REPORT
SEA CUCUMBERS ON HERON REEF

THE UNIVERSITY OF QUEENSLAND
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ENVM7203 CORAL REEF PROCESSES AND MANAGEMENT

Course Coordinator: Dr. David Neil
Lecturer: Dr Ann Peterson

Reef Flat Group:

Monica Alvarez	43067596
Kristiane Midtaune	43643262
Ekaterina Mirskaya	43264863
Dillon Ponzo	43643486
Ma Fernanda Sanchez	42827104

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ABSTRACT

Heron Island and its adjacent reef flat are subjects to a change from its natural state due to the inception of a boat channel and bund walls. The infrastructure (Neil 1998) has impacted the characteristics of the seabed strata where species like the sea cucumbers inhabits. Sea cucumbers digest sand and excrete calcium carbonate and may play an important role in the future as a buffer against ocean acidification due to climate change. This report aims to analyse the channel and the bund walls impact on the sea cucumbers distributions and abundance. The objectives are to analyse the distribution and abundance of the sea cucumber in the Heron Island reef flat and their correlation with the seabed strata, current velocity and the sediment flux to understand how the channel and the bund walls on the north and south side impact the species. The abundance and distribution of sea cucumbers and the percentage of seabed microhabitat was measured using linear transects perpendicular to the shore. Currents direction and velocity and sediment traps were recorded along the transects. All measurements were recorded during low tide, as the tide flow affects the currents. Based on the results obtained, a clear relationship among the channel (and its bund walls) effects on the reef flat system and species richness of sea cucumbers was not found. Nevertheless, the results showed an obvious difference among the reef flat and the transects plotted inside the channel, where a higher abundance and species richness was recorded. Future climate change would have a greater impact on the Heron Island reef system, which causes a need of management actions. This report evaluates various management options and the related responsibilities.

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1 INTRODUCTION

Being true examples of pure beauty, coral reefs form intricate mega diverse ecosystems that provide habitat to a wide range of species (Schneider et al. 2011a). Heron Island is one of examples of reach ecosystem of coral reefs, but human impact has led to the decimation of these ecosystems in recent history. The Heron Island system is subject to a change from its natural state due to the inception of a boat channel and bund walls (Gourlay et al. 1992; Berkelmans et al. 1998, Neil 1998). But the coral reef is diverse and dynamic. It is comprised of vital role-playing organisms that contribute to the health of the system including invertebrates (Przeslawski et al. 2008).

In a period of impending climate change, a group of organisms of particular interest is the class Holothuroidea. Sea cucumbers digest sand during feeding and excrete calcium carbonate, which increases local alkalinity. This buffers against ocean acidification and impedes the decline of pH due to an increase in atmospheric carbon dioxide (Byrne 2011). As a result, sea cucumbers play a role in mitigating the effects of climate change and sustaining reef health. In the delicate system of a reef flat, any perturbation could negatively impact sea cucumbers abundance leaving the reef more susceptible to acidification. Due to their abundance on Heron Island and capacity to buffer pH, sea cucumbers are important to study in the presence of human activity.

This research was conducted to evaluate the potential influence of the channel and the bund walls construction on sea cucumbers abundance and distribution. Considering the complexity of the whole system this purpose needed to answer the following research questions. What is the influence of the channel on the sediment transport in surrounding areas? What is the influence of the channel on the directions and velocity of tidal currents? What is the impact of the channel on seabed cover? What is the response of sea cucumbers to the changes in sediment transport, current velocities and seabed cover caused by the channel? What are the projections of future changes as an effect of predicted climate change and possible management response?

The main objectives of this research included the analysis of distribution and abundance of sea cucumbers on the reef flat at the distance of 600m from the channel in both directions. Seabed strata on the reef flat was also analysed and correlated with the occurrence of sea cucumbers. Impact of the channel and its bund walls on current velocities and directions was analysed in this research as well as sediment transport on the reef flat at the distance of 600m from the channel in both directions. Research objectives also encompassed the identification of management implications on the reef system related to target species survival as well as recommendations for future management actions considering the consequences of predicted climate change.

2 LITERATURE REVIEW

The literature review in this report is focused on a general background about sea cucumbers' biological and ecological features, Heron Island system and its management history, climate change influence in the GBR, coral cays and Heron Island; and finally, on the relationship between *Holothurians* and Climate Change.

2.1 Sea Cucumbers

The sea cucumbers' relevant biological and ecological characteristics from the literature viewed, were synthetised, as well, the general characteristics of the five sea cucumber species considered in this research.

Sea cucumbers are echinoderms classified as benthic invertebrates that belong to the Class of Holothuroideaia (Blainville 1834). They are widely distributed along the Great Barrier Reef (GBR), with 127 species reported, and greater abundance in the south of the GBR (Hutchings et al. 2007). This wide distribution and abundance is, in part, a consequence of their capacity to occupy diverse kind of habitats, from exposed reefs to deep lagoons, and intertidal areas (Hutchings et al. 2007). The most abundant sea cucumbers belong to the Aspidochirotacea Subclass, mainly *Holothurians* and *Stichopus* species (Hutchings et al. 2007), which are the main focus of this research. Klinger, Johnson and Jell (1994) specified that Aspidochirotida were abundant in the Heron Island lagoon and within its reef flat.

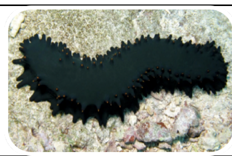
Sea cucumbers act as bioeroders that constitute a keystone species in the Heron coral reef flat ecosystem due to two main reasons: they increase the alkalinity of the habitat and enhance the nutrients cycle by excreting ammonia (Schneider et al. 2011). Sea cucumbers are deposit (sediments) feeders, with a wide range of grain sizes preferences, from 0.74±0.14 to 0.43±0.19 (Klinger, Johnson and Jell 1994). Therefore, their occurrence and survival is highly related to the substrate type (seabed cover and type of coral cover) (Kostylev et al. 2001). Sea cucumbers ingest coral sand and rubble to digest the attached organic matter while dissolving the $CaCO_3$ (calcium carbonate) particles, contributing to a net positive flux of $CaCO_3$, which helps the coral reefs to endure and reduces water acidification (Schneider et al. 2011).

Additionally, as a by-product of their digestive activity, sea cucumbers secrete ammonia (NH_3), increasing the nutrients in the water and leading to greater coral reefs productivity (Schneider et al. 2011a). Furthermore, this ammonia is ionized to ammonium in the salty water, contributing to a further increase in the alkalinity of the water. Consequently due to the contribution of carbonate and ammonium, sea cucumbers double the sum of alkalinity produced by other endolithic species and by the carbonate sediments of coral reefs (Schneider et al. 2011a).

The sea cucumbers analysed in this research were Black Sea Cucumber (*Holothuria atra* Jaeger,1833), Stained Sea Cucumber (*Holothuria leucospilota* Brandt, 1835), Brunt Sausage Sea Cucumber (*Holothuria edulis* Lesson, 1830), Greenish Sea Cucumber (*Stichopus chlorontus*

Brandt, 1835) and Variegated Sea Cucumber (*Stichopus variegates* Semper, 1868). The last species was excluded from the data analysis after found it was not representatively abundant on transects, but it was counted in the field stage. The species display a diverse array of characteristics, grouped in Table 1 as the seabed cover that they prefer, and he position where the normally adopt in natural environments in relation to seabed; this table also indicates some notes about the characteristics that were decided to be important for later analysis.

Table 1 General characteristics of the Sea Cucumbers species analysed in this research

PHOTO	SPECIE	SEABED COVER	POSITION	NOTE
	Black Sea Cucumber (*Holothuria atra*)	Rubble Coral patches	Camouflaged by a coating of sand	Most distributed
	Stained Sea Cucumber (*Holothuria leucospilota*)	Rubble Boulders	Under and near boulders, corals and seaweed clumps	Tolerant to salinity and temp change
	Greenish Sea Cucumber (*Stichopus chlorontus*)	Hard substrates	Sheltered areas of coral rubble	Found in the channel
	Brunt Sausage Sea Cucumber (*Holothuria edulis*)	Sandy and muddy substrates, coral rubble, seagrass meadows	Hide under rocks or corals	Nocturnal found in the channel
	Variegated Sea Cucumber (*Stichopus variegatus*)	Sedimentary or silty sand bottoms	Deeper waters and farther from the shoreline	Not representative

2.2 Heron Island system (history and channel)

Heron Island has only been exposed to human activity for less than 100 years of its thousands of year's history. The change that people have caused to the system and how it negatively impacts the island is of major concern. Heron Reef is part of the Capricorn-Bunker group, a system of reefs that proceeded to grow after the sea level rose following the last glacial maximum (Neil 1998). The reef caught up with the peak sea level during the interglacial period then it was exposed as sea levels dropped slightly. The exposed part of the reef accumulated sediment that formed a cay on the leeward end of the reef flat (Neil 1998).

The cay and its adjacent reef flat were meant to follow this natural design; however, the anthropogenic impact has changed it system. In the late 1940s, the reef rim was blasted to improve boat access to the island. A channel was dredged from the rim to the island. This created a strong flow from the reef flat to the open water. It is believed that this has a strong effect on the physical and biological environments of the system, but the extent is unknown.

To limit sediment deposition into the channel, bund walls were built in the 1960s. The channel was periodically dredged and new bund walls were built in 1993 (Neil 1998). Additionally a resort was established in the island in 1932 and a research station was built in 1951 (Neil 1998). The presence of this infrastructure presented a myriad of problems for the island ecosystem and enhanced the use of the channel due to tourists and researches visiting it periodically.

2.3 Climate change in GBR, coral cays and Heron Island

It is estimated that coral reef cover in the GBR cover has declined by 15 to 20 % since 1990 and if continued present rates of coral growth and disturbance, coral cover in the southern region is likely to decline from 5 to 10% by 2022 (De'ath et al. 2012). Thus, this subsection will include estimated climate change impacts on the GBR and in Heron Island.

Changes have been observed in ocean properties of relevance to climate during the past 40 years, including temperature, salinity, sea level, carbon, pH, and oxygen (Rhein et al. 2013, p. 48). Moreover according to the GBR Outlook Report (GBRMPA 2014), climate change is the most serious threat and will continue to impact the GBR through multiple stressors: 1) oceans warming, 2) ocean acidification, 3) sea level rise and 4) intense weather events. Hence, all these stressors together with other terrestrial impacts such as nutrient run-off and sedimentation will continue to reduce resilience on the GBR.

Since Heron Island is located on the offshore reef of the south GBR region, is not as vulnerable to coastal development and agricultural runoff as inshore reefs are (De'ath et al. 2012). Moreover, climate change effects on Heron Island and other coral cays will depend on combined effects of three factors: sea level rise, rising temperatures and weather patterns (GBRMPA 2011). Nevertheless, the impacts of sea level rising are not straight forward in coral cays, weather cays grow to keep pace with rising sea levels (GBRMPA 2011).

2.4 Sea cucumbers and Climate Change

Low calcification and low alkalinity super-saturation are estimated to be two of the conditions that increase vulnerability to climate change in the southern offshore region of the GBR where Heron Island is located (Fabricious et al. 2007). Therefore, sea cucumbers become relevant species to focus on due to their relevant role in climate change mitigation. Thus, the following section will focus on the characteristic of sea cucumbers and their relevance in climate change adaptation.

Since ocean pH, pCO_2 (carbon dioxide partial pressure) and $CaCO_3$ change constantly with ocean temperature, predicting future outcomes for marine invertebrates is challenging (Byrne 2011). One limitation is that the majority of studies of climate change impacts on invertebrates' development have been documented for few number of species. Thus, climate change pressures such as ocean warming and acidification on development in marine invertebrates is poorly understood and controversial between scientists (Lough 2007).

It has been predicted that possible changes to ocean currents in the GBR have potential major impacts on the recruitment of benthic invertebrates and food availability (Lough 2007). Besides, it is expected that impacts of ocean acidification will be greater in surface or shallow water (Lough 2007) where plenty of sea cucumbers inhabit. Nevertheless, much remains to be investigated regarding the ability of invertebrates to adapt to higher temperatures (Lough 2007).

Although there is a lot of uncertainty regarding the impacts of climate change on invertebrates including sea cucumbers, evidence has shown that they play a key role in the coral reef processes (Schneider et al. 2011). As described before, sea cucumbers excrete $CaCO_3$ from their digestive system and secrete ammonia, increasing ambient alkalinity, helping corals to endure and contributing to nutrient cycling; which in general improve productivity of coral reefs (Schneider et al. 2011). Thus, since evidence shows that the digestive physiology of sea cucumbers by CaCO3 dissolution (mostly at night) plays a fundamental role in the life cycle of coral reefs (Schneider et al. 2011) they should be prioritized in coral reef conservation and climate change mitigation policies.

