Spring 2011

A Habitat and Abundance Study of Octopus cyanea in Southwest Madagascar

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SIT Study Abroad

Belazis, Michael. April 2011. The University of Colorado

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Acknowledgments

Many thanks go out to Blue Ventures NGO for their generosity in sharing data and resources for this study. Special thanks go out to the village of Beheloke for its unconditional welcome, Sylvain, Francis, and Rivo for their illuminating guidance and undivided assistance, and most of all, to Holy Andriamitantsoa, without whose brilliant ideas, enthusiasm, and boundless patience this project would not have been possible. And of course, a tremendous thank you goes out to the staff of SIT for providing me with the tools and preparation for this once-in-a-lifetime adventure.

Abstract

The increased demand for marine products has fueled a worldwide overexpansion of the fishing industry. Furthermore, the shift of lower-income countries, like Madagascar, from subsistence to market-based cash economies has led to increased fishing pressures on marine resources. Recent commercialization of fisheries in Southwest Madagascar has caused an over-exploitation of octopus in the Toliara region. In an effort to create sustainable octopus fisheries, Blue Ventures, a UK-based NGO, created the world's first community run Marine Protected Area (MPA) for octopus near Andavadoaka called Velondriake.

Here, the results of an *Octopus cyanea* habitat study performed near Beheloke, a fishing village on unprotected waters, are compared with the results of a similar study done by Blue Ventures in the Velondriake conservation zone. By comparing the results of the two studies and their relationships between abundance and the benthic health of *O. cyanea*'s habitat, the effectiveness of an MPA's ability to enrich the density of octopus populations around the island can be further understood.

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Introduction

Octopus Fisheries in Southwest Madagascar

The fishing industry in Madagascar has come to play a vital role in the national economy. Seafood is now the number one exported resource out of the country and a substantial earner of foreign currency (Hansen 2011). In the past, traditional Malagasy fishermen would dry and trade their product in local markets. However, the increased value and demand for fresh seafood has attracted foreign owned seafood exporters to monopolize Madagascar's fishing industry. Although its fisheries are undeveloped, compared to other East African countries that have been targeted primarily by Japanese and European operators, Madagascar's fishing industry is expanding rapidly (Nash et al., 2004).

In 2003, Southwest Madagascar experienced the arrival of seafood export companies, shifting their subsistence fishing economy to a market-driven one (Humber et al. 2006). This increased exploitation of seafood, caused by the proliferation of cash economies, has strengthened the fishing pressures on *Octopus cyanea*, among other species (Nadon et al., 2005). Internationally, the amount of octopus exploited has been steadily rising. Over a fifteen-year period, between 1990 and 2004, the yearly octopus catch, worldwide, increased from 294,000 to 355,000 tons (Loic

2006).

In the Toliara region of Madagascar, Copefrito and Murex dominate the commercial trade of seafood. For nearly 420 km up and down the coast, from Androka to Morombe, Copefrito alone collects their product from more than 3000 Vezo fishermen of 74 villages (Copefrito). Primarily collecting *Octopus cyanea, Octopus aegina,* and *Octopus macropus,* the two companies are exporting, on average, 2-4 tons of octopus a day (Director). In recent years, local fishermen have expressed discontent because of the decline in yield from local fishing sites (Humber et al., 2006).

