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Sea Urchin Predation in Misali Island Marine Park

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1. Acknowledgements

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2. Abstract

The populations of sea urchins and their main predators, triggerfish (Balistidae), wrasses (Labridae) and emperors (Lethrinidae), were studied in the extractive and non-extractive zones of the Misali Island Marine Conservation Area in order to (1) evaluate the applicability of a sea urchin-sea urchin predator model developed in Kenya’s fringing reefs, (2) gain baseline data on Misali’s coral reef, and (3) evaluate the recovery status of the protected zone. This study revealed the predictive power of the sea urchin-sea urchin predator model for the reef ecosystem of Misali Island. As expected, a decline in sea urchin predators as a gross trophic group was attributable to fishing pressure and corresponded with an increase in sea urchin density. Furthermore, a comparison between the sea urchin predator species of the non-extractive and extractive zones showed that the proportion of triggerfish, which studies have suggested to be the dominant sea urchin predator, has increased in the absence of fishing as expected (McClanahan, 2000).

3. Introduction

Top trophic level predators are crucial structuring forces of ecosystems. Removal of a top level predator due to fishing may lead to an ecological release of their prey and a possible shift in the structure and diversity of the ecosystem. McClanahan showed this trophic cascade phenomenon in his studies of the relationship between sea urchins, their predators and the fishing of these predators in Kenyan reefs (2000). In heavily fished areas, the populations of triggerfish dropped, resulting in the proliferation of sea urchins, reef substratum bioerosion, a reduction in reef topographical complexity, and an associated decline in species richness and diversity.

In areas of low disturbance, the red-lined triggerfish (*Balistapus undulatus*) has been found to be the dominant sea urchin predator, both in terms of number and in interspecific competition interactions (Bean et al, 2002 and McClanahan, 2000). In a study on predation intensity on sea urchins, McClanahan found that triggerfish preyed on over 80% of experimental sea urchins, possibly due to specialized eating and foraging habits. Due to these specialized feeding habits and its territorial behavior, the triggerfish is most likely to dominate baited sites and is therefore highly susceptible to exploitation (McClanahan and Polunin, 2002). Subordinate predators of sea urchins include wrasses (Labridae) and emperors (Lethrinidae) who, as generalists, are able to tolerate greater levels of fishing pressure and have been found to be common in well developed fisheries. The decline of triggerfish in response to fishing pressure may result in replacement by some wrasses and emperors; however, studies have shown that these predators are unable to fully take the niche of the triggerfish and are less effective at controlling sea urchin populations (McClanahan, 2000). Triggerfish are therefore considered to be a “keystone species” due to their unique ability to regulate sea urchin populations and impact reef ecology.

When an area is relieved of fishing pressure, the initial response of a reef ecosystem is the recovery of gross trophic groups (sea urchin predators), ecological functions (predation), and a corresponding drop in certain prey populations (sea urchins). This initial recovery may give a false impression of reef health and justify a conservation policy that allows unsustainable human disturbance. In McClanahan’s study on recovery rates of sea urchin predators, he found that as time progresses, the composition of the sea urchin predator guild changes; generalists, such as the wrasse (*Coris* genus), which has been found to dominate in heavily fished areas, declines and the population of triggerfish increases (2000). The composition of the sea urchin predator guild and the associated sea urchin abundance may be indicative of the recovery stage of a protected area and the effectiveness of conservation efforts. Careful monitoring of the recovery rates of keystone predators, such as the triggerfish, and their ecological succession may provide information that is crucial to planning fishery reserves and deciding upon management options, such as having a permanently closed area versus having fishing off-seasons. Focusing on such key information is important to the management planning and performance assessments of marine conservation areas because most are located in developing countries where limited resources inhibit large-scale studies on reef ecosystems (Kamukuru et al, 2000). However, due to wide variations in fishing intensity and natural ecological and structural states of reefs, indicator species that may be useful for an evaluation of the health and recovery of one reef may not be useful to the assessment of another.

Due to its high biodiversity and socio-economic value, Misali Island is an important area to conservation. The 9.4 km fringing reef that encircles the island supports 42 hard coral genera and over 400 fish species, including the endangered Humphead Wrasse (MIMCA, 2006). In addition, the reefs may act as a ‘source’ or a ‘sink’ for larvae and thereby play an important role in the distribution pattern of marine species due to its strong currents and proximity to the Pemba Channel. As a breeding ground for commercial fish species, Misali waters offer fishing opportunities that support the livelihoods of over 7000 people in over 20 Pemba communities (MIMCA 2006). Few studies have investigated the impact of fishing on the coral reef ecosystem of Misali; however, the high abundance of sea urchins in some areas suggest that finfish fisheries, upon which the food security of Pemba depends, may be changing the structure and diversity of Misali reefs by removing key top level predators, such as triggerfish (Balistidae).

Due to the lack of quantitative data on Misali’s reefs, visual surveys of sea urchin and sea urchin predator abundances were conducted in each zone in order to get a reasonable picture of the ecological changes associated with fishing and to evaluate the recovery stage of the core zone of Misali. It was expected that the gross trophic group of sea urchin predators would be higher in the non-extractive zone than in the extractive zone and that sea urchin abundance would have a negative correlation with predator abundance. Furthermore, it was expected that the composition of the sea urchin predator guild would be different between the two zones and may be indicative of the recovery stage of the protected zone. According to McClanahan, complete recovery takes up to 30 years, and therefore it was expected that triggerfish in Misali may have not yet reclaimed their niche as the dominant sea urchin predator (2000).

2. Study Area

Field observations and measurements were taken in Misali Island Marine Conservation Area (MIMCA), which is centered at $5^{o}15'$ S and 39^{o} 6' E, approximately 10 km off the west coast of Pemba. Pemba is located 50 km north of Unguja and is separated from mainland Tanzania by the Pemba Channel, which reaches over 800 m in depth (Fig. 1 and 2). Although there is no permanent human habitation on the island, Misali waters are accessible to Pemban fishermen throughout the year.

MIMCA is divided into 2 management zones: non-extractive use (Core) and extractive use. The total conservation area covers 21.58 km^2, including a 9.4 km ring of coral that surrounds the island. The Core zone is 1.4 km^2, or 8.5% of the total area. This study was performed in both zones in order to assess fishing pressure on the reef ecology of Misali.

