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The interaction between the orange striped triggerfish *Balistapus undulatus* (Park, 1797) and the most common sea urchins at the coast of Zanzibar, Tanzania.

Bachelor-Thesis (B.Sc. Biology)

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Table of contents

List of abbreviations

Abbreviation	Scientific name	Common name
B. undulatus	*Balistapus undulatus* (Park, 1797)	Orange striped triggerfish (GARILAO, 2008)
D. setosum	*Diadema setosum* (Leske, 1778)	Hatpin urchin (BLICKWINKEL, 2011)
D. savignyi	*Diadema savignyi* (Michelin, 1845)	Blue eye urchin (NATUURINFORMATIE)
E. mathaei	*Echinometra mathaei* (Blainville, 1825)	Rock boring urchin (PACIFIC-ISALND-CORAL-REEF-PROGRAM, 2007)
E. diadema	*Echinothrix diadema* (Linnaeus, 1758)	Blue-black urchin (PACIFIC-ISALND-CORAL-REEF-PROGRAM, 2007)
CHICOP		Chumbe Island Coral Park
SEM		Southeast monsoon
NEM		Northeast monsoon
MPA		Marine protected area

Abstract

The growing knowledge and awareness of climate change and ocean exploitation over the last 15 to 20 years arouse an increase in studies about coral reef ecology. The present study was performed in tropical coral reefs of Zanzibar, Tanzania, where the interaction among reef dwellers became of high interest. Loss of predators due to overfishing is thought to cause a change in species composition of reefs. Hints for such changes in the reef community are increasing numbers of sea urchins and decreasing numbers of predators in unprotected areas which are extensively fished. High populations of sea urchins cause a negative impact on reef ecology by grazing on seagrass meadows, indirectly inhibiting the recovery and growth of fish populations. This thesis studies and analyses the interaction of the most common sea urchins *Diadema setosum, Diadema savignyi, Echinothrix diadema* and *Echinometra mathaei* with the orange striped triggerfish *Balistapus undulatus* in East African reefs using underwater census. No correlation between the densities of dead sea urchins and *B. undulatus* was found. Further, changes in the abundance of both sea urchins and triggerfish from 2009 to 2012 were analyzed. An overall population decline was determined for all species at all study sites. Surveying protected and non-protected study sites allowed for assessment of differences in population densities of the species under study. In 2009, densities of sea urchins in protected study sites were higher than in non-protected study sites. Further, the density of sea urchins in a study site where *B. undulatus* was absent was lower than the density of sea urchins on study sites with *B. undulatus* present. The long-term goal of further studies on reef ecology is to verify the importance of marine protected areas and their ability to conserve the richness in species and food sources for future generations.

KEYWORDS: Zanzibar, coral reef, *Balistapus undulatus*, *Diadema setosum*, *Diadema savignyi*, *Echinothrix diadema*, *Echinometra mathaei*, population structure, density estimates, nature conservation

Zusammenfassung

Der wachsende Wissensstand und das wachsende Bewusstsein über den Klimawandel und die Ausbeutung der Meere in den letzten 15 bis 20 Jahre rufen ein Wachstum der Forschungen und Studien über Riffökologie hervor. Die vorliegende Arbeit wurde in tropischen Korallenriffen vor Sansibar, Tansania, durchgeführt, wo die Interaktion zwischen Riffbewohnern mit starkem Interesse beforscht wird. Es wird vermutet, dass der Verlust von Prädation durch Überfischung eine Veränderung in der Zusammensetzung der Arten die das Riff bewohnen hervorrufen kann. Erste Hinweise auf diese Veränderungen können jetzt schon in der steigenden Anzahl der Seeigel und der sinkenden Anzahl deren Räuber in nicht geschützten Gebietern mit einem hohen Druck durch Fischerei beobachtet werden. Große Seeigelpopulationen können einen schädlichen Einfluss auf die Riffökologie haben. Dies geschieht durch Abweidung vor allem von Seegraswiesen und durch eine dadurch indirekte Verhinderung der Regeneration und des Wachstums der Fischpopulationen. In dieser Thesis wird die Interaktion der am häufigsten vorkommenden Seeigelarten *Diadema setosum, Diadema savignyi, Echinothrix diadema* und *Echinometra mathaei* mit dem Orange-gestreiften Drückerfisch *Balistapus undulatus* in ostafrikanischen Riffen durch Unterwasserzählungen analysiert. Es wurde kein Zusammenhang zwischen den Dichten der toten Seeigel und des *B. undulatus* gefunden. Desweiteren wurde die Veränderung der Abundanz der verschiedenen Arten zwischen 2009 und 2012 analysiert und eine artübergreifende Abnahme der Dichten in jedem Untersuchungsgebiet festgestellt. Daten aus geschützten und ungeschützten Untersuchungsgebieten lassen eine Einschätzung der Unterschiede von Populationsdichten der untersuchten Arten zu. Es wurde herausgefunden, dass die Seeigeldichten im Jahr 2009 in geschützten Untersuchungsgebieten höher waren als in nicht-geschützten Untersuchungsgebieten. Außerdem war eine geringere Dichte der Seeigel in einem Untersuchungsgebiet wo der Räuber *B. undulatus* abwesend war verglichen mit der Dichte der Seeigel in Untersuchungsgebieten wo *B. undulatus* anwesend war vorhanden. Das langfristige Ziel weiterer Studien über Riffökologie ist es, die Bedeutung der marinen, geschützten Gebiete zu bestätigen und den Artenreichtum sowie die Nahrungsquelle für kommende Generationen und zu erhalten.

1. Introduction

Zanzibar, an archipelago of Tanzania, East Africa, is located in the western Indian Ocean about 30 km east of the Tanzanian coastline (Fig. 1). It consists of two main islands, Pemba and Unguja and hundreds of small islands. Unguja with its capital Stone Town is informally referred to as Zanzibar Island, for the sake of convenience this name will be used throughout this whole Thesis. Approximately one million inhabitants are living on the archipelago (SILVA, 2006). Their most important source of food and income are fish and seafood, which they procure and harvest from the reefs around the islands. Another very important source of income is tourism (JIDDAWI AND ÖHMAN, 2002, MCCLANAHAN ET AL., 2008).

Fig. 1: Location of Zanzibar offshore Tanzania's coastline, East Africa. Zanzibar Island lies in the Indo Pacific as part of the Zanzibar archipel. (NATURE-CONSERVANCY, 2012)

Exploitation of local coral reefs has become an issue threatening the livelihood of large parts of Zanzibar society. With exploitation being pushed by tourism and fishing for commerce more than personal requirements, marine animals' diversity and productivity declines. Nowadays, unique and highly diverse shallow water reefs of the Tanzanian and Zanzibarian coasts are being exploited and destroyed mainly by pollution, coastal development, sedimentation and overfishing (JIDDAWI AND ÖHMAN, 2002, OBURA ET AL., 2004, SILVA, 2006). Predatory fish and sea urchins play a key role in the reefs' ecosystem as they regulate the populations of many reef inhabitants and act as major bioeroders (KNUDBY AND NORDLUND, 2009). Four of the most abundant species of sea urchins in Zanzibarian reefs are *Diadema setosum, Diadema savignyi, Echinothrix diadema* and *Echinometra mathaei*. They are mostly found on hard substrates like corals and stones depending on their specialization.

