al. 2003) könnten somit auf lange Sicht zur Zerstörung ganzer Korallenriffe führen (Wilkinson 2004), wobei vor allem Korallen der Art *Acropora* besonders empfindlich auf Stress reagieren (Riegl und Velimirov 1991; Anthony und Kerswell 2007).
Sedimenteintrag durch Küstenverbauung oder -erosion (Riegl und Velimirov 1991; Nyström et al. 2000), aber auch durch Taucher und Schnorchler (z.B. Barker und Roberts 2004; Dirnwöber und Herler 2007) verursachte Sedimantation ist ein zusätzlicher Grund für Korallenschädigung (Rogers 1990; Zakai und Chadwick-Furman 2002). Diese führt folglich zur Abnahme der Korallenbedeckung, Veränderung der Korallengemeinschaft (Nyström et al. 2000; Bellwood et al. 2004) und vermehrtem Korallensterben (Munday 2004). Die Idee zur Überprüfung der „Taucher-Belastbarkeit" eines Riffs (Davis und Tisdell 1995), welche durch die maximale Anzahl an Tauchgängen pro Tauchgebiet pro Jahr definiert ist, und deren Umzusetzung, bleibt ein wichtiges und nützliches Mittel zum Riffmanagement (Zakai und Chadwick-Furman 2002). Dieses Konzept könnte auf die allgemeine Nutzung des Riffs ausgeweitet werden.
Korallenschäden wie Bruch, Gewebeverlust und Algenaufwuchs (Riegl und Velimirov 1991) werden vermehrt im Seichtwasserbereich von Riffen festgestellt (Wilkinson 2004). Zudem spielt Netzfischerei und sog. „trampling" (Hawkins und Roberts 1993) eine bedeutende Rolle. Dass Korallenbruch mit der Wuchsform einhergeht, ist vor allem daran ersichtlich, dass verzweigt wachsende viel anfälliger auf Bruch (Zakai und Chadwick-Furman 2002), wie z.B. durch „reef walker" (Leujak und Ormond 2008) oder Wassersport-Touristen (Riegl und Riegl 1996; Zakai und Chadwick-Furman 2002) sind. Der von Jameson et al. (1999) entwickelte „coral damage index" hat sich hierbei als guter Indikator für den Riffzustand und Schweregrad der Korallenschädigung erwiesen (Zakai und Chadwick-Furman 2002).

Ein weiterer Grund für Korallenschädigung ist die immer häufiger auftretende korallivore Schnecke *Drupella cornus* (Schöpf 2008) die von gebrochenen Korallen angezogen zu sein scheint (Forde 1992 und Morton et al. 2002, zitiert in Schöpf 2008). Bei Populationsausbrüchen, kann sie zur Zerstörung ganzer Riffbereiche beitragen (reviewed in Schöpf 2008), wie sie auch durch ein Massenauftreten des Dornenkronen-Seesterns *Acanthaster planci* (Kotb et al. 2004) verursacht werden kann.

Zahlreiche Studien haben bereits gezeigt, dass gefährdete Riffe einen negativen Einfluss auf die Artzusammensetzung und Verteilung von Fischen haben (Jones et al. 2004; Munday 2004; Dirnwöber und Herler 2007; Schiemer et al. 2008). Die Abnahme von Korallen und die Änderung der Korallengemeinschaft im Riff führt dabei zu einer Abnahme der Mannigfaltigkeit der Fischfauna (Jones et al. 2004). Insbesondere korallenspezialisierte Arten werden negativ beeinträchtigt (Jones et al. 2004; Dirnwöber und Herler 2007; Schiemer et al. 2008), wodurch lediglich ein kleiner Anteil „quickly reaching maturity“ Arten bestehen bleibt (Connell 1978).

Riegl und Velimirov (1991) beschrieben die Schwierigkeit Korallenschäden zu deuten, und fanden es oftmals sehr schwierig zwischen natürlichen und anthropogenen Schäden zu unterscheiden. Zudem sind die Folgen von Schadstoffeintrag auf verschiedene Korallenarten oft schwer abzuschätzen (Riegl und Velimirov 1991), wodurch Langzeitstudien dringend nötig werden (Rinkevich und Loya 1977; Riegl und Velimirov 1991; Edinger et al. 1998; Zakai und Chadwick-Furman 2002). Korallenriffe sind entgegen der „natürlichen Balance“ von terrestrischen Lebensräumen wenig ausgeglichen (Birkeland 1997). Das Auftreten natürlicher Störungen und gleichzeitig steigender Druck durch anthropogene Einflüsse erschweren eine Systemstabilität umso mehr (Bythell et al. 2000). Der von Connell (1978) entwickelten „Hypothese der mittleren Störungen“ („The intermediate disturbance hypothesis“), laut der weniger konkurrenzfähige Arten nur aufgrund von mäßigen Störungen koexistieren können, liegt allerdings ein evolutiver Zeitraum zugrunde (Connell 1978; Nyström et al. 2000). Dieser ist jedoch wiederum durch quantitativ steigende anthropogene Störeinflüsse nicht gegeben (Nyström et al. 2000).

In dieser Studie wurde der Riffzustand nördlich des Napoleon-Riffs (Golf von Aqaba, Rotes Meer, Ägypten) untersucht. Bei diesem Gebiet handelt es sich um ein Seichtwasser-Saumriff, welches im Unterschied zum weiter nördlich gelegenen Tauchplatz „Islands“ weniger beeinträchtig ist. Trotzdem ist dieser Riffabschnitt durch die Zunahme an Wassersport-Touristen und zusätzlichen natürlichen Störungen wie Springtiden-Ebben, gefährdet. In einem Areal von 23 500 m² (Fig. 1) wurden insgesamt 51 Transekte á 50 m gelegt. Jeden Meter wurde ein Substratpunkt (Tab. 1) ermittelt, welcher zudem mit Foto dokumentiert wurde. Dies diente zur späteren einheitlichen Bestimmung der Korallen („species index“). Für Langzeitmonitoring wurden zudem alle 50 x 50 m die (Plots, Fig. 1) GPS Koordinaten registriert.

Das folgende Projekt wurde initiiert um den Gefährdungsgrad dieses Riffes festzustellen und die Notwendigkeit eventueller Schutzmaßnahmen zu prüfen und in weiterer Folge, ob eine Regelung für die momentane und zukünftige Nutzung des Riffareals nördlich des Napoleon-Riffs mittels Managementplans benötigt wird.

Evaluation of reef condition of a potentially threatened shallow-water reef in the Red Sea (Sinai, Egypt)

S. Kompatscher

Department of Marine Biology, University of Vienna, Althanstraße 14
A – 1090 Vienna, Austria

2 Abstract

The coral reefs of the world are under threat, whereby the reefs of the northern Red Sea, as a case study, are increasingly suffering under a growing number of tourists. Foremost the reef flat and reef crest are affected through natural and anthropogenic stressors. To assess the reef condition, a shallow-water reef at the lagoon of Dahab (Sinai, Egypt) was investigated. On the fringing reef flat north of Napoleon-Reef, in an area of 23 500 m², transects were laid and the substrate type was recorded. For further analysis (species index) the photo line point intercept method was used. For long-term monitoring, GPS coordinates were recorded every 50 x 50 m. Around 84% of the coral colonies at the reef flat already showed signs of damage such as breakage, partial mortality or algal overgrowth. The high abundance of coral damage was correlated with the decline of coral coverage. This is known to alter the composition of coral communities and to reduce fish abundance, ultimately impacting ecosystem stability. Therefore the reef area north of Napoleon-Reef needs to be managed to protect it from further threats and ensure recovery of already damaged areas.

3 Introduction

As the name fringing reefs implies, they border the coast. Fringing reefs consist of coral reefs that are close to or often continuous with the shoreline. The degree of expansion towards the sea depends on how precipitous the sea bottom is. Such “lateral” growth – up to 100 m – proceeds by cementation to coral rubble on the outer reef slope (Schuhmacher 1988). Through bio-corrosion and erosion, the shallow-water area of the reef can form a lagoon, yielding a so-called lagoon fringing reef. The steeply sloping Red Sea coastline is almost exclusively covered by fringing reefs (Schuhmacher 1988). Reef growth worldwide is endangered by relative sea-level movements, coral bleaching and global climate change (Wilkinson 2002), although ultimately these factors are apparently not the dominant factors which influence coral growth (Kennedy and Woodroffe 2002; Wilkinson 2002). The effects of pollutants on different coral species are often difficult to assess (Riegl and Velimirov 1991), and long-term investigations are necessary for quantification (Rinkevich and Loya 1977; Riegl and Velimirov 1991; Edinger et al. 1998; Zakai and Chadwick-Furman 2002). Beside natural stress on coral reefs, the growing world human population entails excessive terrestrial runoff, sea water pollution, overfishing, coral mining, increasing water sport tourism, all of which are associated with reef degradation and changes in reef community structure (Wilkinson 2004; Dikou and van Woesik 2006).

Riegl and Velimirov (1991) found that in the Red Sea (Hurghada, Egypt and Eilat, Israel), coral breakage was from all observed damages the most frequent category and, moreover, significantly higher at reefs with high visitor frequency. The concept of diver carrying capacity would be an important tool for coral reef management (Davis and Tisdell 1995; Zakai and Chadwick-Furman 2002). This would limit the dives per site per year, based on the number of divers a reef can tolerate without becoming significantly degraded. Sedimentation, e.g. through divers or snorkellers, is a further cause of coral damage (Rogers 1990; Zakai and Chadwick-Furman 2002). It leads to a decline of coral cover, change of coral communities and increased partial mortality (Rogers 1990). Riegl and Velimirov (1991) found that in all damage categories (breakage, tissue loss, algal overgrowth) the most frequent damage occurred within the first ten meters depth (see also Leujak and Ormond 2008). Coral damage occurs mainly due to tourism (e.g. through divers or snorkellers) (Zakai and Chadwick-Furman 2002; Loya 2004), but fishermen also play a role in coral breakage through trampling (Leujak and Ormond 2008) and net fishing. Partial mortality along with a “coral damage index” (Jameson et al. 1999) have been shown to be good indicators for reef condition and to estimate the severity of coral damage due to natural or anthropogenic stressors.