Figure 1. Map of Tanzanian coastline, including Pemba, Zanzibar (Unguja) and Mafia Islands.

Figure 2. Map of Pemba Island, including Misali Island (west of Chake Chake) and the Pemba Channel.

2.1 Extractive Zone: Section A

In the extractive zone, data was collected in an area designated as Section A by J.C. Horill in his study of the status of Misali's coral reefs (MIMCA, 2006). Section A is located on the northeast side of the island and is exposed to frequent boat traffic due to its proximity to the visitor's center, ranger's hut, and fishermen's camp. Studies performed by Frontier-Tanzania in 2004 recorded the coral cover of section A to be 1-30%. The reef is approximately 2.6 km long, with the highest coral cover along a narrow reef crest and on rocky outcrops, forming a steep slope to a depth of 20 m. Section A also includes a shallow reef flat that is situated between the northern side of the Core zone and the western end of Mbuyuni beach. The reef flat is covered with isolated coral patches, or “bommies,” and large populations of sea urchins. Transects were performed along both the reef crest and reef flat.

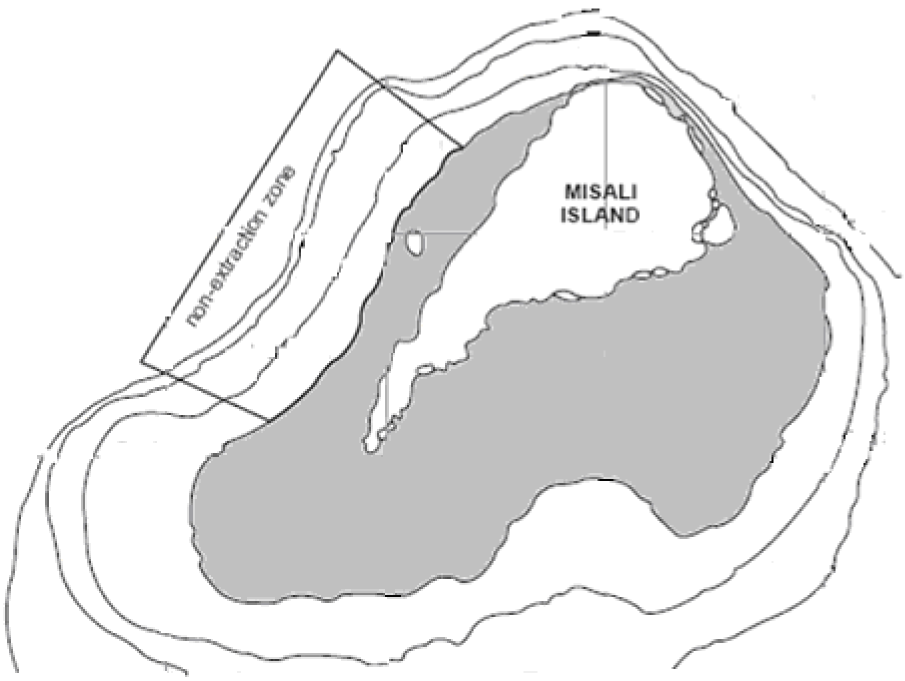

Figure 3. Map of Misali Island with non-extractive zone outlined (Daniels *et al*, 2003).

2.2 The Core zone: Section B

The second study site was located in Section B of Misali’s reefs, which lies on the western side of the island in the Core zone. This area permits non-extractive activities, such as diving, boating, and scientific research. The reef is approximately 1.5 km long, reaching depths up to 70 m and supporting dense coral growth to 35 m. In 2004, Frontier-Tanzania recorded coral cover ranging from 11-30%, indicating a recovery from the bleaching event of 1998 that had reduced coral cover to 7%. Section B also includes a large reef flat that consists mainly of sand and massive corals. Transects were surveyed in both the reef flat and reef crest.

2.3 History of MIMCA

Misali Island was established as a conservation area in 1998 as a result of lobbying pressure from conservation groups that recognized the unique biodiversity of the island and from fishing communities that wanted to protect their access to the fish stocks of Misali waters. In 1993, the government granted a private company exclusive access to the island for hotel development; however, the government reversed its decision due to strong opposition from the local fishing community. By setting up a multi-use area, MIMCA aims to address the interests of these various stakeholder groups. Estimates range from 7-15% for the proportion of Pemban fishers that are active in Misali waters (MIMCA, 2006). The second main activity in Misali is nature-based tourism. Revenue generated from tourist fees benefits local communities by funding projects, such as the construction of schools, roads, and health facilities.

In 2005, MIMCA became a core zone of the Pemba Channel Conservation Area (PECCA). As a model for conservation and revenue-sharing, MIMCA is expected to play a critical role in the development of similar protected areas within PECCA. Therefore, Misali is a particularly important site for ecological and socio-economic research as it may dictate policy for other coastal and marine areas of Pemba in the coming years

3. Methodology

3.1 Ecological data

Population measurements of triggerfish, predatory wrasses, and emperors were performed along 50 x 5m belt transects. A total of 13 transects were completed in the non-extractive zone and 21 in the extractive zone. Population measurements of sea urchins were performed using $1m^2$ quadrats that were placed at 5 m intervals along each transect. A total of 130 quadrats were completed in the non-extractive zone and 210 in the extractive.

For the belt transects, a 50 m tape measure was laid down such that there was a constant depth along the transect. Five minutes were allowed for fish to resume their natural behavioral patterns. Transects were surveyed at a constant speed by monitoring the time it took to swim from one quadrat to the next. All sea urchin predators located within 2.5 m of the center of the transect were identified to family and counted. Triggerfish were identified to the species. Another 5 minutes were allowed for fish to resume natural behavioral patterns before the fish survey was repeated.

A $1m^2$ quadrat was used at every 5 m along the transect to count sea urchins. All sea urchins that had their entire body within a quadrat were counted. Benthic cover was qualitatively assessed within each quadrat by estimating the percentage of sand, algae, and coral cover.

In order to estimate structural complexity of the reef, the tape measure was laid along the contours of the reef for 10 m and each end was marked. The tape measure was then pulled tightly from end to end in order to measure the linear distance of the same section. The substrate rugosity index was the ratio of contour distance relative to linear distance.