Sea urchins are feeding on algae and seagrass (MCCLANAHAN AND MUTHIGA, 2007). Adult sea urchins play an important role in reef ecology due to their grazing behavior (DUMAS ET AL., 2007); they reduce the reefs biomass, especially that of seagrass. Consequently, when the population of sea urchins increases on a reef, the reef and seagrass community will be affected. Grazing fronts with an extremely dense population of up to 600 individuals per square meter are a drastic example for this (MACIÁ, 2000). They are capable of eroding large seagrass meadows with a size up to thousands of square meters (MACIÁ, 2000). Seagrass meadows near reefs are important breeding and nursing areas for fish, the largest part of the reef inhabiting fish reproduce here. A reduction of seagrass due to grazing sea urchins can, therefore, decreases fish populations. Excessive fishing further assists the decline of fish populations and, as fish are the main predators of sea urchins, can in turn cause problems like overpopulation of sea urchins (HAY, 1984, MCCLANAHAN AND MUTHIGA, 1988, MCCLANAHAN, 1998, MCCLANAHAN, 2000, CARREIRO-SILVA AND MCCLANAHAN, 2001). CARREIRO-SILVA AND MCCLANAHAN (2001) report that especially *D. setosum* plays a major role for bio erosion and the benthic ecology of western Indian Ocean coral reefs. Among the most common sea urchins, it has the highest herbivory and bio-erosion rate and is the most abundant one in East African reefs. Further, its main predators like Balistidae and Labridae are extensively fished (MCCLANAHAN, 1995, MCCLANAHAN AND ARTHUR, 2001, MCCLANAHAN AND MUTHIGA, 2007, KNUDBY AND NORDLUND, 2009). Its abundance and distribution affects the appearance and dispersal of many coral reef organisms (CARREIRO-SILVA AND MCCLANAHAN, 2001, LARSSON, 2009). Therefore, removing the population control by predators will, ultimately, affect the whole coral reef by disturbing the natural food chains and introducing population imbalances (MCCLANAHAN AND SHAFIR, 1990, JIDDAWI AND ÖHMAN, 2002). The overpopulation of sea urchins outlined above is only one example of a shift within the reef ecology. By feeding on the reef, sea urchins remove a large amount of coral algae and calcium carbonate; this is important for the circulation of nutrients within the reef. If the circulation is too voluminous it will cause destruction in the reef as e.g. a thick layer of sediment will cover corals and kill them by shading them from light (CARREIRO-SILVA AND MCCLANAHAN, 2001).

The orange striped triggerfish *Balistapus undulatus* (Tetraodontiformes: Balistidae) is the most common predator for sea urchins around Zanzibar (MCCLANAHAN, 1997, MCCLANAHAN, 2000, MCCLANAHAN, 2008A, KNUDBY, 2009). Due to overfishing the population of *B. undulatus* declined. To recover its population it takes more than 30 years, as these fishes do not respond rapidly to a decline of fishing (MCCLANAHAN, 1997, MCCLANAHAN, 2000). The average carrying capacity of an intact reef is about 5 individuals per 500 m² (MCCLANAHAN, 2000, KNUDBY, 2009). The present population in East African marine parks has declined to 1 individual per 500 m² (MCCLANAHAN, 2000). Since they are very aggressive fish, Balistidae are one of the most susceptible families. In protected reefs their population recovers faster and is higher than in unprotected reefs (McClanahan and Arthur, 2001). *B. undulatus* is responsible for more than 80% (n= 273) of observed predation (McClanahan, 2000). It is twice as abundant as other predators like wrasses (McClanahan, 2000, McClanahan and Muthiga, 2007). Even though *B. undulatus* is slowly colonizing, it is competitively dominant in protected reserves (McClanahan, 2000). Therefore, it is suggested that triggerfish are controlling the number of sea urchins in protected reefs and is thought to indirectly influence the reef growth (McClanahan, 2008a). After several years of predation recovery and an increasing number of predators like triggerfish, a significant decline of sea urchin density has been observed by Babcock et al. (2010). They also noted higher predation level for smaller urchins than for larger urchins.

This thesis aims to determine the percentage of dead sea urchins in relation to the density of *B. undulatus*. It is expected to find more dead sea urchins in regions where more *B. undulatus* are existing. A second objective is to establish the abundance of the sea urchins and *B. undulatus* over time on the different study sites in 2009 and 2012. A third objective is to find out if there is a significant difference between open and closed reef sites referring to the number of living *D. setosum, D. savignyi, E. diadema, E. mathaei* and the number of *B. undulatus*.

Ultimately this knowledge can explain reef recovery and may therefore help the development of new methods of reef control and more efficient ways of reducing the human footprint on coral reefs.

2. Material and Methods

2.1 Study area and study sites

Zanzibar is located about 30 km east of the Tanzanian coastline, in the Indo Pacific (ONKALO AND SULAIMAN, 2011). The study areas: Grave Island, Changuu Island, Bawe Island and Chumbe Island are located approximately 1,5 – 5,5 km off the west side of Zanzibar Island (MCCLANAHAN ET AL., 2009). The Islands range in size from 3,6 ha (Grave Island) (BLOFELD, 2011) to 22 ha (Chumbe Island) (RIEDMILLER, 2000). Six sites on four reefs around these indo-pacific islands were selected for this study (Fig. 2). One study site is located at Grave Island (Fig. 3), one at Changuu Island (Fig. 4) and one at Bawe Island (Fig. 5). Three sites are on the reef of Chumbe Island, one on the south-west reef, one on the north-west reef and one on the north-east reef around Chumbe (Fig. 6). All sites except for Chumbes' south-west and north-west reefs are open to fishing and tourism. They are situated on shallow reef flats and fringing reef slopes at depths between 0 m and 5 m (low tide; tidal range 3,5 m) for an optimal access during high tide and low tide. They represent an average shallow water habitat and are physically continuous.

Data collection in 2009 took place on the 10.02.09 (Chumbe Island east), 11.02.09 (Chumbe Island south), 17.02.09 (Bawe Island, Changuu Island and Grave Island) and 19.02.09 (Chumbe Island west). In 2012 data was collected on the 07.05.12 (Bawe Island, Changuu Island and Grave Island) and 10.05.12 (Chumbe Island south, Chumbe Island west and Chumbe Island east). The islands are listed in the order they were surveyed.