The Gulf of Aqaba is the north-eastern extension of the desert-enclosed Red Sea (Fig. 1). The Gulf represents the northernmost limit for coral reefs (29.5° N) (Al-Rousan et al. 2003). The coral reef system of the Red Sea, as well as of the Gulf of Aqaba itself, has a special biodiversity, which is shown in the species quantity of corals (ca. 300 hermatypic – reef-building corals) and fishes (over 1400) (Wilkinson 2004). It is also high in endemic species (Schuhmacher 1988; Bryant et al. 1998; Wilkinson 2004). These reefs are particularly endangered by anthropogenic stress (Fishelson 1995; Wielgus 2004). This semi-isolated basin is separated from the Red Sea by the Straits of Tiran (Al-Rousan et al. 2003), with an average net evaporation of 1 m^3 per day, and an arid climate (Loya 2004). As a result of predominant northern winds, the Gulf's waters are extremely saline, ranging between 40 and 42‰, with water temperatures ranging from 20.5 (winter, northern Gulf) up to 28°C (summer, southern Gulf) (Schuhmacher 1988; Loya and Klein 1997). The maximal range of tides in the Gulf is around 1 m and therefore small (Loya 2004). Springtide ebbs, where entire reef flats can be exposed to the air, are quite rare (Rosenberg and Loya 2004), but can then cause complete desiccation of the reef flat (Loya and Klein 1997; Rosenberg and Loya 2004).

The survey area, north of Napoleon-Reef (28°28'00'' N, 34°30'21'' E) at the lagoon of Dahab (Sinai, Egypt) is such a shallow-water reef. The reef flat is moderately exposed to waves. For example, the more sheltered reef flat area north of Napoleon-Reef has a higher diversity of *Acropora* corals, whereas the reef slope is less species rich compared to the reef slope of nearby dive sites (Dirnwöber and Herler 2007). This area is less affected through anthropogenic stress than the nearby "Islands" site, which is highly frequented by an increasing number of snorkellers and divers. However, this reef is under threat of direct physical damage due to increasing water sports tourism and additional natural impacts such as coral damage after springtide ebbs (Herler, pers. obs.). The present project was therefore designed to assess the condition of this potentially threatened fringing reef and to determine whether this reef is under severe threat and whether management measures are necessary to protect it.

Via photo point intercept transect method, in an area of 23 500 m^2 substrate was examined. 51 transects á 50 m were laid, whereof at each meter a substrate point (11 categories, Tab. 1) was fathomed and photographed for further analysis. For potential follow-up long-term monitoring, GPS-coordinates of every 50 m x 50 m (or 50 m x 40 m) quadrats (plots, Fig. 2) were taken.

4 Material and Methods

4.1. Study area

Sampling was conducted between July and November 2007 at Dahab in the southern Gulf of Aqaba, northern Red Sea (Sinai, Egypt). The study site is situated on a fringing reef flat, approximately 500 m north of Napoleon-Reef (28°28’00’’ N, 34°30’21’’ E) at the lagoon of Dahab (Fig.1).

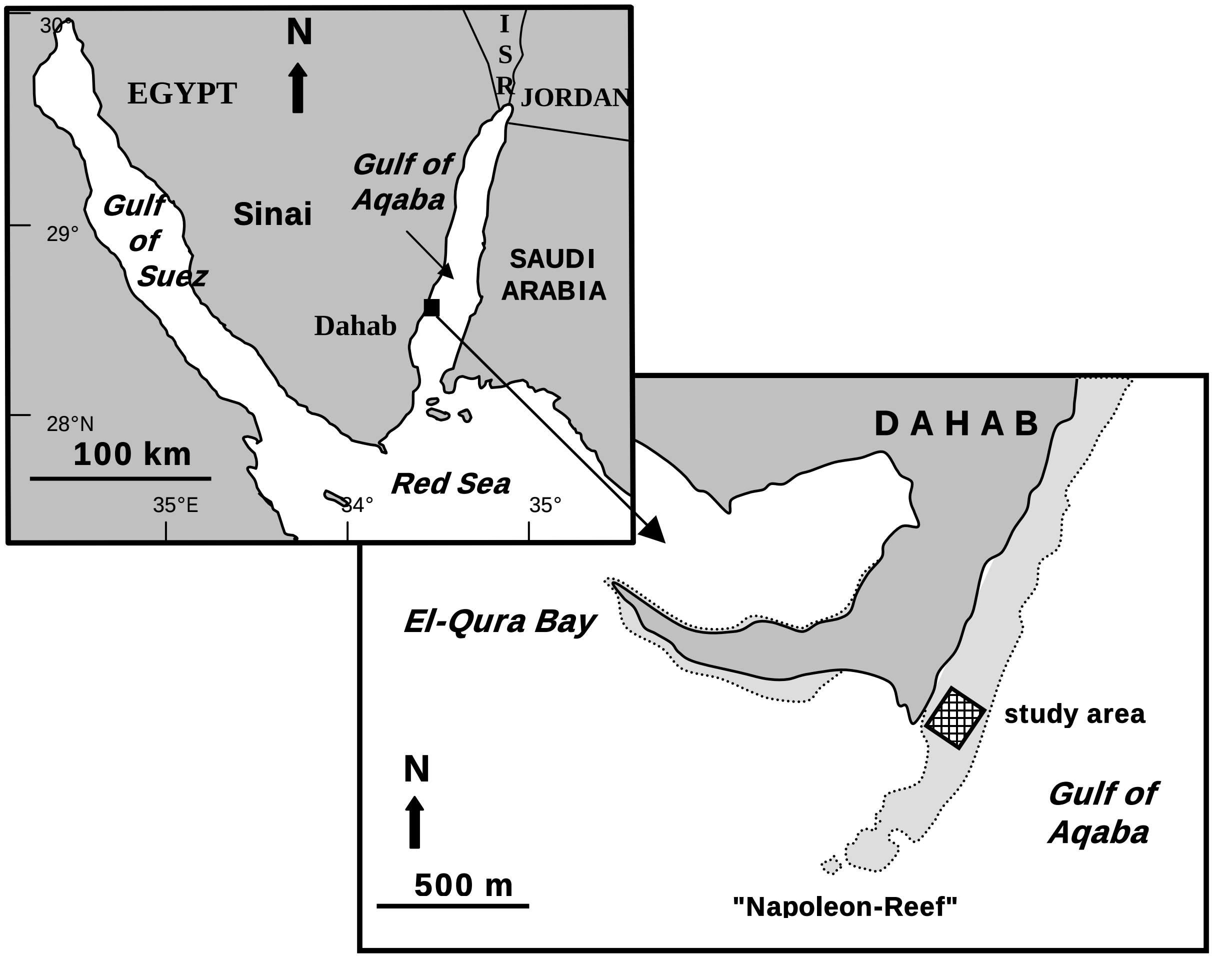

Fig. 1: Sampling area near Dahab, Sinai. Insert shows the Gulf of Aqaba, northern Red Sea, and the Sinai Peninsula, Egypt. The dotted line indicates the course of the reef crest and the chequered square the study area where transects were taken.

To determine the condition of this potentially threatened fringing reef, used as a day trip destination for many snorkellers and as a fishing area for locals, an area of 23 500 m² was examined.

Based on a satellite photo by Google Earth, the area was divided into 50 m x 50 m or rather 50 m x 40 m quadrats (plots I - X, Fig. 2). The vertices of the grid pattern (balloons, Fig. 2) were fixed by GPS-coordinates in Google Earth. They were used for potential follow-up long-term monitoring, which is the most common approach to provide data and information on the status and long-term trends of coral reefs.

4.2. Sampling design

Sampling was carried out by visual census and photo documentation, snorkelling on the reef flat (tidal rage between 0.4 m and 0.9 m; WXTide32 version 4.7).