3 METHOD

Sea cucumber's distribution and abundance are determined by various factors. The number of individuals depends on the habitat preference (Drumm and Dzeroski 2003); the preferred habitat differs from species to species, the microhabitat preferred by the various species was represented within a hundred meter (Klinger, Johnson, Jell, 1994). Sediment transport varies with current velocities (Neil 1998) which may be affected by the channel. The methods in this research were based on these assumptions and focused on regarding enough data to reach its objectives.

3.1 Time importance and recording

One of the most important aspects of the methodology followed in this research was the time at which the activities were carried out. As one of the assumptions was that the tidal currents are affected by the draining effect created by the channel (Berkelmans et al. 1998), the activities were limited to two hours before scheduled low tide until two hours after. This time timing enable the analysis of the effects caused by the channel on the current velocities, as well as the possibility to count the sea cucumbers on the reef flat easily. Therefore, the time for every activity developed was recorded.

3.2 Sea cucumbers abundance, distribution and seabed cover

By looking at the sea cucumbers distribution and abundance a variation of the method described by Klinger (2003) with linear regression was used. All the environmental variables that were expected to influence the preferred habitat of sea cucumbers were recorded within a distance of 100m from the shoreline. The dense coral cover from 100m towards the reef crest limited further distance of measurements.

Therefore, the distribution and abundance of the sea cucumbers were measured by the emplacement of ten 1x100m belt transects plotted on map and verified in the field. The initial point of each transect was located at the start of the reef flat, extending towards the inner reef flat, perpendicular to the shoreline (Figure 1). The initial start and endpoints were recorded using a GPS. Along every transect a 1x1m quadrant was placed from the starting point and flipped 100 times. In each quadrant the number of each species of sea cucumbers, and the percentage of seabed strata observed were recorded. This result in 100 observations recorded along each of the ten 100m transects, considering the different species of sea cucumbers (Table 1) and the seabed cover classified into: sand, massive corals, rubble, death corals, branching corals and macro algae.

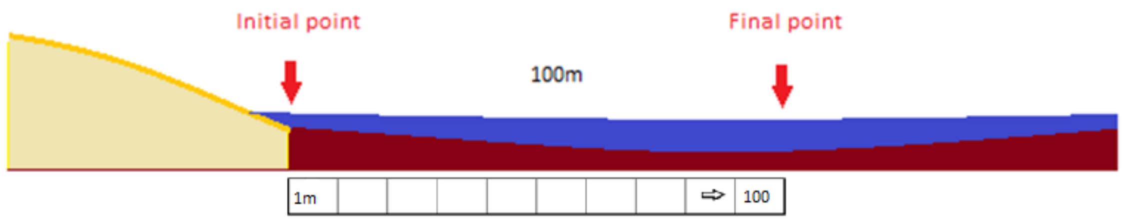


Figure 1 Graphical description of the location of the transects and length in the field

The transects were defined on the basis of their distance from the channel (Table 2). Therefore, four transects were plotted on the reef flat starting next to the bund wall towards the northern area of the island, and four transects to the southern in a constant range of distance. The first two northern transects were plotted next to the channel one meter apart from the bund wall, one inside the channel and the other one on the reef flat; the next three transects were plotted approximately at 100m, 200m and 600m alongside distance from the bund wall. The same pattern were followed for the transects plotted towards the southern area. The location of the transects are describe in Table 2 where they are physically plotted on a map.

Table 2 Codification and location of the transects placed in the field

LOCATION IN STUDY AREA	# TRANSECT	CODE IN MAP	DISTANCE ALONG SHORE FROM THE CHANNEL (m)	MAP OF HERON ISLAND WITH THE TRANSECTS PLOTTED
North of the channel	Transect 7	T7	550	
	Transect 9	T9	200	
	Transect 6	T6	100	
	Transect 5	T5	0	
Inside the channel	Transect 8	T8	0	
	Transect 4	T4	0	
South of the channel	Transect 1	T1	0	
	Transect 10	T10	100	
	Transect 2	T2	200	
	Transect 3	T3	600	

3.3 Measuring sediments

Six sediments traps were placed at the middle point of the six transects adjacent to the channel: T6, T5, T8, T4, T1 and T10. Due to lack of resources and time limitation the sediment traps were placed at a distance of 50m from the shore, to represent the mean sediment flux of the 100m transect. The selection of transects and numbers of sediment traps were based on the proximity to the channel. The traps used were built with three plastic tubes of 67mm, attached to each other and to a weight that helped to fix the traps on the seafloor. The sediment traps were collected after one tide cycle (24 hours). Finally, the water was extracted from the traps and the sediments were dried and weighted (grams of dried weight).

3.4 Measuring current velocity

The current velocity was measured with an electromagnetic flow meter (Valeport) at three places along each transect, namely within the first five meters from starting point, 50 m further out (central point) and the end point of the transect (100m). The chosen location along the transect gave a representation of the changes in current velocity in function of the distance from shore, to find out the current velocities that the reef flat system is facing in presence of the channel at ebb tides. The mean current and the standard deviation were recorded in meters per second (ms^{-1}) within a 45 seconds sequence. Finally, the water depth at each measuring point was recorded. All the measurements were executed twice per point at different time during low tide.

3.5 Tide (pole)

Tidal water level has a significant effect on the currents and generally increase the velocity as the tide reaches half time to minimum low tide (Roberts et al. 1983). Since the velocity measured at different time in relation to the tide, the changes in current during low tide were recorded. To measure tides, a two-meter long pole was marked every five centimetres. The pole was attached to one of the jetty pilings via zip ties. The height of the water was recorded frequently during the end of ebb tide through the beginning of flood tide. Only the change in surface height is relevant to this measurement.

4 RESULTS

4.1 Sea Cucumbers Abundance and Distribution

A total of 354 sea cucumbers were recorded in the ten transects (Figure 2). The Black Sea Cucumber was the most abundant in the study area, with 248 individuals (70.1%), followed by the Greenish Sea Cucumber and the Stained Sea Cucumber with 41 (11.6%) and 37 (10.5%) individuals respectively.

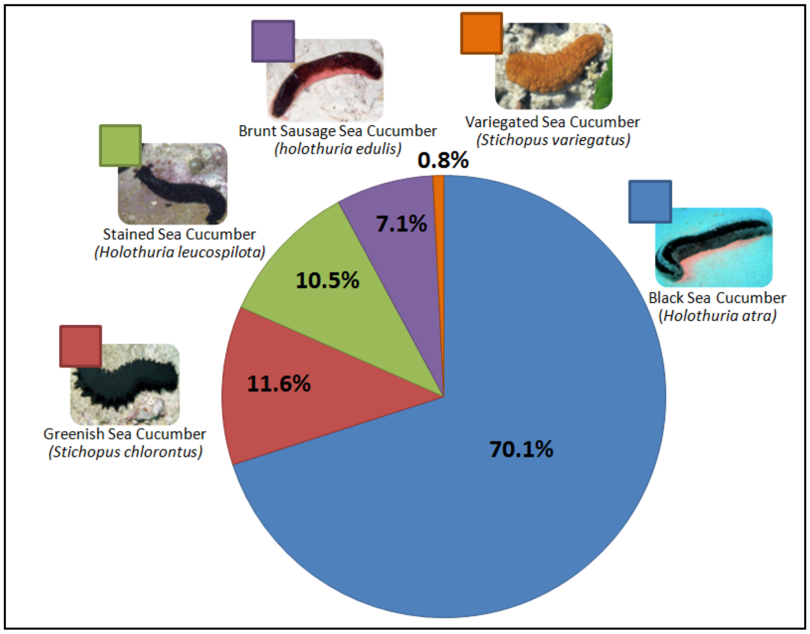


Figure 2 The percentage abundance of sea cucumbers species in the study area.

The results obtained per transect (Figure 3), showed that Black Sea Cucumber besides being the most abundant at total level, it was also the most abundant per transect, especially in the channel, where 46 and 51 individuals were recorded respectively in T8 and T4. The same trend was observed in T9, located approximately 200m north from the correspondent bund wall, where 45 individuals were found. In the remaining transects, the number of Black Sea Cucumbers varied from 7 to 29 without showing a clear distribution pattern.

The Greenish Sea Cucumber was observed in all the transects, except in T10; despite its abundance was lower than the Black Sea Cucumber (from one to nine individuals) the trend was similar, it was more abundant inside the channel (T8 and T4) and in T9 with 17, 11 and 6 individuals respectively. Additionally, the Stained Sea Cucumber was present in eight out of ten transects without following any clear trend. Finally, the Brunt Sausage Sea Cucumber was mostly found in the channel with 10 and 12 individuals in T8 and T4 respectively.

Finally, the Variegated Sea Cucumber was only found in two transects T4 and T2 with 1 and 2 individuals respectively, therefore, as it was not representative within the area analysed in this research, this sea cucumber was excluded for further analysis.

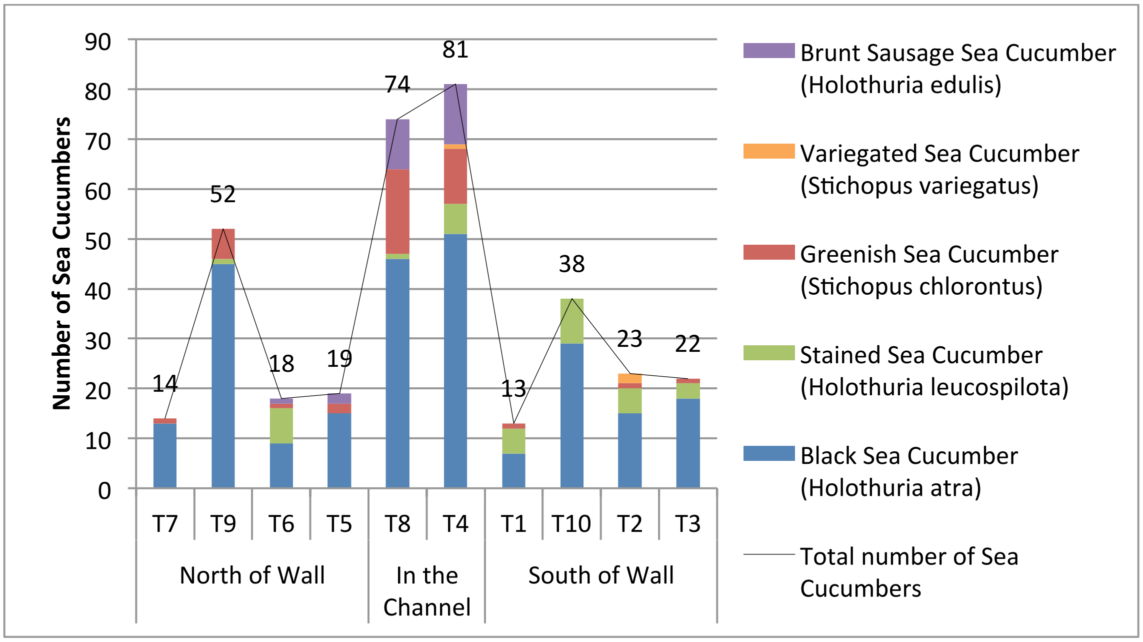


Figure 3 Abundance of Sea Cucumbers per transect and classified per species.

The percentage of species found in the channel and on the reef flat (Figure 4), showed that most of the Brunt Sausage Sea Cucumbers (88%) were recorded in the channel, the same trend was observed for the Greenish Sea Cucumber but in less percentage (68.3%). On the other side, the data showed that Black Sea Cucumbers and Stained Sea Cucumbers prefer to inhabit the Reef flat with 60.9% and 81.1% of individuals.

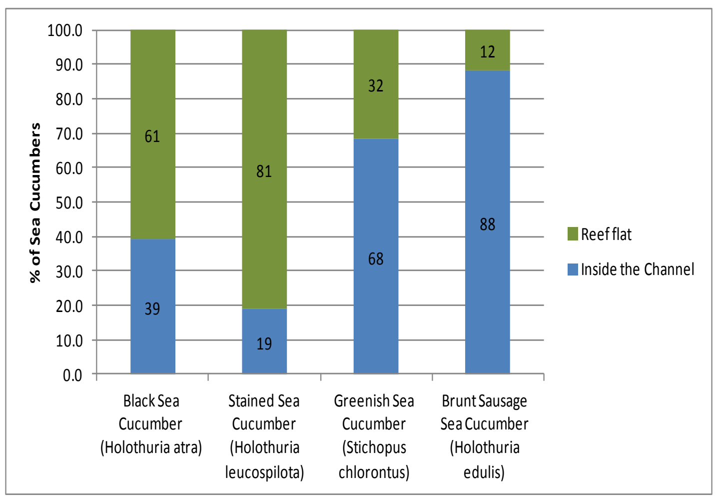


Figure 4 Percentage of each species of Sea Cucumbers inhabiting the reef flat and the inside part of the channel

Finally, the distribution of sea cucumber species was analysed as the number of individuals every 10 meters of each transect. These results were graphically synthetised in series of figures (Figure 5 to Figure 14), showed below; the figures are presented according to order that the transects were located on the field, starting from the farthest transect in the north side, going through the channel and ending in the farthest in the south side.

