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Herbivores effect on coral reefs - relationships between sea urchins, coral health and algae cover

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Abstract

Coral reefs are vital to marine ecology. The population dynamic on coral reefs are complex and sensitive to natural and anthropogenic changes. Various factors can affect the population dynamic and inflict change. Coral bleaching is threatening coral reefs worldwide and is a hot topic in today's climate challenges. The main cause is increasing water temperatures. A bleached coral has higher mortality and is more likely to be covered in macro algae which reduces its chances to recover. The herbivores facilitate the competition between algae and corals through grazing. Thus, the herbivorous taxa may be crucial for the ability of reefs to recover after disturbance. This field study was done in north-west Madagascar, in the water channel between the two islands Nosy Be and Nosy Komba. The aim of this study is to better understand the role that herbivorous sea urchins and algae coverage has on the reef status. This will facilitate to understand the ecological processes in the reef system. Through diving surveys, data was collected to study the interactions between coral health, algae coverage and sea urchins. The main research questions are 1) how prevalent coral bleaching is in the surveyed areas, 2) if reef status and algae coverage is correlated in the area and 3) if the numbers of grazing sea urchins are related to reef status and algae cover. Along an 80 meter transect the benthic composition and number of sea urchins within 2.5 meter from the line was noted. For each survey, a new place was randomly chosen in the channel to get a broader understanding of the area between the islands Nosy Be and Nosy Komba. The results were used for statistical analysis in R. The results show no significant correlations between coral health, algae coverage and sea urchins. There are weak trends, which can be supported by earlier research in this field. These weak trends are that herbivores have a negative influence on algae cover and algae cover has a negative influence on healthy corals. On the area studied coral bleaching was 0.01% out of the total amount of coral, which was lower than expected. Degraded corals and algae cover were widespread in the surveyed area. One conclusion is that over-fishing of herbivorous fish can be one reason for the degradation rather than coral bleaching. Another conclusion is that the sampling number in this study is too small to get significant results. Improvements of the method used is needed to get a higher quality data suitable for statistical analysis.

Sammanfattning

Korallrev är av stor betydelse för marina ekosystem. Populationsdynamiken i korallrev är komplex och känslig för naturliga och antropogena förändringar. Olika faktorer kan påverka populationsdynamiken och orsaka förändringar. Korallblekning är ett hett ämne i dagens klimat-debatt och ett hot världen över. Den största orsaken till korallblekning är stigande vattentemperatur. En blekt korall har högre dödlighet och blir lättare täckt av makroalger vilket minskar chansen för korallen att överleva. Herbivorfiskar och invertebrater underlättar för korallerna i konkurrensen mot makroalger då de betar på makroalgerna. Därför kan herbivortaxan vara betydelsefull för revens chans att återhämta sig från störningar. Denna fältstudie utfördes i nordvästra Madagaskar, i havskanalen mellan öarna Nosy Be och Nosy Komba. Målet med denna studie är att få en ökad förståelse för hur herbivorer och algutbredning påverkar korallrevets status. Dessa resultat skulle göra det enklare att förstå de ekologiska processerna i korallrevet. Data samlades in under vattnet med dykutrustning och användes för att undersöka interaktioner mellan korallrevets status, algutbredning och antal havsborrar. De frågeställningar som denna studie fokuserade på var 1) i vilken grad är det undersökta området påverkat av korallblekning, 2) om korallrevets status och algutbredning är korrelerat i området och 3) om antalet havsborrar är korrelerat med revets status och algutbredning. Längsmed en 80 meter lina studerades havsbotten och antal havsborrar. För varje tillfälle då data samlades in valdes en ny plats ut att studera för att få en bredare överblick över området mellan öarna Nosy Be och Nosy Komba. Datan analyserades statistiskt i R. Resultaten visar inga signifikanta korrelationer mellan korallrevets status, algutbredning och havsborrar. Det förekommer vissa svaga trender, vilka kan styrkas av tidigare publicerat material. Dessa svaga trender är att havsborrar har en negativ effekt på algutbredning och att algutbredning har en negativ effekt på korallrevets status. I det studerade området är 0.01% av korallerna blekta, vilket var lägre än förväntat. Dålig korallstatus och algutbredning var brett förekommande i det undersökta området. En slutsats är att herbivorfiskar har fiskats till låga bestånd, vilket lett till ökad mängd makroalger kan vara en anledning till att korallrevets låga status snarare än korallblekning. En annan slutsats är att antalet prov är för få i denna studie för att få några signifikanta resultat. Metoden som används behövs även förbättras för att få data av högre kvalitet, bättre lämpat för statistisk analys.