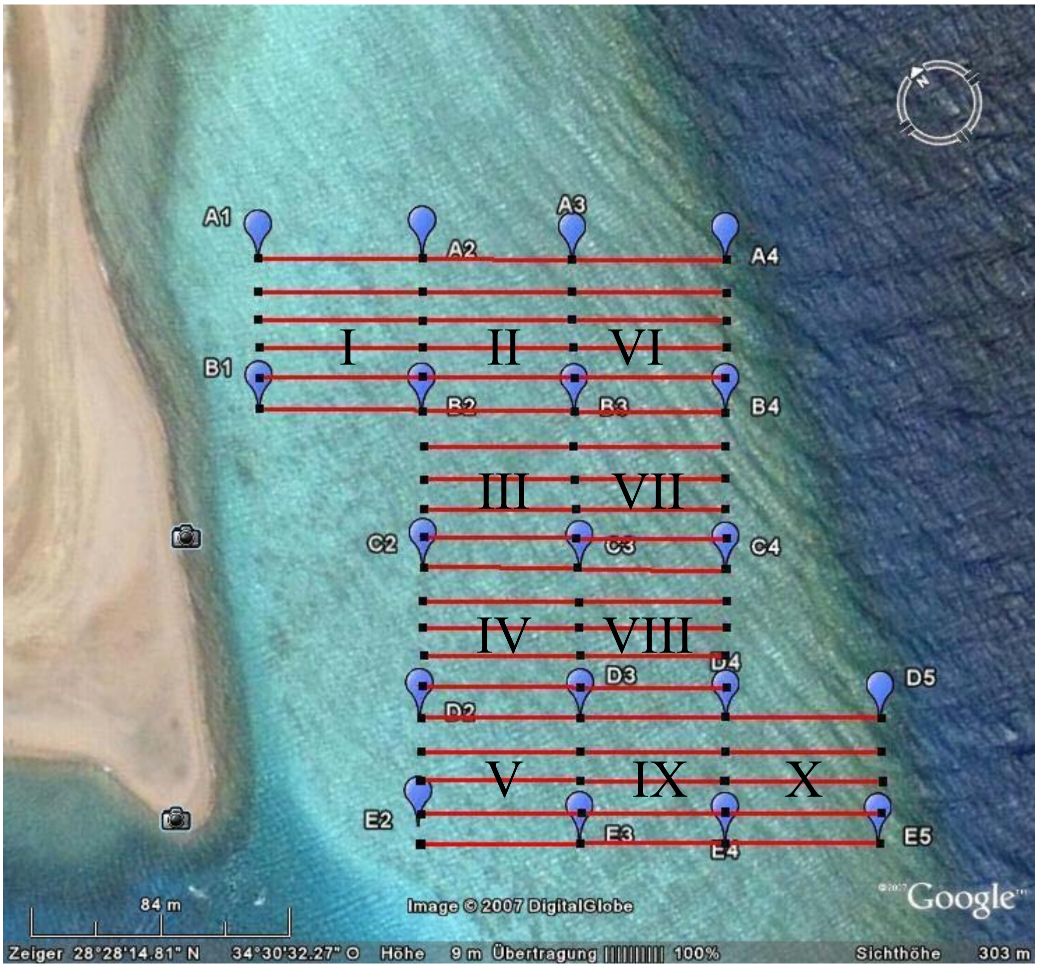

Fig. 2: Satellite photo (Google Earth 4.3 (Beta)) of the sampling area north of Napoleon-Reef with transects (red lines), GPS-markers (blue balloons) and ten plots (I to X) for every 50 m x 50 m and 50 m x 40 m quadrats, respectively.

Transects were laid perpendicular to the shoreline and parallel to each other every 10 m (red lines Fig. 2). The transect length varied from 100 to 150 m (subdivided into two or three 50 m transects) depending on the reef flat width (Fig. 2). A total of 51 transects á 50 m were surveyed by the photo point intercept transect method. A measuring tape of 50 m length was used as a transect line. At each meter the substrate point (Tab. 1) was fathomed, recorded on an underwater datasheet and photographed, yielding 2550 data points.
In the field, markers (A1 to E5, Fig. 2) were placed at the GPS locations. The 19 markers (blue balloons, Fig. 2) – hooks attached to coral rock with a dowel – were provided with a numbered tag. For every marker position GPS coordinates (App. 1) were taken with a handheld GPS (Garmin Geko 201) to aid future relocation.
The investigation area was divided into four zones (A to D) from north to south and in four sections (1 to 4) from west to east. Furthermore ten plots (I to X) of 50 m x 50 m and 50 m x 40 m, respectively, were defined (Fig. 2).

4.3. Photo documentation

To determine the reef condition and the proportion of different reef substrate cover components, the photo point intercept transect method was used. In this method, a substrate point (Tab. 1) was identified every meter and documented on an underwater datasheet and with a photo (App. 1) for further analysis (to classify corals). Such a photographic survey can be archived, thereby providing a long-term record and later re-examined and new sets of data can be generated. Substrate was classified in eleven categories: algae, broken coral colony, broken coral fragment, coral rock, dead coral, dead coral with algae, hard coral, rubble, rubbish, soft coral and sand. For live corals, four classes of partial mortality (PM) (1: < 25%, 2: 26% - 50%, 3: 51% - 75%, 4: 76% - 99%) and four classes of broken corals (BC) (1: < 25%, 2: 26% - 50%, 3: 51% - 75%, 4: 76% - 99%) were defined. Live corals were mostly identified at genus level, except for *Acropora*, which above a minimum diameter of around 10 cm was identified at species level.

4.4. Statistical analysis

4.4.1. Hierarchical cluster analysis

Hierarchical cluster analyses were performed using PC-ORD v4.25. To arrange substrate abundance of transects into cluster groups, agglomerative hierarchical cluster analysis (AHCA) using Sorensen (Bray-Curtis) distance and flexible beta (β = -0.25) linkage function was used. “Flexible beta with β = -0.25 is a space-conserving method that avoids distortion and has less propensity to chain" (Reese et al. 2005). To determine the optimum number of cluster groups, a significance test and effect size (*A* = within group agreement) of groups using a multi-response permutation procedure (MRPP, Sorensen distance) was done (Reese et al. 2005).

Tab. 1: Abbreviations for selected substrate categories in the investigation area north of Napoleon-Reef, Gulf of Aqaba, northern Red Sea.

Substrate	Abbrev.	Substrate	Abbrev.
algae	AL	hard coral	HC
broken coral colony	BCC	coral rubble	RB
broken coral fragment	BCF	rubbish	RU
coral rock	CR	soft coral	SC
dead coral	DC	sand	SD
dead coral with algae	DCA		

4.4.2. Community analysis

"The relative abundance (RA) of each genus was calculated according to its contribution to living cover:

$$RA = \frac{P_i}{P_{total}}$$

where P_i = pooled living coverage of the i^{th} genus from all transects at a given site (plot or exposition) and P_{total} = pooled total living coverage of all genera in all transects at a given site (plot or exposition). The resulting values were then transformed into abundance categories (%): not recorded (RA = 0), uncommon (RA = 0.1 – 1), common (1 < RA < 10), abundant (RA = 10 – 20) and dominant (RA > 20)" (Perkol-Finkel and Benayahu 2004).

As a second measure of the information entropy of the diversity of the substratum along the transect, the Shannon-index H',

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

was calculated. H' gives a measure of diversity in categorical data where n_i = the number of individuals in each genus (the abundance of each genus), S = the number of genera, N = the total number of all individuals and p_i = the relative abundance of each genus is. p_i was calculated as the proportion of individuals of a given genus to the total number of individuals in the community $\frac{n_i}{N}$. The advantage of the Shannon-index is that it takes into consideration the number of genera and the Evenness (E, measure of diversity) of the genus.

4.4.3. Coral Damage Index (CDI)

Two forms of physical damaged corals, which best incorporate past (rubble) and more recent (broken coral) degradation, are used for the coral damage index (CDI) (Jameson et al. 1999). It is designed to determine whether this reef is under threat and to obtain the intensity of physical damage to coral. As "hot spots" characterized sites have in any transect a percent broken coral colonies (BCC) $\geq$ 4% or a percent cover coral rubble (CR) $\geq$ 3% (Jameson et al. 1999).

5 Results

5.1. Hierarchical cluster analysis

Cluster analysis of the substrate assemblage per transect yielded a dendrogram (Fig. 3) containing two main clusters with two subclusters each.

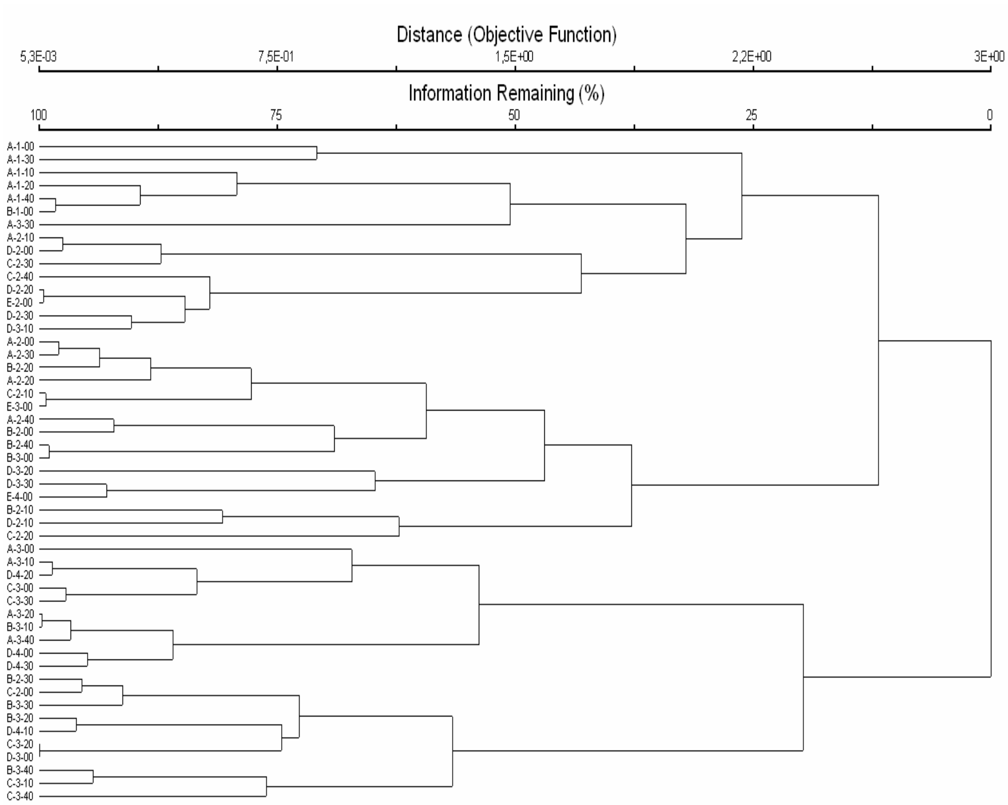

Fig. 3: The dendrogram yielded by a hierarchical cluster analysis of 51 coral reef substrate composition transects shows two main clusters with two subclusters each. The dendrogram is scaled in two ways; by Wishart's "objective function" describing the amount of information remaining, and by the objective function converted into a scale of percentage of information remaining.

Results from a multi-response permutation procedure (MRPP analysis, Tab. 2) found high within-group agreement (*A*) with three clusters (A = 0.26; 20% information remaining). The more negative the test statistic T is (Tab. 2), the stronger the separation between the cluster groups, which means three clusters (one main cluster and two subclusters, Fig. 3) have a stronger and 2 clusters (main clusters) a lower separation.

Tab. 2: Multiple-response permutation procedure (MRPP) results comparing from the different number of cluster groups the information remaining (%), the test statistic *T* which describes the separation between the groups, the chance corrected within-group agreement *A* which describes within-group homogeneity, compared to the random expectation and the *p*-Value. This approach is useful for evaluating how likely it is that an observed difference is due to chance.