North of Bund Wall

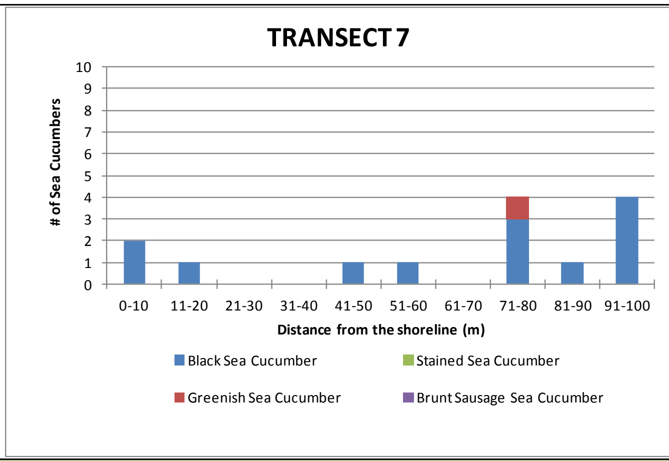


Figure 5 Distribution in transect 7, located approximately 600m from the northern bund wall.

The Black Sea Cucumber was the most abundant along this transect with presence of one Greenish Sea Cucumber at 71-80m. Absence of sea cucumbers from 21 to 40m and from 61 to 70m.

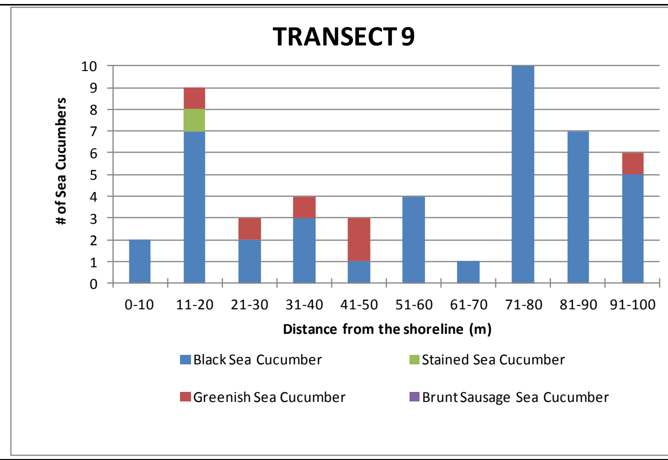


Figure 6 Distribution in transect 9, located approximately 200m from the northern bund wall.

The Black Sea Cucumber was the most distributed along this transect with the presence of one to two individuals of Greenish Sea Cucumber from 11 to 50m and one individual at 91-100m.

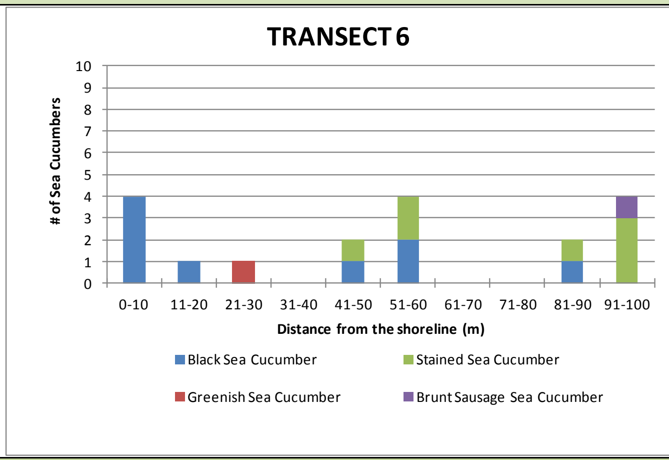


Figure 7 Distribution in transect 6, located approximately 100m from the northern bund wall.

The number of Stained Sea Cucumbers increased at further distance while Black Sea Cucumbers decreased. Absence of sea cucumbers from 31 to 40m and from 61 to 80m.

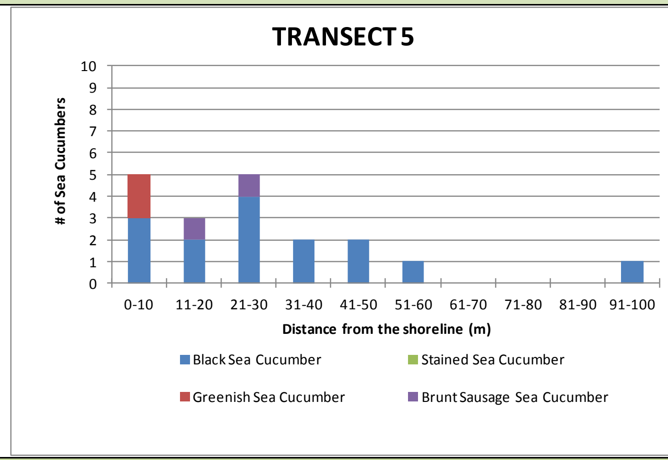


Figure 8 Distribution in transect 5, located next to the northern wall on the reef flat side.

The Black Sea Cucumber distribution increased at further distance. The Greenish Sea Cucumber was present in the first 10 meters and the Brunt Sausage Sea Cucumber from 11 to 30m.

Inside the channel

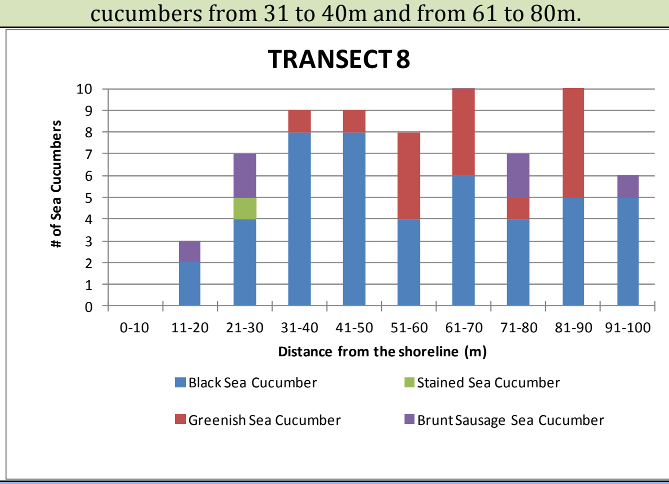


Figure 9 Distribution in transect 8, located next to the northern bund wall inside the channel.

The Black Sea Cucumber was the most distributed along this transect. The Greenish Sea Cucumber was found from 31 to 90m, while the Brunt Sausage Sea Cucumber from 11 to 30 meters and from 61m to the end of the transect, both without any specific

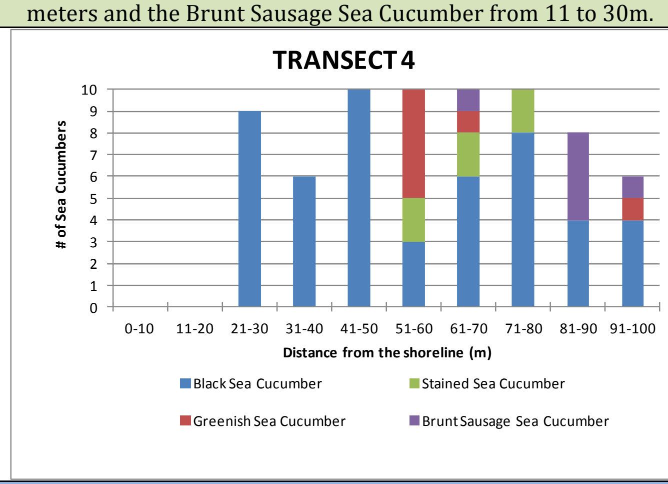
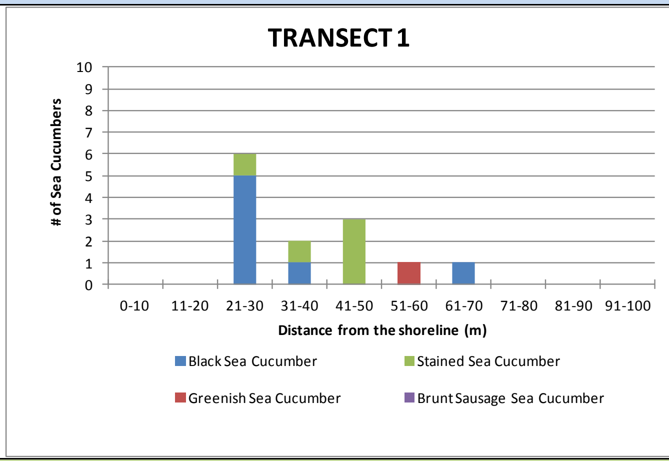
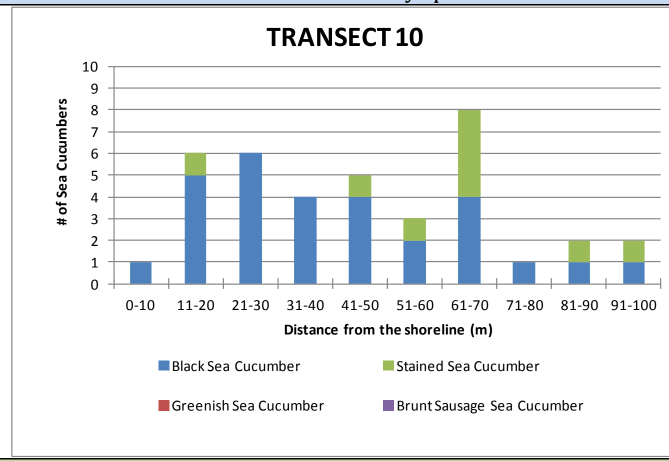
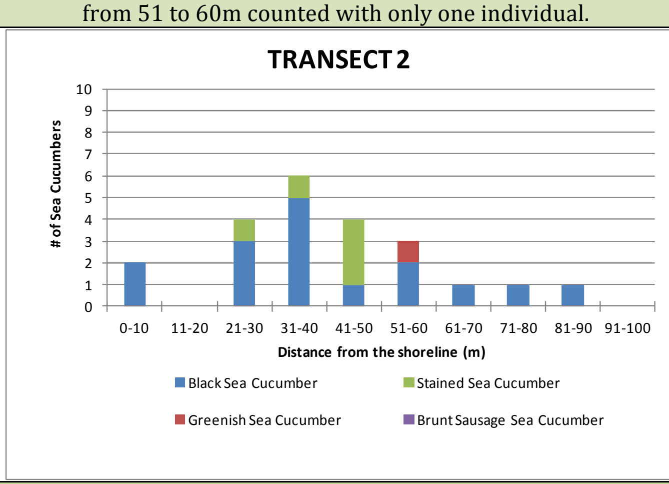
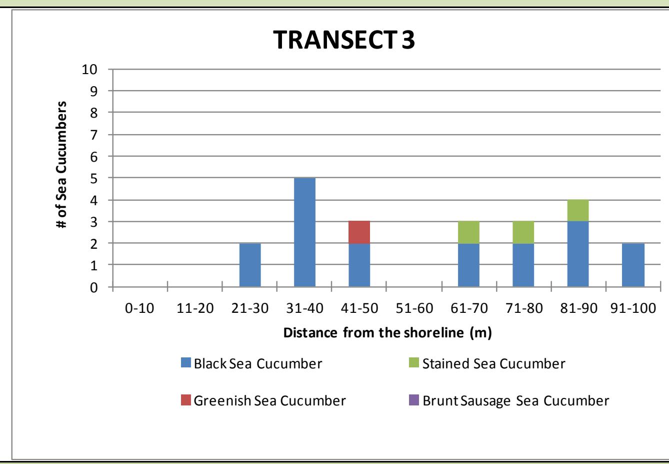


Figure 10 Distribution in transect 4, located next to the southern bund wall inside the channel.