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1 Introduction

Despite occupying merely 0.1% of the oceanic floor, coral reefs support over 25% of all species that live in the ocean and are of significant importance to marine ecology. The coral reefs worldwide have an estimated value of more than US $20 trillion annually through the ecosystem services it provides (Olguín-López et al. 2017). In terms of biodiversity, coral reefs are the most rich, complex and productive marine ecosystems on earth (Olguín-López et al. 2017).

Warm-water coral reefs are found in warm waters at shallow depth where sunlight can reach the reef. The water must be alkaline in order for the corals to grow and calcify fast enough to maintain and build their calcium carbonate structures (Hoegh-Guldberg et al. 2017). In many warm-water coral reefs the limestone-like calcium carbonate is high enough for the coral reefs to establish carbonate structures. As a result, gradually, a three-dimensional reef matrix is built up by the corals secreting calcium carbonate skeletons (Fisher et al. 2015). Over time the corals die and their dead skeletons, through activities of other organisms such as encrusting coralline algae, are fused together (Glynn and Manzello, 2015). The coral reef structures provide habitat for thousands of fish and other marine species such as turtles and invertebrates (Fisher et al. 2015).

The population dynamic in the coral reef is complex and is an important part of the ecology for coral reefs. Many factors can affect the population dynamic and inflict change in the ecosystem – both in coral dynamic and other organisms living on the reef. The change triggering factors can be of abiotic nature like temperature change or biotic such as predation, overfishing and competition. Consequently, the population in a reef are part of a dynamic system which changes in structure and size over time. By studying short and long-term changes in population, (eg. size, structure and age distribution) and understanding the ecological drivers behind these the vulnerability of the ecosystem can be assessed (Verburg et al. 2002). The complexity of these ecosystems and their vulnerability to natural and anthropogenic disturbances, increase the risk of habitat loss for fish populations and invertebrates. This is because these marine organisms are depending on the coral reefs and the benthic substrate (Wilson et al. 2001).

Coral bleaching is a global issue and a highly relevant subject in today's climate challenges. Many factors are contributing to the decline in coral health, however climate change is the most damaging (Hughes et al. 2017). Because of the rich biodiversity around coral reefs, they are seen as rainforest under water. Corals live in symbiosis with zooxanthellae algae which provide the coral with energy through photosynthesis. If the water gets too warm, the coral will expel the algae. This will turn the coral white, which gives the event the name "coral bleaching" (Lesser 2010). A coral can survive without the algae but has higher mortality once it has lost the symbiosis relationship. During a coral bleaching event, corals can be covered in other kinds of algae, which put the corals under more stress and reduces their chances to recover (Nash et al. 2016). Herbivorous fish and invertebrates affect the interaction between corals and macro algae by limiting algal growth through grazing. Subsequently, the herbivorous taxa may be crucial for the ability of reefs to recover after disturbance (Wilson et al. 2010). Coral degradation caused by coral bleaching impose a major threat to coral reefs. The increased mortality caused by widespread bleaching creates dead coral skeletons that are rapidly colonised by algal turf. Moreover, according to Gardner et al. (2003), human induced pressures such as abnormally warm water and overfishing cause substantial and ongoing reef degradation and possibly forcing a shift from coral to algae-dominated reefs. Disturbances causing changes from coral to macroalgal dominance to corals symbolize the global degradation of coral reefs (Cheal et al. 2010).

1.1 Scope of This Study

This study focuses on the interactions between corals, algae and the herbivores of the algae in coral systems with a varying degree of bleaching. To examine this we analyze the correlation between algae coverage, herbivores and coral health. The herbivores in this study is limited to sea urchins only. The species studied are *Diadema setosum, Diadema savignyi, Echinothrix diadema, Echinostrephus molaris, Echinometra mathaei, Heterocentrus mamillatus, Tripneustes gratilla* and *Parasalenia gratiosa*. This study focuses only on sea urchins because they are easy to identify and they are not moving which means there is very low risk in miscounting. Herbivorous fish was not considered in this study.

1.2 Aims and Objectives

This field study focuses on interactions between coral reef health and herbivorous sea urchins and possible anthropogenic driven changes in the reef (eg. water temperature and over-fishing). The aim of this study is to better understand the role that the herbivores and algae cover has on the coral health status. This will help to understand the ecological processes in the reef systems, something critically needed to facilitate coral recovery. This is important to understand the ecological mechanisms and trophic level interactions, as well as how we can manage vital systems under threat.

The objective with this research is to study ecologically important species interactions on the coral reef. This will be done for three groups: corals, algae and herbivores. To examine presence and strength of interactions, the coral reefs, their status (degree of bleaching), type of algae (micro or macro), amount of algae cover on the reef and the presence of grazing invertebrates will be studied.