3.1 Socio-economic data

Local fishermen camping on Misali were surveyed in order to evaluate fishing pressure on sea urchin predators. Semi-structured interviews were conducted in order to gain information on the numbers of each predator that they caught per month, gear used, and fishing location. They were also questioned on changes in any of these aspects over the past 10 years, since the establishment of Misali Island as a conservation area.

4. Results

In a total of 34 transects (50 x 5m), sea urchin predators that were observed included the red-lined triggerfish (*Balistapus undulatus*), the picasso triggerfish (*Rhinecanthus aculeatus*), the halfmoon triggerfish (*Sufflamen chrysopterus*), predatory wrasse (Labridae), and emperors (Lethrinidae). In a total of 340 quadrats ($1m^2$), sea urchin species observed included *D.savignyi*, *D. setosum*, *E. diadema*, *E. mathaei*, and *T. pileolus*.

4.1 Relationship between sea urchins and their predators

Scatter plots of sea urchin density and predator density indicate a weak negative correlation between sea urchins and their predators, with an R^2 value of 0.21, and between sea urchins and % triggerfish, with an R^2 value of 0.21 (Figures 4 and 5). Box and whisker plots show that sea urchin density in the non-extractive zone is significantly lower ($p<0.05$) than in the extractive zone (Figure 6). The average sea urchin density in the non-extractive zone is 13.5 +/- 8.17 ($\#/10m^2$) and in the extractive zone is 32.6 +/- 18.9 density ($\#/250m^2$). In contrast, similar plots indicate that urchin predator density is significantly higher ($p<0.05$) in the non-extractive zone than in the extractive zone (Figure 7). The average predator density in the non-extractive zone is 8.08 +/-3.23 (individuals/250 m^2) and in the extractive zone is 5.62 +/- 2.73 (individuals/250 m^2)

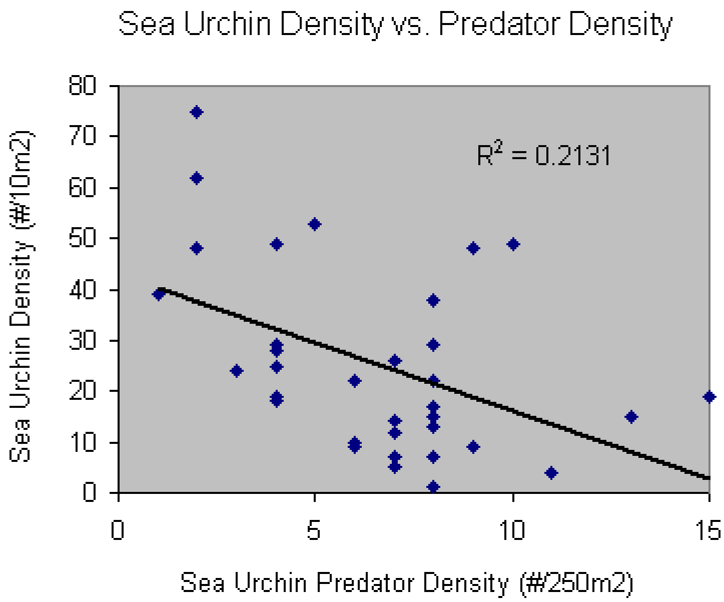

Figure 4. Relationship between sea urchin density and predator density, representing data collected from both the non-extractive and extractive zones.

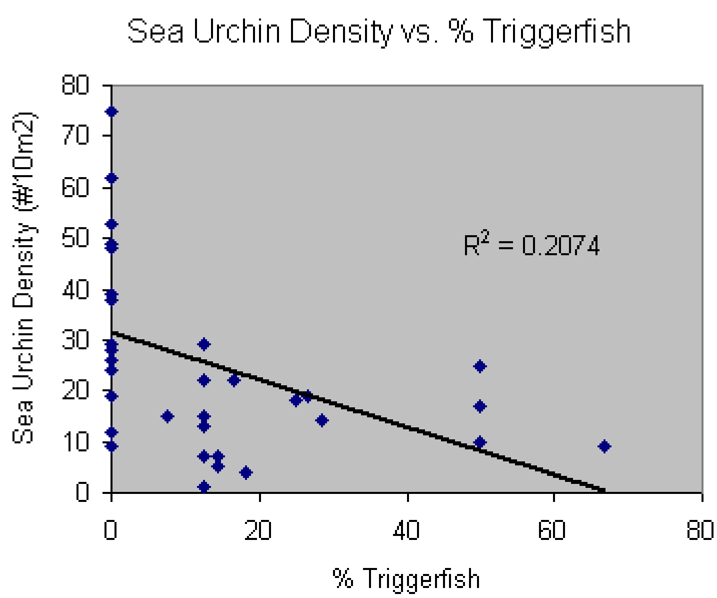

Figure 5. Relationship between sea urchin density and % triggerfish of the predator guild, representing data collected from both the non-extractive and extractive zones.