Fig. 2: Study regions in the western Indian Ocean around Zanzibar. The islands studied are highlited in red circles (GOOGLE EARTH, 2012).

2.1.1 Grave Island

Grave Island located at 6°07'36.66'' S and 39°11'32.63'' E (GOOGLE EARTH, 2012) is the closest to Zanzibar. The study site is located about 400 m east and 200 m north of the south tip of the island (see open diamond in Fig. 3).

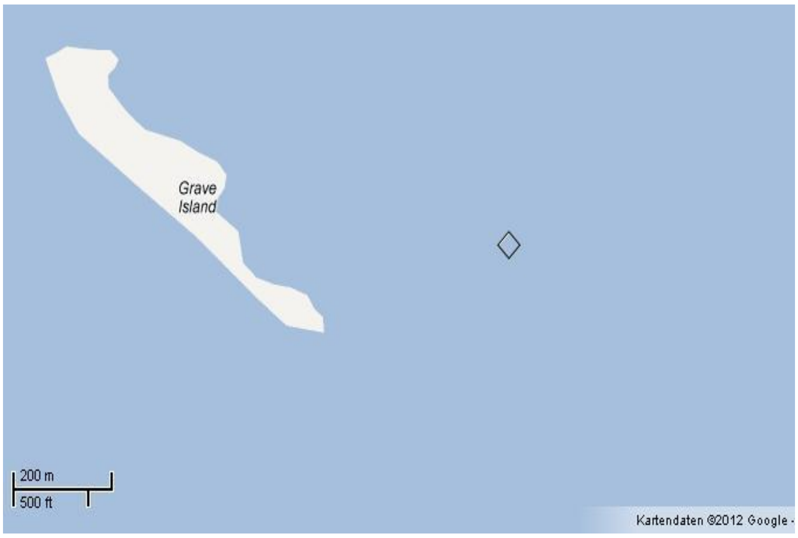

Fig. 3: Map of Grave Island. Open diamond: study site, non-protected reef (GOOGLE EARTH, 2012).

2.1.2 Changuu Island

At Changuu Island (6°07'10.11'' S, 39° 10'01.37'' E (GOOGLE EARTH, 2012)) reef, the study site is located approximately 300 m east and 170 m north of the northernmost point of the island (see open diamond in Fig. 4).

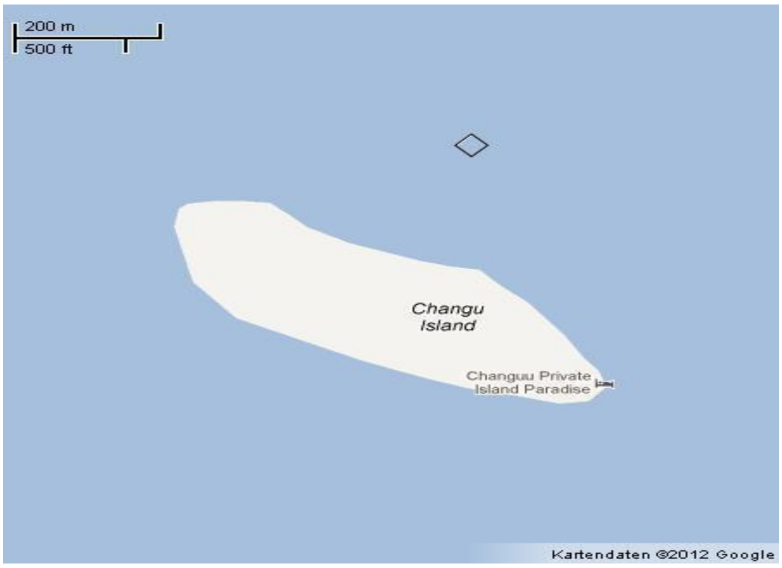

Fig. 4: Map of Changuu Island. Open diamond: study site, non-protected reef (GOOGLE EARTH, 2012).

2.1.3 Bawe Island

Bawe Island lies at 6°08'59.72'' S and 39°07'53.77'' E (GOOGLE EARTH, 2012). It is the site the furthest away from Zanzibar. The study site is located about 400 m east and 100 m south of the island (see open diamond in Fig. 5).

Fig. 5: Map of Bawe Island. Open diamond: study site, non-protected reef (GOOGLE EARTH, 2012).

2.1.4 Chumbe Island

Located at 6°16'43.55'' S, 39°10'38.82'' E (GOOGLE EARTH, 2012), Chumbe Island (Fig. 6) has 3 study sites, one site at the east side of the island, approximately 130 m east and 320 m south of the northernmost tip of the island and open for fishing (see open diamond in Figure 6). Two more locations at Chumbe (one about 50 m south and 200 m west of the south tip and one approximately 150 m west and 200 m north of the westernmost tip of Chumbe) are located in the CHICOP (Chumbe Island Coral Park), a private marine park closed for fishing and only open for snorkeling or research diving, indicated by the filled diamonds in Figure 6. CHICOP is closed since 1991 (RIEDMILLER, 2000) and has a high biodiversity, like corals, fish and echinoderms. According to MCCLANAHAN ET AL. (2009) the CHICOP reserve has a total size of 0,3 km².

Fig. 6: Map of Chumbe Island. Open diamond: study site, non-protected reef. Closed diamonds: study sites, protected reef (GOOGLE EARTH, 2012).

2.2 Field methods

Data of the study sites was commonly collected during low tide, when a water depth between 0 - 5 meters could be assured at the studied sites. These water depths also allowed good access during low as well as high tide. Using underwater counting, data on *B. undulatus*, *D. setosum, D. savignyi, E. diadema* and *E. mathaei* were collected. Only one person surveyed the sites, and therefore, according to McClanahan et al. (2007), underwater fish count variance could be excluded. The data were collected through snorkeling and skin-diving along the transects and were noted on a diving tablet and digitalized after the collection.