Number of clusters	Information remaining (%)	Test statistic	Within-group agreement	*p*-Value
2	12	-13.77	0.17	0.000
3	20	-14.41	0.26	0.000

The clusters follow a west-east distribution, in addition for two clusters named as "sheltered" and "exposed" and for three clusters as "nearshore", "intermediate" and "offshore".
The eleven substrate categories (Tab. 1) were, to reach a higher n in the categories, pooled in five new categories: sand (SD; n = 790), living substrate (LS: algae, hard coral, soft coral; n = 919), dead substrate (DS: coral rock, dead coral, dead coral with algae, rubble; n = 748), broken corals (BC: broken coral colony and broken coral fragment; n = 89) and rubbish (RU; n = 4; not included in further analysis because of low n). In the inner reef (sheltered) there was more than twice as much sand (39.1%) as in the outer reef part (exposed) (18.4%; Fig. 4). Living and dead substrate had higher values in the exposed area (LS: 41.8%; DS: 37%) than in the sheltered (LS: 32.2%; DS: 24.4%). Broken corals (BC) were more often found in the protected area (3.9% related to 2.8% in the exposed area) (Fig. 5).

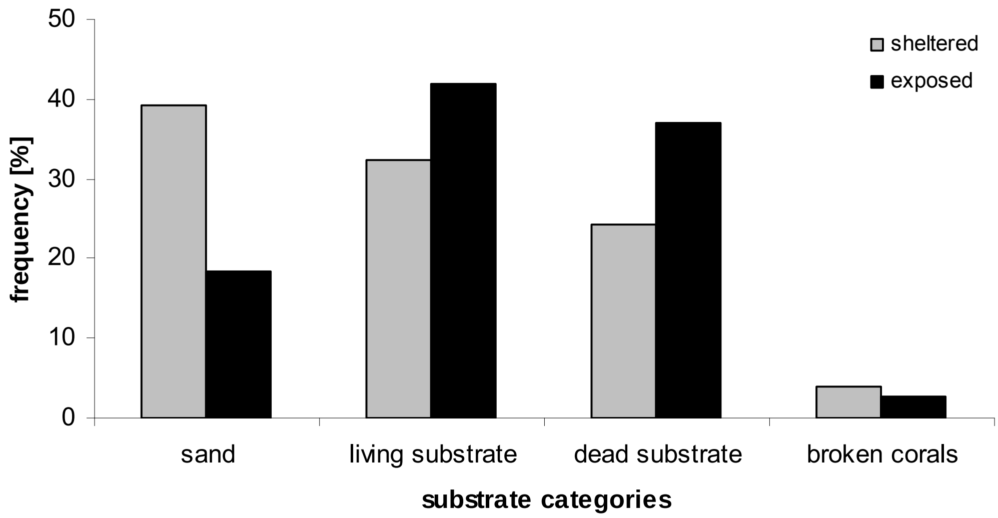

Fig. 4: Frequency [%] of the pooled substrate categories (sand; living substrate: algae, hard coral, soft coral; dead substrate: coral rock, dead coral, dead coral with algae, rubble; broken corals: broken coral colony and fragments) in the sheltered (inner reef part) and exposed (outer reef part) area of Napoleon-Reef (p = 0.005).

Across the three expositions sand decreases significantly from the “nearshore” to the “offshore” reef part (45.9% - 18.4%) meanwhile living (27.6% - 41.8%) and dead substrate (22.9% - 37%) increases significantly (Fig. 5).

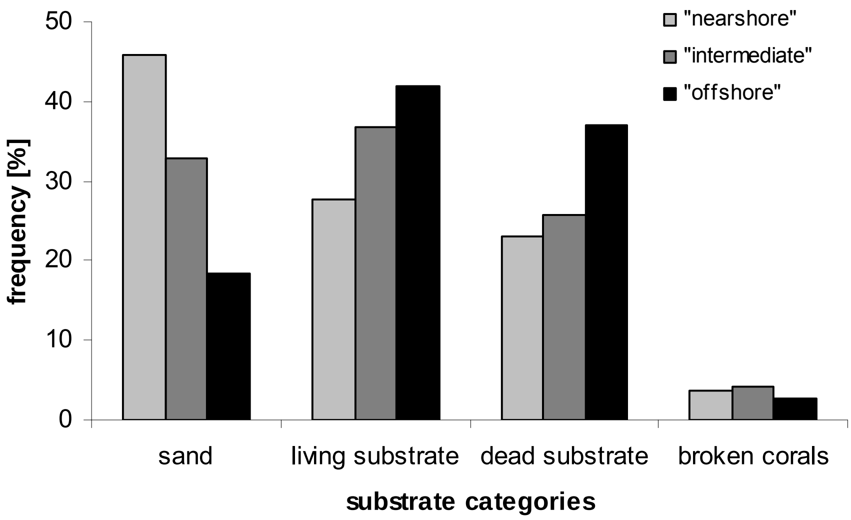

Fig. 5: Frequency [%] of the pooled substrate categories (sand; living substrate: algae, hard coral, soft coral; dead substrate: coral rock, dead coral, dead coral with algae, rubble; broken corals: broken coral colony and fragments) in the “nearshore”, “intermediate” and the “offshore” area of Napoleon-Reef.

5.2. Coral community

Five different families of hard corals were recorded (Tab. 3) in the investigation area. The dominant family was the Acroporidae (59.8% of all corals, Tab. 3), whereby *Acropora* (52.1%) had the highest relative abundance (RA) in every plot, in all four zones as well as in all three expositions (Tab. 4). Another representative, *Montipora* (7.5%), was also common to abundant everywhere. In Pocilloporidae (n = 204), the second most common family with 24.3%, *Stylophora* (19.9% with n = 167) was highly abundant in all plots (except plot II) and *Pocillopora* (4.4%) was common to abundant everywhere. Faviidae (7.6%), represented by *Favites* (2.4%; common in all plots except III and VIII), *Cyphastrea* (2.1%) and 3.1 % others, including four genera with less then 2 % (*Favia*, *Goniastrea*, *Leptastrea*, *Platygyra*). Poritidae (6.9% with n = 58) were represented by *Porites*, and Milleporidae (1.2% with n = 10) by *Millepora*. Unidentified corals contributed 0.2% (n = 2).

Tab. 3: Coral community (families and genera) of the investigation area north of Napoleon-Reef, Gulf of Aqaba, northern Red Sea in abundance [n] and frequency [%].

family	genus	n	%
Acroporidae	*Acropora*	438	52.1
	Astreopora	1	0.1
	Montipora	63	7.5
Σ Acroporidae		502	59.8
Pocilloporidae	*Pocillopora*	37	4.4
	Stylophora	167	19.9
Σ Pocilloporidae		204	24.3
Faviidae	*Cyphastrea*	18	2.1
	Favia	6	0.7
	Favites	20	2.4
	Goniastrea	3	0.4
	Leptastrea	1	0.1
	Platygyra	16	1.9
Σ Faviidae		64	7.6
Poritidae	*Porites*	58	6.9
Σ Poritidae		58	6.9
Milleporidae	*Millepora*	10	1.2
Σ Milleporidae		10	1.2
unidentified	*unidentified*	2	0.2
Σ unidentified		2	0.2
total n		**840**	**100**

Acropora (n = 438) were identified at species level. The most common species was *A. gemmifera* (36.5%), followed by *A. selago* (24.4%), *A. eurystoma* (6.4%), *A. samoensis* (6.2%), *A. variolosa* (5.9%), *A. loripes* (4.3%), *A. subulata* (4.1%), *A. hyacinthus* (3.4%), *A. secale* (2.7%), *A. accuminata* (2.5%) and *A. digitifera* (1.6%).

Tab. 4: Relative abundance (RA: see *Material and methods*) of coral genera with n ≥ 20 in 10 different plots (I to X) according to their contribution to living coral coverage.

genera	I	II	III	IV	V	VI	VII	VIII	IX	X
Acropora	****	****	****	****	****	****	****	****	****	****
Stylophora	***	****	***	****	**	***	***	***	****	***
Montipora	**	**	**	**	**	**	***	***	**	***
Porites	-	**	**	**	**	**	***	***	**	***
Pocillopora	**	**	**	**	***	**	**	**	**	**
Favites	**	**	-	**	**	**	**	-	**	**

Genera are listed with the following categories of relative abundance: - not recorded (RA = 0); * uncommon (RA = 0.1 – 1); ** common (1 < RA < 10); *** abundant (RA = 10 – 20); **** dominant (RA > 20).

The species evenness (Tab. 5) is in plot II at the lowest and in plot VII and VIII at the highest level. Going from nearshore to offshore (west to east), the more genera are present in the sample, they are more even their representation, and the diversity is greater. Going from north to south (zone A to D) the evenness remains almost the same.

Tab. 5: Shannon-Index H' and Evenness E of the coral genera in the different expositions (expo1 = "nearshore", expo2 = "intermediate", expo3 = "offshore"), zones (A, B, C and D) and plots (I to X).

	sheltered	exposed	expo1	expo2	expo3	A	B	C	D
H'	1.47	1.64	1.61	1.31	1.64	1.51	1.34	1.56	1.62
E	0.56	0.66	0.65	0.53	0.66	0.61	0.61	0.68	0.65

plot	I	II	III	IV	V	VI	VII	VIII	IX	X
H'	1.52	1.21	0.93	1.41	1.51	1.62	1.60	1.53	1.38	1.73
E	0.69	0.58	0.45	0.64	0.73	0.70	0.77	0.79	0.60	0.69

5.3. Partial mortality

The relative frequency of coral families among all with or without partial mortality (PM, Fig. 6A) shows, that Acroporidae (n = 502) were the most affected with 44% PM, followed by Pocilloporidae (n = 204) with 20.1%, Faviidae (n = 64) with 6.9%, Poritidae (n = 58) with 6.2% and Milleporidae with 0.7%.