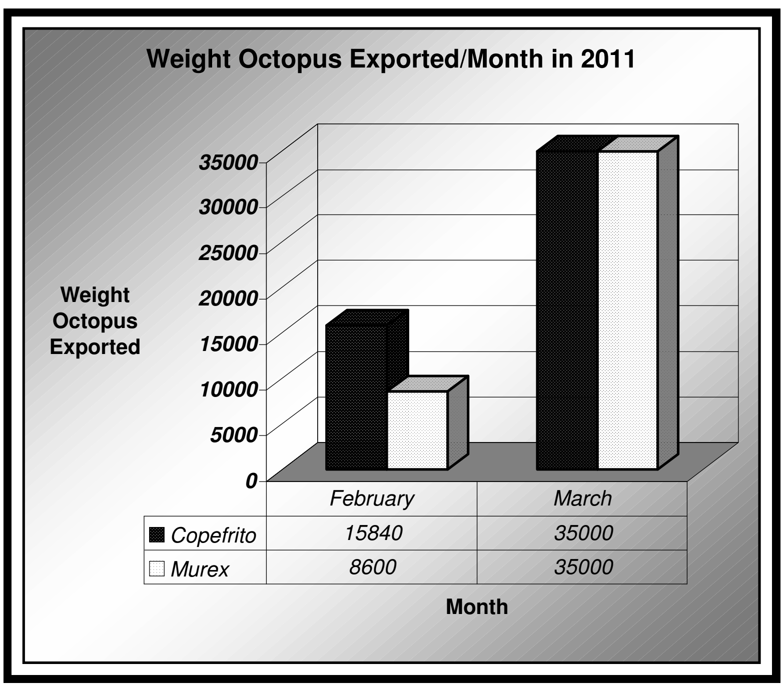


Figure 1*: A Comparison of octopus weight exported by Toliara's largest seafood companies, Copefrito and Murex. Between the two, nearly 90,000kg of octopus have been exported in March and February*

The increasing catch rate of this already over-exploited resource may lead to negative environmental and socio-economic impacts, including the depletion of *O. cyanea* populations in the Toliara region.

Madagascar's Southwest coastline possesses one of the largest coral reef systems in the Western Indian Ocean (Harris and Roy 2007). Furthermore, the island's west coast supports over 90% of the country's coral reefs (Cook et al., 2003). Both management and monitoring of Madagascar's marine resources is needed to promote sustainable fishing methods in order to maintain benthic health of this vast coastal reef and its inhabitants.

Velondriake: A Conservation Effort

As over-exploitation of Madagascar's Southwestern coast persists, several management programs have been implemented to conserve the marine ecosystems. One in particular, Velondriake, Malagasy for "to live with the sea," aims to maintain the sustainability of octopus populations and abundance in the Andavadoaka region, about 120 km north of Toliara.

In November of 2004, Blue Ventures decided to trial a No-Take Zone (NTZ) in the Velondriake conservation zone. The area was closed to reef flat octopus fishing in order to promote sustainable yields for local fishermen. With the hope that the NTZ would increase the size of octopus caught, it was ultimately aimed at increasing the price paid to the fishermen for their product (Humber et al., 2006). Blue Ventures found that shortly after the closure periods, both number and mean weight of octopus caught by local fishermen had significantly increased (Humber et al., 2006).

At the same time, Blue Ventures set up a fishery-monitoring program at Andavadoaka to develop an understanding of traditional fishing techniques. The NGO could then determine patterns of fishing pressures across local marine ecosystems. Through collaboration with Copefrito, researchers were able to collect day-to-day catch data of traditional fishermen across the region. Primarily, they monitored changes in catch size and composition over time (Nash et al., 2004).

Specifically, Blue Venture's Octopus fishing monitoring program collected data concerning the total mass of octopus collected. Knowledge of total weight and total numbers of octopus caught from the coast has been used to determine the CPUE (catch per unit effort). Such a calculation can be used to determine the current fishing pressures on octopus populations in the region.

In 2010, data from Blue Venture's monitoring program in Beheloke, the site of this paper's study, was analyzed to calculate the CPUE over a four-month period