The Black Sea Cucumber was highly distributed from 21 to 50m but slightly dropped after. No sea cucumber found from 0 to 20m. Two individuals of Stained Sea Cucumber were found in each quadrant from 51 to 80m. The remaining species were present

<table>
<tr><td></td><td>trend. Absence of sea cucumbers in the first 10m.</td><td>from 51 to 100m without any specific trend.</td></tr>
<tr><td rowspan="6">South of Bund Wall</td><td>
</td><td>
</td></tr>
<tr><td>Figure 11 Distribution in transect 1, located next to the southern bund wall on the reef flat side.</td><td>Figure 12 Distribution in transect 10, located approximately 100m from the southern bund wall.</td></tr>
<tr><td>This transect showed the least species richness in this research. No sea cucumbers found in the first section of the transect (0-20m) and at the end (71 to 100m). The Stained Sea Cucumber distribution increased greatly from 21 to 50m. The Black Sea Cucumber was found mostly from 21 to 40m and in less number from 51 to 70m. The presence of the Greenish Sea Cucumber from 51 to 60m counted with only one individual.</td><td>The Black Sea Cucumber was the most distributed along this transect with a great presence of Stained Sea Cucumber, specially from 41m until the end of the transect and only one individual form 11-20.</td></tr>
<tr><td>
</td><td>
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<tr><td>Figure 13 Distribution in transect 2, located approximately 200m from the southern bund wall.</td><td>Figure 14 Distribution in transect 3, located approximately 600m from the southern bund wall.</td></tr>
<tr><td>The Black Sea Cucumber was the most distributed all along this transect, decreasing slightly in the middle area of the transect (21-60m). The Stained Sea Cucumber was greatly present form 41-50m and less presence from 21-30m. A low percentage of Greenish Sea Cucumber was reported at 50-60m. Absence of sea cucumbers from 10 to 20m and from 90 to 100m.</td><td>The Black Sea Cucumber was the most distributed all along this transect, decreasing slightly in the middle area of the transect (41-80m). Three individuals of Stained Sea Cucumber were found from 61-70m. One Greenish Sea Cucumber was found at 41-50m. Absence of sea cucumbers from 0 to 20m and from 51 to 60m.</td></tr>
</table>

Different species of sea cucumbers have different habitat preferences depending on the seabed characteristics (Drumm and Dzeroski 2003); shelter and harder or softer substrate (**Ошибка! Источник ссылки не найден.** to **Ошибка! Источник ссылки не найден.**). The following figures illustrate the results of the various species' distribution in relation to the seabed strata. The seabed cover was divided into groups of microhabitat: sand, rubble, macro algae, dead, massive-, and branching corals. For each transect the microhabitat and the species were analysed in percentage of occurrence within intervals of 10 meter.

North of Bund Wall

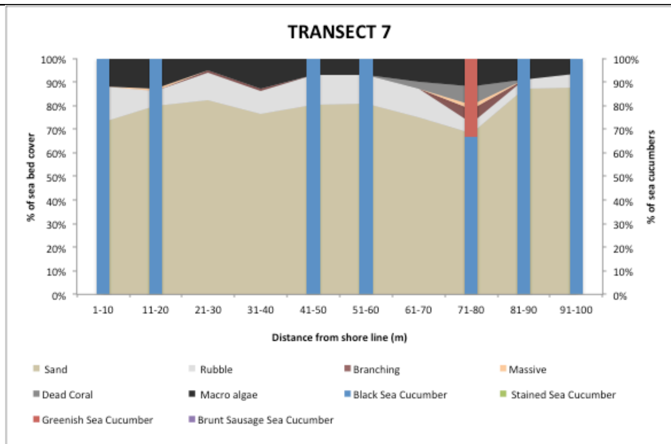

Figure 15 Distribution in transect 7, located approximately 600m from the northern bund wall.

The seabed cover mainly consisted of sand, but a portion of rubble runs along this transect. As the occurrence of Black Sea Cucumber was high in this transect, it seemed that Black Sea Cucumber prefers sand strata. Where some seabed strata slightly varied (71-80m), Greenish Sea Cucumber was found.

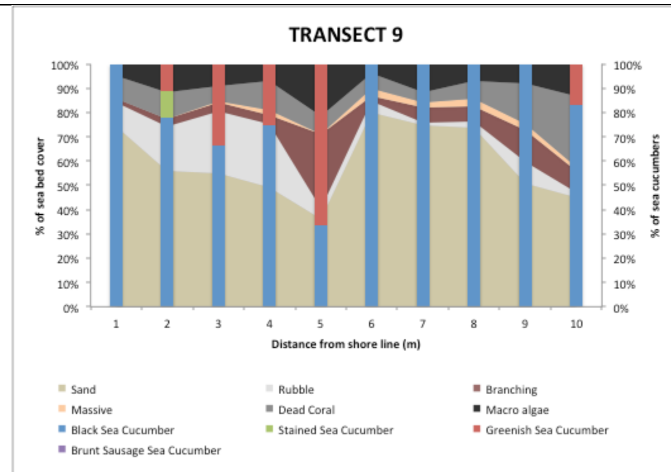

Figure 16 Distribution in transect 9, located approximately 200m from the northern bund wall.

The seabed cover encompassed all the microhabitats in this transect with a higher percentage of sand. The Black Sea Cucumber was distributed throughout the transect with a higher percentage in areas with more sand. Greenish Sea Cucumber was higher represented in areas with more branching corals.

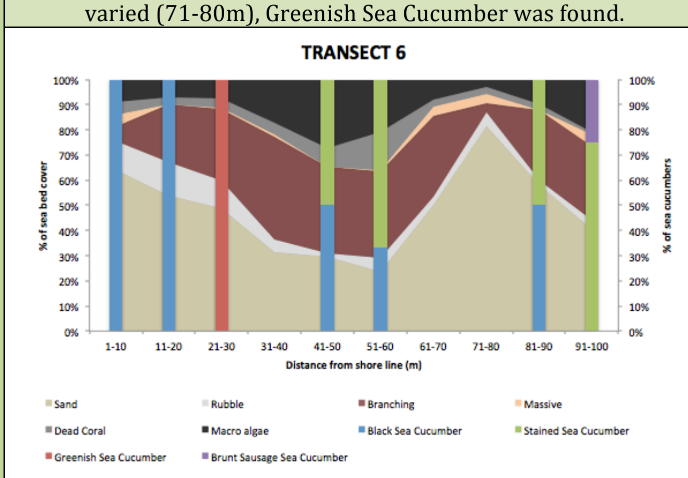

Figure 17 Distribution in transect 6, located approximately 100m from the northern bund wall.

The distribution of branching corals and sand was relatively high. Low percentages of rubble, massive corals and dead corals were visible. The percentage of Black Sea Cucumber was higher closer to shore with higher representation of sand. The Greenish Sea Cucumber was present in an area encompassing all microhabitats. Stained Sea Cucumbers had a higher percentage in areas with more macro algae and less sand.

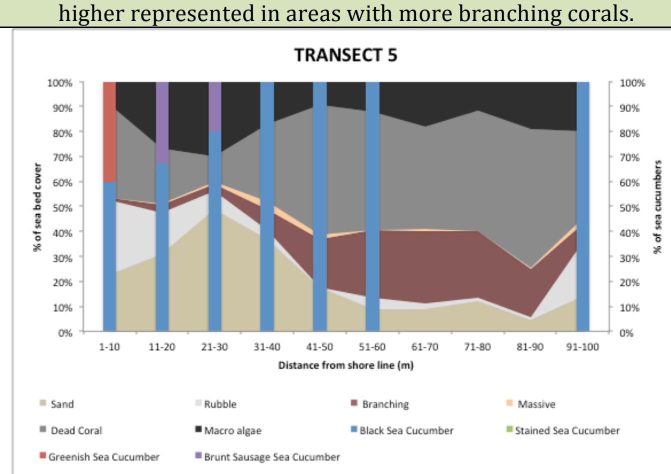

Figure 18 Distribution in transect 5, located next to the northern wall on the reef flat side.

The percentage of dead coral was the high along the transect (roughly 40%), especially from 40m to 100m. The proportion of macro algae and branching corals was also significant, with a higher percentage of Greenish, Black and Brunt Sausage sea cucumbers in areas of more sand and a more even distribution of the various microhabitat.

Inside the channel

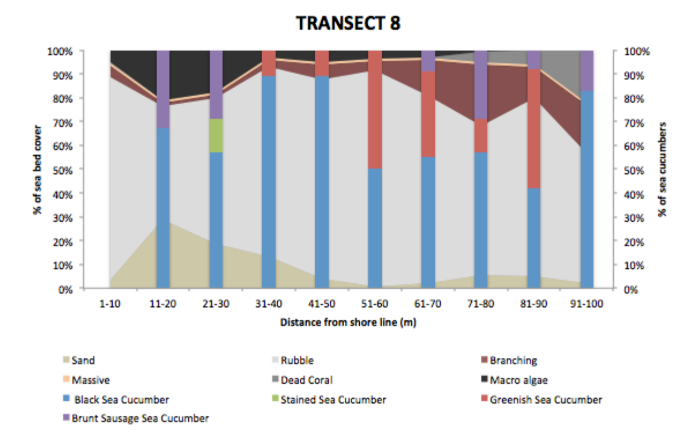

Figure 19 Distribution in transect 8, located next to the northern bund wall inside the channel.

This transect had the highest percentage of rubble. Sand and macro algae were present within the first 50m where the Stained Sea Cucumber was recorded. From 50m the percentage of branching and dead corals increased parallel with the present of Greenish Sea Cucumber and Brunt Sausage Sea Cucumber. Black Sea Cucumber was distributed roughly evenly throughout the transect.

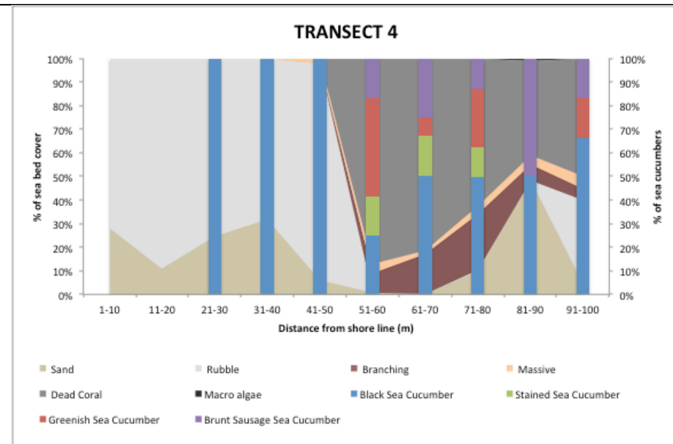

Figure 20 Distribution in transect 4, located next to the southern bund wall inside the channel.

This transect showed a clear change in seabed cover at 50m with roughly 90% sand and 10% rubble. The Black Sea Cucumber was highly distributed here. After 50m the seabed cover was mainly dead corals with presence of massive, branching- and dead corals.

South of Bund Wall

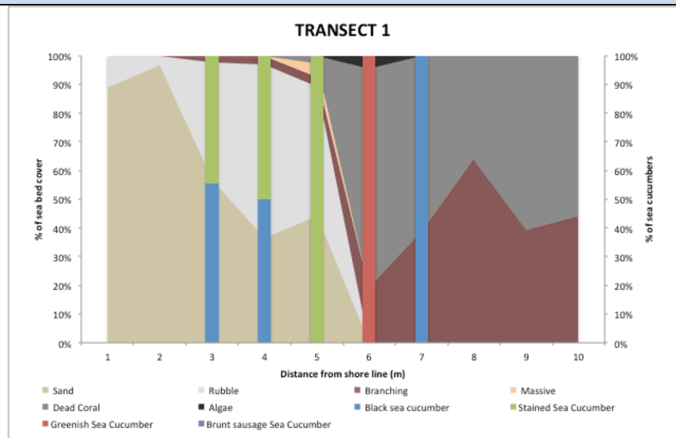

Figure 21 Distribution in transect 1, located next to the southern bund wall on the reef flat side.

This transect had a clear alteration in seabed cover at 50m. From the shoreline to 50m the composition of microhabitat mainly consisted of sand and rubble. In this area the percentage of Black Sea Cucumber decreased in direct relation with sand and the Stained Sea Cucumber increased parallel to rubble presence. After 50m the microhabitat consisted of only branching and dead corals, where low presence of Greenish Sea Cucumber and Black Sea Cucumber were found.