The main research questions are:

1) how prevalent coral bleaching is in the surveyed area,

2) if reef status and algae coverage is correlated in the area,

3) if the numbers of grazing sea urchins are related to reef status and algae cover.

2 Methodology

The methodology describes the methods used in this study in chronologic order as the study was conducted. The study was conducted in north-west Madagascar in the Nosy Vorona Passage between the islands Nosy Be and Nosy Komba. The area surveyed is in close proximity to villages and mangrove forest where the reef is affected by runoff water and heavy sedimentation. The distance to shore was not measured in the surveys. It reaches further away from the land where the fishing pressure is a little lower and the reefs are patchy.

2.1 Underwater Visual Surveying

Underwater surveys were conducted using SCUBA during April and May 2019 in north west of Madagascar. The underwater surveys were done in the Nosy Vorona Passage between the islands Nosy Be and Nosy Komba, which is shown in figure 1 below. Data collected in the same way the previous three months (January, February and March 2019) was also used in the analysis. Possible changes in the measured parameters depending on seasonal changes were not considered in this study. In total, 16 different surveys were used in the data analysis for this study. During each survey data on both benthic composition and herbivores were collected, see below for details.

Figure 1. Map of Nosy Vorona passage. The marked area is where the surveys where done.

2.2 Benthic Inventory

An 80 meter reel was used to study the benthic composition on the sea bottom. For each survey the reel was placed in a random location, and laid out in a straight line to ensure a broader understanding of the reef. The benthic composition was studied directly under the reel for the total 80 meters and each centimetre of the benthic composition was described and written down on a slate. The benthic categories recorded along the transect were sand, rubble, bare rock, short branching coral, long branching coral, tabular coral, laminar coral, encrusting coral, massive coral, sub-massive coral, mushroom coral, sponge, hydroid, soft coral, anemone, zoanthid, micro algae, macro algae. If the coral was bleached (partly or fully) or dead, was noted together with the identified species. Bleached or dead coral was categorized as unhealthy coral. The total distance of healthy and unhealthy corals and algae cover were calculated from the data. Distances where transformed into the percentage cover in the analysis.

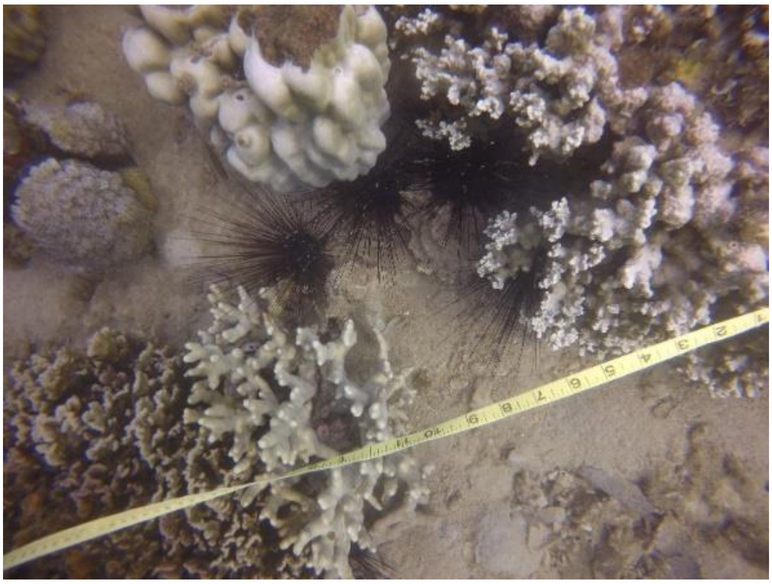

Figure 2. Transect line *Photo: Linnéa Fridén 2019*

2.3 Herbivore Inventory

The herbivores where identified and counted in an area spanning of 2.5 m from each side of the same 80 meter reel used in the benthic survey. The number of sea urchins and the location were noted.

