UPPSALA UNIVERSITET

Human impact on invertebrate abundance, biomass and community structure in seagrass meadows
- a case study at Inhaca Island, Mozambique

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FOREWORD

I have undertaken a Minor Field Study financed mainly by the Swedish International Development Cooperation Agency (Sida) through SLU External Relations. It is also a Degree Project within the Master program in Natural Sciences, profile Biology.

The reason I chose to do this is because around the world there are more than one billion people living in extreme poverty, so extreme that they have to survive on less than one dollar per day. These people need aid focused on their perspective and interests to help them improve their living conditions. The aid should not be charity, but it should be about the right not to be poor. To achieve this goal money is not enough, of greater importance is to provide people with knowledge.

Aid should be implicated on several levels, from individual to overall society structure. The efforts can be directed straight to poor people, but also to more indirect structural changes. It is very important to support democracy and the increased respect for human rights. To contribute to the development of the country side, water resource administration, coastal development and marine environmental protection are also of high priority. Development is when people's freedom, wellbeing and dignity are increasing in a safe and fair society with a sustainable economic growth. For a possible development, poor people must be able to take part in the political, social, economical and environmental work (Sida, 2006).

Many poor people are dependent on the ocean and this is one reason why the coastal zones of the world are densely populated. Already ten years ago more than half of the world's population lived within 60 km of the coastline and the numbers are rapidly increasing (UNEP, 1995). As the coastal regions become more and more densely populated, coastal water quality will suffer, wildlife will decrease, and shorelines will erode (ISOCARP-IAIA, 1998). The coastal zone is a unique resource which provide humans with a major food source, especially protein, but also multiple products and services such as medicine and recreation. To be able to fight the poverty it is important to preserve and maintain these resources.

More than 80 % of the population in the Western Indian Ocean region lives in the coastal areas (World Bank, 2001). Therefore it is essential for the people living in these areas to understand the importance of sustainable use of ocean resources (ISOCARP-IAIA, 1998). An overexploitation of the coastal and marine resources will probably lower the chances for development and sustainable economic growth for the countries possessing these valuable coastal environments (World Bank, 2001).

Mozambique is one of the world's poorest countries and in the Human Development Report from 2005 it is ranked on place 168 out of 177 countries (Sida, 2006). It is important to support Mozambique and other countries in the same situation, to build up a self-sustainable community. Mozambique stretches 2500 km on the south-east coast of Africa and has a coastline of 6942 km (Fitzpatrick, 2000; Earth Trends, 2003). In a country with a coastline of this length many people are going to exploit the coasts and the ocean.

Hopefully, my study can contribute with baseline scientific knowledge, which could be used in the perspective of management and conservation of seagrass meadows in Mozambique and other countries lacking this kind of information.

ABSTRACT
Humans are known to affect natural habitats negatively. This study aims to examine if different anthropogenic activities have an impact on invertebrates in seagrass communities. The study was performed by comparing abundance, biomass and community structure of invertebrates as well as seagrass characteristics among 3 different localities, one marine reserve (control), one area exploited by invertebrate collectors (women and children) and one area close to the harbour at Inhaca Island in Mozambique. No differences in seagrass biomass were found between the marine reserve and the exploited area, whereas the harbour area showed significantly lower biomass than the two other localities. The marine reserve showed by far the highest macro invertebrate density, biomass and diversity. This study has shown that anthropogenic activity is affecting the seagrass and the animal community. It has also shown the importance of marine protected areas to preserve a high biodiversity.

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Front page photo: Elena collecting invertebrates during low tide. Photo: Lina Nordlund

1. INTRODUCTION

1.1 SEAGRASS MEADOWS AND THEIR ECOLOGICAL IMPORTANCE

Seagrasses are vascular plants that can be found all over the world except in Antarctica (den Hartog, 1970). In shallow waters, e.g. lagoons or estuaries, they can form dense vegetative meadows, which are dominating habitats of the coastlines around the world (Green and Short, 2003). Seagrass meadows are of ecological importance providing a high biodiversity and production of both plants and animals (Howard *et al*., 1989; Duarte and Chiscano, 1999). They are important for both fish and invertebrates using these habitats for foraging, for protection against predators and as nursery grounds (Orth *et al.*, 1984; Bell and Pollard, 1989; Nagelkerken *et al.*, 2000). Further, seagrass meadows play a key role since they trap and stabilise sediments by their dense network of rhizomes, which in turn prevents coastal erosion. The canopy of seagrass leaves act as dampers and they reduce water movement (Stout, 2005). Research has shown that faunal diversity in seagrass meadows is affected by both water movements and wind disturbance that may act as mechanisms creating and maintaining great animal diversity (Boström, and Bonsdorff, 2000).

Seagrass meadows are important also from an economical perspective since they function as a habitat for many commercially important species. Due to the high productivity and the important role for coastal fisheries, seagrass meadows may constitute a great direct value for humans in many tropical rural communities (e.g. de la Torre-Castro and Rönnbäck, 2004). Furthermore, seagrass meadows play an important role in the coastal environment since they often function as a link between mangroves and coral reefs (e.g. Parrish, 1989). These three ecosystems may depend on each other; for example, many of the animals utilise mangrove and seagrass habitats during early life stages and when large enough to escape predators they migrate to coral reefs where they live as adults (Nagelkerken, 2001; Dorenbosch et al., 2005).

There are about 60 species of seagrass described in the world (Green and Short, 2003). In the Western Indian Ocean region thirteen of these species are found and of which the most commonly found are *Thalassia hempriichii* and *Thalassodendron ciliatum* (formerly *Cymodocea ciliate*). *T. hempriichii* can usually be found in more protected areas or on intertidal flats, whereas *T. ciliatum* usually can be found in habitats that are exposed or semi-exposed (Gullström *et al.,* 2002).

1.2 ANIMAL-SEAGRASS INTERACTIONS

In general, species richness, abundance and biomass of animals associated with seagrass meadows are greater compared to adjacent unvegetated habitats (Edgar, 1990; Boström and Bonsdorff, 1997). According to Lewis (1984), the high abundance of animals in the presence of macrophytes – such as seagrasses – can depend on (i) the amount of physical structure (usable as living space), (ii) the number of microhabitats, (iii) sediment deposition and stabilization, (iv) food resources, (v) protection from predators, and (vi) reduced hydrodynamic forces. Further, Connolly (1994) showed that the abundance and production of epifauna were higher in seagrass patches than in unvegetated patches, whereas they were intermediate in patches where he had removed the seagrass canopy. It was shown that removal of seagrass may affect its associated fauna negatively.

Research has shown that meio- and macrofaunal biomass in seagrass meadows can vary between seasons (Paula *et al*., 2001). In terms of spatial variability, macroinvertebrate communities may be positively correlated to seagrass biomass, i.e. a meadow with a dense plant population comprise of a greater macroinvertebrate biodiversity than a sparse meadow (Attrill *et al*., 2000). One of the most abundant groups of invertebrates in shallow coastal waters is suspension-feeding bivalves, commonly associated with seagrass.

It has been shown that grazing by herbivorous organisms reduces the amount of seagrass biomass (Hughes *et al.*, 2004). Sometimes the grazing effect can be so intense as to control the seagrass density (Alcoverro and Mariani, 2002).

1.3 CAUSES OF DECLINE OF SEAGRASS MEADOWS AND ASSOCIATED FAUNA

In a worldwide perspective, seagrass habitats are rapidly decreasing due to natural and anthropogenic activity like overexploitation and devastation from for example nutrient enrichment and sediment overloading (Green and Short, 2003). The run-off from agricultural municipal areas often contains high concentrations of inorganic nutrients, particularly nitrogen and this is a important reason for our eutrophicated costal waters. Nutrient and sediment overloading can reduce water clarity and decrease light penetration, which will affect the seagrass that need light to survive. With low light less oxygen is produced resulting in oxygen shortage in roots and rhizomes which die from sulphide toxicity (Dunton, 1999). Changes in food webs (due to e.g. overfishing), mechanical damages such as dredging as well as weather and climate changes are also serious threats to seagrass ecosystems. In addition, boating, water sports, increased tourism, construction work in the costal areas that are already densely populated is also harmful for this environment. Eckrich and Holmquist (2000) showed in a trampling study on seagrass that trampling for a couple of months impacted the seagrass negatively regarding among other things canopy height, standing crop and shrimp density. Contessa (2004) showed that removal of shrimp and the disturbance when collecting these shrimps with bait pumping or digging on mudflats decreases shrimp abundance, porosity and organic carbon content of intertidal sediments. Collecting animals most likely have an effect on animal abundance and the sea bed.

High incidence of boat propeller-damage from fishing or tourist boats damages the meadows e.g. propeller scarring on the seagrass (Sargent et al., 1995). A more general problem that is harmful for this environment is the human-induced global warming, which may subsequently cause unusual water levels, storms and waves. As a result of the fast decrease of this valuable ecosystem seagrass meadows have been classified as a threatened biotope in the Rio convention. Unfortunately today, seagrass ecosystems are seldom included in coastal management programs. Seagrass meadows are of both national and international concern and that is why this valuable global resource is in great need of conservation (Green and Short, 2003).

Research about seagrass ecosystems is usually performed in developed countries and based on site-specific studies (Green and Short, 2003). Research from Caribbean, Indian Ocean, Southeast Asia and the Pacific are especially insufficient (Green and Short, 2003). More knowledge is needed to generate more general interest and recognition about this important ecosystem. Seagrasses are endangered which is critical to the people taking advantage of the benefits from the seagrass meadows. Advantages from seagrass meadows can be that (i) people find greater animal density compared to sand areas; (ii) protection of homes and fields from erosion; (iii) fishermen get larger catches when there is a nursery grounds for fishes. Worldwide there are some marine reserves to protect the coastal zones, including seagrass habitats, but more are needed (Green and Short, 2003).