In February 2009 the following methodology was used: countings of the living sea urchins *D. setosum, D. savignyi, E. diadema* and *E. mathaei*, the dead urchins as well as the orange striped trigger fish were combined. Each belt-transect had a width about 4 m width and 13 m length (= 52 m²) with a depth between 0 - 5 m. At each site, 9 to 13 transects were recorded within a 5 minute time period. While snorkeling along the transect (see Fig. 7), all alive *B. undulatus* were counted and within each transect a 2m² quadrat was used to count all *D. setosum*, *D. savignyi*, *E. diadema* and *E. mathaei* as well as the dead urchins. Dead urchins were noted if there was at least a skull and some broken spines in the same location. This identification was chosen in order to make sure that the sea urchin was killed by a predator rather than dying a natural death. Site characteristics like the ground topography, the visibility and the condition of the coral substrate were noted in addition to the numbers of animals. For the second data recording in 2012 the methodology was revised to get more reliable data by observing the transects sequentially for *B. undulatus* and *D. setosum*, *D. savignyi*, *E. diadema* and *E. mathaei.*

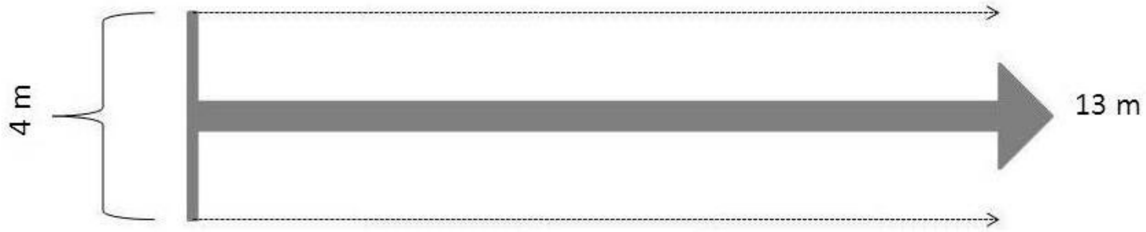

Fig. 7: Schematic representation of a belt-transect used in 2009. During snorkeling along the coral substrate for exactly 5 minutes, *B. undulatus* as well as *D. setosum, D. savignyi, E. diadema*, *E. mathaei* and dead urchins were counted.

In 2012, the belt-transect (50 x 5 m = 250 m²) method for monitoring *B. undulatus* was used (McClanahan and Arthur, 2001, McClanahan et al., 2007, McClanahan, 2008b). In each sample area 4 transects were observed covering a total area of 1000 m² per research site, except at Grave Island, where only 500 m² have been surveyed due to bad weather and visibility conditions. In each transect fish and sea urchins were surveyed sequentially, *B. undulatus* was observed first. To estimate the density of the *B. undulatus* population, the following equipment was used: a boat with driver, equipment for snorkeling, a 50 m measuring line and a diving tablet prepared with the data entry chart and a pencil. The location of the transects was chosen randomly and the 50 m line was carefully placed and anchored on the coral substrate. After installing the line the reef dwellers were given 15 minutes to revive after the disturbance. Along the transect line a 2,5 m wide corridor to either side (Figure 8) of the line was surveyed and the numbers of individuals of *B. undulatus* were counted (McClanahan, 1997, McClanahan and Arthur, 2001, McClanahan et al., 2007, McClanahan et al., 2008, McClanahan, 2008b). McClanahan et al. (2007) showed that 500 m² is the minimum area over which a community variability stabilizes when comparing quadrats of different sizes. Therefore, an overall transect size of 1000 m² per reef was scanned in order to minimize this bias and to make the data comparable to previous studies using the same area (McClanahan, 2000).

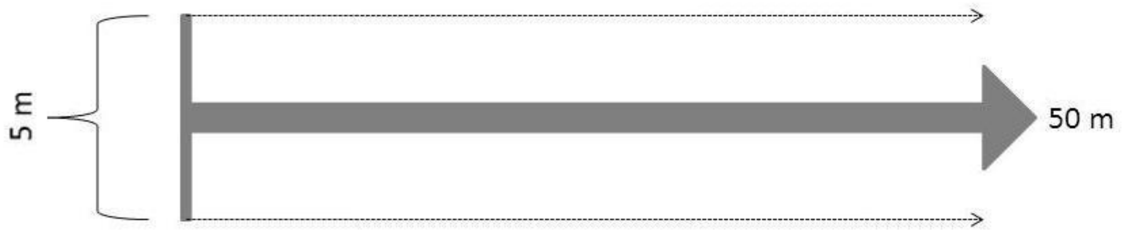

Fig. 8: Schematic representation of the belt-transects used in 2012. A measure tape was used to define the transect size of 50 m in each study site. To either side of the measure tape 2,5 m were observed and the orange striped triggerfish was counted.

To determine the sea urchin populations in 2012 quadrat analyses were used (Fig. 9). The quadrats or t-transects were randomly placed at 5 to 7 locations, depending on the density of the sea urchins, along the transect line of the fish census. A quadrat was sized to 1 m by 50 cm to either side (=1 m²) and measured with a stick of 1 m length. In each t-transect the abundance and species of the sea urchins was counted and identified respectively.

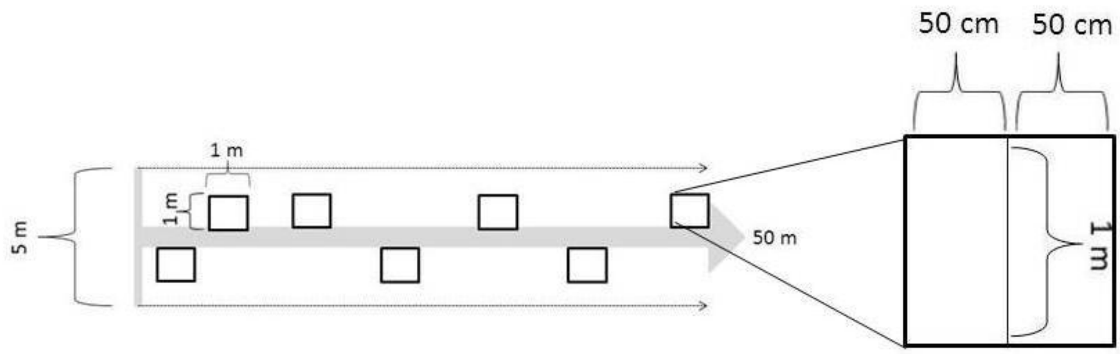

Fig. 9: Schematic representation of the t-transects. Quadrats of 1m² were laid randomly along the belt-transect line. They were admeasured using a 1 m stick and putting it in a 90° angle at the measure line and observing 50 cm to either side of the stick. The appearing sea urchins of the species *D. setosum, D. savignyi, E. diadema*, *E. mathaei* and dead urchins within the quadrat were counted.

In order to allow comparison between different sized observation areas the data was normalized to the survey area and is reported as individuals/m² for sea urchins and *B. undulatus*.

2.3 Data analysis

Data were analyzed using STATISTICA 10.0 and SigmaStat 2.0. Mind Map 2010 was used for creating the schemes of belt- and t-transects (Figures 7, 8 and 9). Since the data are not normally distributed they were evaluated by median-Tests and Spearman rank correlations. This allows evaluation of significant relations between the tested variables. A summary of all raw data can be found in table 1. Data are reported chronically, starting with Bawe Island, the first observed study site and ending with Chumbe island west, the study site which was observed last. The following correlations were analyzed by the methods mentioned above: (i) the correlation between the density of dead sea urchins and *B. undulatus* in closed study sites in 2009, (ii) the difference between the abundance of *D. setosum, D. savignyi, E. diadema* and *E. mathaei* and the triggerfish *B. undulatus* at each study site comparing 2009 to 2012 and (iii) the difference between the densities of the sea urchins and the orange striped triggerfish in an open reef site and a closed reef site for 2009 and 1012.