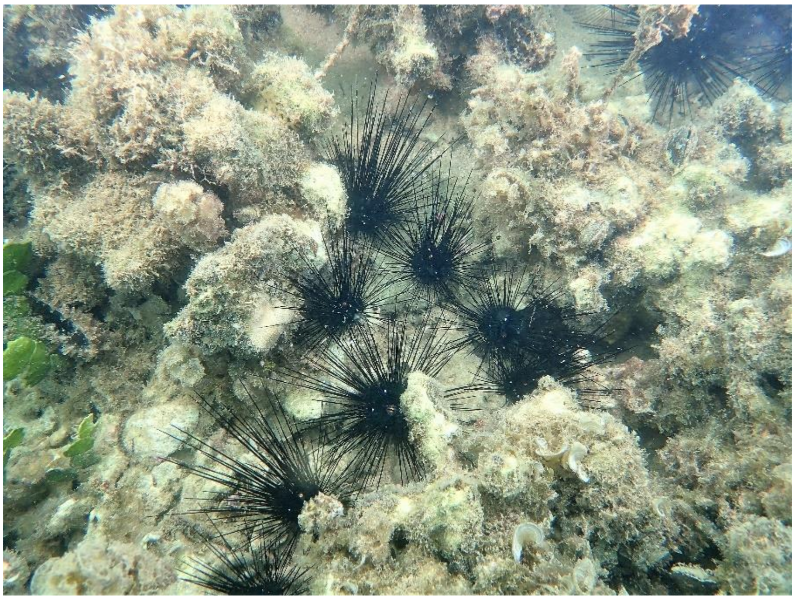

Figure 3. Diadema setosum on dead coral covered in algae. *Photo: Linnéa Fridén 2019*

2.4 Data Analysis

I analysed the relationship between coral health and algae cover in order to study research question number two. This analysis was done using pairwise correlation and linear regression for the data recorded of healthy corals, unhealthy corals and algae cover in a software programme for statistical analysis called R. For this analysis algae coverage was set as the independent variable to see whether algae coverage influences coral health.

To analyse the relationship between number of grazing herbivores, algae cover and reef status pairwise correlation and linear regression was used for the recorded data of sea urchins, algae cover, healthy and unhealthy corals. Again, the same software programme was used for statistical analysis. This was done in order to answer research question number three. For this analysis the number of sea urchins was set as the independent variable to see whether sea urchins as grazer influences coral health and algae coverage.

R studio version 1.2.1335 was used for the statistical analysis.

3 Results

The results are presented under the subheadings, which are related to the research questions apart from the first subheading General Observations.

3.1 General Observation

No significant correlations were found between algae coverage, sea urchins and the health status of the reef. Although the results do not show statistical significance, there are weak correlations. Figure 4 shows the influences represented as scatter plots. In this figure the number of sea urchins are correlated to amount of unhealthy coral, although the result is insignificant statistically. Algae cover and amount of healthy coral also show a slight negative trend, although it is also statistically insignificant (all $p > 0.05$).

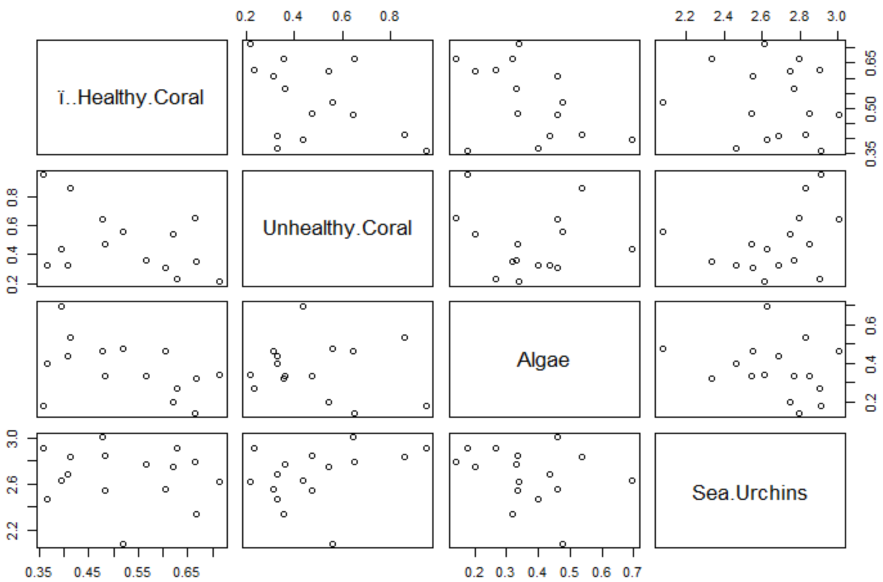

Figure 4. Pairwise correlation done in R showing the influences between the variables as scatter plots.

3.2 Coral Bleaching

This result is related to the first research question. The results of the benthic composition show that coral bleaching is not prevalent. The percentage of bleached coral was 1.01 % of the total amount of corals. In 5 out of the total 16 surveys bleached corals were recorded. The degraded (unhealthy) corals were either dead or covered in too much algae to see if they were bleached. Thus, degraded coral covered in algae might suffer from coral bleaching. In this study it was not possible to determine if the dead corals died because of coral bleaching.

Table 1. Distance recorded of bleached and hard corals in each survey. The percentage of bleached corals in the surveyed area is shown at the bottom of the table.