1.4 OBJECTIVES

The overall objective of the study was to examine if different anthropogenic activities have an impact on invertebrates in seagrass communities. The seagrass meadows were mostly dominated by the seagrass *Thalassodendron ciliatum*. This was studied by investigating invertebrate abundance, biomass and community structure at localities with different kind of anthropogenic impact, i.e. collection by women and harbour activities. Moreover a descriptive comparison of seagrass and animal parameters, like biomass and diversity, among the different localities were carried out. A further goal was to compare the results from removal of edible animals by a collecting woman at the same three localities as above. The study may be of importance as baseline data for future research and monitoring efforts.

2. STUDY AREA

2.1 INHACA ISLAND

The study was conducted around Inhaca Island, which is situated 37 km east of Maputo in southern Mozambique. The island is positioned between latitudes 25°58'S and 26°05'S and longitudes 32°55'E and 33°00'E.

The western side of the island is relatively protected and has a gentle topographic slope. Tides are bi-diurnal and vary between 0.3 and 3.8 m (Tabela de Mares do Porto de Maputo). Winds are mainly gentle and of southwest and northeast directions. The bottom substrate on the intertidal flat is sandy on the west coast of the Island (Kalk, 1995). The environment at Inhaca is well described by Kalk (1995).

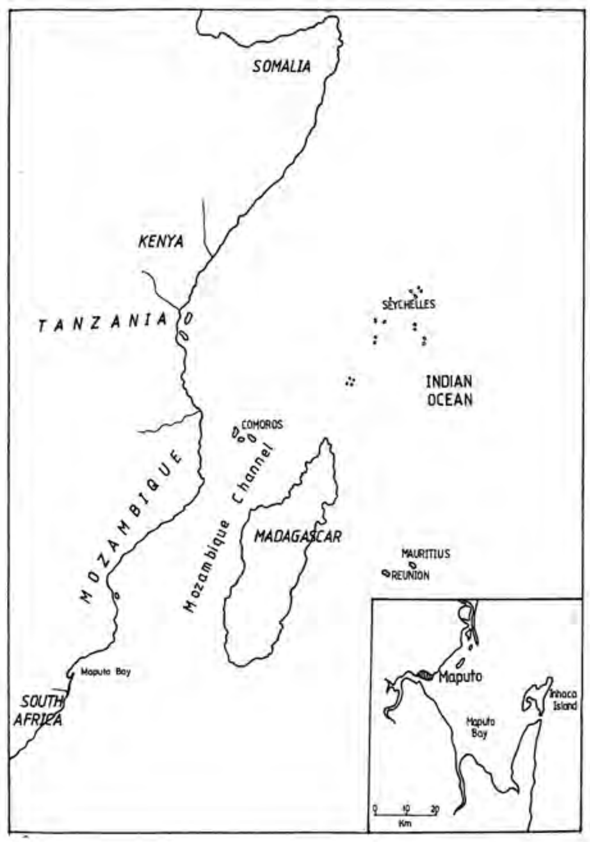

Figure 1. The Western Indian Ocean region and an enlargement of southern Mozambique, including Inhaca Island (Gullstöm *et al*. 2002)

Inhaca is a relatively small but quite crowded island that shows increasing problems from anthropogenic activities on the marine environment. Thus, it is important to highlight issues concerning sustainable management of important resources such as agriculture and fishing. Most of the population on Inhaca is either directly or indirectly dependent on the marine environment for their daily livelihood. The men mainly work as fishermen and are taking care of cattle. Women primarily work in subsistent agriculture, but due to the low fertility of the sandy soils, crops are small. This is one reason why women with some help from children also collect invertebrates in the intertidal seagrass meadows (De Boer *et al*., 2002). They collect invertebrates during low spring tide, usually for 3 hours starting 1.5 hours before low tide. At Inhaca Island there is one tourist resort, Inhaca Island Lodge, with 40 rooms and bungalows, and the hotel can accommodate more than 100 guests. The hotel offers boat excursions and different kinds of water sports daily. This may have an impact on the adjacent shallow seagrass communities in front of the hotel. The hotel with its beach front is located right next to the harbour. Just inland from the harbour and the hotel the largest village on the island is situated.

Around the island there are several species of seagrass, i.e. *Cymodocea rotundata* Ehrenb. et Hempr. Ex Aschers, *Cymodocea serrulata* (R. Br.) Aschers. et Magnus, *Halodule sp.*(Forsk.) Aschers. in Bossier, *Halophila ovalis* (R. Br.) Hook. *f*., *Nanozostera capensis* Setchell., S*yringodium isoetifolium* (Ascherson) Dandy *Thalassia hemprichii* (Ehrenberg) Asherson and *Thalassodendron ciliatum* (formerly *Cymodocea ciliata*) (Forskål) den Hartog. *Thalassodendron ciliatum* is often mixed with *Cymodocea serrulata* on Inhaca Island (Bandeira, 2002).

2.2 *Thalassodendron ciliatum* SEAGRASS MEADOWS

Thalassodendron ciliatum (Family: Cymodoceaceae; Order: najadales) is a dioecious species. This seagrass species form extensive meadows throughout the tropical Indo-West Pacific. They can tolerate great wave action and may therefore occupy hard substrates, but is intolerant to freshwater. *Thalassodendron ciliatum* meadows are common in East Africa and play an important role in nearshore marine environments. This seagrass often forms single-species meadows. *Thalassodendron ciliatum* is a branched seagrass species with thick and hard vertical below-ground rhizomes, 5-10 mm in diameter, and several wiry branching roots arising at each rhizome node. This enables attachment to hard substrata, which is very unusual for seagrasses. The vertical stems with numerous of leaf scars may grow to 30-40 cm in height at Inhaca Island. In other areas of Mozambique they can reach over a meter in height. Usually each shoot has between five and seven strap-like leaves, which are about 10 cm long and 1 cm broad. Older leaves enclose younger ones and when leaves are shed the stem get conspicuous scars (see photo 1 in appendix; Kalk, 1995; Waycott, 2004).

2.3 SAMPLING LOCALITIES

Three seagrass meadows dominated with *T. ciliatum* were chosen as study sites. At each locality I sampled in an area of 100 m*10-50 m with the GPS position in the middle of the site. The localities are marked with a plus in Figure 2. The study period was end of October 2005 until beginning of January 2006.

2.3.1 Control site

The control site (25°59'009S, 32°54'725E) was located in the south adherent marine surroundings of a land reserve Portuguese Island (Figure 2). There are always two guards protecting the reserve and thus there are no fishing and/or invertebrate collection performed within seagrass meadows of this site (personal observations; see photo 2 in appendix, Figure 2).

2.3.2. Exploited site

The exploited site (25°59'357S, 32°55'250E) was located north of the harbour. In this area I observed women and children (1-20 day^{-1}) collecting invertebrates during low spring tide (see front page photo, Figure 2). There is seldom any boat traffic in this area.

2.3.3. Harbour site

The harbour area (26°00'100S, 32°54'786E) is greatly influenced by human activity. I counted the number of boats during November and December at noon and at least 5 times per month. In November it was an average of 16 boats with motor and usually around 10 sailing boats. In December, during tourist high season, I registered an average of 20 boats with motor and around 12 sailing boats. When the fishing boats came in daily to the harbour there were 20-100 people treading around in the water, sometimes also in the seagrass meadows, to buy fish from the boats (see photo 3 in appendix). The hotel arranges snorkel and dive excursions, fishing trips and have a renting service for e.g. kayaks. Where the boats are anchored depends on the tide and what time people will use them again. No animal collectors were seemed in the harbour area during the study period. However, this area often had a thin layer of petrol and oil on the water surface (personal observation; see photo 4 in appendix; Figure 2).

Figure 2. Satellite image over Inhaca Island and Portuguese Island (top left) with the localities marked with a plus: Control site (top), Exploited site (middle) and Harbour site (bottom). The image is a subscene from the Landsat ETM, 2001-05-07, band 5, 4, 3 as RGB (revised by Prof. Bengt Lundén at the Department of Physical Geography and Quaternary Geology at Stockholm University)

3. METHODS

3.1 FIELD METHODS

Within each site I investigated five transects with a length of 9 m with 5 squares of 0.25 m^2 (Figure 3). The five transects were randomly placed during low spring tide in the selected *Thalassodendron ciliatum* meadows. Each square was visually inspected to collect quantitative data about moving animals such as crabs. 1/4 of the square was then excavated and filtered through a sieve (mesh size: 1 mm). First all seagrass and animals in the sieve were collected. Secondly, the rest of the square was excavated and sieved to collect all animals larger than 1 mm, but also to be sure that animals not visible were collected (e.g. animals buried in the bottom substrata, hiding in the seagrass or those of very small size). When sampling organisms, it is very important to consider the tides to get reliable and comparable data. Thus, I always worked at low spring tide, which was also the case for invertebrate collection by a local woman (see below).

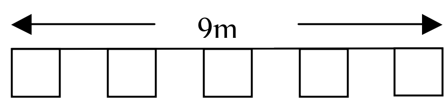

Figure 3. Transect of 9 meters with 5 squares.

3.1.1 Edible invertebrate collection

A native woman was hired to collect animals exactly as she usually does except that I decided area and time. I randomly chose an area of 225 m^2 where she was collecting for 1.5 hours right before low spring tide and also another area of similar size for 1.5 hours just after low spring tide. All areas in the same area as the transects were done. All collected animals were counted and measured. Linear regression analysis of 35-150 animals (depending on species) was used to calculate dry weights.