3. Results

This section summarizes the results of the data analysis from fieldwork in both 2009 and 2012. The underwater counting data have been analyzed for (i) the correlation between dead sea urchins and *B. undulatus*, (ii) the population dynamics at each site between in 2009 and 2012 and (iii) the difference in populations between open and protected study sites. This allows for the investigation of temporal changes in population densities.

The following table summarizes all data collected in 2009 and 2012 for all species studied. The results show that *D. setosum* is the most abundant of all sea urchins, followed by *E. mathaei*, *D. savignyi* and *E. diadema*. The triggerfish *B. undulatus* is only present in protected areas like Chumbe Island west and Chumbe Island south.

Table 1: Absolute numbers of sea urchins and *B. undulatus* collected in 2009 and 2012 on the study sites at Bawe Island, Changuu Island, Grave Island, Chumbe Island east, Chumbe Island south and Chumbe Island west.

	D. setosum	*D. savignyi*	*E. diadema*	*E. mathaei*	*B. undulatus*
Bawe Island, 2009	14	18	10	23	0
Bawe Island, 2012	159	0	5	0	0
Changuu Island, 2009	198	1	5	2	0
Changuu Island, 2012	105	4	1	0	0
Grave Island, 2009	0	0	0	0	0
Grave Island, 2012	86	0	0	0	0
Chumbe Island east, 2009	147	0	2	143	0
Chumbe Island east, 2012	176	6	0	0	0
Chumbe Island south, 2009	84	0	1	0	4
Chumbe Island south, 2012	2	0	0	0	0
Chumbe Island west, 2009	99	3	1	0	12
Chumbe Island west, 2012	36	2	7	0	3

Grave Island is lacking samples because of bad weather conditions and poor visibility, which made census impossible. In 2009 there was no count at all, neither of sea urchins nor of *B. undulatus*. In 2012 the visibility was only about 2m so that a correct identification of the sea urchins could not be guaranteed and a spotting of *B. undulatus* was unlikely. It therefore is excluded from the following analysis. Median-tests and Spearman rank correlations, analyzing the correlation between 2 variables of not normally distributed data, are used to determine whether there is a significant relation between the 2009 and 2012 data. A median-test is performed to determine if there is a significant connection between the abundance of dead sea urchins and *B. undulatus*. The Spearman rank correlation is used to describe the dependence between the number of dead sea urchins and the number of *B. undulatus*. The following hypothesis are the basis for the analysis performed on these data: 1) more dead sea urchins are expected where *B. undulatus* is abundant, 2) a population decrease in 2012 compared to 2009 and 3) more *B. undulatus* and less sea urchins are present in protected than in open sites.

3.1 Correlation of dead sea urchins and *B. undulatus*

First, the population density of dead sea urchins and *B. undulatus*, on protected study sites in 2009 is correlated. Data of 2012 shows a considerable decrease in abundance of all species and is expressed in the following table 2. Therefore only data of 2009 is displayed in Fig. 10.

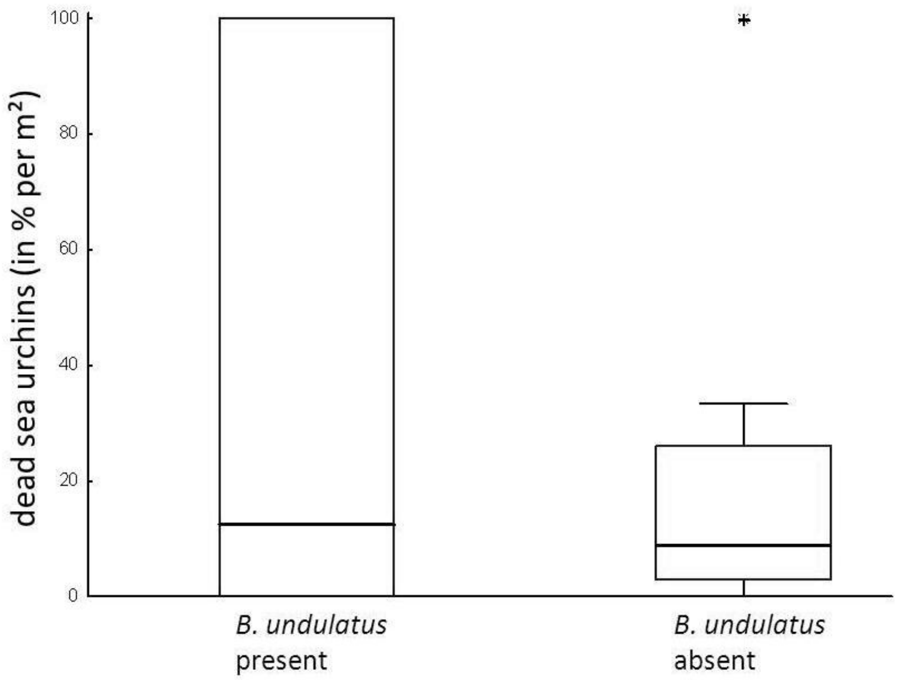

Fig. 10: Relation between dead sea urchins (in % and m²) and the presence or absence of *B. undulatus* in 2009, data of closed study sites, $n_{present}$=11, n_{absent}=8. Display: median, 25% - 75% percentile, whisker: minimum – maximum, circle: outlier, star: extremum.

In Fig. 10 the density of the dead sea urchin in percent is plotted against the presence and absence of the key predator *B. undulatus*. The dead sea urchins' percentage is calculated by dividing the total number of dead sea urchins by the total number of all urchins. The left plot shows the percentage of dead sea urchins in the presence of *B. undulatus*. The right plot shows the percentage of dead sea urchins in absence of *B. undulatus* in protected study sites, 2009. The data for the presence of *B. undulatus* has a larger statistical spread (0% to 100%) than the data for the absence of *B. undulatus* (0% to 33,3% with an extremum at 100% for site Chumbe Island west in 2009). The median of the data for the presence of *B. undulatus* lies at 12,5%, the one of the data for the absence of *B. undulatus* at 8,93%. Since these medians are very close, a median-test with the median of all samples and the presence and absence of the predator is performed. A random distribution is assumed and tested whether a positive or negative deviation of the over-all median is significantly connected to a random distribution. No significant connection could be found (median-test: n_{P+}=11, n_{P-}=8, $median_{collective}$=0,095, p=0,4, not significant, $P+_{,\leq}$/ $P-_{,>}$ = -0,78947, $P+_{,>}$/ $P-_{,\leq}$= 0,78947), consequently, median values were not significantly different and therefore, a random distribution is confirmed. To determine if there is a significant correlation between the number of dead sea urchins and the number of orange striped triggerfish a Spearman rank correlation was done (Spearman rank correlation: n=19, R=-0,088757, t=-0,367404, p=0,717852, not significant), indicating that the percentage of dead sea urchins does not depend on the number of *B. undulatus*.