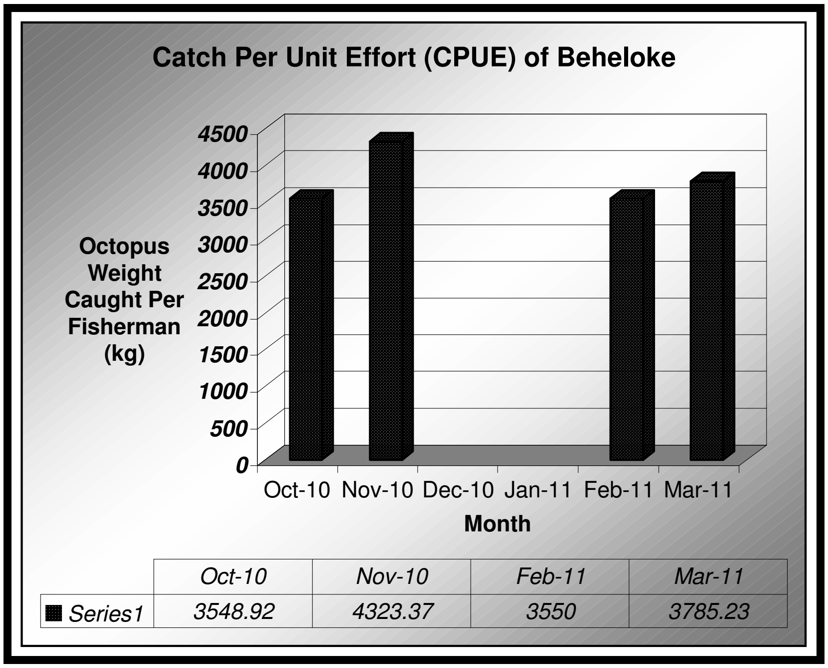


Figure 2: *A four-month comparison of CPUE in Beheloke, a village just south of Toliara. The CPUE represents the average weight of octopus caught per fishermen over a one-month period (Data provided by*

No data was collected from December through January because of the national closure of fishing implemented across the Toliara region. In November, one month before the closure, there is a clear spike in CPUE. This spike may have been due to increased effort of the fishermen, anticipating the upcoming interdict against fishing. Anecdotal data suggests that the beginning of each year tends to be the slow season for fishing yield per fishermen. This is represented by the low CPUE calculation for February and March.

These CPUE calculations are important for this study because they aid in determining patterns of fishing pressures on the study site. Furthermore, the difference in fishing pressures across various fishing sites in Beheloke provided a diverse set of study sites to choose from, prior to evaluating Beheloke's reefs. It is important to analyze marine habitats that have been heavily fished in the past, as well as those that have experienced a low anthropogenic influence to understand a rich cross-section of marine habitats off the coast of Beheloke.

The Biology and Ecology of *Octopus cyanea*

Octopus cyanea is a cryptic cephalopod species that typically inhabits holes and crevices found in coral reefs, sea grass beds, and across rock, sand, or mud bottom areas of the ocean. Although this species is not endemic to the waters of Madagascar, it is the primary species caught and exploited on the Southwest coast of the island. O. Cyanea's shelter provides it safety from predators and a site for egg laying (Van Heukelem 1983). In fact, the octopus may occupy the same shelter for up to 35 days (Van heukelem 1983). Although *O. cyanea* can inhabit depths up to 150 m, those who inhabit inter-tidal ecosystems are subject to foraging by traditional fishing of the local villages in Southwest Madagascar (Humber et al., 2006). It is important to note that only these individuals were the subjects of this study.

Like all cephalopods, O. cyanea fertilizes through direct mating. Although males copulate with multiple partners, the males and females die after a single season of brooding (Van heukelem 1976). A typical clutch of eggs can contain up to 700,000 eggs and can take up to 5 months to hatch (Nash et al., 2004). However, the number of eggs a female octopus produces is proportional to her size. In other words, the larger the female, the more eggs she will produce.

For *O. cyanea,* sexual maturity can be reached at a wide-range of body sizes. While males tend to reach maturity at approximately 320 grams, females will mature closer to 600 grams (Nash et al., 2004). Although, sizes of sexually mature octopus can vary within this range, a female smaller than 500 grams generally has not already had the chance to reproduce.

From a biological standpoint, the tactic of protected areas, such as Velondriake, can surely benefit the regeneration of octopus populations. Because a large female octopus, for example, tends to lay more eggs than a young one, implementing a protected area with limited access to fishermen will allow individuals the capability and opportunity to reproduce. This theory is supported by the results of Blue Ventures first trial of "No-Take-Zones" in November 2003. After the first NTZ of Nosy Fasy, a fishing site near Andavadoaka, results show that octopus abundance and weight increased rapidly during closure periods (Humber et al., 2006). Furthermore, Blue Ventures decided that leaving the reef flats protected for several months before peak spawning would drastically increase reproduction and recruitment of *O. cyanea* (Humber et al., 2006).