3.2 LABORATORY METHODS

In the laboratory, the collected animals were identified to species (or to the lowest taxonomic level possible). The animals were counted and weighed, wet and dry. The shoots and roots from *T. ciliatum* and its associated seagrass species were weighed (wet and dry), and the shoots were also counted separately to get shoot density. The plants were measured for mean length (i.e. canopy height) per transect. Drying of both animals and plants was done until no weight loss was recorded, but always for a minimum of 48 h at 70º C.

3.3 STATISTICAL METHODS

Prior to statistical analyses, all data were checked for normal distribution, and log 10 transformed when necessary.

3.3.1 SEAGRASS AND ANIMALS

One-way ANOVA and post-hoc Tukey test were used to examine differences among localities for total seagrass biomass, above-ground seagrass biomass, below-ground seagrass biomass and shoot density, but also for animal biomass, number of animals and number of different animal species. Linear regression analysis was used to investigate relationships between total seagrass biomass and canopy height, shoot density, animal biomass and animal density, respectively. All univariate analyses were conducted using the statistical software MINITAB® Release 14.

3.3.2 COMMUNITY STRUCTURE OF ANIMALS

To detect patterns in community composition of seagrass assemblages multivariate techniques are considered sensitive (Bowden et al., 2001).

Spatial patterns of invertebrate communities were examined for density and biomass with non-parametric multivariate technique (Clark and Warwick, 1994). One-way analysis of similarities (ANOSIM) tested for differences in invertebrate community structure among localities (Clark and Warwick, 1994). Patterns of similarities were visualized using non-parametric multidimensional scaling (nMDS) plots based on square-root transformed data and Bray-Curtis similarities. The similarity of percentages (SIMPER) procedure was carried out to determine which invertebrate species contributed most to dissimilarities within and among localities (Clark, 1993). These multivariate analyses were carried out using Primer version 5.2.4 (Clark and Gorley, 2001).

Further multivariate data analysis was carried out using principal components analysis, PCA, implemented with the program CANOCO 4. Prior to the analysis, all data were square-root transformed. PCA was used to be able to summarize and to examine spatial variation of invertebrate community structure – based on biomass data – within and among seagrass meadows of different exploitation and to include other factors e.g.seagrass biomass and number of different species. Ordination is used for a number of related statistical tests to reduce the data complexity, reduce the number of dimensions, and to find and illustrate similarities and differences between objects. Dimensions here mean measurable and immeasurable factors which affect the objects in measure. The presentation of the results is mostly reduced to the first two axes that show most variation in the analyzed dataset. Site and species scores that are similar will appear close to each other and the dissimilar ones will appear far apart (ter Braak and Šmilauer, 1998).

3.3.3 INVERTEBRATE COLLECTION

Edible animal catch was described and compared among the different localities using univariate statistics, i.e. ANOVA and Kruskal-Wallis tests. All these analyses were conducted using the statistical software MINITAB® Release 14.

4. RESULTS

4.1 SEAGRASS AND ANIMALS

Significant relationships were found between total seagrass biomass and all parameters tested. Number of animals, animal biomass and number of seagrass shoots were all positively correlated with total seagrass biomass (Figure 4 a-c). Canopy height, however, showed a negative relationship with total seagrass biomass (Figure 4 d).

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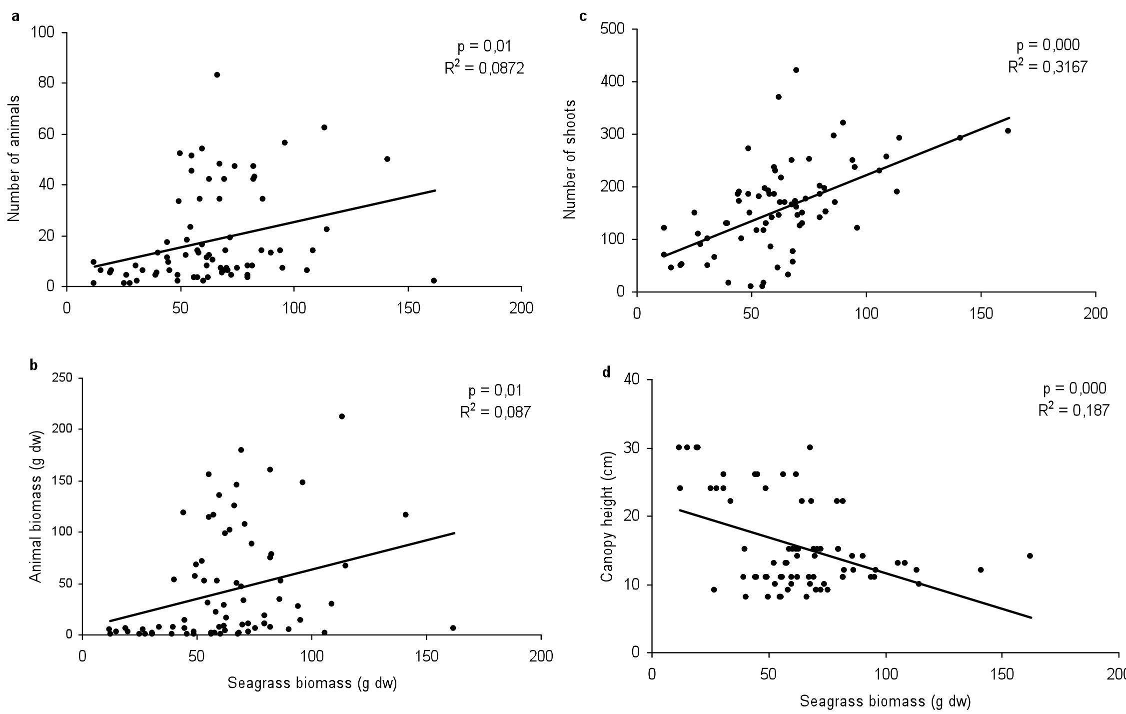


Figure 4. Relationships between seagrass biomass (g dry weight) and (a) number of animals, (b) animal biomass, (c) number of shoots, and (d) canopy height.

Relationships between number of shoots and animal biomass (Linear regression analysis; r^2=0.00, p=0.868) and number of animals (Linear regression analysis; r^2=0.60, p=0.516), respectively, were tested, but showed no correlation.

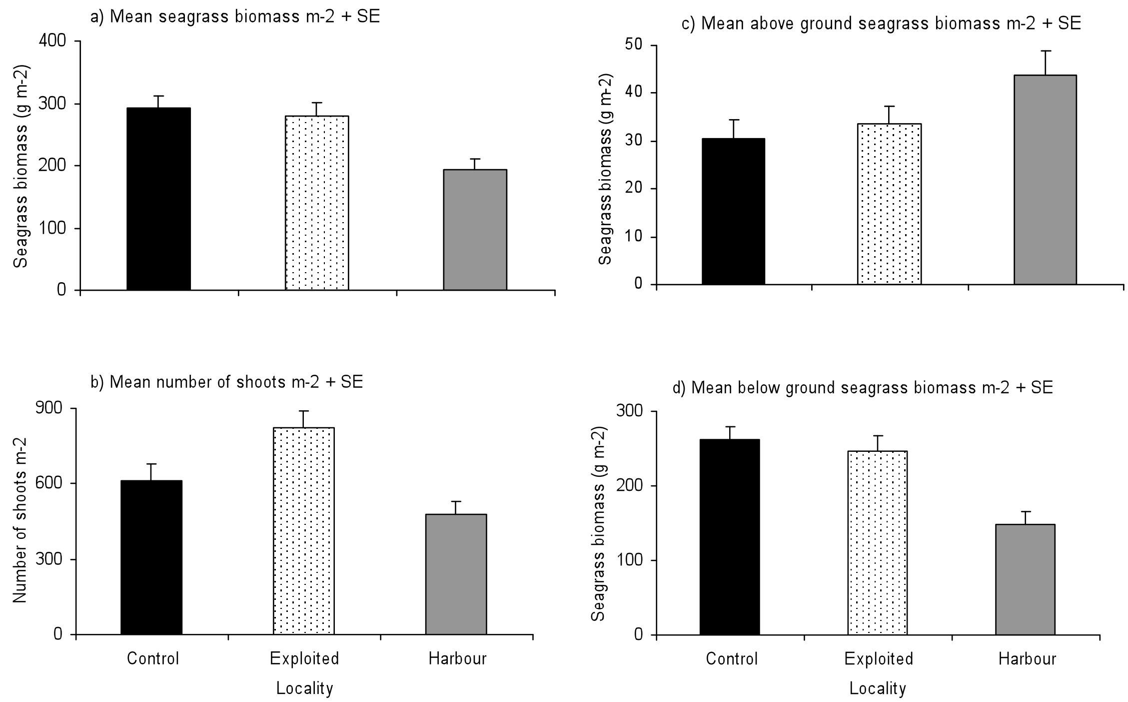


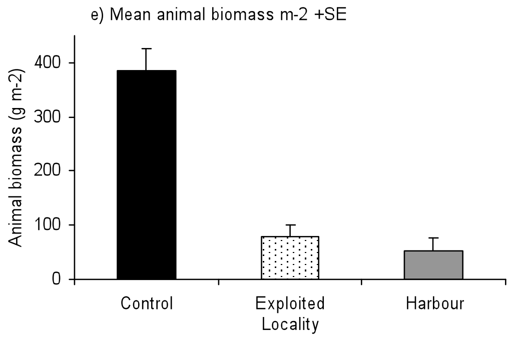
Figure 5. Differences between localities for a) seagrass biomass, b) number of shoots, c) above-ground biomass, and d) below-ground biomass.