Among all coral genera (Fig. 6B), *Porites* (n = 58) was with 89.7% of all coral colonies the most affected genus by any partial mortality categories, followed by *Stylophora* (n = 167) with 82.6%, *Montipora* (n = 63) with 77.8% and *Acropora* (n = 438) with 73.1%. Genera with n < 40 were pooled in "others" (*Astreopora*, *Cyphastrea*, *Favia*, *Favites*, *Goniastrea*, *Leptastrea*, *Millepora*, *Platygyra*, *Pocillopora* and unidentified genera; n = 114) and yielded a partial mortality of 78.2%.

Within *Acropora* (Fig. 6C), *A. eurystoma* (n = 28) was with 85.7% of all coral colonies the most affected by any partial mortality category, followed by *A. variolosa* (n = 26) with 84.6%, *A. selago* (n = 107) with 75.7% and *A. gemmifera* (n = 160) with 73.1%. *A. samoensis* (n = 27) was the species with the least partially dead colonies (n = 40.7%). Species with n < 20 were again pooled (*A. acuminata*, *A. digitifera*, *A. hyacinthus*, *A. loripes*, *A. secale*, *A. subulata* and unidentified *Acropora)* and had a partial mortality of 72.2%.

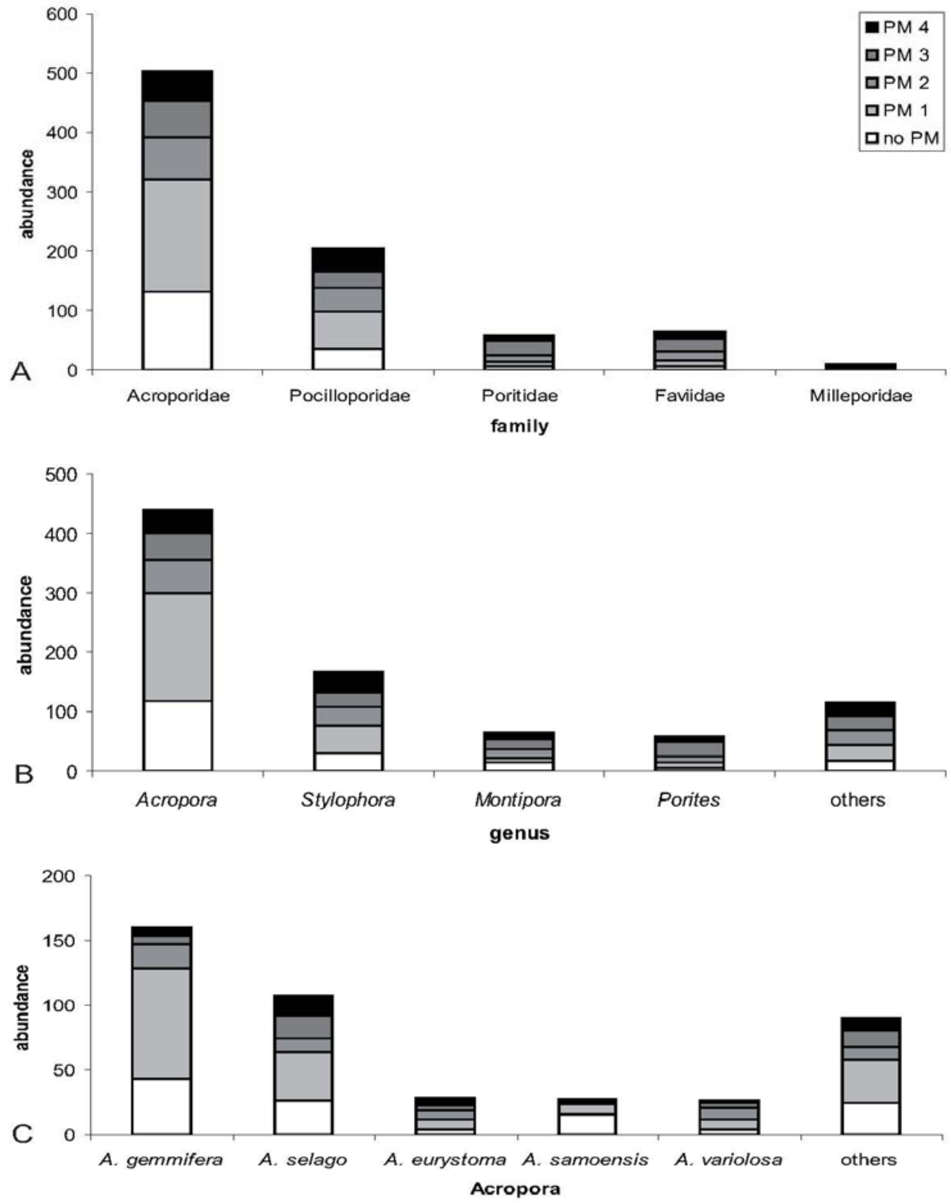

Fig. 6: Abundance of partial mortality (PM) categories (no PM = 0%, PM 1 = < 25%, PM 2 = < 50%; PM 3 = < 75% and PM 4 = > 75%) across **A**: family, **B:** genera (others with n < 40: *Astreopora, Cyphastrea, Favia, Favites, Goniastrea, Leptastrea, Millepora, Platygyra, Pocillopora* and unidentified genera) and **C:** Acropora species (others with n < 20: *A. acuminata*, *A. digitifera*, *A. hyacinthus*, *A. loripes*, *A. secale*, *A. subulata* and unidentified *Acropora*).

The abundance of PM was positively correlated with live coral cover (HC and BCC combined; R^2 Linear = 0.866; Fig. 7). The average PM-rate was 77% (± 11 St.D) per transect.

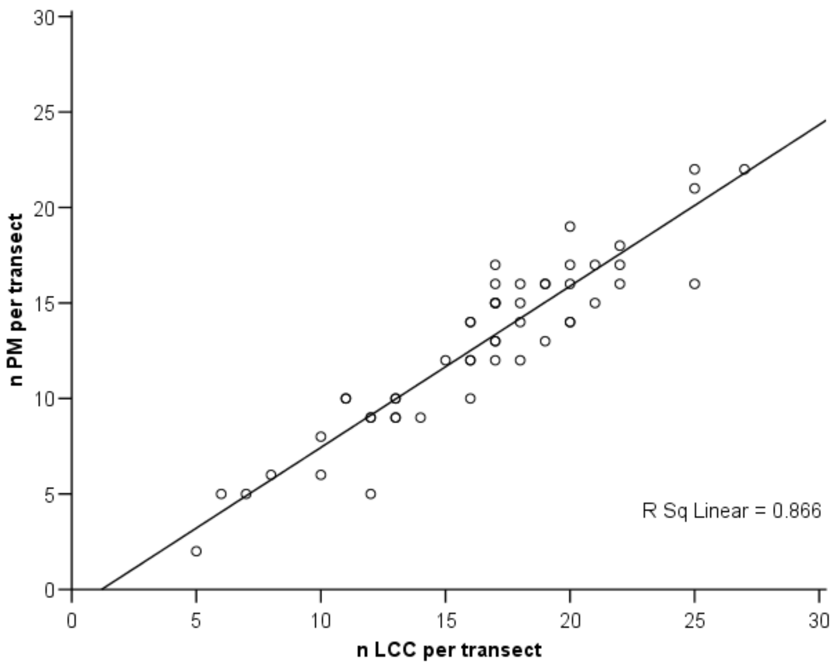

Fig. 7: Linear regression between live coral coverage (LCC: unbroken and broken coral) of 51 line point intercept transects and partial mortality (PM) per transect (R^2 linear = 0.866).

The amount of PM per LCC ranged between 68.3% (plot I with a LCC of 20%) and 85.1% (plot X with a LCC of 38%) while the LCC per plot ranged between 20% (plot I) and 41.6% (plot IX). The more living corals per plot is, the higher the abundance (%) of corals with PM.

5.4. Coral Damage Index (CDI)

In all cases of damage, *Acropora* was the most frequently affected genus regarding coral breakage (87.8% of all broken corals). 10.2% of broken colonies were *Stylophora* and 2% were *Pocillopora*. This index was applied to the species level only in *Acropora*, whereby *A. selago* was the most affected species (coral breakage 51.2%), followed by *A. gemmifera* with 18.6%, *A. eurystoma* with 7%, *A. acuminata*, *A. secale* and *A. variolosa* each with 4.7% and *A. loripes*, *A. samoensis*, *A. subulata* and not identified *Acropora* each with 2.3%.

Regarding plots (Fig. 8), plot III had the highest amount of broken coral colonies (BCC with 3.2%), followed by plots IV (2.5%) and V (2.4%). All other plots had a BCC frequency of ≤ 2% per transect. In terms of coral rubble (RB), plot V was the most affected with 8.4%, followed by plot VII with 7.6% and plot VI with 7.3%. All other plots had a RB frequency of ≤ 6% per transect. The most affected plots regarding CDI were V, VII and IX; plot VIII was the least affected.