In this study, data is presented concerning the abundance of *Octopus cyanea* and its relationship with the degradation of its habitat in Beheloke. By comparing these results with a similar study performed in the

Velondriake protected area, the effects of marine protected areas on *Octopus cyanea* and its habitat are revealed. Initial hypotheses predicted a direct relationship between rugosity, benthic health, and octopus abundance. Likewise, the Velondriake conservation zone was predicted to yield higher rugosity, superior coral cover, and overall greater octopus shelter abundance.

Methods

Study Site: Beheloke

Beheloke is a small Vezo fishing village approximately 61 km south of Toliara. The village is divided into three areas, Beheloke Haute, Beheloke Bas, and Behinta. Although it only has a total population of only 930 people, more than of third of Beheloke's villagers are registered fishermen. Of these 315 fishermen, 243 of them glean the reef flats, fishing for octopus (Sylvain).

Figure 3: *A Map showing the location of Beheloke, on the Southwest coast of Madagascar and its distance from Toliara, 61 km (GoogleEartch)*

This study was performed during the 15th of April to the 21st of April. Over this seven-day evaluation of *Octopus cyanea's* population density and the benthic health of its habitat, I was able to study seven popular octopus-fishing sites off the coast of the village. The study sites included: Anihosa, Ankarana, Antanivao, Ambatobe, Lavadafo, Antanifaly, and Maromalinike.

Figure 4: *A map indicating the seven study sites off the coast of Beheloke. Points were marked on site using a GPS (GoogleEarth)*

The seven day period of this study was dependent on spring tides, a low-tide period approximately every 9-13 days, where the reef flats are accessable by foot for only 3-7 successive days. The project was limited to this 7 day period to ensure accurate data collection. For the Vezo fishermen, these spring tides allow men, women, and children octopus catchers to “glean” the reef flats on foot for octopus holes. Three of Beheloke’s octopus fishermen, all men, aided this project as guides to provide site location and size, to find octopus holes, and to locate the octopus. Using a *Voloso,* a long, slender spear used to catch octopus, the three fishermen were able to locate *Octopus cyanea* for this study.

The evaluated sites were chosen based on high and or low catch rates per site recorded during the months of October and November in 2010, prior to the national fishing closure in December and January, a period of high fishing pressures on octopus.

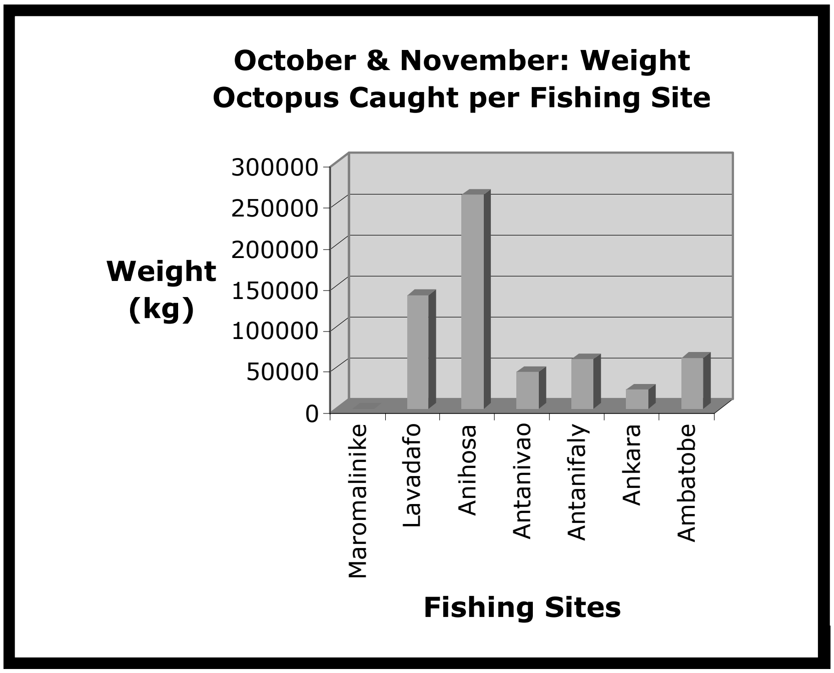


Figure 5*: This graph represents the amount of octopus caught during October and November of 2010 at seven fishing sites chosen for this project. Each site was chosen based on having a significantly high and or low catch rate to provide a rich cross-section of fishing sites in Beheloke. (Data provided by Blue Ventures).*

In evaluating the abundance and the benthic health of the coral reef flats in Beheloke, three different methods were used. These methods included 50 X 3 meter belt transects, 50 meter line intercept transects, and 10 meter rugosity measurements.