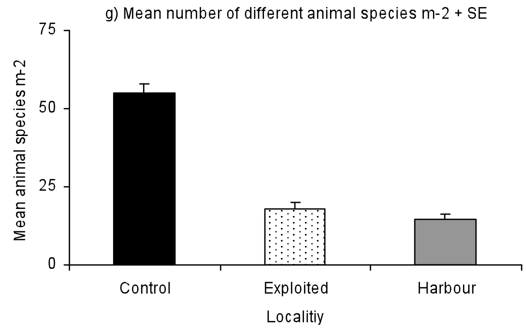
There was a significant difference in total seagrass biomass between the control and the harbour sites ($p < 0.05$) as well as between the exploited and the harbour sites ($p < 0.05$), but not between the control and the exploited sites ($p > 0.05$; Figure 5a, Table 1). Number of shoots in the control site differs from the exploited site ($p < 0.05$) as well as between the exploited site and the harbour site, whereas no difference was found between the control and the harbour sites ($p > 0.05$, Figure 5b, Table 1)). There was no difference in above-ground seagrass biomass among the localities ($p> 0.05$; Figure 5c, Table 1). For below-ground seagrass biomass there was a significant difference between the control and the harbour sites as well as between the exploited and the harbour sites ($p < 0.05$; Figure 5d, Table 1).

Table 1. Results of testing different responses; seagrass biomass, number of shoots, above-ground seagrass biomass, below-ground seagrass biomass, animal biomass, number of animals, number of different animal species between localities; Control (C), Exploited (E) and Harbour (H) with One-way ANOVA and post-hoc Tukey test. Bar charts can be found in figure 5 and 6.

Response variable	Bar chart	r^2	p	p C - E	p C - H	p E - H
Seagrass biomass	a	16.54	**0.001**	0.898	**0.003**	**0.010**
Number of shoots	b	17.80	**0.001**	**0.048**	0.294	**0.001**
Above-ground seagrass biomass	c	6.85	0.078	0.865	0.078	0.218
Below-ground seagrass biomass	d	24.38	**0.000**	0.807	**0.000**	**0.001**
Animal biomass	e	50.90	**<0.000**	**0.000**	**0.000**	0.825
Number of animals	f	67.12	**0.000**	**0.000**	**0.000**	0.443
Number of different animal species	g	74.93	**0.000**	**0.000**	**0.000**	0.489

Animal biomass differed between the control site and the other localities, which was also the case for the number of animals and the mean number of different animals ($p < 0.05$); Figure 6, Table 1).





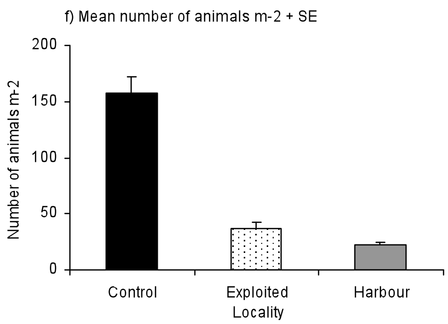


Figure 6. Differences between localities for e) animal biomass, g) number of animal, f) number of different animal species.

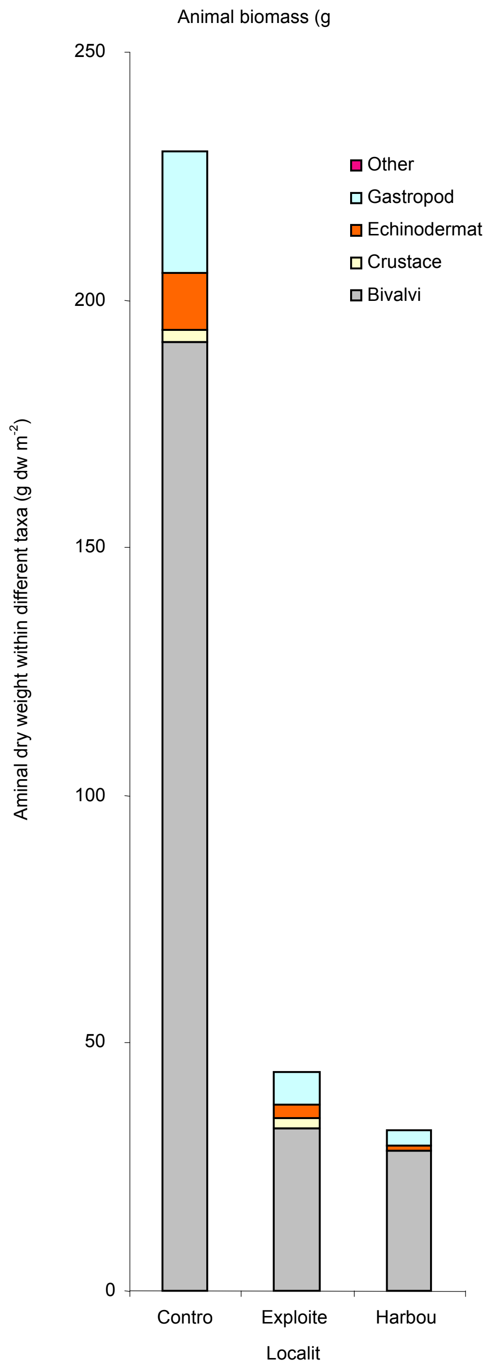


Figure 7. Animal biomass separated into different taxa.

In general, Bivalvia is the most common taxon followed by Gastropoda and Echinodermata (figure 7).

4.2 COMMUNITY STRUCTURE OF ANIMALS

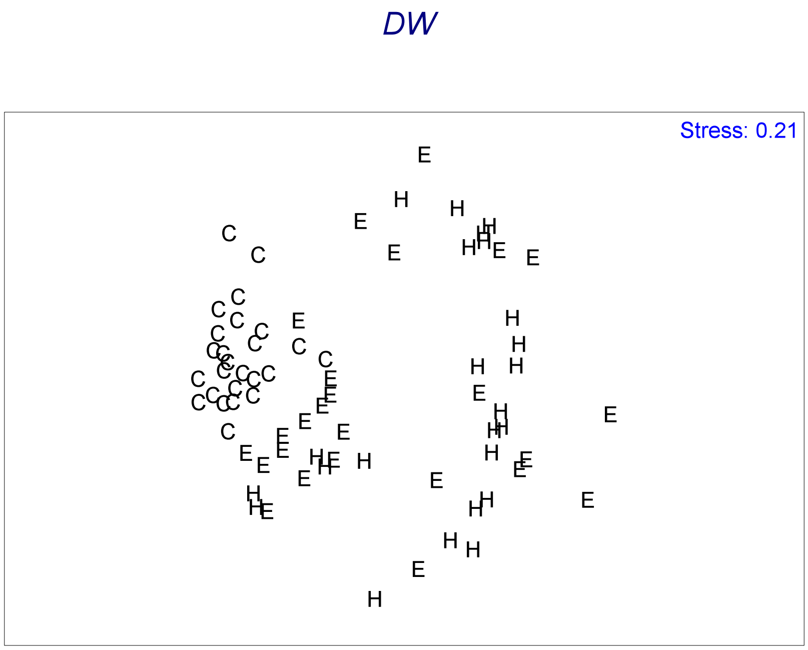


Figure 8. Non-metric multidimensional scaling (nMDS) ordination of macroinvertebrate community composition for samples from three localities; Control (C), Exploited (E) and Harbour (H) based on Bray-Curtis similarity index using square-root transformed biomass (dw) data.

In total, 3227 g dry weight animals were sampled from 75 squares. Figure 8 shows differences in community structure between localities regarding animal biomass. The significance of this separation was confirmed by ANOSIM (global $R = 0.425$, $p < 0.001$). Average similarity (%) and species contributing to similarities within a locality can be seen in Table 2. Average dissimilarity (%) and species contributing to dissimilarities between localities can be seen in Table 3. Dominating species at the different sites can be seen in appendix.

Table. 2. Average similarity (%) and species contributing to similarities (%) within three localities; Control (C), Exploited (E) and Harbour (H) regarding animal biomass.

Locality	Average similarity %	Contributing species (%)
C	24.18	*Gafrarium divaricatum* (31.49), *Modiolus auriculatus* (20.27), *Pinctada* sp. (11.66), *Pinna muricata*(10.10), *Modiolus ligneous* (5.67)
E	11.45	*Modiolus auriculatus* (68.28), *Aaptos cf. chromis* (9.49), *Tellina* sp. (8.97), *Nassarius coronatus* (5.52)
H	6.75	Polychaeta (40.95), *Anodontia edentula* (22.70), *Modiolus auriculatus*(16.38), *Tellina* sp. (11.49)

Table 3. Average dissimilarity (%) and species contributing to dissimilarities (%) between localities; Control (C), Exploited (E) and Harbour (H) regarding animal biomass.