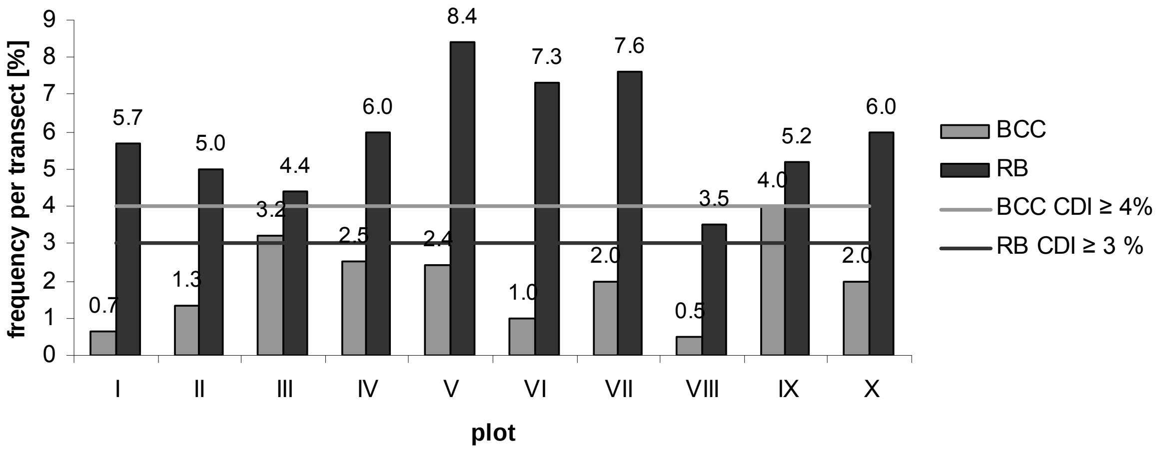

Fig. 8: The coral damage index (CDI) shows the frequency (%) of broken coral colonies (BCC) or coral rubble (RB) per transect across the plots. "Hot spots" are plots with a BCC frequency ≥ 4% or RB ≥ 3%, which means that all plots are so-called "hot spots" within RB, and plot IX is also a "hot spot" with regard to BCC.

Accordingly, 23.5% of all transects in regard to broken coral colonies (BCC) and 76.5% of all transects in regard to RB were such "hot spots". Only 19.5% of the transects had a CDI between 0% and 2% and were thus not "hot spots". Overall, the investigated area north of Napoleon-Reef has a CDI of 1.9% BCC and 6% RB

6 Discussion

Worldwide coral reefs are under threat. In the northern Red Sea, one of the habitats most at risk is fringing reef flats (Riegl and Piller 2000). Natural stress such as coral damage after springtide ebbs, and global warming in general, have recently increasingly impacted health (Kotb et al. 2004). Further pressures include the increasing anthropogenic damage to fringing reefs in the Red Sea due to terrestrial runoff, sea water pollution, coastal construction, urban sewage, siltation, destructive fishing methods and increasing water sport tourism (Rosenberg and Loya 2004; Kotb et al. 2004). The survey area north of Napoleon-Reef (Gulf of Aqaba, northern Red Sea, Egypt) is one such potentially threatened shallow-water reef. This is reflected in the high partial mortality rate (positively correlated with live coral coverage, Fig. 7) and the high coral damage index (Fig. 8).

The survey area was divided into different exposure regimes, based on substrate. Within-group agreement (A) of clusters is commonly below 0.1, whereas A = 1 implies all items identical within groups, so that A = 0.26 (with three clusters) is fairly high (McCune and Grace 2002). The exposure regimes follow a west-east distribution, parallel to the shoreline. Near shore, where the flow channel causes higher sedimentation (Fig. 2) and sand is the most common substrate, coral abundance is minimal. Living and dead substrate increase on the reef flat almost equally from west to east, which corresponds with decreasing sand cover. The higher percent cover of dead substrate in the outer reef supports the conclusion of Riegl and Velimirov (1991) that the damage in the northern Red Sea is clearly concentrated on the reef flat and reef edge. This might be caused by wave action, which cannot be the main cause of damage (Riegl and Velimirov 1991) in this semi-enclosed basin, and the past and continuing *Acanthaster* (crown of thorns starfish) outbreaks in the Red Sea (Kotb et al. 2004). As reported, they are a major predator plague for scleractinian corals (Loya 1972) and probably caused an up to 17% decrease of coral cover between 1997 and 2002 in the Gulf of Aqaba (Kotb et al. 2004). Coral diversity generally increases from the sandy area in the inner reef part towards the outer part. This might be because of the greater disturbance due to sedimentation along the shore, which leads as a sublethal stress to a decline in coral cover, a different coral community (Nyström et al. 2000) and increased partial mortality (Rogers 1990). As described in Riegl and Piller (2000), sedimentation damages the *Acropora*/*Stylophora* community on the shallow hardgrounds of the northern Red Sea and is a key factor in the disturbance of healthy coral reefs.

According to Abou Zaid (2000), the Gulf of Aqaba is home to 47 coral genera, whereof 13 were found on the reef flat north of Napoleon-Reef. In Loya (1972), *Stylophora* showed the highest dominance on the reef flat (Eilat, Gulf of Aqaba, Egypt). Alter (2004) and Sheppard et al. (1992), however, reported that *Acropora* prevailed over *Stylophora* on the reef flat, as found in the present study. The mean coral coverage of 33% found here north of Napoleon-Reef agrees with coral coverage found in the Gulf of Aqaba by Kotb et al. (2004) and Dirnwöber and Herler (2007), i.e. a mean of 35% and 37%, respectively. Coral cover is significantly lower than in the Red Sea (45%; Kotb et al. 2004), but considered to be in a good condition if living coral coverage is within a range of 20% to 50% of the reef (Kotb et al. 2004).

Over 84% of the coral colonies north of Napoleon-Reef flat showed signs of damage (breakage, partial mortality and algal overgrowth). The causes of high partial mortality (PM) rate in the reef (78% of live coral community) can be varied and are often difficult to differentiate. Extreme midday low tides can cause complete desiccation of the reef flat due to high temperatures and high solar radiation (Anthony and Kerswell 2007) leading to rapid coral mortality (Loya 2004). The global coral bleaching event in 1998 played only a subordinate role in the northern Red Sea (Kotb et al. 2004), whereas coastal development, crone of thorn outbreaks, destructive fishing methods, water sport tourism and reef walking have already caused a decline in coral coverage of more than 30% in some areas of Egypt (Kotb et al. 2004). A decline in coral cover due to partial mortality and changes in the coral community structure on the reef flat, can negatively influence the coral-associated fish (Jones et al. 2004; Schiemer et al. 2008) and other commensal species such as crabs and shrimps (Caley et al. 2001).

In corroboration of previous studies (Loya 1972; Riegl and Velimirov 1991; Anthony and Kerswell 2007), species from the families Acroporidae and Pocilloporidae (*Acropora*, *Pocillopora* and *Stylophora*), which dominate the shallow areas of the reef, are most affected by damage relative to their numerical abundance. The most abundant *Acropora* species in Napoleon-Reef, *A. gemmifera*, showed the poorest health condition at the study site (confirming Wall and Herler (in press)). Coral damage is strongly associated with growth form, because some forms are fragile and break upon contact. Riegl and Velimirov (1991) found that the branching forms (e.g. *Acropora*, *Stylophora*) are most algal-overgrown, and those proportionally more often affected by tissue loss and breakage. As seen in this study, of all broken coral colonies (BCC) of the investigated area, 54% were branching forms (*Acropora*, *Pocillopora* and *Stylophora*) and 46% perforated plates or tables (*Acropora*). They are particularly easily damaged by physical disturbances, such as reef walkers (Neil 1990; Liddle 1991; Hawkins and Roberts 1993) or water sport tourists (Zakai and Chadwick-Furman 2002; Loya 2004). This is reflected here in the coral damage index (CDI), whereof rubble (RB) and broken coral colonies (BCC) are indicators. The higher percentage of RB indicates that past breakage was responsible for most of the observed damage on the reef flat north of Napoleon-Reef. The lower frequency of BCC could point to a lower present threat to the reef flat, but in some parts BCC reached "hot spot"-status. Regarding RB, the entire investigated area requires management action, because 76.5% of all transects were such "hot spots".

Riegl and Velimirov (1991) found that of all observed damages (breakage, tissue loss, algal overgrowth) the most frequent occurred within the first ten meters depth. In the Red Sea, coral damage occurs mainly due to tourism (e.g. through divers or snorkellers) (Zakai and Chadwick-Furman 2002; Loya 2004), but fishermen play also a role in coral breakage through trampling (Leujak and Ormond 2008) and net fishing. All these factors are found at the study area. Partial mortality, along with a coral damage index (Jameson et al. 1999), have been shown to be good indicators for the reef condition and to estimate the severity of coral damage due to natural or anthropogenic stressors.

Algal overgrowth is one after-effect of coral damage (Riegl and Velimirov 1991) because algae are known to colonize dead parts of coral colonies. Another factor for coral damage is the corallivorous gastropod *Drupella cornus*, which is attracted by mechanically damaged corals (Forde 1992 and Morton et al. 2002, cited in Schöpf 2008). These snails have a mean density of 7.28 (± 5.07 St.D) per m² (Schöpf 2008) in study areas north of Napoleon-Reef at 1m depth, and are therefore responsible for a certain amount of partial mortality in the reef.

Several recent studies (Hughes et al. 2003; Jones et al. 2004; Loya 2004) have expressed concern over the worldwide reduction in coral cover due to global climate change. High temperature can be a stress factor that triggers extensive loss of zooxanthellae (Gates et al. 1992; Hoegh-Guldberg 1999). Corals generally grow in waters of 18-19°C and above. The Gulf of Aqaba has a relatively constant, warm water body measuring around 20°C to 28°C (Schuhmacher 1988; Loya 2004), whereby we measured a mean temperature of 22.5°C (from October to April) on the reef flat. Water temperature governs coral reef distribution (Fricke and Schuhmacher 1983). As the Gulf of Aqaba is a semi-enclosed body of water, the reefs show low frequencies of physical coral damage due to water motion or tropical storms (Zakai and Chadwick-Furman 2002), although it is frequently difficult to differentiate between natural and man-made damage (Riegl and Velimirov 1991).

Decisive for the stability of ecosystems and the ability to recruit after disturbances is the development of a complex network (Tilman 2000). The simultaneous occurrence of natural stressors (e.g. spring tide ebbs, *Drupella* outbreaks) and the increasing pressure due to anthropogenic effects, as found in the investigated area, counteract this stability (Done 1992; Moberg and Folke 1999; Nyström et al. 2000; Birkeland 2004). To allow reefs affected by mechanical damage to recover requires protecting such reefs from additional future damage and also requires protecting undamaged reefs in the area (Edinger et al. 1998; Zakai and Chadwick-Furman 2002). Destructive activity by visitors and fisherman in the reef can often be ascribed to a lack of understanding and ignorance (Leujak and Ormond 2008). A management plan with visitor education should be assessed; this could significantly reduce reef walking (by up to almost 40% in the southern Gulf of Aqaba, northern Red Sea; Leujak and Ormond 2008).