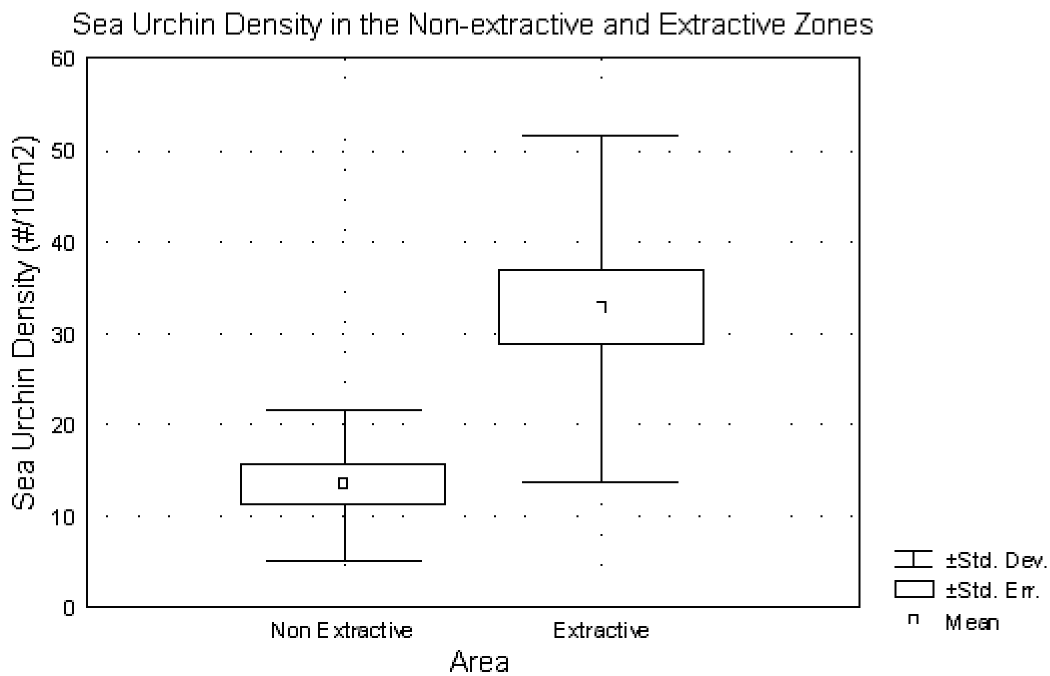

Figure 6. A comparison between sea urchin densities in the non-extractive and extractive zones. The average sea urchin density in the non-extractive zone is 13.5 +/- 8.17 (individuals/10 m^2) and in the extractive zone is 32.6 +/- 18.9 (individuals/10 m^2).

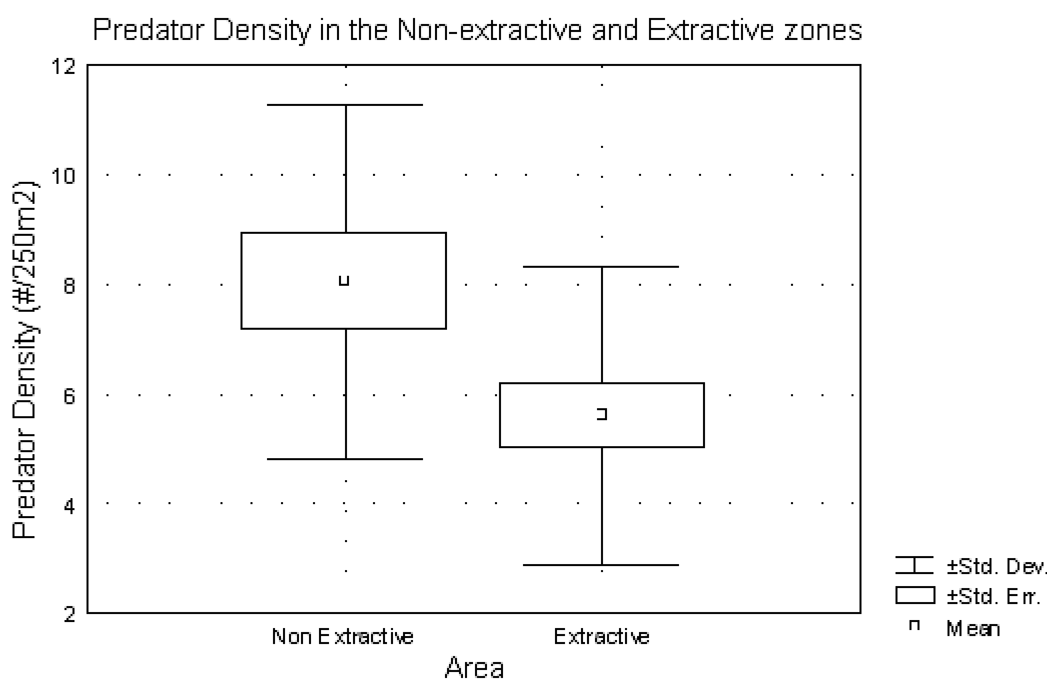

Figure 7. A comparison between predator densities in the non-extractive and extractive zones. Average predator density in the non-extractive zone is 8.08 +/- 3.23 (individuals/250 m^2) and in the extractive zone is 5.62 +/- 2.73 (individuals/250 m^2).

4.2 Composition of the Sea Urchin Predator Guild

The composition of the sea urchin predator guild was found to be different between the non-extractive and extractive zones (Figures 8 and 9). The average triggerfish density in the non-extractive zone was 2.08 +/- 1.26 (#/250 m^2), which is significantly higher ($p < 0.05$) than the triggerfish density in the extractive zone, 0.24 +/- 0.44 (#/250 m^2) (Appendix A). Of the total number of predators observed, the percentage of triggerfish in the non-extractive zone was 27% and in the extractive zone was 4% (Figures 8 and 9). However, while there were significantly more ($p < 0.05$) picasso and halfmoon triggerfish observed in the non-extractive zone than in the extractive zone, there was no significant difference ($p>0.05$) observed between the density of red-lined triggerfish between the two zones (Appendix A).

There was a higher percentage of emperors and a lower percentage of wrasses in the non-extractive zone than in the extractive zone (Figures 8 and 9). Emperor density in the non-extractive zone was 3.46 +/- 2.6 (#/250 m^2), which is significantly higher than emperor density in the extractive zone, 1.90 +/- 1.8 (#/250 m^2) (Appendix A). Wrasse density was 2.38 +/- 2.1 (#/250 m^2) in the non-extractive zone and 3.47 +/- 1.9 (#/250 m^2) (Appendix A). Although wrasse density was higher in the extractive zone, the difference was not significant ($p>0.05$).

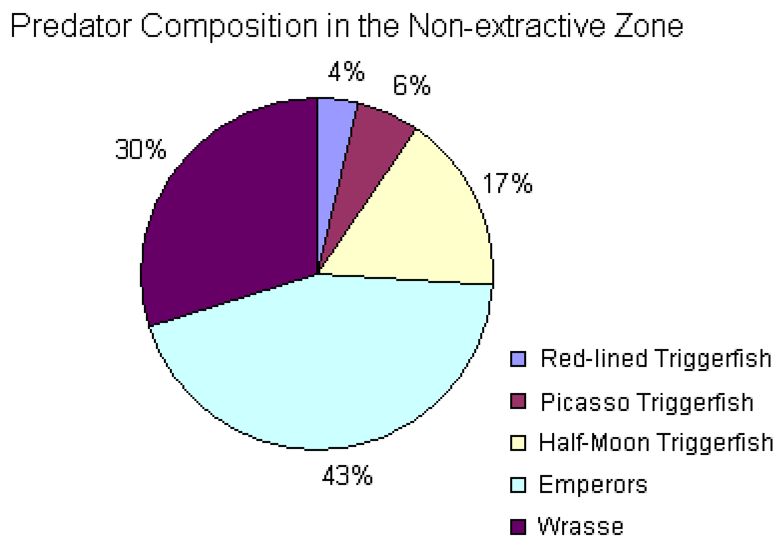

Figure 8. Composition of urchin predators in the extractive zone.