Survey	**Bleached Coral (cm)**	**Hard Coral (cm)**	**Transect (cm)**
2019-01-11	52	1117	8000
2019-02-05	0	1924	8000
2019-02-06	0	2490	8000
2019-03-28	21	2682	8000
2019-03-28	0	1721	8000
2019-03-29	0	2489	8000
2019-04-01	175	1028	8000
2019-04-02	0	958	8000
2019-04-04	43	2727	8000
2019-04-09	0	2880	8000
2019-04-11	0	1721	8000
2019-04-12	0	2293	8000
2019-04-15	0	1260	8000
2019-04-30	0	1273	8000
2019-05-01	0	1653	8000
2019-05-02	22	2413	8000
Total cm	313	30629	128000
Bleached/Tot Amount Coral	**1.01%**		

3.3 Correlation Between Algae Cover and Coral Health

This result is related to research question number 2. Table 2 shows the results from a linear regression model done in R Studio of how algae cover influences healthy coral.

Table 2. Relationship between algae cover and amount of healthy coral by estimate value, standard error, t-value, r-value and p-value.

	Estimate	**Std. Error**	**t-value**	**r-value**	**p-value**
Healthy coral	-0.53	0.29	-1.81	-0.43	0.092

Figure 5 shows the relationship between algae cover and the amount of healthy corals.

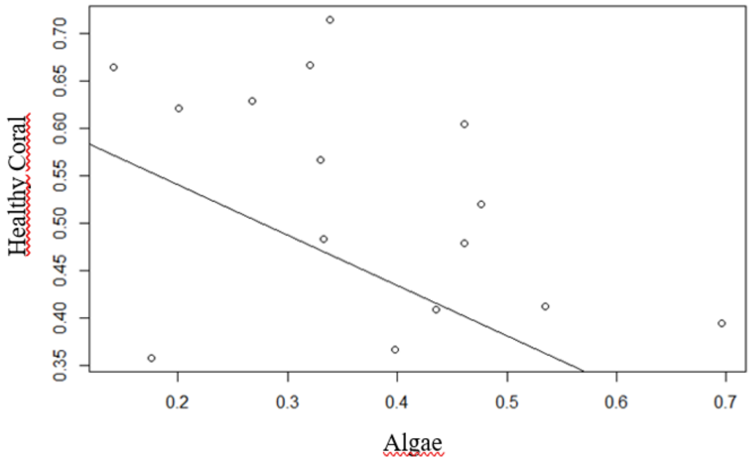

Figure 5. Scatter plot showing the correlation between algae cover and amount of healthy coral. The dot in the bottom left corner is affecting the distribution as it differs a lot from the other samples. This could be an error, and if it was excluded the results would be more significant.

There was no correlation between the amount of unhealthy coral and algae cover ($p>0.05$), see table 3.

Table 3. Relationship between algae cover and amount of unhealthy coral by estimate value, standard error, t-value, r-value and p-value.

	Estimate	**Std. Error**	**t-value**	**r-value**	**p-value**
Unealthy Coral	-0.079	0.18	-0.44	-0.12	0.66

The relationship between algae and unhealthy coral is shown as a scatter plot in figure 6 below.

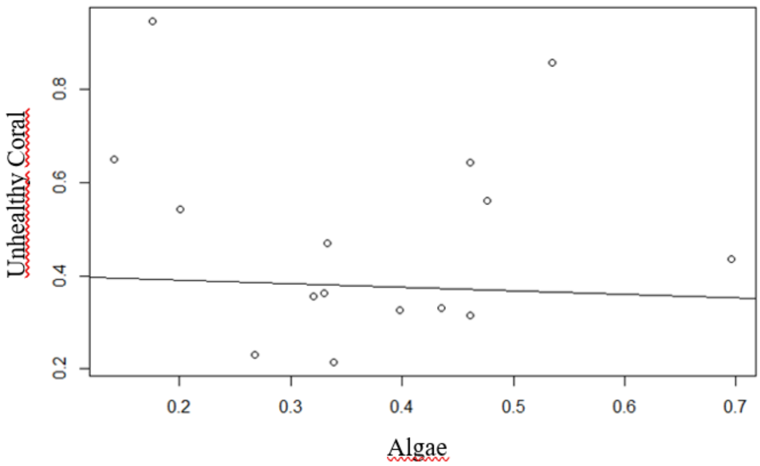

Figure 6. Scatter plot showing the correlation between algae cover and amount of unhealthy coral which is very weak and insignificant.