Table 2: Data of dead sea urchins/m² and *B. undulatus*/m² on the study sites in 2012.

	dead sea urchins/m²	*B. undulatus/m²*
Bawe Island	0,002	0
Changuu Island	0	0
Chumbe Island east	0,007	0
Chumbe Island south	0,003	0
Chumbe island west	0	0,003

Relating the data of 2012, it is shown that a decline of dead sea urchins/m² and *B. undulatus*/m² took place between 2009 and 2012. The highest density of dead sea urchins is found on the study site of Chumbe Island east (0,007 individuals/m²) and no dead sea urchins are found on Changuu Island and Chumbe Island west. *B. undulatus* was exclusively found on the study site of Chumbe Island west (0,003 individuals/m²).

3.2 Sea urchin abundance at each study site comparing 2009 to 2012

The following section summarizes the results of the counts for *D. setosum, D. savignyi, E. diadema, E. mathaei* and *B. undulatus* per m² on the study sites in 2009 and in 2012.

Table 3: Density of the different species on the study sites in 2009.

	Bawe Island	Changuu Island	Chumbe Island east	Chumbe Island south	Chumbe Island west
D. setosum/ m²	0,583	8,250	5,654	4,667	4,125
D. savignyi/ m²	0,750	0,042	0,000	0,000	0,125
E. diadema/ m²	0,792	0,208	0,077	0,056	0,042
E. mathaei/ m²	0,958	0,083	5,500	0,000	0,000
B. undulatus/ m²	0,000	0,000	0,000	0,009	0,019

Table 3 shows that *D. setosum* has the highest densities at Changuu Island (8,25 individuals/m²) and Chumbe Island east (5,65 individuals/m²) in 2009. The lowest density of *D. setosum* exists at Bawe Island (0,583 individuals/m²). The two protected study sites at Chumbe Island south and Chumbe Island west lie in the middle. The allied *D. savignyi* is less abundant. Its highest density appears on Bawe Islands study site (0,75/m²). No Diadema sea urchins were found on Chumbe Island east and south. Chumbe Island west has a density of 0,125 individuals/m² for this species. *E. diadema* is present at all study sites and has, compared to the other sea urchins, a medium number of individuals/m² in each study site. The highest (0,792 individuals/m²) and the lowest densities (0,042 individuals/m²) are not as diverse as the highest and lowest numbers of *D. setosum*. *E. mathaei* has a noticeably high density on Chumbe Island east (5,5 individuals/m²) and is not present at Chumbe Island south and west. The orange striped triggerfish appears only in protected areas. It´s density on Chumbe Island south (0,009 individuals/m²) is close to the expected carrying capacity of >5 individuals per 500 square meters (= 0,01 individuals/m²) and the density on Chumbe Island west (0,019 individuals/m²) is almost double of the expected carrying capacity, which indicates an area where environmental and habitat conditions are appropriate for this species.

Table 4: Density of sea urchins at the study sites in 2012.

	Bawe Island	Changuu Island	Chumbe Island east	Chumbe Island south	Chumbe Island west
D. setosum/ m²	5,300	5,000	7,333	0,069	1,440
D. savignyi/ m²	0,000	0,190	0,250	0,000	0,080
E. diadema/ m²	0,167	0,048	0,000	0,000	0,280
E. mathaei/ m²	0,000	0,000	0,000	0,000	0,000
B. undulatus/ m²	0,000	0,000	0,000	0,000	0,003

The data of 2012 (Fig. 4) show an overall decrease in individuals compared to 2009. *D. setosum* is still the most abundant sea urchin. The highest density (7,333 individuals/m²) is at Chumbe Island east, the same area as in 2009, here the density rose about 1,676 individuals/m² within 3 years. The lowest numbers for species *D. setosum* are found in Chumbe Island south (0,069 individuals/m²). At this study site, the population declined by 4,598 individuals/m². The largest decrease for *D. setosum* is found to be 5,240 individuals/m² at Bawe Island. *D. savignyi* is the second most abundant in 2012. In 2009 it had been the least abundant of all surveyed species. Its highest density can be found on the study site on Chumbe Island east (0,250 individuals/m²). Compared to 2009, where none of these sea urchins were found here, it increased. No *D. savignyi* is appearing at Chumbe Island south in 2009 and 2012, a density of 0,190 individuals/m² can be determined at Changuu Island in 2012. The density of *E. diadema* decreased at all but one study site, Chumbe Island west, where the highest concentration in 2012 is found to be 0,280 individuals/m². None were found at Chumbe Island east and Chumbe Island south. *E. mathaei* was not found on any study site in 2012. Compared to 2009, this is a decline at open study sites but is equal with the density at protected study sites. The studied triggerfish *B. undulatus* appears only in Chumbe Island west with a density of (0,003 individuals/m²). *B. undulatus* is absent on the open study sites in 2009 as well as in 2012. Its density has declined on Chumbe Island south from 0,009 individuals/m² in 2009 to 0,00 individuals/m² in 2012.

3.3 Comparison of open and closed study sites

The third objective is to determine if there is a significant difference in open and protected study sites in numbers of living sea urchins and *B. undulatus*.