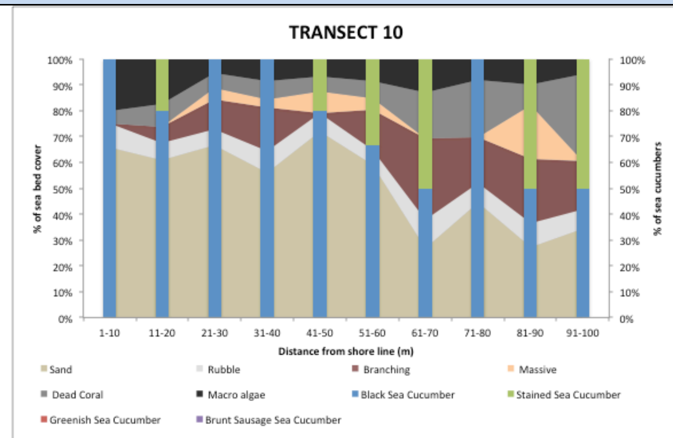

Figure 22 Distribution in transect 10, located approximately 100m from the southern bund wall.

This transect had a moderately constant distribution of the different microhabitat with a higher percentage of sand. The Black Sea Cucumber and the Stained Sea Cucumber were distributed along this whole transect. The percentage of Stained Sea Cucumber increased in negative relation with sand and at higher percentage of massive, dead and branching corals. The Greenish Sea Cucumber and the Brunt Sausage Sea Cucumber were absent.

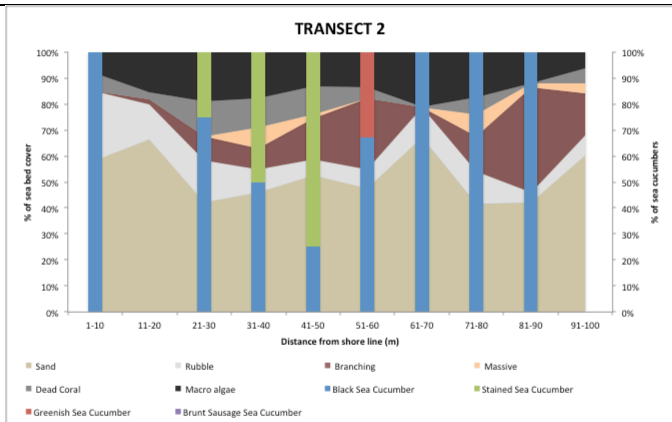

Figure 23 Distribution in transect 2, located approximately 200m from the southern bund wall.

Seabed characteristics of T2 were similar to T10, with a higher percentage of macro algae and lower percentage of dead corals. The Black Sea Cucumber was present throughout the transect and the Greenish Sea Cucumber was present between 20 and 50m from the shoreline consisting in more dead and branching corals.

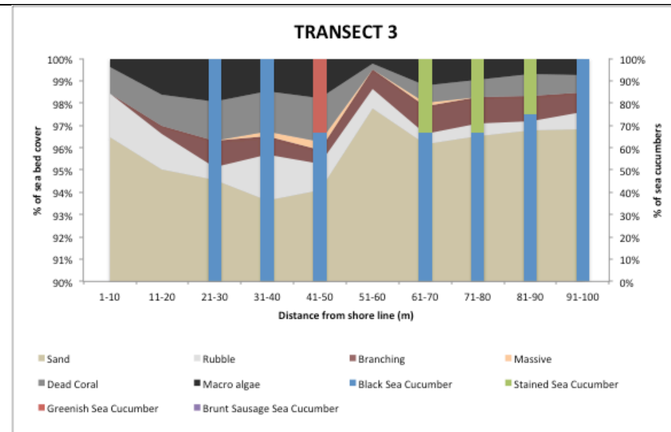

Figure 24 Distribution in transect 3, located approximately 600m from the southern bund wall.

In T3 roughly 50% of seabed cover was sand and the remaining 50% was equally divided between macro algae, rubble, branching and dead corals. The Greenish Sea Cucumber was present in the area with less sand. The Stained Sea Cucumber was found from 60 to 90m from the shoreline where higher sand percentage was recorded. Black Sea Cucumber showed no specific trend.

4.2 Channel influence on the Reef flat system

4.2.1 Current velocity behaviour and co-relation with seabed cover

Current velocity measurements were carried out at three sites along each transect - at 5m, 50m and 100m from the shore. Considering all measurements were implemented during the second half of ebb tide, the currents represented the main trend around the island toward the channel for 5m and 50m sites. For 100m sites measurements showed a slight (10-15 degree) change in the direction of flow toward the edge of the reef.

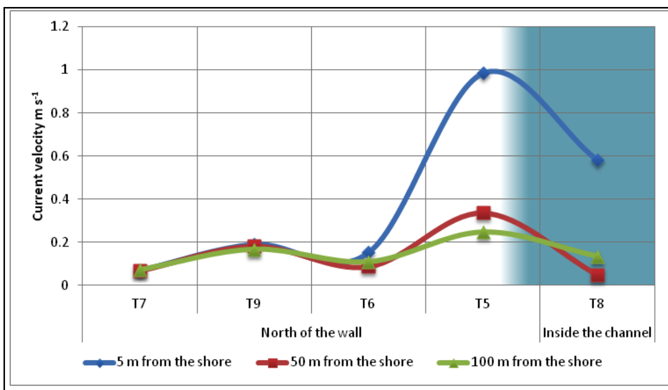

Figure 25 Current velocity behaviour at the transects located north of the wall

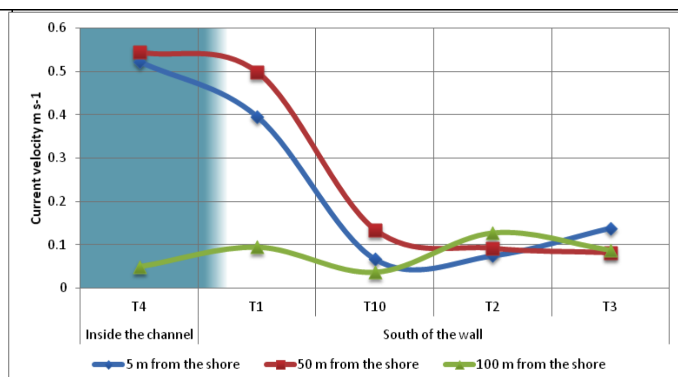

Figure 26 Current velocity behavior at the transects located south of the wall

Ebb tides generated currents as strong as 5-55 cm s^{-1} in some areas, with a maximum recorded current velocity of 98.5 cm s^{-1}. The lowest current velocity was noted at the greatest distance from the channel (600 m) in T7 and T3 (Figure 24 and Figure 25). Transects T3 and T7 were characterised by weak fluctuations of current velocity along the transects without significant changes with increasing distance from the shore. Transects T9 and T2, as well as T6 and T10, away from the channel at 200 and 100m respectively, showed a slightly gradual increase of current velocity by approaching the channel. The highest current velocity for the above transects was fixed at 5m from the shore.

Transects T5 and T1 (Figure 25 and Figure 26) indicated abrupt and substantial increase of flow velocities in close proximity to the bund walls. Measurements at 5 and 50m from the shore showed four times increase in flow velocity outside the southern bund wall. Measurements performed in the same transect at 100m from the shore showed no increase in current velocity. Transect T5 was also characterized by a dramatic (six times) increase in current velocity outside the northern bund wall at 5m from the shore, less significant (three times) increase at 50m and a slight increase at 100m. Comparison of the data for T1 and T5 allowed suggesting that the southern side is more affected by the channel than the northern one.

Transect T8 (Figure 25) showed a sharp decrease in the rate of flow in the channel after crossing the wall all along the transect. Transect T4 (Figure 26) showed a continued increase in flow velocity inside the channel after crossing the wall. This difference in the behaviour of water flow in different parts of the channel could be caused by the differences in bottom morphology or engineering features of the walls.

The data were analysed in terms of proximity to the channel, proximity to the shore, the correlation between current velocity and the seabed cover, as well as target species distribution.

Current velocity data was compared with the percentage composition of seabed cover for each transect. Results of the analysis for the 5m area along all transects (Figure 27) showed that outside the channel with low and moderate velocity of 6.9-39.6 the predominant type of coverage was sand with a percentage of 60-98%. Nevertheless, 5m areas inside the channel were characterised by moderate velocities and high content of rubble 74-83%. Northern area (T5) on the reef flat the channel was characterised by high velocities and high content of dead corals 36%, which greatly exceeded the content of branching corals on the same area.

Similar trends were typically found for a distance of 50m from the shore (Figure 28). Low velocity areas outside the channel were characterised by high sand content of 60-82%. Moderate to high velocity areas outside the channel contained 36-78% of dead corals, which is 3-6 times higher than the content of live branching corals recorded at the same areas. The average percentage of dead corals in 50m area in all transects was two times higher than the percentage of live corals. Inside the channel, the northern low velocity part was characterised by high rubble content, and southern by high percentage of dead corals, with 90 and 76% respectively.

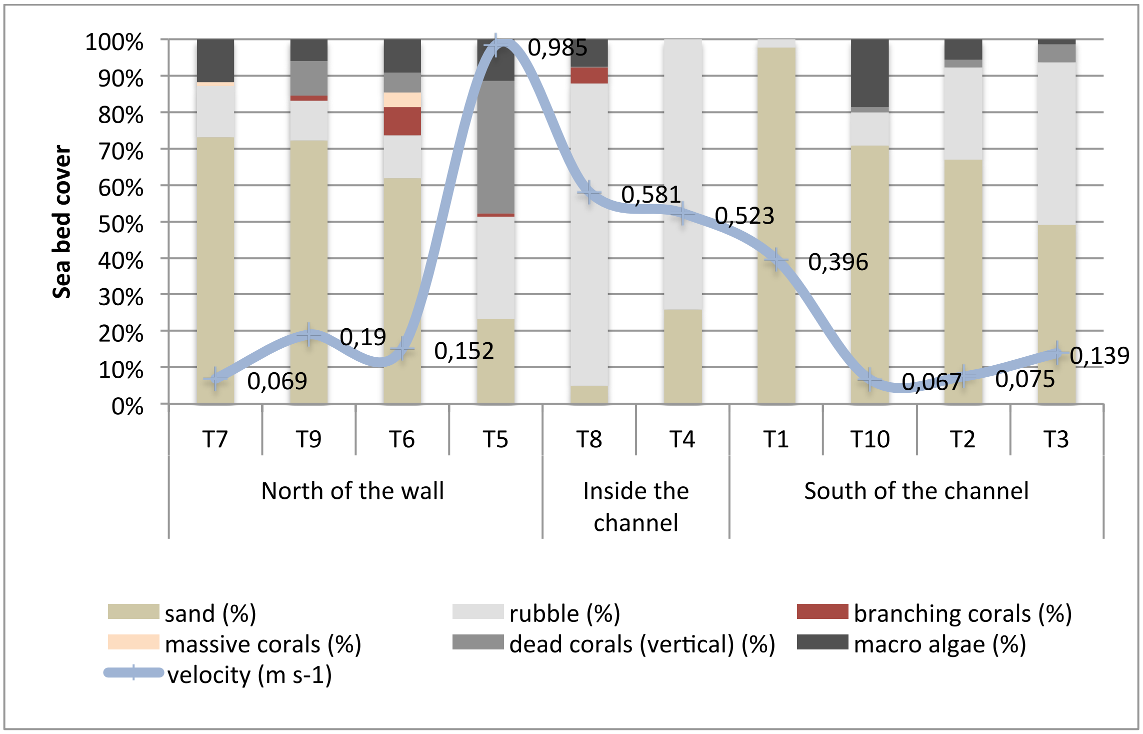

Figure 27 Relationship between current velocity and seabed cover at five meters from the shore