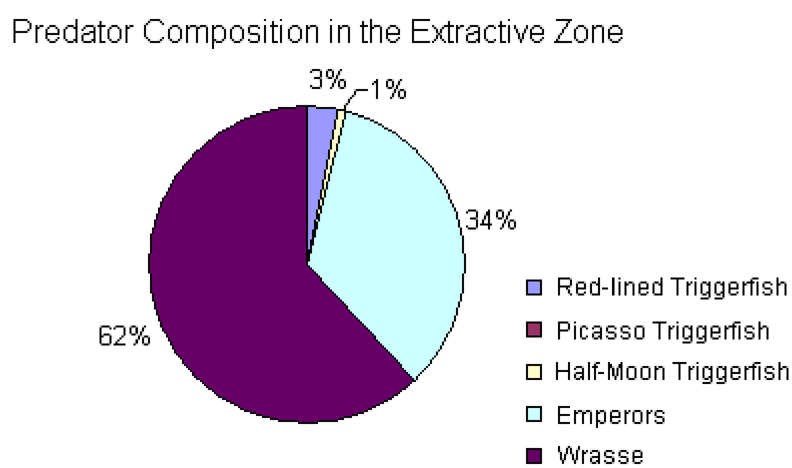

Figure 9. Composition of urchin predators in the non-extractive zone.

4.3 Composition of the Sea Urchin Guild

There was no significant difference ($p > 0.05$) between the composition of the sea urchin guilds in the non-extractive and extractive zones. The dominant sea urchin in both zones was *D. savignyi*, with an average density of 5.78 +/- 5.6 (#/10m^2) in the non-extractive zone and 15.5 +/- 19.0 (#/10m^2) in the extractive zone. Other sea urchins observed included *E. diadema,* with average density of 0.22 +/-4.2 (#/10m^2) in the non-extractive zone and 3.12 +/- 4.9 in the extractive zone, and *E. mathaei*, with density of 1.11 +/- 1.5 (#/10m^2) in the non-extractive zone and 4.35 +/- 5.6 (#/10m^2) in the extractive zone. *T. pileolus* was also observed, but its numbers were negligible in comparison with the other sea urchin species.

4.4 Benthic Cover

In the non-extractive zone, benthic cover types included sand (55%), dead coral cover (18%), live coral cover (25%), and algal cover (2%). In the extractive zone, benthic cover types were sand (45%), dead coral cover (30%), live coral cover (23%), and algal cover (6%). There was no significant difference between benthic cover of the non-extractive and extractive zones. A scatter plot of sea urchin density versus algal cover for both zones shows almost no correlation ($R^2 = 0.0028$) (Appendix B).

4.5 Substrate Rugosity

The substrate rugosity index was 1.3 +/- 7.5 in the non-extractive zone and 1.2 +/- 8.3 in the extractive zone. This difference is not significant ($p > 0.05$). (0.38) A scatter plot of sea urchin density versus substrate rugosity for both zones shows almost no correlation ($R^2 = 0.0054$) (Appendix B).

4.6 Interviews

Ten fishermen camping on Misali were interviewed in groups of five (Appendix C). All fishermen caught triggerfish for subsistence using mainly basket traps and identified a decline in triggerfish catch over the past 10 years (Figure 10). The first group said that each individual caught 40 triggerfish/month ten years ago, 16 triggerfish/month five years ago, 8 triggerfish/month one year ago, and currently catches 1-2 triggerfish/month. The second group estimated that each individual caught 60 triggerfish/month 10 years ago, 20 triggerfish/month five years ago, 8 triggerfish/month one year ago, and currently catches 4 triggerfish/month.

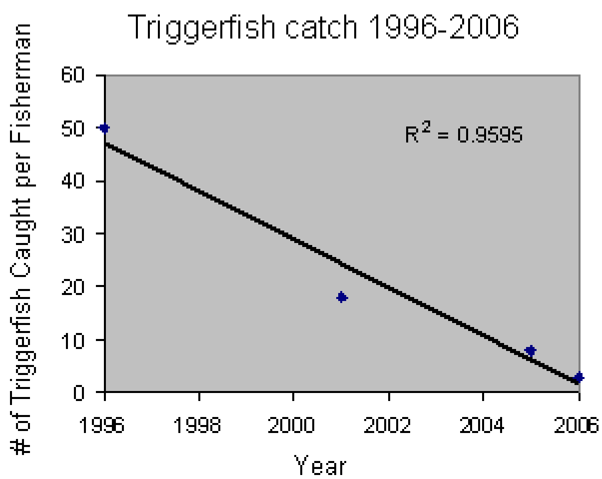

Figure 10. Number of triggerfish caught per Misali fisherman per month over the past 10 years.

Five fishermen thought the decline in triggerfish catch was caused by a reduction in triggerfish populations in the area. The other five fishermen suggested it was due to an increase in numbers of fishermen in Misali waters; the triggerfish populations have not changed, but the catch is smaller per individual because it is spread out over a larger number of fishermen.

5. Discussion

This study investigated the populations of sea urchins and their predators in the non-extractive and extractive zones of Misali Island. A comparison between the two zones reveals how gross trophic groups of sea urchins and their predators respond to fishing pressure and evaluates the ecological recovery state of the protected zone based on a sea urchin-predator model that has been tested frequently in Kenyan reefs (McClanahan 2000). There was no significant difference between the substrate rugosity and algal cover of the two zones; therefore, differences in urchin populations can be largely attributable to differences in predator populations rather than food availability or refuge space. Furthermore, differences in predator populations can be largely attributable to the presence or absence of fishing pressure rather than refuge space that is offered by topographical complexity.