Localities	Average dissimilarity %	Contributing species (%)
C and E	92.86	*Gafrarium divaricatum* (16.76), *Modiolus auriculatus*(13.88), *Pinctada sp.* (8.65), *Pinna muricata*(8.21), *Pentaceraster mammilatus*(5.85)
C and H	97.22	*Gafrarium divaricatum* (17.10), *Modiolus auriculatus* (14.62), *Pinctada sp.* (8.87),*Pinna muricata* (8.21) *Pentaceraster mammilatus*(6.16)
E and H	95.21	*Modiolus auriculatus*(35.49), *Aaptos cf. chromis* (8.61), *Tellina sp.* (4.67), *Anodontia edentula* (4.65), *Nassarius coronatus* (4.17)

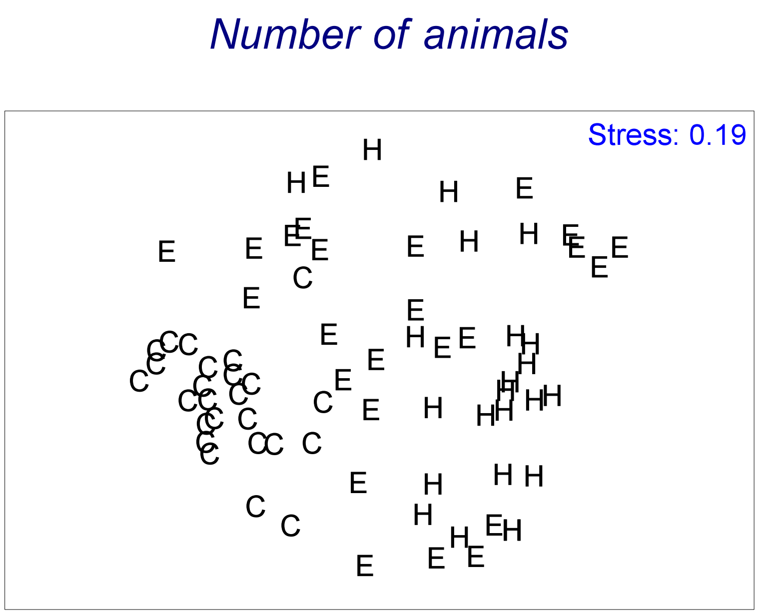


Figure 9. Non-metric multidimensional scaling (nMDS) ordination of macroinvertebrate community composition for samples from three localities; Control (C), Exploited (E) and Harbour (H) based on Bray-Curtis similarity index using square-root transformed density data. The statistical stress is 0,19.

The entire data set contained 1360 animals (see appendix for species list). Figure 9 shows differences in animal density between localities. The significance of this separation was confirmed by ANOSIM (global $R = 0.515$, $p<0.001$). Localities differed considering the animal density. Average similarity (%) and species contributing to similarities within a locality can be seen in Table 4. Average dissimilarity (%) and species contributing to dissimilarities between localities can be seen in Table 5. Animal density of the different species at the different sites can be seen in appendix.

Table 4. Average similarity (%) and species contributing to similarities within a locality; Control (C), Exploited (E) and Harbour (H) regarding animal density.

Locality	Average similarity %	Contributing species (%)
C	34.47	*Modiolus auriculatus* (20.72), *Modiolus ligneus* (16.02), *Gafrarium divaricatum* (14.57), Polychaeta (9.92), *Pinctada* sp. (6.43)
E	18.03	*Modiolus auriculatus* (25.13), *Tellina* sp.(21.65), Polychaeta (14.98), *Aaptos cf. chromis* (13.42), *Pinnotheres* sp. (0.35)
H	25.83	Class Polychaeta (62.14), *Tellina* sp. (*18.41*) *Anodontia edentula* (9.84)

Tab. 5. Average dissimilarity (%) and species contributing to dissimilarities between localities; Control (C), Exploited (E) and Harbour (H) regarding animal density.

Locality	Average dissimilarity %	Contributing species (%)
C and E	88.54	*Modiolus ligneus* (11.19), *Gafrarium divaricatum* (10.93), *Modiolus auriculatus* (9.91), *Pinctada* sp. (5.37), *Sipunculus* sp. (5.20)
C and H	91.76	*Modiolus ligneus (12.24), Gafrarium divaricatum(11.31), Modiolus auriculatus (10.91), Pinctada* sp. *(5.53), Sipunculus* sp.*(5.52)*
E and H	85.69	*Tellina* sp. (15.66), Polychaeta (12.30), *Modiolus auriculatus* (12.07), *Aaptos cf. chromis* (9.84), *Anodontia edentula* (5.16)

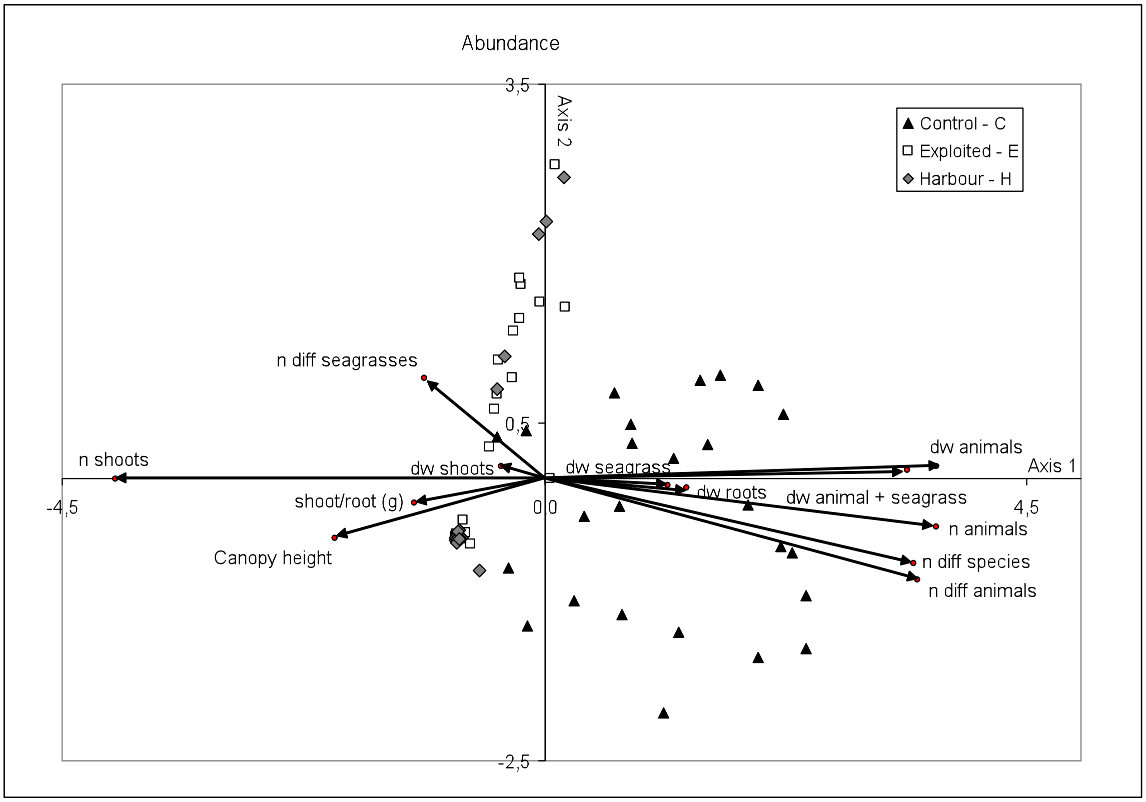


Figure 10. Site ordination diagram based on animal biomass – within and among seagrass meadows with different exploitation. Plot of the first two axis of the PCA ordination showing sample scores marked according to locality, see figure. Seagrass and animal parameters are also shown by biplots. Locality explanation in figure.

Figure 10 shows a community analysis based on animal biomass. It is similar to the MDS but more data is included. The data set contained 1360 animals and 93 species of animals (see appendix) and 75 samples including 2989 counted seagrass shoots. The eigenvalues for the first four PCA ordination axes were 0.33, 0.10, 0.07 and 0.06, respectively. Axis 1 explains most of the variation in animal biomass as can be concluded from its high eigenvalues compared to that of axis 2 (Figures 10 and 11).

The analysis with many parameters simultaneously in the seagrass animal community show similar results as shown in figure 5 and 6, which implies that these factors are not really affected by other factors. The diagram (figure 10) clearly visualize that the control are mostly distinguished from the exploited and harbour area due to number of different animal species, number of animals, animal biomass and number of different species of seagrass and animals even when a greater amount of data is taken in to account. The canopy height was the shortest at the control site.