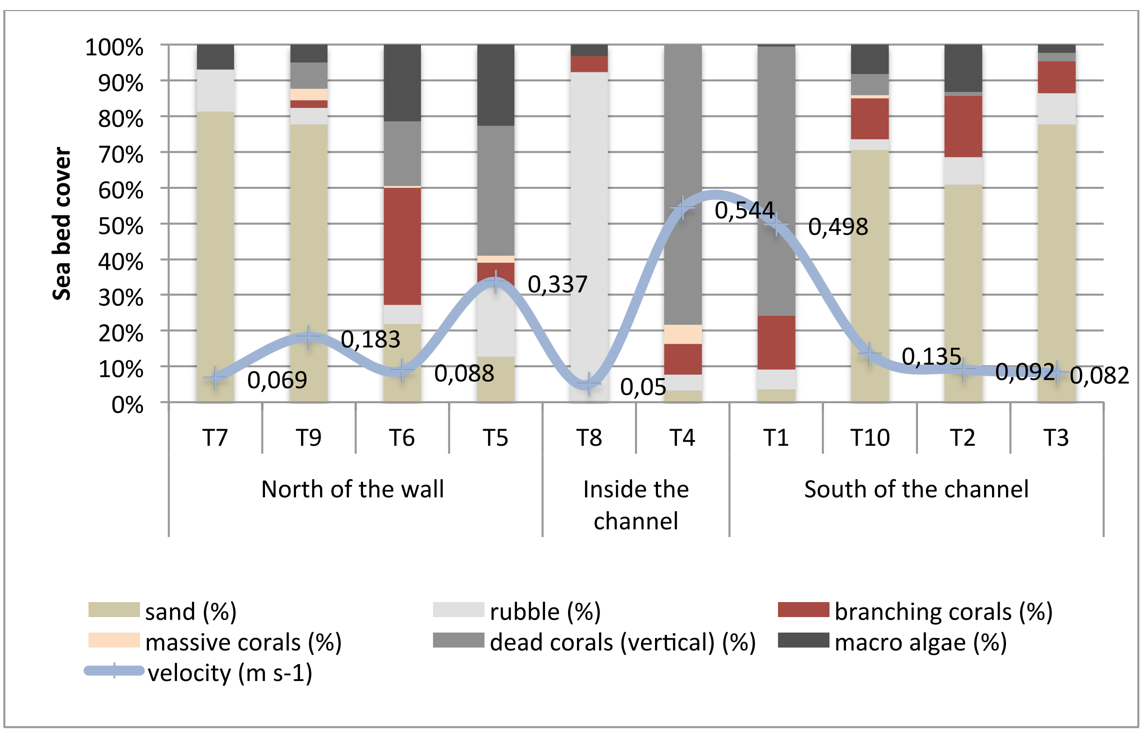

Figure 28 Relationship between current velocity and seabed cover at 50 meters from the shore

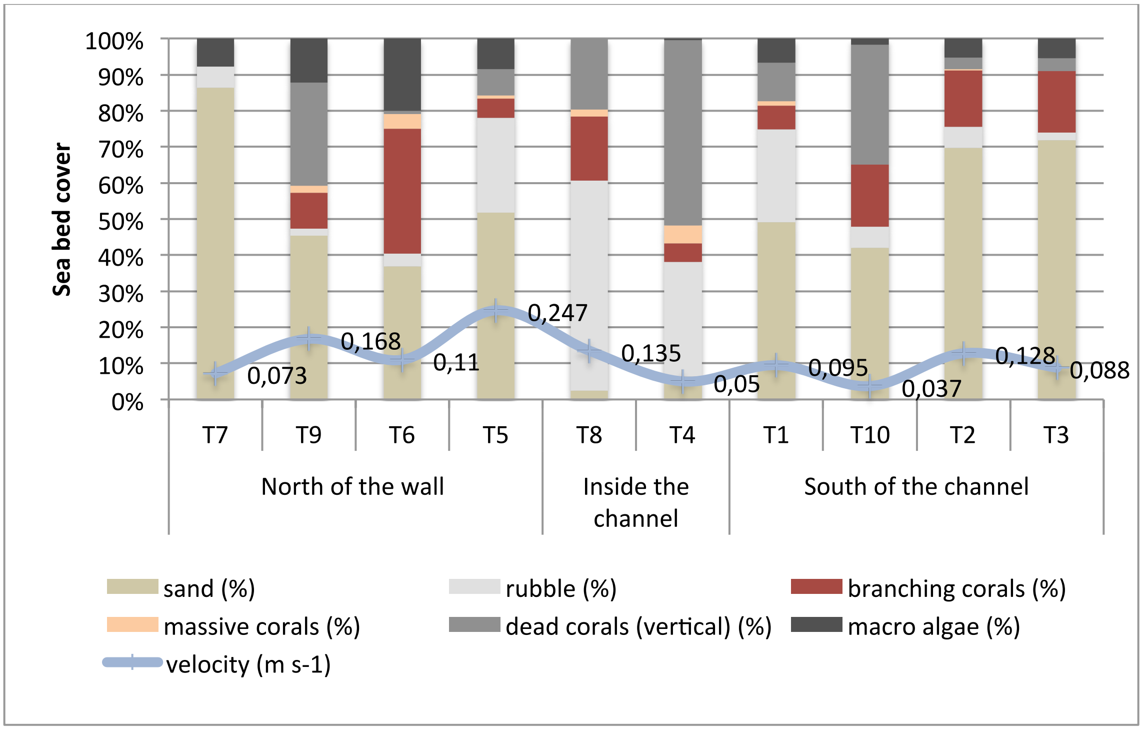

Figure 29 Relationship between current velocity and seabed cover at 100 meters from the shore

The 100 m area (Figure 29) was a zone of low velocity for all transects outside and inside the channel. Outside areas were dominated by sand with a content of 48-88%. On average, the percentage of live and dead of corals was equal. Areas inside the channel were also characterised by a high content of dead material. The total content of dead corals and rubble for the northern and southern parts of the channel was 90 and 80% respectively.

4.2.2 Sediment Flux

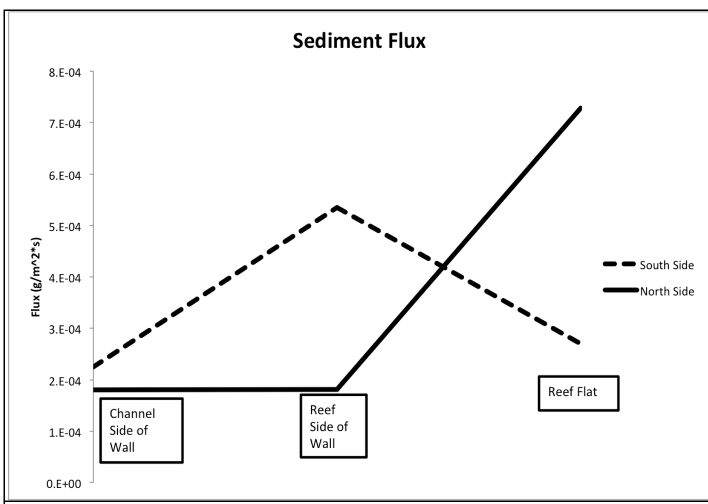

Figure 30 Sediment fluxes taken from around the bund wall and in the reef flat. North of channel compared to south of channel.

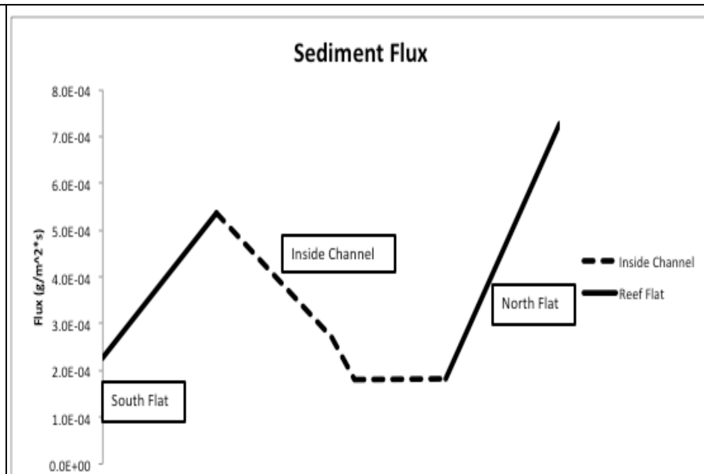

Figure 31 Sediment fluxes viewed continuously from South to North.

Sediment fluxes were calculated from total mass of dried sediment collected in the traps over a full tidal cycle. On the north side of the channel, the fluxes were consistent on both sides of the wall and spiked in the reef flat. On the south side of the channel, the flux spiked on the reef side of the bund wall and was lower in the flat and in the channel.

4.2.3 Tides

Tidal data was collected as often as possible during the bottom half of the tide on the 25th of September. Current velocities were measured at transects 6 and 7 twice during the tide. These current velocities were compared with the tide. It was expected that the current velocity increased at the lower portion of the tide. This showed the draining effect of the channel.

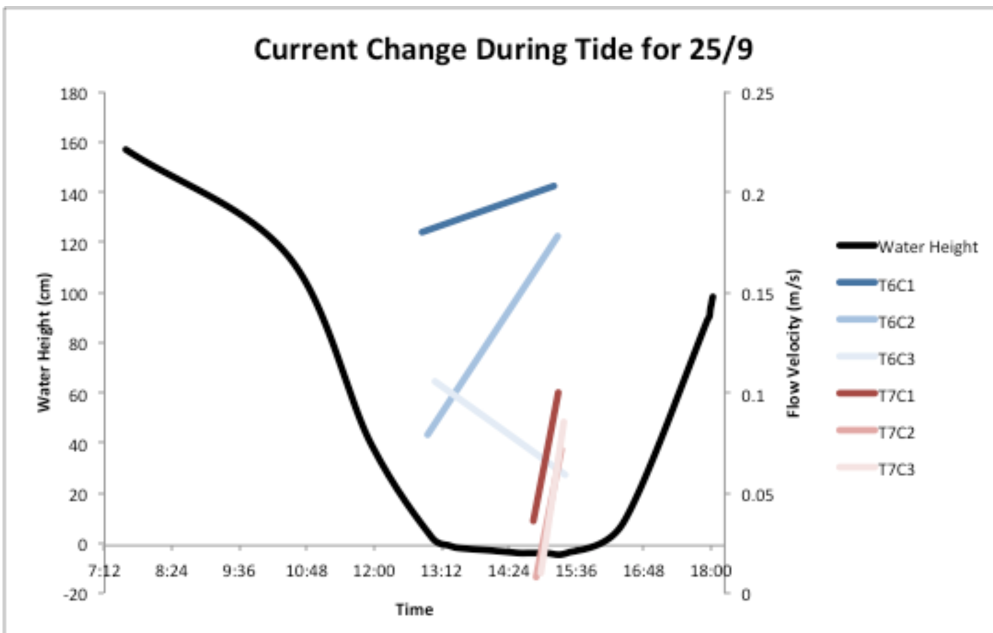

Figure 32 Flow velocity data for Transects 6 and 7 at different points in the tide.

Figure 32 shows how the flow velocity changed during low tide. The lowest portion of the tide was from about 13:10 to about 16:00. At this time the tide was well below the bund wall and it was draining into the channel over the walls or through breaches close to the beach. The measurement taken at T6C1, closest to the beach, was relatively fast at approximately 0.18 m/s-1 and increased in speed to approximately 0.2 m/s during the low portion of the tide. The currents at T6C2 started out slower but nearly tripled between measurements, while at T6C3, the current actually decreased in velocity by half. At T7, each spot that was measured showed similar trend. The current velocity started between 0 and 0.05 m/s and increased to 0.07-0.1 m/s over a short period of time.

5 DISCUSSION

5.1 Sea cucumbers' abundance and distribution in relation to seabed strata

The abundance and distribution of the sea cucumbers analysed in this report were specific to the study area, they did not show a general picture of the whole reef flat. It would be necessary to make several further studies that consider the same methodology covering broader areas, as well as longer times, to get an accurate understanding of sea cucumbers abundance and distribution. The influence of the channel was not evident for the abundance and distribution of sea cucumbers in the reef flat, nevertheless, there was a clear difference between inside the channel transects and reef flat transect, as analysed below.

The areas in the outer reef flat adjacent to both northern and southern of the bund walls showed greatly dense coral communities, mostly by branching *Acropora* species, supporting Berkelmans et al. (1998), who stated a great recovery on coral growth on areas adjacent to the channel after the re-design of the bund walls in 1993. Those changes occurred at the seabed strata level, should had a potential influence on the sea cucumbers distribution and abundance. Therefore, in the field it was observed that the number of sea cucumbers on the transects located in the reef flat next to the bund walls (T5-north and T1-south), showed very low abundance (19 and 13 individuals, respectively). Nevertheless, it is important to mention that the coral cover was greatly dense; therefore the results obtained could be underestimated, especially for Brunt Sausage Sea Cucumber, which prefers sheltered areas.

Inside the channel (T4 and T8), the highest number of sea cucumbers was observed; nevertheless, the first 20m on T4, in between the jetty and a highly disturbed anthropogenic beach, no sea cucumbers were found. This area is covered by fine sand which is possibly transported by the currents and due to the trampling effects on the beach; suggesting that in this specific area the influence of tourism is causing negative impact on sea cucumbers.