Similar to previous studies performed on Kenyan fringing reefs, this study shows that sea urchin density is negatively correlated with both overall predator density and percentage of triggerfish (McClanahan and Kurtis, 1991). Interviews conducted with fishermen revealed that a decline in triggerfish abundance has been observed over the past 10 years. The field data collected in the non-extractive and extractive zones supports this observation, indicating that there is a lower triggerfish density in the presence of fishing and corresponding increase in sea urchin populations. Similarly, results suggest that there is a negative correlation between emperor and sea urchin density, which coincides with past evidence from sea urchin reduction studies (McClanahan *et al*, 1999). It is possible that the lower density of emperors in the extractive zone could be a direct consequence of fishing or it could be caused by competition with sea urchins for food.

On the other hand, the density of wrasses was higher in the extractive zone than in the non-extractive zone, indicating that fishing actually benefits wrasse species. In fished areas, wrasses may experience an ecological release due to the reduction of larger, more fishing-susceptible predators and competitors. It is also possible that small-bodied, fusiform wrasses, such as the goldbar wrasse (*Thalassoma hebraicum*), may be less vulnerable to getting caught in nets. Although fishing seems to have benefited certain sea urchin predators, the sea urchin population is still higher in the extractive zone. This suggests that other fish, such as wrasses, are unable to occupy the sea urchin predator niche as effectively as triggerfish.

According to the sea urchin-predator model developed in Kenyan reefs, the predator assemblage in the non-extractive zone should be indicative of its recovery stage (McClanahan 2000). McClanahan's study showed that the reef's response to the removal of fishing pressure begins with changes in gross trophic groups, such as a rapid increase in overall predator abundance, followed by a decline in sea urchin populations (2000). However, the recovery of the natural composition of the sea urchin predator guild has been shown to take more time. Although it depends on the particular reef's initial conditions and natural steady state, McClanahan's study of five marine protected areas (MPAs) shows that the wrasses steadily declined and the red-lined triggerfish increased in the first five years of protection. However, the recovery of the red-lined triggerfish as the dominant predator in terms of its percentage of the total predator guild may require greater than 30 years.

After eight years of being closed to fishing, results show a gross recovery of sea urchin predators, including triggerfish, in the non-extractive zone. Wrasses are still the dominant predator, in terms of numbers, indicating that there is still potential for greater triggerfish populations. However, results from this study estimates that the average triggerfish density in the non-extractive zone is 2.08 +/- 1.26 individuals per 250 m^2, which is relatively high, considering observations from previous studies that male-female pairs of triggerfish defend a 100-200 m^2 territory (McClanahan 2000). McClanahan suggested that the carrying capacity of triggerfish is expected to be greater than 5 individuals per 500 m^2 in appropriate environmental conditions. It is possible that the natural predator assemblage of Misali's reef differs from the reefs in which the sea urchin-predator model was developed and that wrasses are the dominant predator; however, it is unlikely due to numerous studies showing the dominance of triggerfish, both in numbers and interspecific competition interactions.

Instead, the composition of the predator guild may have been skewed by limitations of the visual censuses utilized by this study; different fish behaviors in response to the diver may have caused an under- or overestimation of fish abundances. Upon sight of the diver, the red-lined triggerfish would frequently hide in dens or crevices, possibly resulting in the underestimation of this species' abundance and masking a stronger correlation between sea urchin density and percentage of triggerfish. On the other hand, the goldbar wrasses were observed to be much bolder; they did not seem to be disturbed by the diver, but would swim quite close. Consequently, this may have led to an overestimation of the proportion of wrasses that makes up the predator guild.

According to the sea urchin-predator model, if this study is repeated over the next several years, a continued increase in triggerfish populations and decline in sea urchin populations is expected to be seen. It is unlikely that a great increase in the gross trophic group of predators will be seen, since this is usually a rapid response to the removal of fishing pressure. However, sea urchin populations may continue to decline if triggerfish populations increase. Due to differences in the dominant urchin species, the time it takes for sea urchin populations to decline to levels that are naturally supported by Misali's reefs in the absence of fishing may take longer than it has been shown to take in Kenyan reefs. This study found that Misali's reef was dominated by the larger-bodied sea urchin species *Diadema savignyi* and *D. setosum,* which have been shown to be more predator-resistant, while Kenya's fringing reefs were largely dominated by small-bodied *Echinometra mathaei,* which are more susceptible to predation. Therefore, careful management and monitoring of Misali's reefs is important in order to prevent sea urchin populations from reaching high levels.

6. Conclusion

This study was based on a general conceptual model of sea urchin-sea urchin predator interaction that has been developed for East African reefs. The model has been employed in studies of several protected and unprotected fringing reefs of Kenya, but has been used much less frequently in Tanzania. In general, the findings from this study agree with the predictions made based on the model, indicating its potential for future monitoring of Misali's reef health. Furthermore, this study offers a baseline evaluation that may be useful to future studies for comparing the populations of sea urchins and their predators.

Due to the potential detrimental effects of high sea urchin abundance, such as erosion of coral reef substratum, a reduction in fish abundance and diversity, and decline in fisheries production, the information that can be gained by this type of survey is of significant importance. It also allows a quick assessment of the effectiveness of the core zone by providing a reasonable picture of its recovery state and helps identify whether there is a need for stricter management of the extractive zone by evaluating populations of keystone species. The sea urchin-sea urchin predator model may prove to be an invaluable tool that enhances the flexibility and appropriateness of management plans of MIMCA.

7. Recommendations

While this study offers useful information on sea urchin and their predators in Misali, the true value of the sea urchin-sea urchin predator model will only be realized if similar studies are conducted periodically to assess the ecological state of the reef as fishing pressure and management of MIMCA changes. Such studies have the potential to reveal long term changes that this study could not, such as erosion of reef substratum or decline in topographical complexity caused by high sea urchin abundances.

In the future, this study could be strengthened in several ways. In addition to the variables surveyed in this study, it would be useful to include fish size. This may provide insight into why certain predators are less affected or benefit from fishing. Secondly, night surveys may provide a more accurate census of sea urchin populations, since many species are nocturnal. Indirect effects of fishing on reef ecology could be studied by investigating whether competitive exclusion of herbivorous fish species by sea urchins is occurring. In addition to visual surveys along transects, predation measurements may be strengthened by tethering sea urchins. Direct observation of tethered urchins may allow predator identification and evaluation of competitive interactions between predators. Finally, SCUBA diving would allow data to be collected at greater depths.