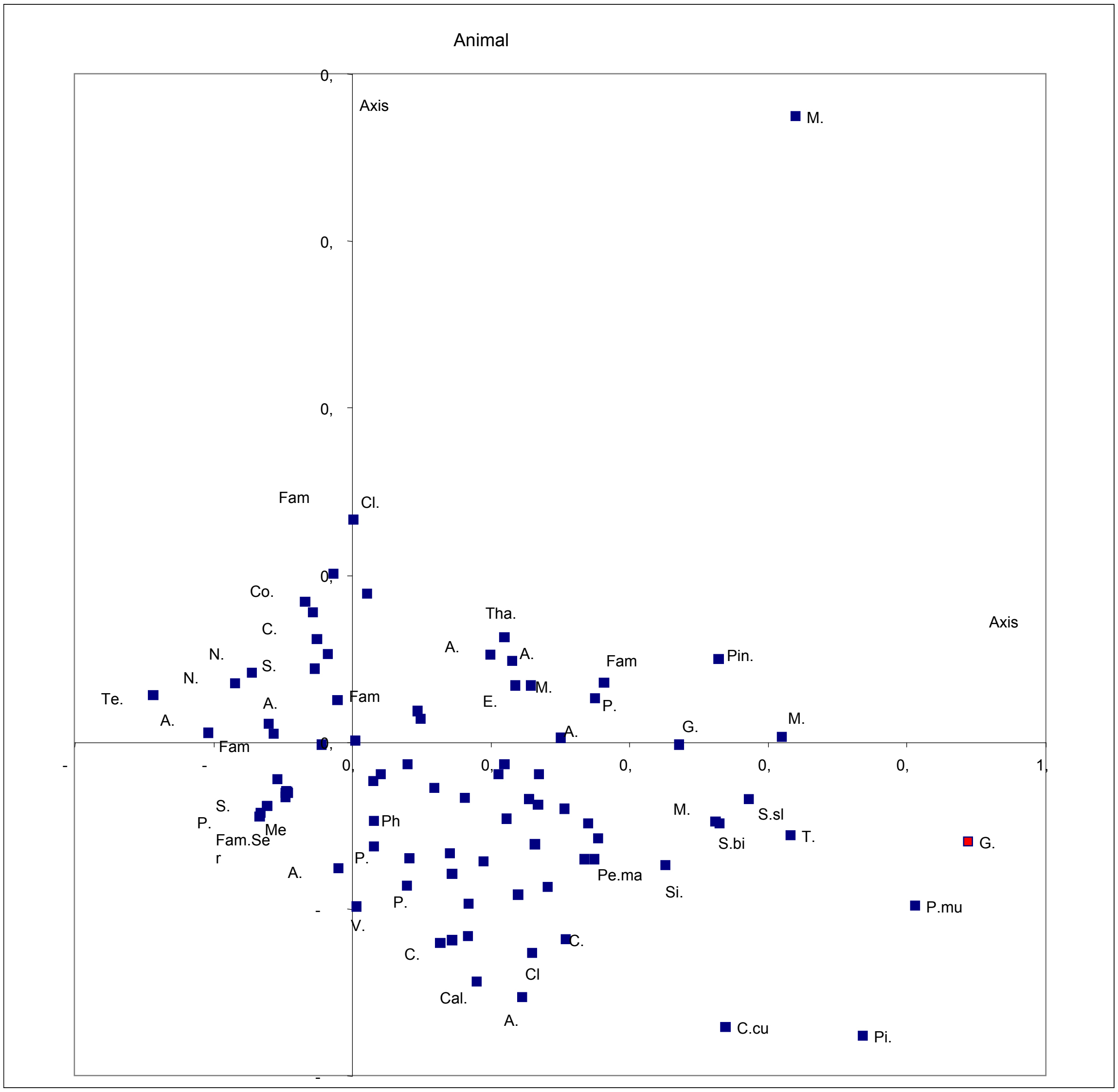


Figure 11. Species ordination diagram. Plot of the first two axis of a PCA ordination showing species scores (value of the species on the axis) marked according to species. Species of interest are in the diagram, abbreviations in appendix.

Figure 11 shows animal distribution. The mussles *Modiolus auriculatus, M. ligneous* and the pen shell *Pinna muricata* and polycheates were common in all localities, especially in the control site. Other species found in all localities were *Calliostoma.* sp. The surf clams *Mactra ovalina, Meropesta nicobarcia,* and the venus shell *Pitar abbreviatus*, the tellin *Tellina* sp. and sipunculid worms, whereas the mud snail *Nassarius coronatus,* the sponge *Aaptos cf. chromis* and the box crab *Calappa hepatica* were found only in the exploited area. I only found fish in the exploited area. The wing oyster *Pinctada* sp., the pea crab *Pinnotheres sp.* and the venus shell *Gafrarium divaricatum* were found in the control and in the harbour sites. The bivalves *Anodontia edentula, Loripes clausus* and *Nuculoma lyardii* were found in the exploited area and in the harbour site. Five different invertebrate species – the spider crab *Menaethius* sp., *Costellaria* sp., the sea cucumber *Holothuria* sp., the moon shell *Polinicices mamilla* and crustaceans from the family

Sergestidae – was found only at the harbour site. The star fish *Pentaceraster mammilatus* together with almost 40 other species were found only in the control site (for species list and species abbreviations see appendix table 1).

4.3 INVERTEBRATE COLLECTION

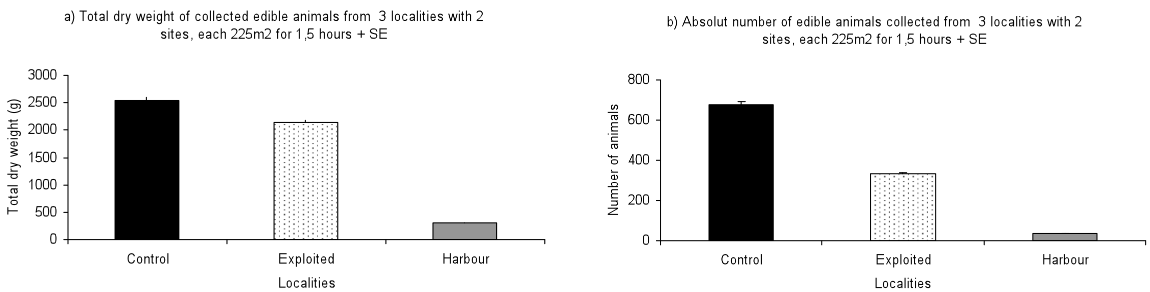


Figure 12. Bar charts of animal catch from 3 localities (2 sites of 450 m^2 for 1.5 hours) showing a) total dry weight of collected edible animals, and b) absolute number of edible animals collected.

The number of collected invertebrate specimens by the woman was in total 1046 having a dry weight of 4926 g and belong to the taxa bivalvia, gastropoda and crustacean (see appendix table 2). There was a significant difference in edible animal biomass catch among localities (ANOVA; $p = 0.026$). Post-hoc tests showed a significant difference between the control and the harbour sites ($p = 0.020$), but no difference between the control and the exploited sites ($p = 0.070$) as well as between the exploited and the harbour sites ($p = 0.589$). In terms of number of edible animal individuals, there was a significant difference among the three localities (Kruskal-Wallis test; $p = 0.022$) (Figure 12). Species list for animals collected see appendix table 2.

5. DISCUSSION AND CONCLUSION

5.1 SEAGRASS MEADOWS AND ASSOCIATED FAUNA

The most significant difference between localities with different anthropogenic activity in this study was animal biomass, diversity and density. The protected area, without direct human activity, showed a much greater animal biomass, diversity and density compared to the area with invertebrate collecting women and the harbour area.

Healthy seagrass meadows hold a great invertebrate diversity and studies have shown that seagrass meadows have greater species abundance than unvegetated habitats (Boström and Bonsdorff, 1997; Edgar, 1990; Nakamura and Sano, 2005).

Thus, destroying seagrass meadows can alter or eliminate the conditions needed for plants and animals to survive and therefore decrease species diversity and density.

Attrill (2000) showed that the amount of plants available in seagrass beds can determine size and composition of an associated macroinvertebrate community. This study showed that with increasing seagrass biomass the number of shoots increased but the canopy height reduced. Patches where the meadows were less dense, the plants were taller (personal observation).

The results from this study showed no differences in seagrass biomass between the control and the exploited area, but a significant difference in animal biomass and density. The lesser animal biomass and density in the exploited area indicates that the exploited area is impacted by invertebrate collecting, since colleting is the only disturbance compared to the control. Also found during the study, when looking at the harbour and the exploited area the animal biomass were similar and overall low but in the control it varied from low to very great. Almost all the animal diversity is, however within the control and there are a few species that contributes mostly to the similarities and dissimilarities within and between the localities.

From my results, I can distinguish several different types of species that can be attributed to separate the localities form each other regarding species composition. All over, the most common animals in the localities were Bivalvia followed by Gastropoda and then Echinodermata.

Multivariate analysis indicated that there were significant differences in macrofaunal community structure between the seagrass meadows sampled. SIMPER and ANOSIM shows which species that are contributing to the similarities and differences within and between the localities. The control showed greater similarities within the locality than the exploited, the harbour were very dissimilar within the habitat regarding animal biomass. The similarity within the control regarding animal biomass is mostly due to bivalves and between localities due to bivalves and sea stars. Concerning number of animals the outcome was similar but there were also a high amount of polychaetes within and more sipunculids in the control compared to other localities. Results show a greater number of taxa in the control. The greatest difference is that the harbour and the exploited area are lacking many of the species that can be found in the control. There were about 40 more animal species in the control. The exploited area was similar within mostly due to horse mussels, sponges, tellins and mud snails and these animals also made it dissimilar to the harbour concerning biomass. Regarding number of animals the similarity within the exploited area was mostly due to horse mussels, tellins, polychaetes, sponges and pea crabs and differed from the harbour due to horse mussels and sponges. The harbour differed from the exploited area mostly due to polychaetes, tellins and *Anodontia* *edentula* concerning number of animals. The anthropogenic impact on the seagrass meadows may alter the animal species composition.

When collecting edible animals the collectors, depending on species or personal preference, either pick up or dig up the animal with a stick (personal observation). The invertebrate collection is a directional out take of invertebrates mostly bivalves, followed by gastropods and then crabs. The most popular invertebrate taxa to collect from *T. ciliatum* meadows at Inhaca are Bivalves. Bivalves are mostly filter feeders, they filtrate the water which makes it clearer and their waste help add nutrients to the sediment. Fewer bivalves will lead to reduced water clarity and loss of nutrient added to the sediment. Digging up animals from the sediment can release nutrients from the sediment when being disturbed, resulting in a decrease in nutrients in the seabed.

Field experiments by Peterson and Heck (2001) showed positive effects on seagrass from interactions with suspension feeders. Their study on the seagrass *Thalassia testudinum* and the horse mussel *Modiolus americanus* showed that when doubling the amount of mussels the nutrient content of the sediment increased and more nutrients were available to the plants. The mussels also reduced the epiphytic load on the seagrass. Habitats with seagrass vegetation also increased the mussel's survival. This implies that many bivalves are good for the seagrass community. It seems important to preserve bivalves in the meadows. Bivalves are important both as a food source and a source of income for many people.

Target species for the collectors differ between localities. In the control it was possible to choose what to collect, in the exploited area it was not likely to choose and in the harbour you collect whatever edible invertebrate you could find. The primary choice in the control was wing oysters and in the exploited area the horse mussels dominated the catch. I did not find any oysters in the exploited area and there are four times more horse mussels in the control than in the exploited locality. In the exploited area where women often collect I found fewer animals of their preferred species. This shows that the collecting women do affect the seagrass fauna, the bivalves seems to be decreasing in numbers in the exploited area. This directional harvesting can also alter the community's natural ratios of predator and prey. It can also decrease mean size of the targeted species, when women always try to collect large specimens. Surprisingly I detected no difference in animal biomass catch during the collecting study, but I believe that it depends mostly on the few amounts of replicates. It seems to be a high level of harvest in relation to invertebrate availability in the *T. ciliatum* seagrass beds.