Belt Transects: Evaluation of Abundance

To investigate the relationship between the distribution of octopus and each of the seven fishing sites in Beheloke, the belt transect method was used. A 50 meter transect, two Vezo fishermen, and their *Voloso*'s were used. The transect was first laid out along the reef flat and secured at each end. The two fishermen then walked along the transect, covering an area of 1.5 meters on either side of the transect, and searched for octopus holes.

As the fishermen carefully walked along side the transect, they recorded how many holes they found, how many were occupied by *Octopus cyanea*, and how many were vacant. A single belt transect covered 150 square meters of the reef flat. 5 to 10 replicates were performed, depending on the size of the site. Smaller sites only required 5 replicates to cover the area, while larger sites required up to 10 replicates. This method provided the study with great insight into the distribution of *Octopus cyanea* at each fishing site. In total, 5250 meters of area was studied on the Beheloke reef flat.

KEY

▪ = Octopus Hole

→ = Fisherman

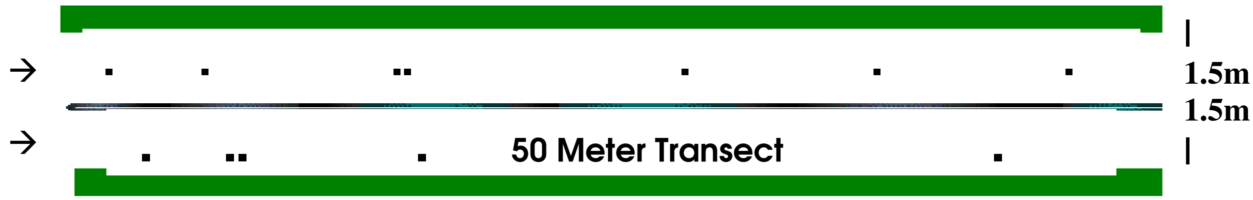
__ = Transect

___ = Perimeter of Area Covered

| = 3m Belt(2 X 1.5m)

Figure 6: *A Diagram and Key of the Belt Transect method. The diagram illustrates a 50 meter* <u>*length*</u> *transect (center line), a 3 meter* <u>*width*</u> *(Belt) stemming perpendicular from the transect, covering a total of* <u>*150*</u> *square meters of area (perimeter indicated in green). The diagram also shows two fishermen (represented as arrows)*

covering the transect's area, search for octopus holes (represented as black dots).



Line Intercept Transects: Evaluation of Habitat

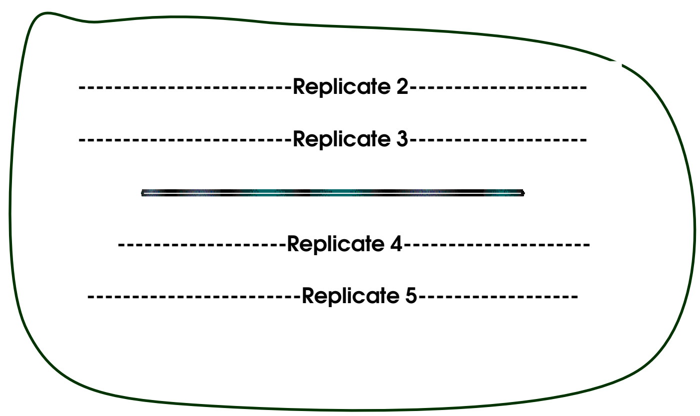
To understand the current state of the reef flat's health, the primary method used was a line intercept transect. For each site, I performed 50 meter line intercept transects (LIT) in order to identify the state of the reef flat's benthic health. An LIT is a linear identification method where a transect tape, 50 meters long, is secured at each end with the tape draped over the reef in between. Observations and identifications are then collected on the species and substrate components, and their length, directly underneath the tape.