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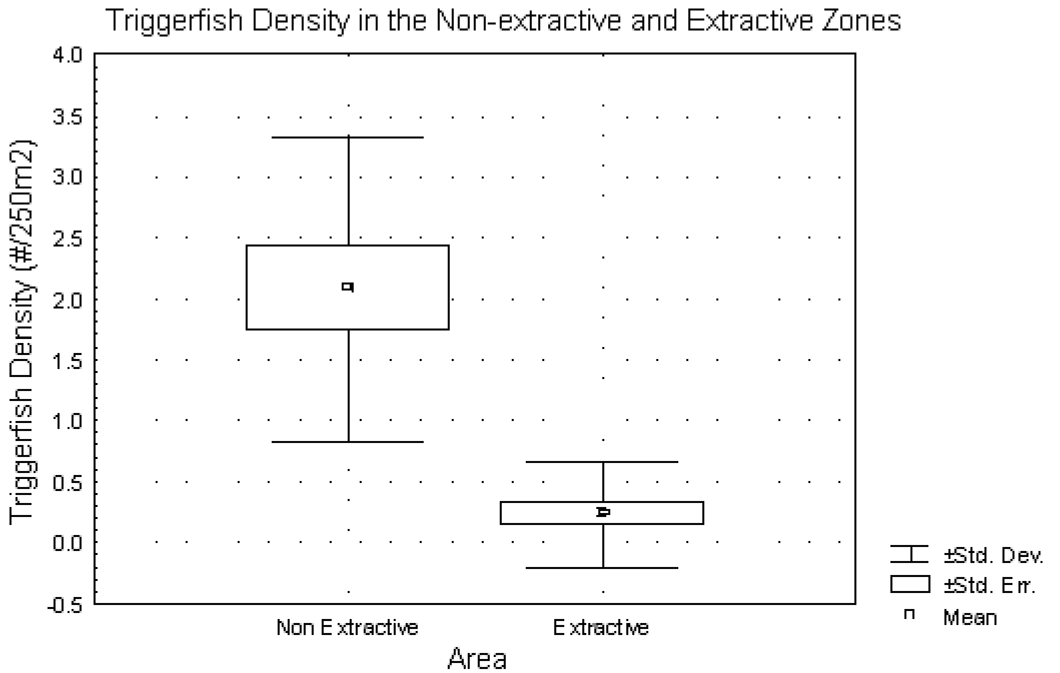
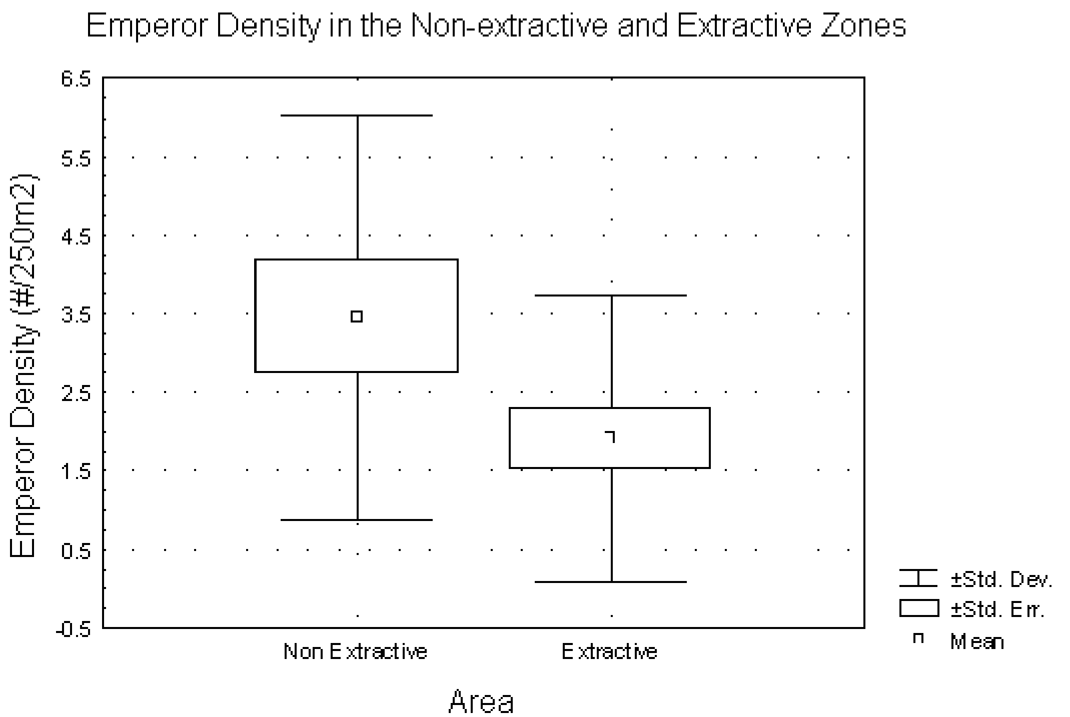
Appendix A



Triggerfish Density in the Non-extractive and Extractive Zones
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Triggerfish Density (#/250m2)
Non Extractive
Extractive
Area
±Std. Dev.
±Std. Err.
Mean



Emperor Density in the Non-extractive and Extractive Zones
6.5
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
Emperor Density (#/250m2)
Non Extractive
Extractive
Area
±Std. Dev.
±Std. Err.
Mean