7 Acknowledgements

I am grateful to Dr. Moustafa Fouda (Nature Conservation Section NCS of the Egyptian Environmental Affairs Agency EEAA) and Mr. Ayman Mabrouk (Nabq Managed Resource Protected Area MRPA) for granting research permission and would like to thank Andreas Tischer and Hans Lange (DiveIn Dahab and D.A.E.D.) for providing the opportunity to conduct the present study. Special thanks to Dr. Jürgen Herler, Prof. Dr. Jörg A. Ott and Dr. Michael Stachowitsch for scientific and English-editing support.

8 Zusammenfassung

Korallenriffe sind weltweit stark gefährdet und im Rückgang begriffen. Vor allem die Riffe im nördlichen Roten Meer, insbesondere jene rund um Dahab, zählen in den letzten Jahren zu den am stärksten frequentierten der Welt (Zakai und Chadwick-Furman 2002). Somit kommen zu natürlichen Störeinflüssen wie Klimaveränderung noch zahlreiche anthropogene Störeinflüsse hinzu. Davon sind vor allem die Riffdächer der Saumriffe (Fishelson 1995; Wielgus 2004) wie das untersuchte Gebiet nördlich des Napoleon-Riffs (Golf von Aqaba, nördliches Rotes Meer, Ägypten) betroffen.

Die Datenaufnahme erfolgte zwischen Juli und November 2007 in Dahab, am südlichen Golf von Aqaba, nördliches Rotes Meer (Sinai, Ägypten). In einem Areal von 23 500 m² wurden insgesamt 51 Transekte á 50 m gelegt. Die Substraterhebung erfolgte mittels der „photo point intercept" Methode am Riffdach nördlich des Napoleon-Riffs. Um Langzeituntersuchungen durchführen zu können wurden GPS-Koordinaten des Untersuchungsgebiets erhoben. Zudem wurde jeder Substratpunkt mittels Foto dokumentiert um einen „species index", „partial mortality" (PM) und Korallenbruch (BC) zu ermitteln. Mittels hierarchischer Clusteranalyse (PC-ORD v.2.25) und MRPP („multi-response permutation procedure") konnte das Untersuchungsgebiet in mehrere Expositionensareale (Tab. 2), welche einem topographischen Gradienten von West nach Ost folgen, unterteilt werden. Der ufernahe Strömungskanal führt durch erhöhte Sedimentation zu einem geringeren Korallenvorkommen. Dieses nimmt zur Riffkante hin zu. Die Korallengemeinschaft des Untersuchungsgebietes setzt sich aus 13 Korallengattungen, die in unterschiedlicher Häufigkeit auftreten, zusammen, wobei der Diversitätsindex zur Riffkante hin ansteigt (Tab. 5). Rund 78% der untersuchten Korallenkolonien wiesen zumindest eine Art der Schädigungen auf (wie Bruch, „partial mortality" oder Algenaufwuchs). Wie für Saumriffe dieser Gegend üblich, wird die Korallengemeinschaft des Riffdachs von *Acropora* und *Stylophora* dominiert. Wie bereits in früheren Studien gezeigt (Loya 1972; Riegl und Velimirov 1991; Anthony und Kerswell 2007) sind von Schäden vor allem im Seichtwasser dominierende, verzweigt wachsende Arten betroffen. Dies spiegelt sich vor allem in den Ergebnissen der Korallengemeinschaftsanalyse wieder (Fig. 6). Die Anzahl an partieller Mortalität der Korallen pro Transekt geht mit der Anzahl an lebenden Korallen einher (Fig. 7). Dies wird zudem durch den „coral damage index" (Jameson et al. 1999) (Fig. 8), ein guter Indikator für den allgemeinen Riffzustand, deutlich. Hierbei fallen 76.5% aller Transekte hinsichtlich

Korallenbruch unter die Bezeichnung „hot spot“ und beschreiben somit die Ernsthaftigkeit der Riffzerstörung in diesem Areal.

Der hohe Anteil an geschädigten Korallen geht mit der Abnahme der Korallenbedeckung einher. Bei einem größeren Areal würde es durch vermehrt auftretende gebrochene Korallen und eine geringe Korallenbedeckung, zu einer niedrigeren Reproduktionsrate der Korallen (Anthony und Kirswell 2007) und dadurch geringen Neubesiedlung durch Korallenlarven kommen. Dies führt weiters zur Veränderung der Artzusammensetzung der Korallen im Riff worunter die Ökosystemstabilität leidet (Bellwood et al. 2004). Ein self-recruitment des Napoleon-Riffs ist jedoch eher auszuschließen.

Wie Riegl und Velimirov (1991) bereits aufzeigten, ist es oftmals sehr schwierig zwischen natürlichen und anthropogenen Störeinflüssen zu unterscheiden, wobei sich im nördlichen Roten Meer die Hauptzerstörung vorrangig auf das Riffdach und die Riffkante konzentriert. Ausschlaggebend für die Ökosystemstabilität und das Vermögen sich von Störungen zu erholen, ist die Ausbildung eines Komplexen Gefüges (Tilman 2000). Das gleichzeitige Auftreten von natürlichen (z.B. Springtiden, *Drupella* Ausbrüche) und der ansteigende Druck durch anthropogene Störeinfaktoren wirken diesem entgegen (Done 1992; Moberg und Folke 1999; Nyström et al. 2000; Birkeland 2004). Leujak und Ormond (2008) führten ein destruktives Verhalten der Riffbesucher auf einen Mangel an Wissen und Ahnungslosigkeit zurück. Ein Managementplan, welcher „reef walking“ um bis zu ca. 40% reduzieren könnte (Untersuchung im südlichen Golf von Aqaba von Leujak und Ormond (2008)) wäre daher dringend nötig.

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10 Appendix

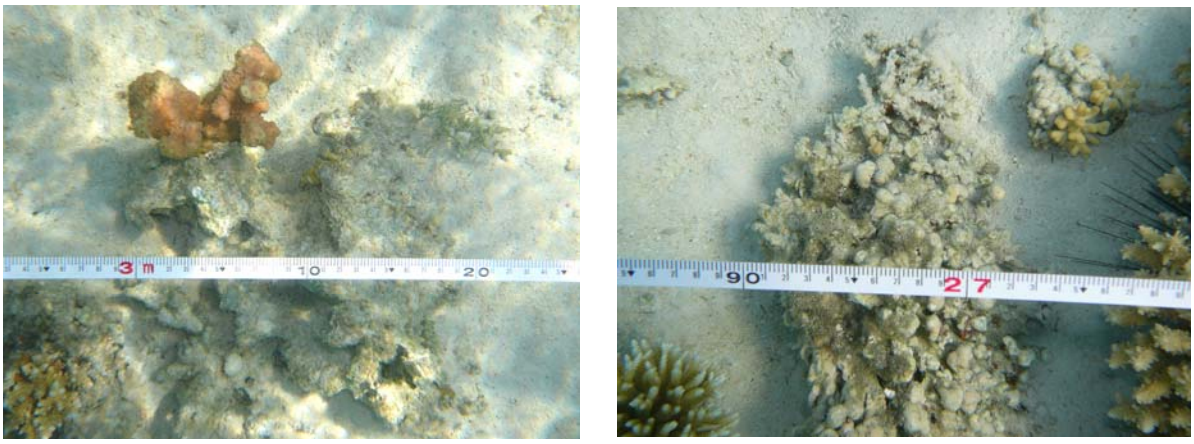
App. 1: Real GPS points of the fixed markers in the area north of Napoleon-Reef.

	1	2	3	4	5
A	28° 28' 18.4" N 34° 30' 31.4" O	28° 28' 17.5" N 34° 30' 32.9" O	28° 28' 16.6" N 34° 30' 34.6" O	28° 28' 15.4" N 34° 30' 35.7" O	
B	28° 28' 17.1" N 34° 30' 30.4" O	28° 28' 16.1" N 34° 30' 31.9" O	28° 28' 15.3" N 34° 30' 33.4" O	28° 28' 14.0" N 34° 30' 34.8" O	
C		28° 28' 14.6" N 34° 30' 30.8" O	28° 28' 13.8" N 34° 30' 32.4" O	28° 28' 12.5" N 34° 30' 33.7" O	
D		28° 28' 13.5" N 34° 30' 29.6" O	28° 28' 12.4" N 34° 30' 31.1" O	28° 28' 11.5" N 34° 30' 32.6" O	28° 28' 10.5" N 34° 30' 34.0" O
E		28° 28' 12.6" N 34° 30' 28.8" O	28° 28' 11.4" N 34° 30' 30.4" O	28° 28' 10.3" N 34° 30' 31.7" O	28° 28' 09.4" N 34° 30' 33.2" O

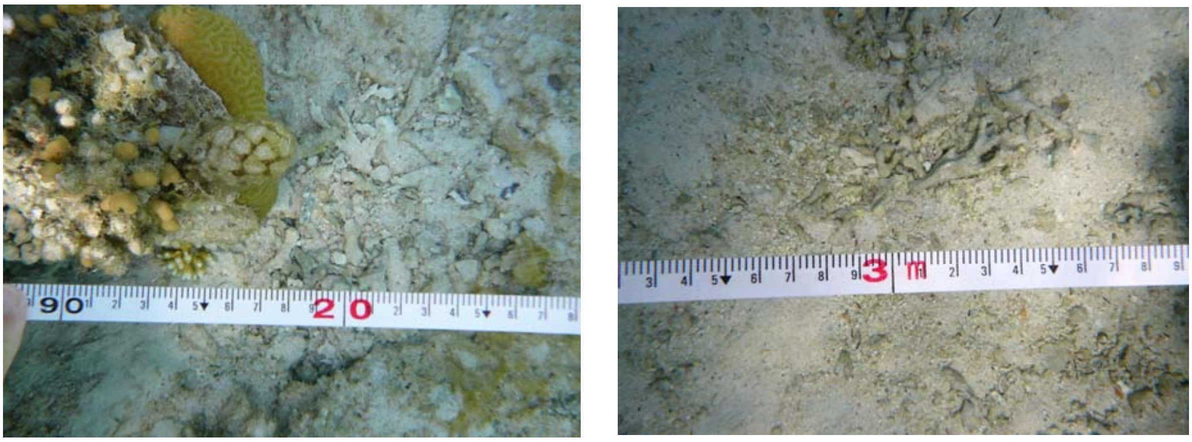
App. 2: Percentage of each substrate (abbreviations see Tab. 2) per plot (I to X) in the area north of Napoleon-Reef