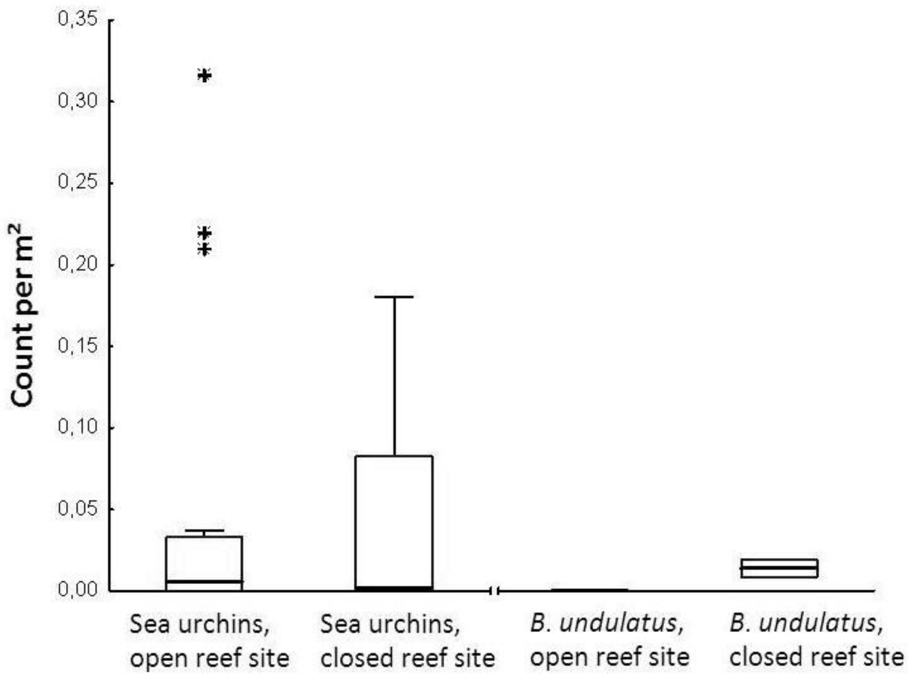

Fig. 11: count of all sea urchins and the triggerfish *B. undulatus* (per m²) on open compared to closed study sites in 2009. $n_{sea\ urchins,\ open}$=16, $n_{sea\ urchins,\ closed}$=8, $n_{B.\ undulatus,\ open}$=4, $n_{B.\ undulatus,\ closed}$=2. Display: median, 25% - 75% percentile, whisker: minimum – maximum, circle: outlier, star: extremum.

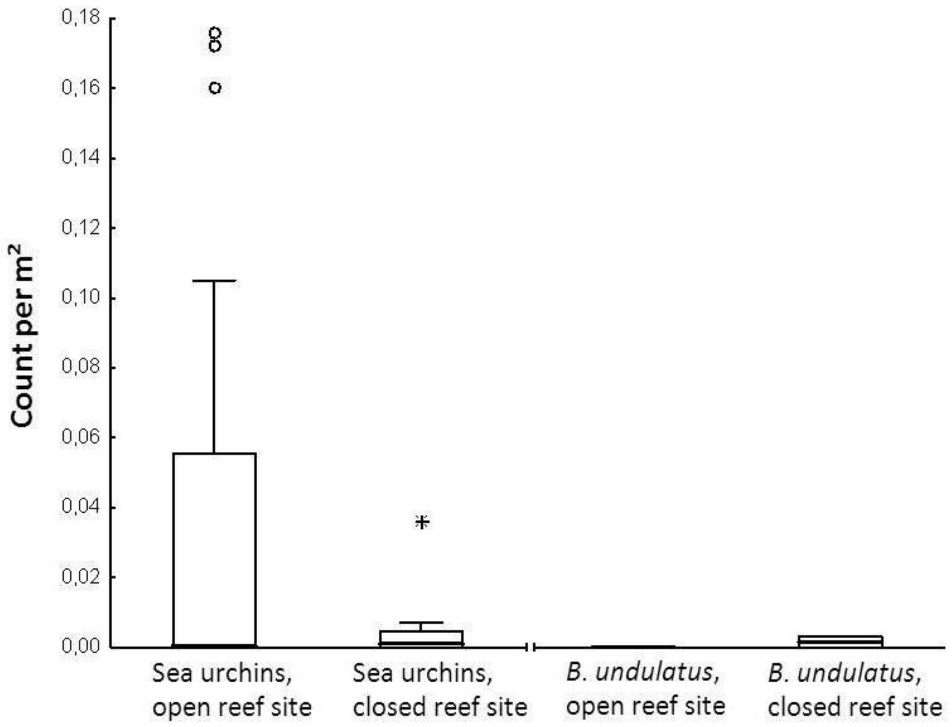

Fig. 12: Number of sea urchins and the triggerfish B. undulatus (per m²) on open compared to closed study sites in 2012. $n_{sea\ urchins,\ open}$=16, $n_{sea\ urchins,\ closed}$=8, $n_{B.\ undulatus,\ open}$=4, $n_{B.\ undulatus,\ closed}$=2. Display: median, 25% - 75% percentile, whisker: minimum – maximum, circle: outlier, star: extremum.

In Figure 11 and 12, the number of individuals per square meter is plotted against all sea urchins and *B. undulatus*, comparing open and protected study sites. It is observed that in 2009 the counted number of sea urchins in open study sites is, unexpectedly, lower than in protected study sites. The density of *B. undulatus* is higher in closed areas than in open ones. Comparing the sea urchins on open reefs with the *B. undulatus* on open reefs, it is a small population with no *B. undulatus*. In the protected areas the sea urchin density is higher with an appearance of *B. undulatus*. Data collection in 2012 result a larger statistical spread of sea urchins in open study sites than in closed study sites but has a similar median (0,0005 counts per m² in open and 0,001 counts per m² in closed study sites). The median of *B. undulatus* in 2012 in protected study sites is 0,0015 counts per m² they are not present in open sites. 3 more *B. undulatus* were counted in 2012 in protected study sites than in open study sites.

Concluding the results, almost all hypotheses are confirmed. Results differing from the expectations: the density of sea urchins on open study sites in 2009 is lower than on protected study sites. A second unusual result is the low number of sea urchins at open study sites where no predator was seen compared to protected study sites where predators were present.

4. Discussion

The results show *D. setosum* to be the most abundant species of sea urchins around Zanzibar both in 2009 and 2012. Sea urchins are diecious. Their occurrence and reproduction is strongly relying on water temperature and light intensity. *D. setosum* spawns continuously with a peak around February - May (lunar days 8-10) whereas the spawning season of its competitor *E. mathaei* is only during the months of the northeast monsoon (NEM: November-February) around March/April. *D. savignyi* spawns continuously with a peak around February - May (lunar days 17-18) (McClanahan, 1988, Muthiga and Nyawira, 1996, McClanahan and Muthiga, 2007). For these reasons, we hypothesized to find more sea urchins in the study period 2012 (May and later in the year) than in 2009 (January till February), but this hypothesis could not be confirmed. In contrary fewer sea urchins were counted found in 2012 compared to 2009 which could be a consequence of the southeast monsoon (SEM) during March until October. The SEM brings cool water, high wave energy as well as fast currents, as a result of which the distribution and survival of sea urchins could be negatively influenced. The expectation, to find more *B. undulatus* in 2009, is confirmed by our data and substantiates the results of Cinner et al. (2007). The northeast monsoon NEM, active in 2009, is known for high fish catch numbers and reproduction of many marine animals, specifically sea urchins and fish.

The change in methodology from 2009 to 2012 was performed in order to compensate for personal changes in the observer team. In 2009 there were two observers whereas in 2012 there was only one. Therefore, and because of the mobility of *B. undulatus* the transect size for *B. undulatus* was standardized to half the size (= 250 m²) of a commonly used belt-transect size of 500m² (McClanahan et al., 2007, Muhando, personal communication, 21.04.2012). The observation methodology for sea urchins was also changed comparing 2009 and 2012. In 2009 a 2 m² quadrat-transect, randomly set within the belt-transect, was observed, while in 2012 a 1 m² quadrat-transect was randomly set along the belt-transect line in order to ease the observation. The change in methodology could be causing for the differences in counted individuals of *D. setosum, D. savignyi, E. diadema, E. mathaei* and *B. undulatus* between 2009 and 2012. The methodology of 2012, being more precise, is strongly recommended for people doing similar studies in future. In order to get completely comparable datasets, it is advised to only use one methodology. A GPS-device would be helpful to pinpoint the exact position of the study site each year and to minimize local errors. Data should be collected at the same daytime, place and tide and at a frequency of at least one collection per month in order to recover time dependent data. Data should be collected by always the same person or by persons trained to follow the same data collection methods in order to reduce the bias.