Additionally, inside the channel, the four species of sea cucumbers analysed were found; which means that this area showed the highest species richness. The Black Sea Cucumber was present in the same trend as in the reef flat, but it shared its habitat with the remaining species. It was found higher presence of Greenish Sea Cucumbers which were vaguely distributed in the reef flat, except on T9, where it was found from 11 to 50m. Additionally, inside the channel the majority of Brunt Sausages Sea Cucumber were found, specially on the deeper half part of the transect, which suggested this species prefers deeper and darker habitats. However, the fact of higher species richness in the channel does not enable the conclusion that the channel is beneficial for sea cucumbers, because the reason for this trend is not well understood, and could vary from movements of gametes or displacement of adult sea cucumbers due to currents effects, to species coming from outside the reef.

The seabed cover inside the channel varied distinctively from the reef flat with the highest proportion of rubble, which covered approximately 75% of the seabed strata in T8, and 80%the first 50m on T4. There is no clear distribution trend of Brunt Sausage Sea Cucumber in relation with seabed cover on T8, rather than the species seemed to be non-specific to a microhabitat, similar to the Greenish Sea Cucumber. However, in T4 the Brunt Sea Cucumber and the Greenish Sea Cucumber were only recorded after 50m from the shoreline, where the seabed cover changed from sand and rubble to mainly dead corals.

Finally, despite Variegated Sea Cucumber was excluded from the analysis because it was not representative in the area covered by the transects, it was greatly distributed in further distances from the shore line on the reef flat, and in deeper areas in the cannel. Therefore this species should be analysed in future studies that consider this distribution features.

5.2 Heron Reef system

Although there is a lack of data on the role of water flow in the feeding, distribution and adaptation of sea cucumbers, the dependence of passive suspension feeders in general on the ambient water current for water movement past or across their filtering structures has been broadly confirmed (Singh 1999; LaBarbera 1984; Holtz and MacDonald 2009).

Singh (1999) confirmed the benefit of higher than average current velocities for certain types of sea cucumbers. Holtz and MacDonald (2009) also argued that, unlike many other kinds of passive deposit feeders, sea cucumbers may predominate at higher velocities. They also noted the highest activity associated with feeding behaviour at velocities up to 55 cm s^{-1} and steady activity decrease at flows above that point. However, these studies did not deny that some species may be better adapted to the particular flow regimes in their own habitats due to the existence of significant variation among different species.

The data from this research did not enabled conclusions to be made about a relationship between current velocity and target species abundance and distribution. A direct impact of current velocity on the distribution of the target species in this research was not obvious. Nevertheless, the absence of such a relationship also can not be confirmed due to the small amount of measurements and short period of data collected. Longer experiments will help to make more precise conclusions about the relationship between the distribution of ea cucumbers and current velocities or the absence of such a relationship.

However, abrupt changes in current velocity can also affect other related living benthic organisms and lead to a change in the physical structure of corals (Monismith, 2007), that in turn will lead to changes in habitat. Since sea cucumbers showed preference to certain habitat as illustrated in the distribution results, changes in current velocity may have an indirect influence on target species abundance and distribution.

Sebens, Witting and Helmuth (1997) demonstrated a direct effect of water flow on the physiology and energetic of corals. They noted two reasons of metabolic costs growth. These reasons were the oxygen depletion and the ability to maintain a given posture in moving water for the most efficient capture of particles. However, for branching corals they determined the highest particle capture rates in the 10-15 cm s^{-1}, considering a significant decrease in particle capture occurrence at a flow rate of 40-50 cm s^{-1}. At the same time, high flow environments caused high density aggregations for better functioning in high flow environments. Long influence can lead to a negative effect, causing changes in the coral skeleton making it thicker, leading to a reduction in the size of the spaces between the branches or even will causing colony overturning and breaking (Reidenbach et al. 2006).

The mechanisms described above may explain the large percentage of dead coral found south area, as it is the most influenced by the channel in relation with current velocities (see Figure 25 & Figure 26). However, these data does not represent the whole picture of the processes; therefore, carrying out repeated measurements in the future, would be necessary to obtain reliable information on the patterns in current velocity and hydrodynamic processes of the reef flat as a whole.

The sediment flux data appeared to be sporadic (Figure 30). Comparing the North side of the flat to the South side of the flat did not yield a trend. It can be noted that the southern side of the bund wall on the South side was a heavily trafficked area, which could contribute to sediment redistribution. Upon further analysis, a trend can be seen when viewing the data continuously from south to north as in Figure 31 where the sediment flux increased steadily, droped in the channel, and continued to increase on the other side. The southeasterly currents could explain this. On the south side of the wall, the current came from the southeast, sweeping across the flat. It then reached the bund wall where it appeared to deposit sediment prior to entering the channel. This blocks sediment from entering the channel, as designed. On the north side, the sediment flux increased at approximately the same rate as it did before the wall on the south side. In the channel there was a noticeable dip in flux. This suggests that the sediment transport was dominated by the south easterly current rather than the low tide currents along the beach towards the channel. This could be explained by the abundance of exposed beach rock on the south side of the island relative to the north side of the island.

The spike in the north flat could be influenced by resort operations as well. Also, there is noticeable sand spit observed close to shore near the bund walls on both sides of the channel as seen below (Figure 33). This occurs where there is a channeling effect at low tide where all of the water is forced to pass through the breach in the bund wall. As shown above, some species of sea cucumbers preferred sandy substrate, so the bund wall could actually be creating more suitable habitat by accumulating sediment. However, some species disfavour sandy bottom structure. According to Drumm and Dzeroski (2003), the black sea cucumber prefers larger grains such as rubble and boulder as opposed to fine sand. The sand spits seen in Figure 33 could in fact be responsible for a lower abundance of holothurians close to shore.

Figure 33 Sad spits near the channel.

Also, as seen in Figure 31 in comparison with Figure 3, sea cucumbers were much more abundant in the channel, where the sediment flux is lower. This could imply that the sea cucumbers preferred sand that is not freshly deposited, but instead sand that has had time to accumulate organic matter as a food source, as stated by Schneider et al. (2011). If that is the case, then the increased sediment flux before the bund wall and decreased flux in the channel could create conditions better habitat for sea cucumbers in the channel. The buffering effects of their excrement are more likely to flow out of the reef system due to the channel, reducing its alkalinity increasing effect on the reef flat. While the consequences are not fully understood, and there is limited data, it is clear that the bund wall has an effect on sediment flux and that could contribute to biota distribution. More data collection would be necessary to obtain more conclusive results. A comparison to a similar reef free of human impact could provide a clear juxtaposition.

As seen in Figure 32, the current generally speeded up as the tide lowed. In T7, the flow increased sharply at each point. At T6, the trend was less drastic, and the flow even decreased at the farthest point. This could be due to the fact that T6C3 was at a point where the current bent around the island close to the channel, and the channel had less of an effect. The data showed that current was approximately twice as fast near the channel at T6 as it was away from the channel at T7. This is especially significant because the data were recorded at about the same time. Close but not directly next to the bund wall, T6 currents were moving much faster than T7 currents that were far away from the bund wall, indicating the draining effect of the channel. Stronger currents were observed near dead low as seen in Figure 32**.**

The peak velocities should be halfway between high and low tide (ESRU n.d.), but five of the six values shown above actually increased. This can be understood by imagining how the drain in a bathtub works. As the water level falls, the water far away does not move so fast, but when the water level gets down to the bottom the water rushes toward the drain. This is a clear effect that the channel has on the reef flat system. Ideally, the flat should drain radially. The distortion of this process could have implications on the physical environment and could affect the distribution of bottom cover and sediment and nutrient transport. It was unclear how this is impacting the biota.

6 IMPLICATIONS FOR MANAGEMENT AND CLIMATE CHANGE

With the results collected from the research, the question arises as to how the problems that the channel and bund wall present should be addressed under a climate change future effects scenario. Therefore, specific measures must be addressed in Heron Island, which are defined as management options in this section of the research. Additionally, an overview of the current management of the GBR and Heron Island and the implications of climate change are described.

6.1 Legislation, management and zoning scheme of the GBR

The 345,000km2 GBR is not only the largest coral reef ecosystem in the world but also includes 3000 individual coral reefs (De'ath et al. 2012). Due it its outstanding ecological value, it was listed as World Heritage Site in 1981 and has been managed under the *Great Barrier Reef Marine Park Act 1975* and other legislations. The main objective of the Act was to provide long term conservation of the environment, biodiversity and heritage values on the GBR system. This led to the establishment of the Great Barrier Reef Marine Park Authority (GBRMPA) and delimitation of the marine park boundaries.

The Commonwealth and Queensland governments manage together the GBRMP since its start and currently are about to release the Long-Term Sustainability Plan for the GBR to set the future management criteria until 2050. It is currently managed under a Zoning Scheme, which identifies which activities are allowed in different sites of the GBR. On this zoning scheme, 33% of the Marine Park is under *Marine National Park* status (fishing and collecting not permitted).

ACTIVITIES GUIDE
(see relevant *Zoning Plans* and *Regulations* for details)

	General Use Zone	Habitat Protection Zone	Conservation Park Zone	Buffer Zone	Scientific Research Zone [2]	Marine National Park Zone	Preservation Zone
Aquaculture	Permit	Permit	Permit [1]	✗	✗	✗	✗
Bait netting	✓	✓	✓	✗	✗	✗	✗
Boating, diving, photography	✓	✓	✓	✓	✓ [2]	✓	✗
Crabbing (trapping)	✓	✓	✓ [3]	✗	✗	✗	✗
Harvest fishing for aquarium fish, coral and beachworm	Permit	Permit	Permit [1]	✗	✗	✗	✗
Harvest fishing for sea cucumber, trochus, tropical rock lobster	Permit	Permit	✗	✗	✗	✗	✗
Limited collecting	✓ [4]	✓ [4]	✓ [4]	✗	✗	✗	✗
Limited spearfishing (snorkel only)	✓	✓	✓ [1]	✗	✗	✗	✗
Line fishing	✓ [5]	✓ [5]	✓ [6]	✗	✗	✗	✗
Netting (other than bait netting)	✓	✓	✗	✗	✗	✗	✗
Research (other than limited impact research)	Permit	Permit	Permit	Permit	Permit	Permit	Permit
Shipping (other than in a designated shipping area)	✓	Permit	Permit	Permit	Permit	Permit	✗
Tourism programme	Permit	Permit	Permit	Permit	Permit	Permit	✗
Traditional use of marine resources	✓ [7]	✓ [7]	✓ [7]	✓ [7]	✓ [7]	✓ [7]	✗
Trawling	✓	✗	✗	✗	✗	✗	✗
Trolling	✓ [5]	✓ [5]	✓ [5]	✓ [5,8]	✗	✗	✗

Figure 34 Activities allowed per Zone within the Zoning Plan (GBRMPA, 2011)

6.2 Heron Island current management scheme

Heron Island is located is located 72km northeast of Gladstone and is part of the Capricornia Group in the southern section of the GBR. It is roughly half *Marine National Park* zone (green zone) and half *Conservation Park* zone (yellow). As stated in the zoning chart and maps bellow (Figure 34 to Figure 36), the Research Station and Resort are located on the green zone, a highly restricted area. Only boating, diving and photography are permitted without a permit and only research, shipping and tourism are allowed with permit. The other side of the island is under yellow zone, which is less restrictive and allows among other activities: crabbing, bait netting, limited collecting, limited spearfishing, line fishing, and even trolling under certain circumstances.

Within the Commonwealth and Queensland constraints, Heron Island is currently managed by three stakeholders: Queensland National Parks and Wildlife Service, Delaware Nth (hotel) and UQ Research Station, who cooperate with the Heron Island Management Committee integrated by representatives of the three bodies (Neil 1998) and are self-regulated under the Heron Island Management Plan.

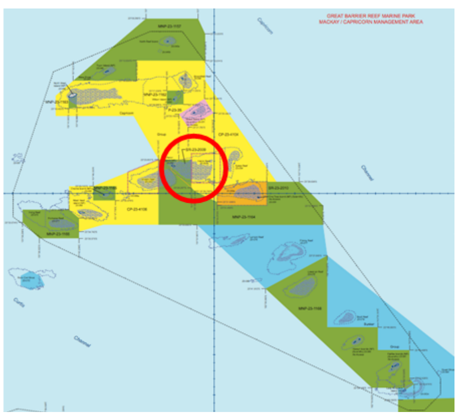

Figure 35 Location of Heron Reef within the Capricornia Group (Source: GBRMPA, 2011)

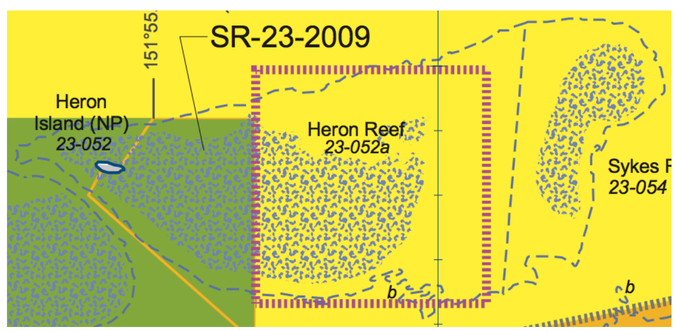

Figure 36 Zoom to the Zoning Scheme in Heron Reef (Source: GRMPA, 2011)

6.3 Implications of climate change on Heron Island

According to the latest Great Barrier Reef Outlook Report (GBRMPA 2014) climate change remains the most serious threat to the GBR. It is already affecting the reef and severe consequences will be evident in years to come. The most important threats projected are: increase on sea temperatures that would lead to coral bleaching, ocean acidification that will restrict coral growth and survival, more intense weather events. These impacts will be amplified by the accumulation of other impacts; consequently climate change remains the most serious threat to the GBR (GBRMPA 2014). Therefore, this section will focus on the implications of climate change on Heron Island.