In this study, I identified marine components such as sea grass, macro-algae, live massive or encrusting coral, dead coral, rubble, sand, and keystone species such as *diadema,* a sea urchin. Keystone species are certain species whose mere presence is enough to suggest positive health of an ecosystem. The LIT identification method is a useful tactic in collecting a general understanding of the diversity and condition of a marine ecosystem. Like Belt Transects, 5 to 10 replications of this method

ILLUSTRATION: SMALL STUDY SITE

Figure 7*: A Diagram of a*

were also performed, depending on the size of the fishing site. Smaller sites only required 5 replicates to cover the area, while larger sites required up to 10 replicates.



Rugosity: Evaluation of Habit

To further the study of *Octopus cyanea's* habitat, rugosity measurements were performed along the Line Intersect Transects at the seven fishing sites. Rugosity is the "roughness factor" of a surface (IUPAC 2006)." It is the measure of amplitude in the height of a surface. In other words, if a reef flat has high variation in height of its surface, it has a high rugosity. On the contrary, surfaces such as a wooden floor, which has no variance in height, have a low or no rugosity. The theory is that high rugosity on a reef flat indicates less degradation and positive benthic health. From an ecological standpoint, rugosity can be an indicator of the amount of available habitat available for benthic organisms to inhabit, as well as shelter for mobile organisms like octopus.

In measuring rugosity of the reef flat, a 10 meter chain was draped over the reef flat and its benthic components. To ensure an accurate rugosity measurement, the chain was carefully placed along the changing surface area of the reef, following the contour of corals, rocks, sand, macro-algae, and even urchins.

As the chain follows the reef flat's varying surface height, its once 10-meter length becomes shorter. The goal of this method is to divide the original length of the chain by its measured change in length. Mathematically, it is represented by:

Rugosity = *Ar / Ag,* where *Ar* is the real surface area (original chain length), and *Ag* is the geometric surface area (new chain length after following the reef flat's contour). The rugosity was measured twice for each LIT replicate. In other words, 10 replicates of rugosity measurements were performed at small sites, and up to 20 rugosity measurements were taken at the larger ones.

Example Rugosity

*** 10 m chain ( ) draped over the reef for 7 m. *Rugosity = 10m/7m = 1.43**

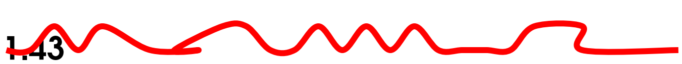


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***Figure 8**:*

Here, a 10 m chain is draped over a 10 m cross-section of the reef flat. The chain, however, only spans 7 m of the reef, as indicated by the transect. This diagram illustrates a typical rugosity measurement.(Indicated in top-right corner: (Rugosity

Data Analysis

All data analysis, including catch per unit effort (CPUE), average weight of octopus caught per fishing site, average rugosity per site, average benthic components per site, average octopus per site, final comparative analyses was completed on Microsoft Excel. The CPUE was used simply to show a monthly mean weight caught per fishermen to understand current fishing pressures affecting the Beheloke reef flats. In comparing this mean weight over time, data was used from over 10 fishing sites off the coast of the village. On the other hand, the mean weight of octopus caught per fishing site was used to choose affected and unaffected study sites prior to evaluating Beheloke's reef flats.

GPS

GPS points were taken at the beginning and end of each 50 meter transect. The points were used to provide insight on the total area covered on the reef, as well as to provide the distance of each site from the village of Beheloke.

Results

GPS

SITE	Distance from Beheloke
AMBATOBE	1.8 km

Figure 9: *Here, a chart illustrating the seven sites and their*

ANIHOSA	2.35 km
ANKARANA	2.51 km
ANTANIVAO	2.69 km
MAROMALINIKE	2.23 km
ANTANIFALY	2.85 km
LAVADAFO	3.18 km

SITE	GPS Point
AMBATOBE	S 23° 54′ 43.3″ E 043° 39′ 38.5″
ANIHOSA	S 23° 54′ 34.9″ E 043° 40′ 13.6″
ANKARANA	S 23° 55′ 23.9″ E 043° 39′ 12.5″
ANTANIVAO	S 23° 53′ 26.6″ E 043° 38′ 52.4″
MAROMALINIKE	S 23° 54′ 59.2″ E 043° 39′ 04.4″
ANTANIFALY	S 23° 54′ 00.4″ E 043° 38′ 48.9″
LAVADAFO	S 23° 53′ 24.3″ E 043° 38′ 56.5″