The exploited area has a very dense seagrass bed and showed the highest seagrass shoot density. Eckrich and Holmquist (2000) showed that intensive trampling in the seagrass meadows will decrease seagrass and animal density. The amount of collecting today on Inhaca Island with treading and digging in the seagrass meadow is probably only a small disturbance to the seagrass and therefore not affecting the seagrass greatly. However, more intensive trampling by collectors could decrease seagrass density. Still, even if the seagrass is dense, the macroinvertebrate diversity is low in the exploited area and probably largely impacted by harvesting. Further, the harbour area where many people are walking and boats are driving showed very low animal biomass and low seagrass density and biomass.

Boats affect the marine environment negatively around Inhaca Island through propeller-contacts exhausts, and turbulence from propulsion systems, noise and waves produced when driving. Boat anchoring causes broken and uprooted seagrass shoots(Francour et al. 1999). In the harbour area, many propeller scars have fragmented the seagrass habitat (personal observations), and it has been shown that these areas have lower macrofaunal abundance and fewer species than seagrass areas without scars (Uhrin and Holmquist, 2003). Conolly (1994) also showed that removing seagrass canopy can affect its associated fauna negatively. Even though seagrass can recover from propeller scars, this is a slow process and the scars may sometimes persist for up to five years (Zieman, 1976). Boat and propeller scars have been shown to result in the loss of essential habitat for associated fauna, sediment erosion and increased water turbidity (Sargent *et al*., 1995). This is probably one of many explanations of the low invertebrate abundance in the harbour area of Inhaca Island. Further explanation is the low amount of seagrass, the muddy water and the extreme anthropogenic activity in the harbour area (personal observation). Further, seagrass meadows play a key role since they trap and stabilize sediments by their dense network of rhizomes, which in turn prevents coastal erosion. In the harbour there are small amounts of below ground seagrass biomass and that can lead to increased erosion of the harbour coast line.

Alcoverro and Mariani (2002) have shown that grazing by sea urchins control seagrass density. That could mean that collection of grazing sea urchins could have a direct positive impact on the seagrass biomass. Fishing pressure influences the herbivore distribution in seagrass meadows; therefore fishing to some extent could have a direct positive effect on the seagrass.

Seagrass ecosystems are probably more adapted to natural changes like light and/or seawater temperature, then to anthropogenic activities such as intensive trampling and boating. With an increasing human population, there will be more anthropogenic activities and use of seagrass ecosystems.

5.2 AN IMPORTANT ISSUE FOR MOZAMBIQUE AND THE WORLD

Marine reserves or marine protected areas, MPAs, are very important to the preservation of high biodiversity. MPA design is a hot topic. One well known theory that is usually applied on terrestrial systems is the SLOSS theory, which asks if a "Single Large area Or Several Small areas with the same total size" preserve more species. McNeill and Fairweather (1993) found that several small seagrass beds had significantly more species than a single large bed in the field, but experiments showed contradictory results. This shows how difficult it can be and how important it is to carefully and critically investigate how to design marine protected areas for seagrass habitats. This study shows that the more untouched meadow the healthier animal seagrass community. In order not to loose healthy seagrass communities with a large biodiversity more protected areas are needed.

In Mozambique seagrass meadows provide many people with food and protect the shorelines from erosion. The meadows hold valuable natural resources and are important to preserve. The seagrass is commonly used, probably because it is easily accessible even for people without resources. The seagrass is subject to increasing pressure from people collecting invertebrates, fishing and tourism. In case the seagrass meadows get harmed or destroyed devastated, it will indirectly have a negative impact on the fishery, since the meadows act as a nursery ground to numerous fish species, including many of commercial interests. In Mozambique fishing and the increasing interest in the aquatic environment is an important source of income. Further, the invertebrate collectors, mostly people with limited resources will have difficulties finding food in the seagrass meadows.

Summarizing the present study on anthropogenic impact on seagrass meadow, there is a negative effect on animal biomass, diversity, density in seagrass meadows with anthropogenic activity. The seagrass is negatively impacted by extreme activities, such as harbour traffic. Invertebrate collecting people seem to have a large impact on the animals in the seagrass community.

On the other hand, the people collecting invertebrates are poor and collect invertebrates as a means of survival. Is the invertebrate collecting today sustainable? Or are the resources slowly but surely decreasing? Unfortunately not enough research is done on seagrass-animal communities, especially in developing countries. Due to the high pressure on seagrass meadows there is a need for more research in sustainable management of seagrass ecosystems. The question is what can we do to improve management of the ocean so we will not lose a very important income and food source? For example, researchers and national management institutions have to collaborate to develop management plans for coastal habitats, but most importantly is that information and knowledge are shared with the local community.

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Table 1. Species list with density and biomass for the different localities.

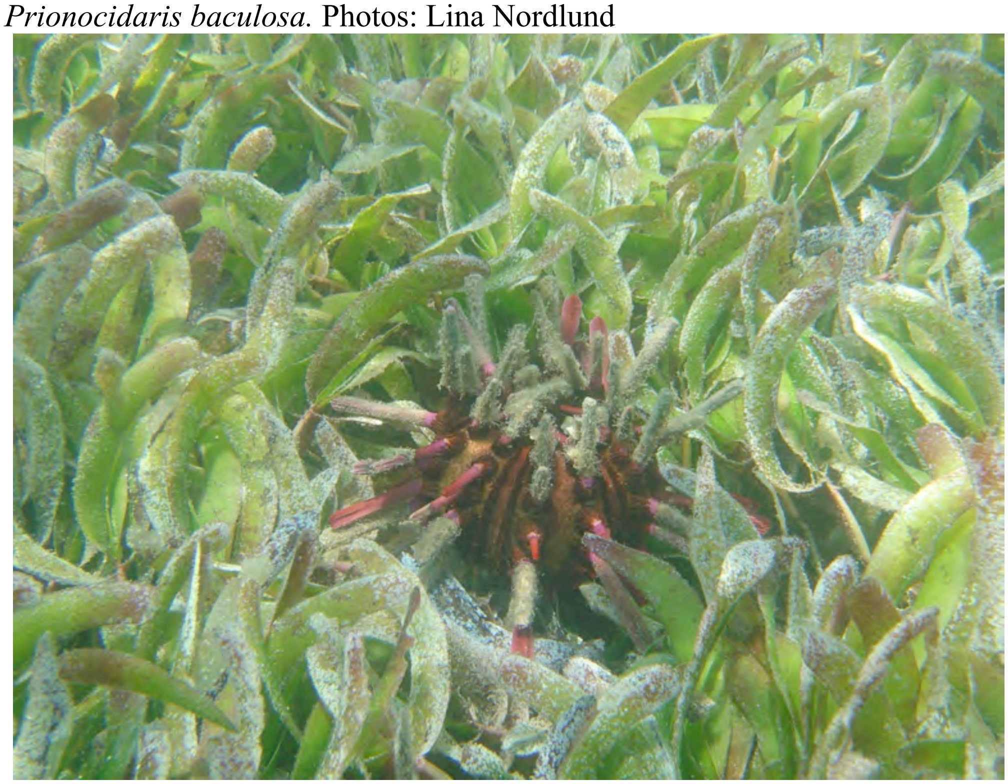
			n m^{-2}			g m^{-2}		
Taxa	Species	Abbreviation	Control	Exploited	Harbour	Control	Exploited	Harbour
Annelida	Class Oligochaeta		1,12		0,16	0,19		0,04
Anthozoa	Order Scleractinia		0,80			0,38		
Bivalvia	*Anadara natalensis*	A. nat	0,80		0,16	4,77		9,03
	Anodontia edentula	A.ede		0,48	2,24		0,19	2,18
	Anomia achaeus	A. ach	0,80			0,46		
	Arca avellana		0,16			0,16		
	Arcuatala capensis	A. cap	0,48			0,56		
	Atrina squamifera	A. squ	0,16			1,19		
	Brechites attrahens		0,16			12,46		
	Chlamys sp.		0,16			0,48		
	Codakia tigerina	C. tig	0,32			18,65		
	Crassostrea cucullata	C. cuc	4,96			10,07		
	Dosinia sp.			0,16			0,04	
	Eastonia solanderi	E. sol	0,80			0,55		
	Gafrarium divaricatum	G.div	20,96	0,16		76,77	1,23	
	Gastrana matadoa	G. mat	1,92			1,11		
	Loripes clausus			0,32	0,16		0,29	0,02
	Mactra ovalina		0,48	0,16	0,16	0,43	0,12	0,07
	Meropesta nicobarica	M. nic	2,08	0,48	0,16	5,90	1,16	0,04
	Modiolus auriculatus	M. aur	20,80	5,76	1,60	45,33	41,52	32,37
	Modiolus ligneus	M. lig	20,80	2,08	0,16	11,22	0,49	0,06
	Nuculoma layardii	N. lay		0,64	0,48		0,17	0,51
	Pinctada sp.	Pi. sp.	10,24		0,16	38,08		0,35
	Pinna muricata	P. mur	7,36	0,32	0,32	45,75	0,91	0,14
	Pitar abbreviatus	P. abb	1,92	0,96	0,48	5,93	2,10	0,20
	Semele striata	S. str		0,16			0,07	
	Septifer bilocularis	S. bil	4,16			5,38		
	Solemya africana	S. afr	0,48		0,32	0,03		0,11
	Solen sloanii	S. slo	7,36			3,43		
	Tapes literatus		0,48	0,16		1,32	0,02	
	Tapes sulcarius	T. sul	4,32	0,32		7,47	1,08	
	Tellina sp.	Te. sp.	0,16	6,56	3,68	0,02	1,06	0,44
	Trachycardium pectiniforme		1,44	0,16		8,76	2,37	
	Venus tiara		0,16			0,09		
Crustacea	*Alpheus sp.*		1,28	1,12		0,10	0,09	
	Family Balanidae		0,32			0,04		
	Calappa hepatica			0,16			0,03	
	Charybdis natator	C.nat	0,16			0,20		
	Chiliopagurus strigatus			0,16			2,99	
	Order Decapoda		0,64	0,16		0,16	0,04	
	Diogenes sp.		0,16			0,18		
	Class Malacostraca		0,64			0,40		
	Menaethius monoceros	Me. sp.	0,16			0,01		
	Menaethius sp.	M. mon			0,48			0,05
	Metapenaus monoceros		0,16			0,02		