3.4 Sea Urchins in Relation to Reef Status and Algae Cover

The species of sea urchins found were: *Diadema setosum*, *Diadema savignyi*, *Echinothrix diadema*, *Echinostrephus molaris*, *Echinometra mathaei* and *Parasalenia gratiosa*. *Diadema Setosum* was the most common species and the only species which was found in every survey.

I found no significant correlation between the amount of sea urchins and amount of healthy coral. However between unhealthy coral and sea urchins there is a weak trend, although the result is statistically insignificant ($p>0.05$). The trend shows that the number of sea urchins increase with increasing amount of unhealthy coral, see figure 7 below.

Table 4. The results of the influence sea urchins have on reef status and algae coverage.

	Estimate	**Std. Error**	**t-value**	**r-value**	**p-value**
Healthy Corals	-0.25	0.54	-0.46	-0.12	0.66
Unhealthy Corals	0.36	0.29	1.27	0.32	0.23
Algae Cover	-0.45	0.43	-1.03	-0.27	0.32

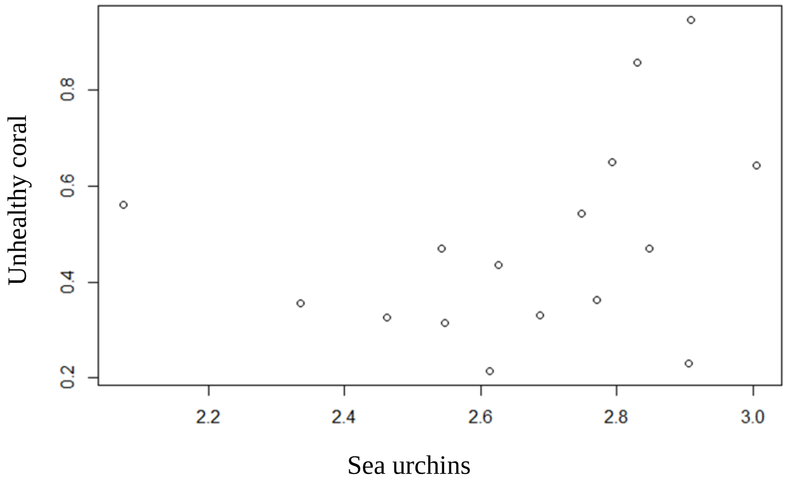

Figure 7. Scatter plot showing the relationship between unhealthy coral and number of sea urchins The dot on the far left has a big impact on the statistical analysis as it differs from the other sample. This could be an error in either sampling or data analysis.

4 Discussion

The overall discovery in this study is that there are no correlations between the parameters studied. The general observation is weak trends which will be discussed further down. It is possible that there are no correlations to be found between the three (coral health, algae cover and sea urchins). It is also possible that there are correlations between these different categories as well as some other not measured in this study, e.g. herbivorous fish, depth and/or temperature. In addition, other anthropogenic driven changes such as over fishing can be affecting the reef and the correlations studied. As only three categories were studied, correlations including other parameters have not been studied. If the method used in this study had been different it could also affect the outcome of results, which will be discussed under each headline. Furthermore, only linear relationships were studied. This means that possible non-linear relationships where not considered. Some correlations might be of a non-linear model, and therefore not found.

4.1 Coral bleaching in the surveyed area

The surveyed area showed that the reef status varied from a healthy state with diverse and live corals to bleached and degraded corals covered in algae. There were not many bleached corals present and in total 1% of the corals were bleached. This result was lower than expected. Parts of the reef in the surveyed area were severely degraded. The degraded corals were often dead or covered in a thick algae cover making it difficult to identify the coral species. This means that the corals can be bleached underneath the algae cover, but not noted in this study. Consequently, coral bleaching could be more prevalent than the results show in this study. During a coral bleaching event, according to Nash et al. (2016) corals can be covered in algae, which put the corals under more stress which reduces their chances to recover. This could be the reason why the corals are degraded in the area studied in this project. It is also possible that coral bleaching was not recorded properly in every survey and was more widespread than represented in the results.

The distribution of degraded corals and healthy corals was not noted. By studying where the degraded corals are found, other parameters such as sedimentation/distance to shore and fishing pressure can be included in the study to bring light to why the corals are degraded in that specific area they were found.

4.2 Reef status in correlation with algae cover

The population dynamic in the coral reef is complex and might change in structure over time (Verburg et al. 2002). Ongoing reef degradation and a shift from coral to algae-dominated reef as reported by Gardner et al. (2003) was visible in one part of the surveyed area. It was observed in the surveyed transects that algae cover was more prevalent where the reef status was in bad condition. In this area, the reef was dominated by widespread algae cover on top of degraded coral. Were degraded coral and widespread algae dominated the biodiversity of fish species was substantially lower (Stokes, L. 2019), but as fish was not studied in this project this is not represented in the results. When the benthic composition was recorded in benthic categories, micro and macro algae were two different categories. The methods used recorded algae as a benthic category without considering what the algae was growing on. The substrate underneath the algae is most likely to be mostly degraded coral. If this had been noted in this study, more degraded coral would have been recorded and more information would have been present on the relationship between reef status and algae cover. The substrate underneath the algae was not considered as it was not always possible to determine what was underneath.