Figure 10: *A chart illustrating the seven study sites and their GPS points.*

Line Intercept Transects

Habitat Results: The Average Percent Cover of Benthic Components

SITE	Benthic Cover						DI
AMBATOBE	51.4%	31%	15%	.2%	0%	1.8%	0%

	RB	SA	MA	MC	EC	DC	DI
ANIHOSA	40.8%	29.9%	23.2%	0.6%	1.4%	2.2%	2.6%
	RB	SA	MA	MC	EC	DC	DI
ANKARANA	65.7%	16.4%	13.2%	1.3%	0.6%	1.6	1.2
	RB	SA	MA	MC	EC	DC	DI
ANTANIVAO	42.3%	20.8%	30.7%	2.50%	0.60%	1.8%	1.3%
	RB	SA	MA	MC	EC	DC	DI
MAROMALINIKE	37.3%	25.6%	35.1%	0.6%	0.25%	0.8%	5.9%
	RB	SA	MA	MC	EC	DC	DI
ANTANIFALY	40.2%	19.5%	33.3%	1.9%	0.5%	3.0%	1.6%
	RB	SA	MA	MC	EC	DC	DI
LAVADAFO	38.8%	16.0%	38.0%	3.3%	1.1%	1.3%	1.5%

An

An Estimation of Total Benthic Cover

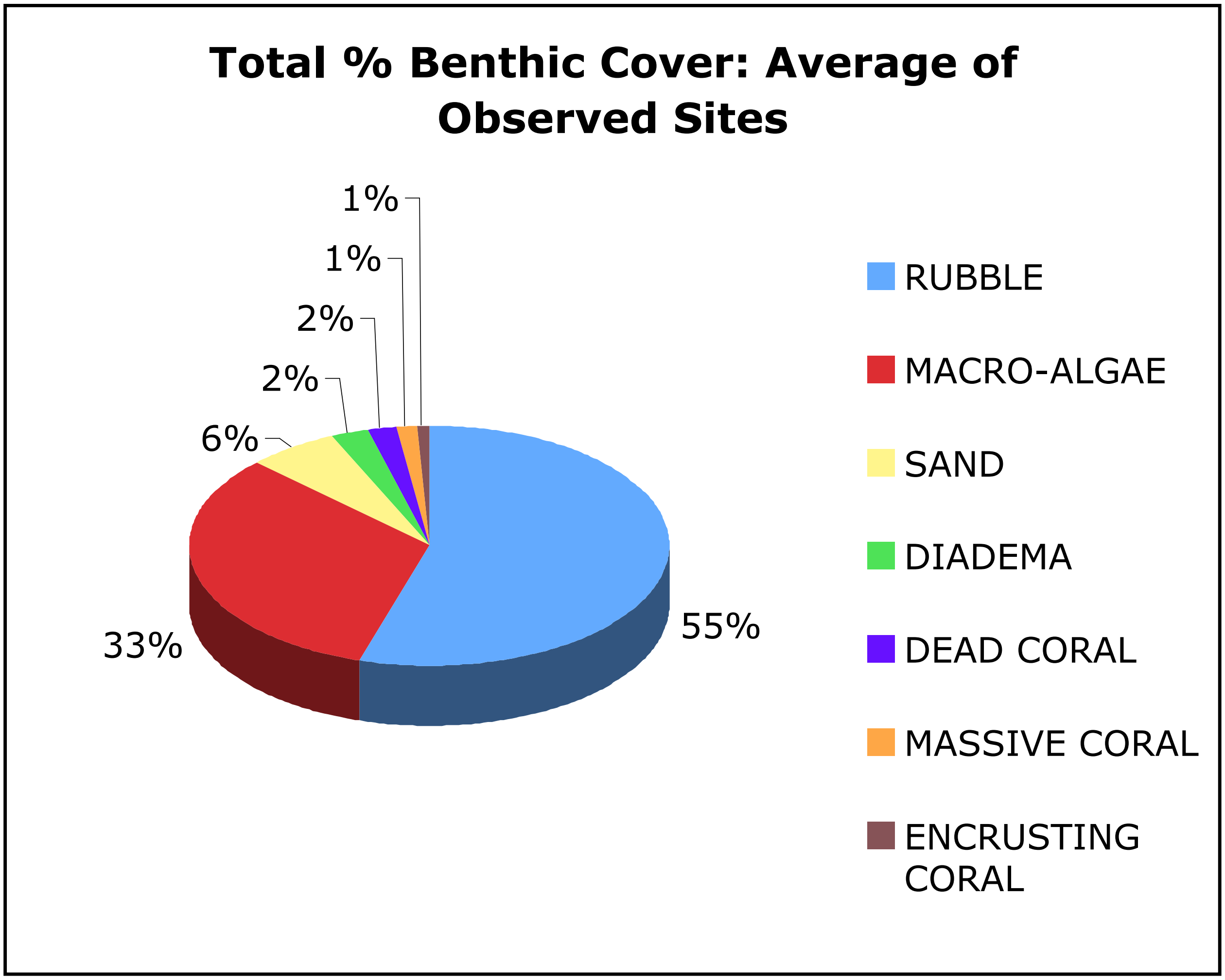


Figure 12: *A pie chart displaying an average of benthic cover on Beheloke's reef.*

flat. This chart is simply a condensed average of all seven sites

Rubble, macro-algae, and sand were the prominent benthic components of Beheloke's reef flat. On the contrary, *diadema* and coral cover were significantly less abundant. It is important to realize that this data does not represent Beheloke's entire reef. It is simply an average of the seven sights, carefully extrapolated to estimate the total benthic cover of *Octopus cyanea's* ecosystem.

Belt Transects

Abundance Results: Average Count of *Octopus Cyanea*

SITE	Mean # of Octopus Holes	Mean # of Occupied Holes	Mean # of Vacant Holes	Mean Percent Occupied
AMBATOBE	9	0.6	8.4	6.6%
ANIHOSA	10.9	3.4	7.5	31.2%
ANKARANA	11	2.4	8.6	21.8%
ANTANIVAO	11.7	0.9	8.8	7.69%
MAROMALINIKE	12.1	1	11.1	8.26%
ANTANIFALY	19.2	1.2	18	6.25%
LAVADAFO	16	2.8	13.2	17.5%

Figure 13:* *Above: *A chart representing the **average** octopus holes and the **average** number of*

octopus found at each study site. These averages represent data collected

Rugosity

Habitat Results: Mean Rugosity Measurements

MAROMALINIKE	1.054
ANTANIFALY	1.058