It is known that coral cays are formed by the physical processes of winds, waves and tides that transport reef-top sediments to form and shape a cay (Gourlay 1988). However, little is known about the trends and changed of air-sea heat flux that will come along with climate change (Rhein et al. 2013) and how this will effect on the reef flat. Cyclones and other extreme events trigger significant changes in cays (Gourlay 1988) and this has lead to significant engineering interventions to repair damage on the channel-bund wall system and to contain increased erosion (Berkelmans et al. 1998). Hence, if weather events become stronger, it will increase the amount of engineering work to maintain the channel.

As in the GBR scale, the Heron Island channel and bund walls system will have to adapt to climate change. Other factor to address is that the channel and bund walls system has had an impact on hydraulics that resulted from lowering the minimum low tide level and the erosion of sediment on the reef flat (Rhein et al. 2013). Therefore, based on our findings and considering with sea level rise, we suggest that it could lead to stronger drainage to the channel increasing current velocity and sediment flux. It is also predicted that with climate change and sea level rise, most low-lying cays are likely to be inundated in the long term (GBRMPA 2013). Thus, considering the precautionary principle, cumulative climate change effects should be considered in management of Heron Island to allow a more resilient from predicted and unknown events

Anthropogenic impacts on Heron Island contribute to these cumulative impacts. Despite the continuous degradation of the ecosystem, there is an increasing number of tourist visiting the island (Neil 1998). No sea cucumber was found between the jetty and the highly disturbed beach next to it. On this regard, studies suggest that reef walking and other tourism activities are causing negative impact on natural reef flat system and on the sea cucumber populations. This is supported by previous studies that show the impacts of reef walking by re-suspension of sediments, disturbance of fish and changes in community structure (Neil 1998). Thus, this will be considered in the next section

6.4 Management option generation for Heron Island

The Independent Assessment of Management Effectiveness for the recently released Outlook Report (GBRMPA 2014) suggested 3 management approaches for the entire GBR: 1) environmental regulation (statuary and non statuary), 2) engagement (coordination of all stakeholders), and 3) knowledge innovation and integration (Hockings et al. 2014). These criteria will be used to generate multiple management options for Heron Island regarding based on our findings and research on the reef flat and its implications with climate change. The three management approaches will be considered for the option generation and then suggestions of responsibilities of the stakeholders involved for each of the options (Table5). The option selection will depend on the values, trade-offs and budget that the stakeholders consider appropriate and will also be weighted.

Although there data gathered is limited, our results show that there is an impact of the channel on sea cucumbers abundance and distribution in the reef flat next to the bund walls. Since the four species of sea cucumbers analysed showed highest species richness inside the channel in our research, we can suggest that they adapt well to the channel. Our studies also reflected an impact of the sediment strata and the currents velocity, which are two relevant factors that have an impact (positive or negative) on different sea cucumber species.

Now each of the outlined management options for the reef flat in Heron Island will be described and the trade-offs that should be considered.

Option 1 – Change Status of Heron Island to Preservation Zone (Pink)
This option is the most extreme and could be considered if climate change consequences become unsustainable to manage. The expected outcome will be an outstanding increase on biodiversity on the reef flat. However, big trade-offs will have to be considered since it will imply to remove all urban development of Heron Island. Removing the channel, the Resort and the UQ Research station will lose all income. For UQ, research would have to be done remotely.

Option 2 - Change status of Heron Island to all Marine Park Status (Green)
This option is the second most extreme solution. The outcome will be a significant increase on biodiversity on the reef flat. It would imply that the resort stops certain activities (mainly fishing activities) and the research station shift to a more limited research (mainly limited collecting) according to the criteria of the zoning scheme. The trade-offs for the resort are significant economic losses and for Research station are limited research possibilities.

Option 3 - Restricted access in island
This option would imply setting tourist and student quotas to access Heron Island. The expected outcome will be a relevant increase on biodiversity. This would reduce significantly the anthropogenic impact on the reef flat. However, also big tradeoffs to be considered. The Resort will lose significant economic income. UQ will lose economic income and potential significant research to be made. This could apply seasonally.

Option 4 - Channel required engineering work
This option includes the maintenance dredging of the channel and also the possible engineering to increase the height of the bund in order to keep up with the sea level rise and “stabilize” the system over time. The outcome will be adaptation of the island to sea level rise. Trade-off will be significant amount of funding required.

Option 5 - Establish no reef-walking sites
This option is supported by our finding that sea cucumbers prefer different types of seabed strata and some of these are located in highly impacted anthropogenic sites (eg. Black sea cucumber prefers sand in sites that are highly impacted by the resort). The outcome of this option would be protection of biodiversity hotspots on reef flat by reducing anthropogenic pressures of reef walking on the reef flat ecosystem that show species richness or vulnerability. The trade-offs would be limited access for resort and for research activities.

Option 6 – Create and risk plan assessment and “Heron emergency Trust”
The expected outcome for this option will be to have risk assessment plan for climate change emergency and based on the results, establish an emergency fund in order to address climate change related emergencies on the whole reef flat system. The trade-off will be to deposit prearranged amount of budget that could be spent in something else.

Option 7 - Communication campaigns and awareness of holothurians ecological role
The outcome of this option is to create awareness to tourists about the important role of holothurians in the reef flat. The trade- offs will be for the resort to allow space in the information centre to display holothurians information and not other relevant material of species more charismatic (eg. Dugons, sharks, turtles).

Option 8 – Further specific research
This option intends to fill some gaps in knowledge that came across while doing this research. The outcome would be better understanding of the system and more targeted and more significant management actions related to climate change impacts. The trade-off is that funding targeted for this is required. We suggest:

- Alkalinity water analysis outside the reef flat related to effects of sea cucumbers excretes that we predict that flows out of the channel compared to the alkalinity inside the channel
- Impact of abrupt changes of current velocity in other related living benthic organisms that play a significant role in the physical structure of corals
- Analysis of the biota distribution based on the assumption that the channel and bund walls have an effect on sediment and current velocities

The following Table 3 shows some suggestions of stakeholders management responsibilities based on the different management options, followed by Table 4 which displays the weighting of the options based on relevant criteria to consider:

Table 3 Suggestions of Stakeholders Management

OPTIONS	APPROACH	RESPONSIBILITIES OF STAKEHOLDERS		
		UQ RESEARCH STATION	RESORT	GBRMPA
Option 1 - Change Status of heron Island to Preservation Zone (Pink)	Legislative	Retire staff of the island and compensate	Retire staff of the island and compensate	Change zoning legislation. Compensate for economic losses and remove infrastructure
Option 2 – Change status of Heron Island to all Marine Park Status (Green)	Legislative	Limits permission for collecting	Limit activities of the resort	Change zoning legislation Remove permits for fishing and collecting)
Option 3 – Restricted Access in island	Legislative	Tourism quotas	Student quotas	Change legislation and enforce regulation. Supervise quotas
Option 4– Required channel engineering work	Voluntary	Further research regarding the impact of the channel and bund walls	Required engineering measures for maintenance.	Provide funding Supervise and control side effects

OPTIONS	APPROACH	RESPONSIBILITIES OF STAKEHOLDERS		
		UQ RESEARCH STATION	RESORT	GBRMPA
			Provide Funding	
Option 5 - Establish no reef-walking sites	Voluntary	Develop a research study of zoning biodiversity hotspots on reef	Stop reef walking activities in hotspots identified by UQ research station	Monitor Control
Option 6 – Risk assessment plan and "Heron Emergency Trust"	Engagement	Climate change risk assessment for Heron Island infrastructure disturbances (modelling of low, med and high impacts). Negotiate budget	Approve plan and negotiate budget	Co-finance
Option 7 - Communication campaigns and awareness of holothurians	Innovation, communic-ation and knwoledge	Provide information and material to resort	Display information of the importance of sea cucumbers in the information centre	Online and visual publication of species information
Option 8 – Further specific Research:	Innovation, communic-ation and knwoledge	Further research*	Provide Funding	Provide Funding

The next table (6) shows the weighting in the previously proposed management options according to different criteria: ecological, cost-effective, long term benefit, climate change relevance and feasibility. For the scoring, 1 refers to the least suitable, 2 medium and 3 most suitable. The average of the sum of this scoring will suggest the most suitable management options to consider, followed by an according explanation.

Table 4 Weighting of options

OPTIONS	COST	LONG TERM ECOLOGICAL BENEFIT	TOURISM IMPACT	CLIMATE CHANGE RELEVANCE	FEASIBILITY	AVERAGE
OPTION 1 Pink Zone	1	3	1	3	1	1.8
OPTION 2 Green Zone	1	3	1	3	2	2
OPTION 3 Restricted access	1	3	1	2	2	1.8
OPTION 4 Engineering work	1	2	2	1	3	1.8

OPTIONS	COST	LONG TERM ECOLOGICAL BENEFIT	TOURISM IMPACT	CLIMATE CHANGE RELEVANCE	FEASIBILITY	AVERAGE
OPTION 5 No reef walking sites	2	2	2	2	3	**2.2**
OPTION 6 Risk plan and Fund	2	3	3	3	2	**2.6**
OPTION 7 Communication	3	3	3	2	3	**2.8**
OPTION 8 Targeted Research	3	3	2	3	3	**2.8**

Targeted research and communication option had the highest scores for choosing them as first option. Risk assessment plan and Heron Emergency Trust had the second highest score and no reef walking sites as third option. As all this showed to be low-cost measures they could all be applied together. Legislative measures (options 1, 2 and 3) should be reconsidered and discussed in the longer term according to climate change effects since the difference in the scoring wasn't that uneven.

7 CONCLUSIONS AND RECOMMENDATIONS

This research helped to understand some components of Heron reef flat system such as currents, tides, seabed cover and how they are affected by the channel in the inner reef flat. Changes in the system would generate changes in the habitat of the reef flat. Consequently, the abundance and distribution of sea cucumbers will vary as the seabed strata varies due to their habitat preferences as stated by Drumm and Dzeroski (2003), and discussed in this report.

The research faced time and resource limitations. Further data collection over a longer period of time would yield more complete and reliable data and make more accurate evaluation of the effect of the channel and bund walls on the reef flat dynamics, bottom cover and target species abundance and distribution. This need of information is specified in the discussion for every gap of information identified. Additionally, a comparison to a nearby reef that is devoid of human impact would provide a clear juxtaposition. A genetic variability comparison among species of sea cucumbers in the channel and on the reef flat would be helpful to understand if they are related or not, to define wether the species richness is due to movement of sea cucumbers from the reef flat or from outside the reef.

Despite the spatial and temporal strains of this research limited the possibility to draw up well supported conclusions about the cumulative effect of the channel and its bund walls on the reef system. It was clear that the abundance and species richness of sea cucumbers were higher in the channel than on the reef flat, and that the Black Sea Cucumber is the most abundant and distributed on Heron Reef flat, which prefers habitats with sand substrate; which in turns was the most represented seabed strata in the study area. The key role of sea cucumbers in mitigation of climate change effects on the reef flat system reducing acidification was probably the biggest revelation for the working group.

Every alteration of the natural system will bring a cascade effects that would need several management actions to be carried out. Nevertheless, it is necessary for managers to be aware about the existent options to evaluate them in order to define the most achievable ones. On Heron Reef the effects of the channel and bund walls seem to get worse under sea level rise scenario related with climate change; more intervention should be done to keep the access to the cay. But the break point will be reached, this would be the time to think in more radical options such as stop using the channel and leave the system to recruit or lose it forever. Therefore, several future studies about how the system is being affected by the channel and models in a climate change impacted future must be carried out in order to make accurate decisions to conserve this ecological important ecosystem within the GBR.

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