	Pagurus zebra	P. zeb	0,16			0,15		
	Philyra platychira	P. pla	0,32		0,64	0,04		0,01
	Pinnotheres sp.	Pin. sp.	7,68	1,60		0,51	0,14	
	Family Sergestidae	Fam. Ser			0,48			0,02
	Thalamita sp	Tha. sp.	0,32	0,16		0,23	0,02	
	Thalamita cf. picta		0,32	0,16		0,03	0,01	
	Family Xanthidae	Fam. Xan	4,32		0,16	1,75		0,01
Echinodermata	*Amphipolis squamata*		0,16					
	Amphiura candida			0,16			0,03	
	Astropecten polyacanthus	A. pol	0,16			0,56		
	Echinometra mathaei		0,48	0,16		1,64	3,96	
	Holothuria sp.				0,32			1,27
	Ophiocoma valenciae			0,32			0,04	
	Pentaceraster mammilatus	Pe. mam	1,12			19,09		
	Tripneustes gratilla		0,16			2,73		
Gastropoda	*Calliostoma sp.*	Cal. sp	0,64	0,16	0,80	0,75	0,04	0,38
	Cantharidus suarenzis		0,48			0,25		
	Chicoreus ramosus		0,16			5,14		
	Conus lividus		0,16	0,32		1,12	4,44	
	Conus tessulatus		0,32			9,40		
	Costellaria sp.	Co sp.			0,48			1,54
	Cronia heptagonalis			0,32			0,98	
	Cymatium sp.		0,80			11,43		
	Cypraea annulus	C. ann		1,12			2,60	
	Class Gastropoda				0,16			0,46
	Family Muricidae	Fam. Mur			0,16			0,39
	Nassarius albescens gemmuliferus		0,32		0,16	0,20		0,18
	Nassarius coronatus	N. cor		0,80			2,49	
	Family Naticidae		0,16			0,23		
	Natica sp.			0,16			0,02	
	Superorder Opisthobranchia		0,16			0,19		
	Pleuroploca trapezium		0,32			7,86		
	Polinices mamilla	P. mam			0,48			2,28
	Polinicinae simiae	P. sim	0,16			0,16		
	Family Terebridae		0,32			0,08		
	Family Turridae	Fam. Tur	0,16			0,04		
	Volema paradisiaca	V. par	0,32			9,72		
Hemichordata	*Class Enteropneusta*				0,16			0,11
Mollusca	*Onithochiton literatus*		0,48			1,62		
Nemertea	*Cerebratulus marginatus*				0,16			0,17
	Phylum Nemertea	Ph. Nem	0,16		0,16	0,05		
Pisces	Family Gobiidae			0,16			0,04	
	Family Teraponidae			0,16			<0,01	
Polychaeta	*Eurithoe complanata*		0,16					
	Class Polychaeta	Cl. Poly	8,48	2,72	6,08	0,96	0,12	0,23
	Family Sabellariidae	Fam. Sab			0,96			0,41
Porifera	*Aaptos cf. chromis*	A. chr		7,20			6,99	
	Clathrinidae sp.		0,32			0,08		
Sipuncula	*Sipunculus sp*	Si. sp.	9,28	1,12	0,16	2,80	0,50	<0,01
	Total		157,92	37,28	22,24	386,86	78,39	53,07

Table 2. Species list for collected edible invertebrates

		Density n 100m^{-2}			Biomass (dry weight) g 100m^{-2}		
Taxa	Species	Control	Exploited	Harbour	Control	Exploited	Harbour
Bivalvia	*Anadara natalensis*		1,33	1,56		26,38	7,35
	Modiolus auriculatus	9,11	67,78		28,02	359,26	
	Pinctada sp.	141,56	0,22		535,61	2,02	
	Trachycardium pectiniforme		1,78			32,59	
Crustacea	*Calappa hepatica*		1,56			15,18	
	Lupa pelagica		1,56	1,11		13,10	16,21
Gastropoda	*Conus tessulatus*		0,22			9,09	
	Cymatium pyrum		0,22			0,71	
	Murex brevispina			1,11			8,11
	Polinices mamilla		1,56	3,33		6,03	8,02
	Strombus gibberulus		1,56	2,00		5,31	26,80
	Volema paradisiaca		1,56			6,04	
	Total	150,67	79,33	9,11	563,63	475,72	66,50

Above: Photo 1, *Thalassodendron ciliatum*; whole plant with shoots, roots and rhizomes. Growth direction from left to right. Below: Photo 2, *Thalassodendron ciliatum* seagrass meadow in the control with a *Prionocidaris baculosa.* Photos: Lina Nordlund



Above: Photo 3, Fishing boats coming in to the harbour to sell fish. Photo: Meredith Ferdie. Below: Photo 4, *Thalassodendron ciliatum* seagrass meadow in the harbour. Low water clarity. Photo: Lina Nordlund

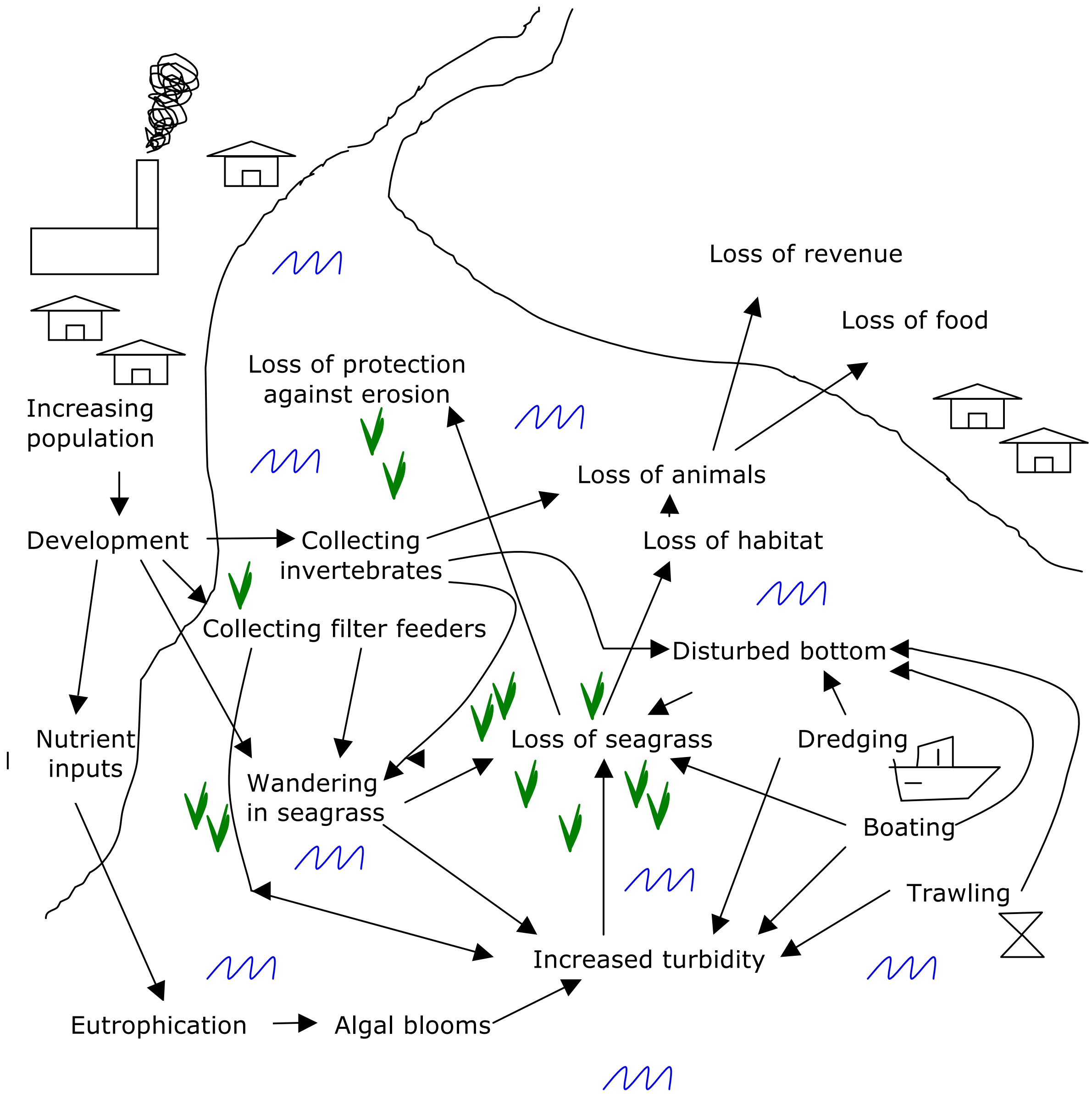


Figure 3. The major factors that contribute to loss of seagrass habitats. Many factors can impact the seagrass and its inhabitants. (Drawing adapted from Montagna, 1996).