% substrate per plot			plot									
substrate	genus	species	I	II	III	IV	V	VI	VII	VIII	IX	X
HC	*Acropora*	*acc*	-	0.3	0.4	-	0.4	-	0.4	0.5	1.2	0.4
		dig	0.3	-	1.2	0.5	0.4	-	-	0.5	-	-
		eur	1.3	0.3	1.2	4.0	1.2	0.7	-	0.5	0.8	0.4
		gem	1.0	5.7	6.8	4.5	1.2	7.0	8.0	7.5	8.0	10.8
		hya	-	0.3	1.2	0.5	1.2	0.3	-	1.0	0.8	0.8
		lor	0.7	0.3	1.6	1.5	2.8	-	-	-	0.4	-
		n.i.	-	0.3	-	0.5	1.6	-	-	-	0.4	-
		sam	-	1.0	2.0	-	1.2	0.7	1.6	2.5	1.6	-
		sec	0.3	-	0.8	0.5	1.2	-	0.4	-	0.4	0.4
		sel	2.0	4.0	6.4	4.0	1.6	3.7	1.6	1.5	5.6	2.8
		sub	0.3	1.0	0.4	-	0.4	-	1.6	2.5	0.8	-
		var	3.7	0.7	0.4	1.5	0.4	0.3	1.2	0.5	0.4	-
	Σ Acropora		9.7	14.0	22.4	17.5	13.6	12.7	14.8	17.0	20.4	15.6
	Astreopora		0.3	-	-	-	-	-	-	-	-	-
	Cyphastrea		0.7	0.3	0.4	-	-	0.7	1.6	1.5	1.2	0.8
	Favia		-	0.7	-	0.5	-	0.7	-	-	-	0.4
	Favites		0.3	1.0	-	1.0	1.6	1.7	0.4	-	0.8	0.8
	Goniastrea		-	-	-	-	-	0.7	-	-	-	0.4
	Leptastrea		-	-	-	-	-	0.3	-	-	-	-
	Millepora		0.3	-	0.4	0.5	1.2	-	0.8	-	0.4	0.4
	Montipora		1.7	0.7	0.8	1.0	0.8	2.7	4.0	6.5	1.6	6.0
	unidentified		-	-	-	-	-	-	-	-	0.4	0.4
	Platygyra		1.0	-	0.4	1.0	1.2	-	-	1.5	0.4	1.2
	Pocillopora		1.3	0.3	0.4	2.5	4.0	0.3	2.0	0.5	1.6	1.6
	Porites		-	1.3	0.8	1.5	1.6	2.0	4.8	5.0	2.8	4.0
	Stylophora		4.0	13.7	6.8	8.5	2.4	4.7	3.6	8.0	8.0	4.0
Σ HC			19.3	32.0	32.4	34.0	26.4	26.3	32.0	40.0	37.6	35.6
BCC	*Acropora*	*acc*	-	-	-	-	-	0.3	-	-	-	0.4
		eur	-	-	-	0.5	0.4	-	-	0.5	-	-
		gem	-	-	-	-	0.4	0.7	-	-	0.8	1.2
		lor	-	-	-	0.5	-	-	-	-	-	-
		n.i.	-	-	-	-	-	-	-	-	0.4	-
		sam	-	-	-	-	0.4	-	-	-	-	-
		sec	-	-	0.4	-	-	-	-	-	0.4	-
		sel	0.7	1.0	2.0	1.0	0.8	-	1.2	-	1.6	0.4
		sub	-	-	0.4	-	-	-	-	-	-	-
		var	-	-	0.4	-	-	-	-	-	0.4	-
	Σ Acropora		0.7	1.0	3.2	2.0	2.0	1.0	1.2	0.5	3.6	2.0
	Pocillopora		-	-	-	-	0.4	-	-	-	-	-
	Stylophora		-	0.3	-	0.5	-	-	0.8	-	0.4	-
Σ BCC			0.7	1.3	3.2	2.5	2.4	1.0	2.0	0.5	4.0	2.0
SD			58.7	37.0	28.0	38.0	41.6	20.3	20.0	19.5	28.4	12.8
CR			2.7	10.0	9.6	1.5	2.0	20.0	14.4	7.5	1.2	16.0
DCA			3.0	7.0	8.0	4.0	6.0	12.3	10.4	8.0	8.0	15.2
DC			6.3	4.0	7.6	4.0	10.8	4.3	4.0	9.0	10.0	4.4
RB			5.7	5.0	4.4	6.0	8.4	7.3	7.6	3.5	5.2	6.0
AL			0.7	1.3	3.6	2.5	0.4	2.3	5.6	5.5	2.4	3.2
SC			3.0	2.0	1.2	2.0	0.4	3.7	2.4	3.0	1.6	4.4
BCF			-	0.3	1.6	4.5	1.2	2.3	1.6	3.5	1.6	0.4
RU			-	-	0.4	1.0	0.4	-	-	-	-	-
n =			300	300	250	200	250	300	250	200	250	250

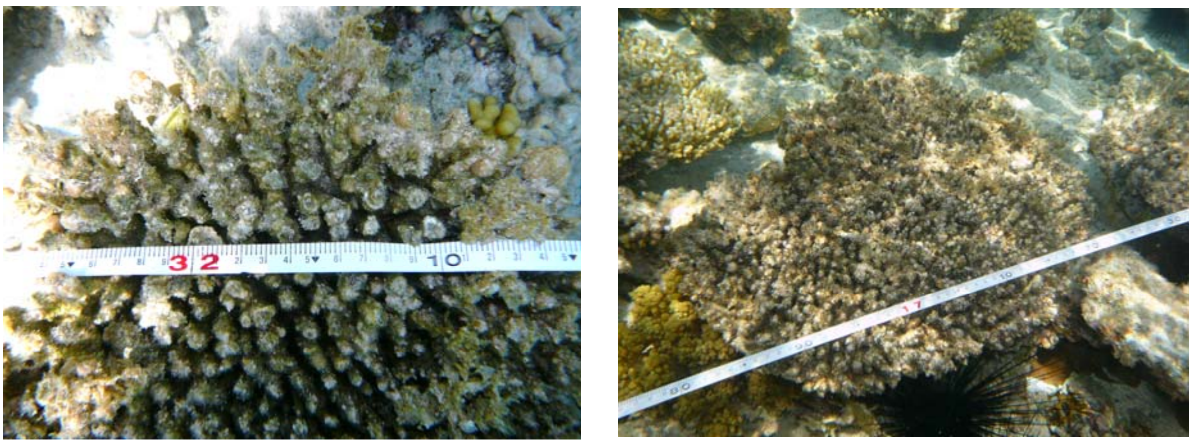
App. 3: Substrate categories and coral damage (Photos: Sarah Kompatscher).



Coral rock

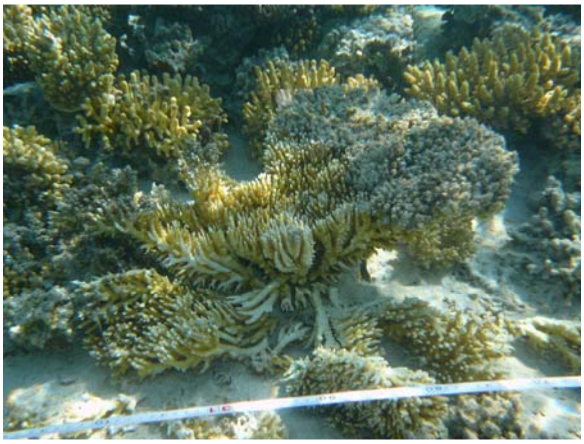


Coral rubble



Dead coral with algae

Coral with partial mortality



Broken coral colonies

Broken coral fragment

Sarah Kompatscher

Persönliche Angaben:

Geburtsort:	Bozen
Geburtsdatum:	01.09.1982
Staatsangehörigkeit:	Italien

Wohnort:

Ort:	39050 Völs am Schlern (BZ)
Straße:	Peterbühelweg 6
Telefon:	0650/3303902
Mail:	sarah_kompatscher@hotmail.com

Schulbesuch:

1989 – 1993: Grundschule Völs am Schlern (BZ)
1993 – 1996: Mittelschule Franziskaner, Bozen
1996 – 2001: Naturwissenschaftliche Oberschule, Meran
Oktober 2001: Biologiestudium an der
Universität Wien (Zoologie, Fachbereich Meeresbiologie)

Exkursionen und Forschungsaufenthalte:

2005: Naturschutzpraktikum Meeresschildkröten, Türkei
2005 & 2006: Projektpraktikum heimischer Fische
2006: Projektpraktikum Fauna und Flora des Mittelmeeres, Rovinj, Kroatien
2006: Meeresökologisches Spezialpraktikum, Calvi, Korsika
2006: Korallenriffpraktikum, Dahab, Ägypten
2007: Feldarbeit DAED (Dahab Association of Environmental Development), Dahab, Ägypten
2008: Meeresbiologische Exkursion zu Küstenlebensräumen Kaliforniens

Sonstiges:

2000: Zweisprachigkeitsnachweis „B“ (Italienisch)
Tauchausbildung:
  2004: CMAS *
  2006: CMAS **
  2008: ProNRC Nitrox Level 2
2008: Führerschein B
gute Computerkenntnisse (MS Office)