4.3 Number of sea urchins in relation to reef status and algae coverage

Although the results from this study shows no significant correlation between sea urchins and algae cover, there is a slight negative influence on algae cover, which aligns the fact that herbivorous fish and invertebrates facilitate the competition between corals and macro algae by limiting algal growth through grazing which Wilson et al. (2010) describes. The same authors state that the herbivorous taxa may be crucial for the ability of reefs to recover after disturbance in the reef. This study did find a weak correlation between sea urchins and unhealthy coral. The sea urchins had a small, yet some influence on unhealthy coral. This is probably because more unhealthy corals mean more algae, which attract more sea urchins. Thus, it does not mean that sea urchins have a direct negative effect on coral health. It was not considered in this study if different species of sea urchins have different preferences or impact on the reef. This could be done as a separate study by surveying the different species and if they are found together with a specific substrate.

In the surveyed area it was clear that the more degraded parts of the reef where algae is taking over the fish diversity was lower. Only a handful of fish species where recorded on the more degraded transects, although fish was not analysed or accounted for in this study. There are also herbivorous fish which graze algae in addition to sea urchins, and if these fish species had been included in this study it is possible that the correlation between herbivores, reef status and algae coverage would have been more prominent.

As for the recording of the benthic composition, the process collecting sea urchin data also might be affected having different people recording. While counting sea urchins is easier and faster done than recording the benthic, the effort and thoroughness might vary between different people. An inaccurate count of sea urchins would make true correlations more difficult to detect. To count the number of sea urchins twice in the same survey and use the average number would improve the accuracy.

A higher number of samples would be needed to better analyse correlations between the variables in this study. A more accurate sampling technique in terms of effort would also be needed to get a high-quality data. To improve sampling quality a shorter transect could be used. Since the benthic composition takes a very long time to record and is a stressful task, this might improve the accuracy of the observer. Additionally, different people did the observations of benthic composition and number sea urchins per transect. Although the method used to record benthic composition and count sea urchins was the same, the effort each person put into the collection can vary.

Another method to study the coral health, algae cover and number of sea urchins could be to study square instead of a transect. To use squares instead of a 80 meter transect could improve accuracy when doing the inventory for each category and improve data quality. In an 80 meter line the conditions can change significantly, but in the end it will all be recorded as one area. If the coral health status differ in parts along the line, it is not shown in the results how these differences in coral health are distributed. Coral health, algae cover and number of sea urchins are recorded and summed up as a total for each transect. By studying squares and doing a complete inventory within the square, it would be easier to find differences between the surveyed squares.

5 Conclusion

The aim of this study was to better understand the role that the change of reef status has on the community of herbivorous sea urchins and gain more knowledge about the ecological processes in the reef systems. This study did not find correlations between reef status, algae cover and number of sea urchins of significant value. Although the trends found were weak in this study, the results can be supported by various other studies.

Wilson et al. describe the complexity of coral reefs' ecosystems, and how they are sensitive to natural and anthropogenic disturbances. Such disturbances can be warming sea temperature and overfishing. Warming temperatures is a threat to coral health, being the main driving force for coral bleaching (Hughes et al. 2017). Such a disturbance in the system can inflict a change that results in habitat loss for marine organisms, which could have a negative effect on the biodiversity. In addition to coral bleaching, according to Verburg et al., overfishing is also a triggering factor which inflict a change in the system. It is possible that overfishing is the main driving force causing the change in reef status rather than coral bleaching in this area since coral bleaching was not very prevalent. The reduction in herbivorous fish can have resulted in increased algae distribution. Without the herbivorous fish the corals do not have enough support to compete with the increased algae production.

The results in this study show very weak correlations and statistically they are insignificant. Nevertheless, the strongest correlations found are the ones which were expected initially. One correlation in the results show that increasing algae coverage is linked to decreasing amount of healthy corals. This means that reef status is correlated with algae cover. As algae covering corals increase coral mortality (Nash et al. 2016), this relationship was expected. Another correlation seen from the results is how the number of sea urchins increase with increasing amount of unhealthy coral. As algae most likely will be found in higher abundance where the coral reef is degraded, a higher number of grazing sea urchins are naturally expected there. A third correlation which is found in this study is how sea urchins have a negative influence on algae coverage, despite being a weak correlation according to this study, it is supported by Wilson et al. who describe how herbivorous invertebrates limit algal growth.