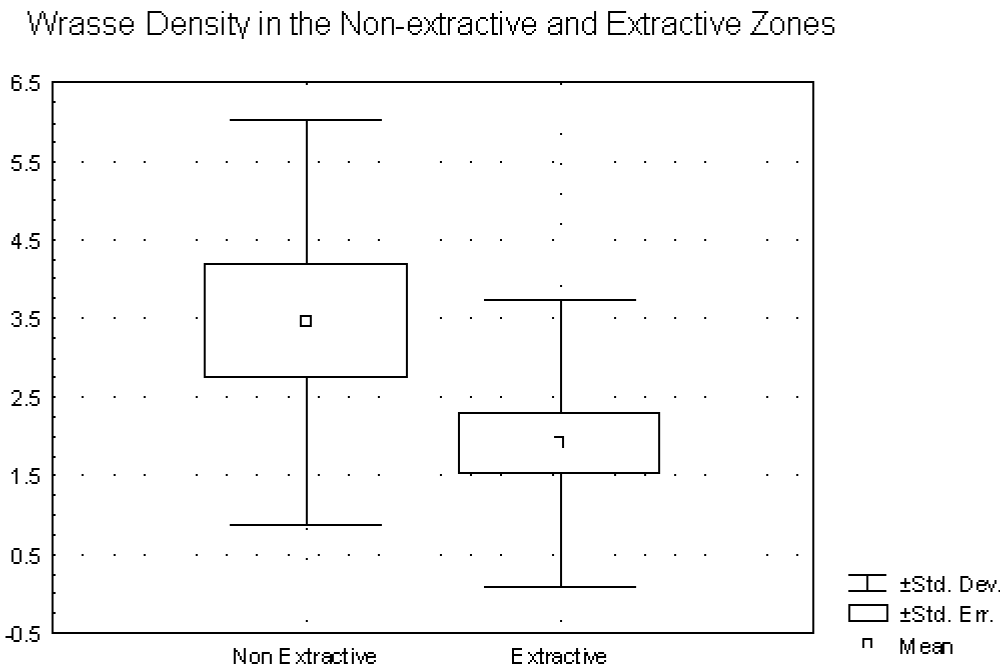


Figure. A comparison between triggerfish (a), wrasse (b), and emperor (c) densities in the non-extractive and extractive zones. Average triggerfish density is 2.08 +/- 1.26 (#/250 m^2) in the non-extractive zone and 0.24 +/- 0.44 (#/250 m^2) in the extractive zone. Average wrasse density is 2.38 +/- 2.1 (#/250 m^2) in the non-extractive zone and 3.48 +/- 1.9 (#/250 m^2) in the extractive zone. Average emperor density is 3.46 +/- 2.6 (#/250 m^2) in the non-extractive zone and 1.90 +/- 1.8 (#/250 m^2).

Appendix B

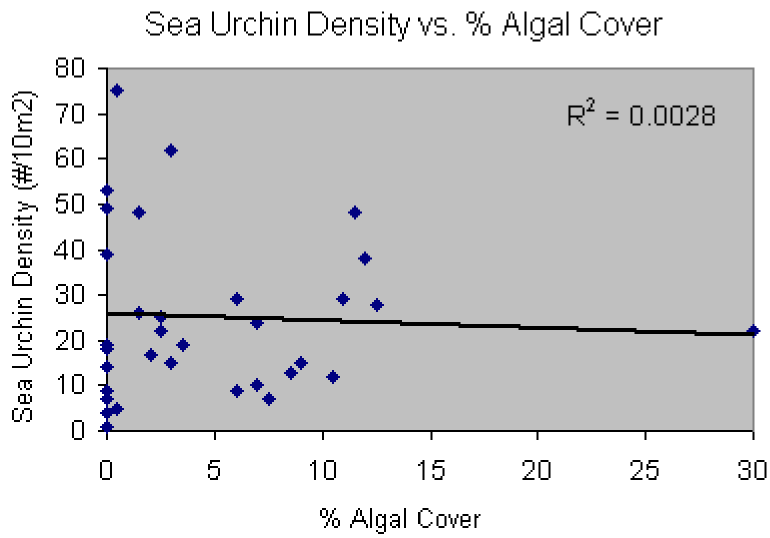


Figure. Relationship between sea urchin density and % algal cover. Shows weak correlation, with R^2 of 0.0028.

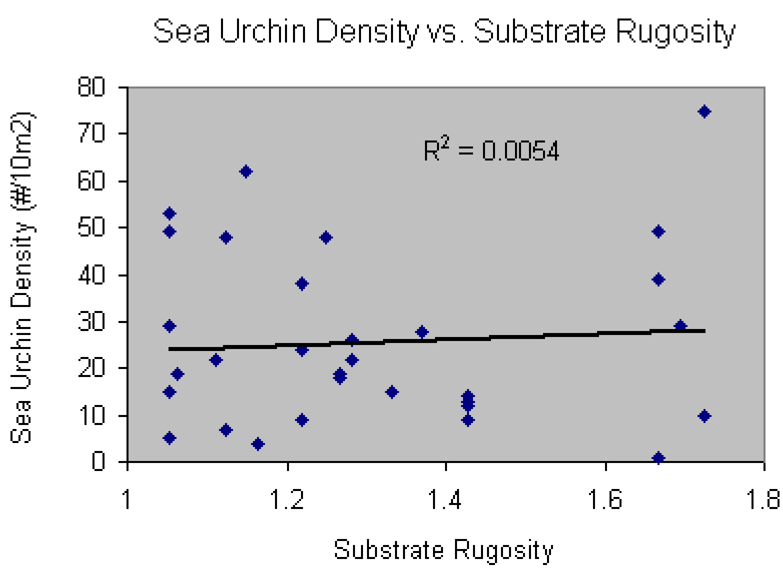


Figure. Relationship between sea urchin density and substrate rugosity. Shows weak correlation, with R^2 value of 0.0054

Appendix C

Questions:

1. Name
2. Age
3. # years they have been fishing in Misali waters
4. Origin
5. # days that they fish in Misali waters per month
6. Location of fishing in Misali
7. Fishing Gear
8. Fish catch
    a. Do you catch (triggerfish/emperors/wrasses)?
    b. How many do you catch per month?
    c. How many did you catch 10 years ago? 5 years ago? 1 year ago?
    d. Why do you think the #'s have changed?

Answers:

Name	Age	# of Years Fishing in Misali
1- Jamal Omari	32	6
1- Ali Mohammed	37	6
1- Said Saliman	17	4
1- Ramadhan Abulli	37	8
1- Ramadhan Mohammed	49	25
2- Khamis Sariboko	36	20
2- Mafkaha Abas	28	8
2- Slaman Haji	15	2
3- Haji Khamis	50	30
4- Haji Jumah	60	40

*Numbers by the name indicate which group they were in.

Origin: Makongwe
# of days fishing in Misali per month: 12-15
Location of fishing in Misali: all of the extractive zone, up to the perimeter of the core zone
Fishing Gear: Spear, hand-line, net

Group	Triggerfish/month: 10 years ago	Triggerfish/month: 5 years ago	Triggerfish/month: 1 year ago	Triggerfish/month: Now
1	40	16	8	1-2
2	60	20	8	4

Reasons for decline

1. Increase in # of fishermen
2. Decrease in # of triggerfish