The following paragraph summarizes the insights which were gained onto the questions that motivated this study.

Firstly, the percentage of dead sea urchins in relation to the density of *B. undulatus* was expected to correlate positively. Our results show a random distribution instead of a significant correlation.

The second objective was to determine the abundance of sea urchins and *B. undulatus* over time from 2009 to 2012 on the different study sites. The overall abundances of our focal species (sea urchins *D. setosum, D. savignyi, E. diadema, E. mathaei* and the triggerfish *B. undulatus*) severely declined from 2009 to 2012.

A third aim was to determine whether a significant difference between open and protected study sites exists referring to the number of individuals of the species surveyed. The results suggest considerable differences in population densities. The density of sea urchins on protected study sites in 2009 is higher than on open study sites in 2009 indicating a success of the CHICOP program. Furthermore, we counted more sea urchins on protected study sites where *B. undulatus* was present compared to open study sites where *B. undulatus* was absent. This could be a result of migration by *B. undulatus* to places where more food is available. There was no significant correlation between the number of dead sea urchins and *B. undulatus* in closed study sites in 2009. This may suggest that the presence of *B. undulatus* has no impact on the mortality rate of sea urchins. This is also confirmed by a median-test showing a random distribution. Medians are expected to be similar in each closed study site. This could be an indicator for the impact of *B. undulatus* and other predators on sea urchins (McClanahan, 2008a). At a new study site where there is a higher median of dead sea urchins surveyed a decrease of the sea urchin population is expected in the future. Therefore, this change might have a predictive power for population evolution.

The correlation analysis of dead sea urchins and *B. undulatus* is performed for closed study sites due to the absence of *B. undulatus* on open study sites which is thought to result from fishing, high mobility or lack of count due to low visibility. This creates a difference between open and protected study sites that is too large to allow for testing. Dead sea urchins are not found on Chumbe island west and Changuu Island in 2012. On Changuu Island this could be due to a strong current removing the skeletons and spines of sea urchins. On Chumbe Island west an intact reef provides lots of small caves, hollows and juts, where skeletons and spines could be drifted by water movement and therefore could not be seen and counted.

The difference between the abundance of *D. setosum, D. savignyi, E. diadema* and *E. mathaei* and the triggerfish *B. undulatus* at each study site in 2009 shows only high or low numbers of individuals/m² in open study sites. This could be a result of an extensive level of fishing. In the marine protected area (MPA), the Chumbe Island south and west study sites, almost all densities in 2009 are high or at a moderate number of individuals/m². This is thought to result from the protection of these areas which, therefore, exhibit a more balanced ecosystem and biodiversity. Nonetheless, even on closed sites this balance seems disturbed, which is expressed in the sea urchin populations on Chumbe Island west in 2009. This effect may be caused by the migration and the extensive fishing on predators. As a suggestion for improvement and to achieve stabilization on other islands as Chumbe Island west, larger protected areas and a longer time of protection of MPAs should be implemented. This will give the populations a better chance to recover. CHICOP already succeeded in keeping up the population of predatory *B. undulatus* even though there is intense fishing at the very border of the MPA. In 2012 it is expected to find less individuals/m² than in 2009 because of over-fishing (CINNER ET AL., 2007). The decline of the density of *B. undulatus* from 2009 to 2012 on Chumbe Island south and west can be based on the migration of these very mobile fish as no fishing is allowed. The lack of *B. undulatus* in the open study sites in 2012 is strongly thought to result from fishing.

In the analyses of the difference between the densities of the sea urchins and the orangestriped triggerfish in an open reef site and a protected reef site for 2009 and 2012 the data of the sea urchin species are combined because *B. undulatus* has no known preference of sea urchins (MCCLANAHAN, 2000). Closed study sites in 2009 contain more sea urchins than open study sites in 2009. A potential reason for this result could be fishing with drag nets where the net scratches along the substrate and collects all rubble and animals, like sea urchins, on the seabed. This might be the reason why on a highly fished site, no sea urchins can be found.

According to McClanahan (1997), abundant sea urchins may suppress the recovery of predator fish populations. Consequently it was expected to find only a few or no *B. undulatus* on study sites with a high density of sea urchins. In 2009 data this expectation could not be confirmed. On protected study sites a high density of sea urchins is found together with a high density of *B. undulatus*. After an increase of the predators' density a decline of the sea urchins' density is expected (Babcock et al., 2010). The ecosystem could be at the edge of a change. Therefore in the protected areas the predator density is expected to increase with sea urchins declining in the future.

On open study sites in 2009 neither sea urchins nor *B. undulatus* was found. This unexpected result could be explained by the destruction of the reef. Among others, the physical growth of sea urchin populations is highly dependent on food availability (McClanahan and Muthiga, 2007). Sea urchins will avoid destroyed reefs and continue grazing at other sites with more corals and seagrass. Since no GPS-device was used in this study, the study sites were most likely moved a few meters between 2009 and 2012. This could be another reason for the differences in sea urchin and *B. undulatus* densities counted. In order to get comparable data on Grave Island it is necessary to search for a more sheltered study site. It is suggested to search on the northwest end rather than on the southeast end of the island. It is also suggested to collect data only around low tide and during NEM where there is no strong wind or rain that could influence the reef and visibility in this area. Both, sea urchins and *B. undulatus* are very mobile and it is, therefore, contended that the variable study site position has little influence of the population density counts.

To get a larger amount and more significant data it is suggested to continue observation of all study sites every month over several years. The closing of new MPAs might be very unpopular for native fishers but it is necessary to conserve the local marine flora and fauna and keep the ecosystem of reefs intact for future generations. Consequently, certain recommendation for fishers for compensating their financial loss has to be made by politics.

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5.2 Figure references

Figure [1]: NATURE-CONSERVANCY. 2012. *Tanzania Field Project* [Online]. Marine Conservation Agreements. Available: http://www.mcatoolkit.org/Field_Projects/Field_Projects_Tanzania.html [Accessed 17.07.2012].

Figure [2 - 6]: GOOGLE EARTH. 2012. [Accessed 17.07.2012]

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Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig verfasst, keine anderen als die angegebenen Quellen und Hilfsmittel verwendet und die Arbeit keiner anderen Prüfungsbehörde unter Erlangung eines akademischen Grades vorgelegt habe.

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