5.1 Further work

A more thorough study of the degraded corals is needed to see whether they are affected by coral bleaching prior to algae cover would help us to better understand whether the reef suffered from coral bleaching. Additionally, to record what algae grows on would add valuable information for the study of the correlations between reef status and algae coverage. It could be that sedimentation from land settling on the corals contribute to a decline in coral health. This could be included in the study by measuring the distance to shore and compare coral health at different locations.

Coral reefs are vulnerable to anthropogenic disturbances (Wilson et al. 2001). To study if a reduction in herbivorous fish caused by overfishing correlate to degraded reef status and/or increased algae coverage is a new research question that could complement this study on sea urchins' effect on the reef. Some areas are fished more than others and to compare amount of herbivorous fish between these sites would bring some light to this. This could be done by sampling areas with different fishing pressure and compare the results from these sites.

6 References

Cheal, A. J., MacNeil, M. A., Cripps, E., Emslie, M. J., Jonker, M., Schaffelke, B. and Sweatman, H. (2010). Coral-macroalgal phase shifts or reef resiliens link with diversity and functional roles of herbivorous fishes on the Great Barrier Reef. *Coral Reefs,* vol 29(4), p 1005-1015. Doi: https://link.springer.com/article/10.1007%2Fs00338-010-0661-y#citeas [2019-04-25]

Fisher, R., O'Leary, R. A., Low-Choy, S., Mengersen, K., Knowlton, N., Brainard, R. E. and Caley, M. J. (2015). *Species Richness on Coral Reefs and the Pursuit of Convergent Global Estimates.* Perth: Current Biology. Doi: https://www.cell.com/current-biology/fulltext/S0960-9822(14)01623-6?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS0960982214016236%3Fshowall%3Dtrue [2019-04-21]

Gardner, T.A., Cote, I.M., Gill, J.A., Grant, A. & Watkinson, A.R. (2003). *Long-term region-wide declines in Caribbean corals.* Science, 301, 958–960. Doi: http://portal.nceas.ucsb.edu/working_group/valuation-of-coastal-habitats/meta-analysis/papers-for-meta-analysis-database/coral-maybe/gardner-et-al-03.pdf [2019-04-21]

Glynn, P. W. and Manzello, D. P. (2015). *Bioerosion and Coral Reef Growth: A Dynamic Balance.* Doi: 10.1007/978-94-017-7249-5_4 [2019-04-21]

Hoegh-Guldberg, O., Poloczanska, E. S., Skirving, W. and Dove, S. (2017). *Coral Reef Ecosystems under Climate Change and Ocean Acidification.* Frontiers in Marine Science. Doi: https://www.frontiersin.org/articles/10.3389/fmars.2017.00158/full [2019-04-21]

Nash, K. L., Graham, N. A. J., Jennings, S., Wilson, S. K. and Bellwood, D. R. (2016). Herbivores cross-scale redundancy supports response diversity and promotes coral reef resilience. *Journal of applied ecology*, 53, 646-655. Doi: https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2664.12430?fbclid=IwAR2hIXzF786-BaS9pi9nBlcD6fHrOvYOKv__ZaVor5hTowZEim3MHOsAleM [2019-05-18]

Olguín-López, N., Gutiérrez-Chávez, C., Hérnández-Elizárraga, V. H., Ibarra-Alvarado, C and Rojas-Molina, A. (2017). *Coral Reef Bleaching: An Ecological and Biological Overview.* Corals in a changing World. Doi: 10.5772/intechopen.69685 [2019-04-25]

Stokes, L., A. (2019). Madagascar Marine Conservation Research Programme. MGM Phase 1191 Science Report.

Verburg, P., Soepboer W., Veldkamp A., Limpiada R., Espaldon V. and Mastura S. (2002). Modeling the Spatial Dynamics of Regional Land Use: The CLUE-S Model. *Environmental Management*, 30, 391-405. Doi: https://doi.org/10.1007/s00267-002-2630-x

Wilson, S. K., et al. (2010). *Crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes.* Journal of Experimental Biology. Doi: http://jeb.biologists.org/content/213/6/894 [2019-04-25]

Wilson, S. K., Depczynski, M., Fisher, R., Homles, T. H., O'Leary, R. A. and Tinker, P. (2010). *Habitat Associations of Juvenile Fish at Ningaloo Reef, Western Australia: The Importance of Coral and Algae.* Doi: https://doi.org/10.1371/journal.pone.0015185 [2019-04-25]