LAVADAFO	1.188
ANKARANA	1.173
ANTANIVAO	1.158

Figure 14:

Here, a chart illustrating the average rugosity measurements of each study site. Ten to twenty rugosity measurements were taken at each site, depending on its size.

Notice: Rugosity across

Discussion

Data Trends: Beheloke Data

It is important to understand that this study was restricted to inter-tidal marine ecosystems. Therefore, all abundance and habitat results are an underestimation, limited by the inaccessibility to *Octopus cyanea*'s cryptic dwellings beyond the reef flat. Nonetheless, the results are applicable to the issue of over-fishing in Southwest Madagascar. This study evaluated those sites affected by current habitat degradation and resource depletion caused by the local fishing industries. Although the results of this study are limited, they are pertinent in understanding these pressures, as well as their effect on the marine ecosystems of *O. cyanea.*

To create further hypotheses from the data collected at Beheloke, a comparative analysis of the results was performed. Correlations between the reef's benthic cover, rugosity, and mean octopus abundance provided great insight into the effects of reef degradation on the abundance of *O. cyanea.* Furthermore, dissimilarity between habitat results in Beheloke and those of the Velondriake conservation zone provide us with a general understanding of an MPA's effect on marine ecosystems.

The Relationship between Coral Cover and Rugosity

In theory, a high rugosity would suggest a less eroded surface and ultimately, a healthier reef. Moreover, a healthy reef system would normally possess a high percent of coral cover. However, this connection between a rugose surface and its health is not always the case. In comparing the mean coral cover and the mean rugosity measurements of Beheloke's reefs, only 4 out of the seven sites displayed parallel trend-lines. The first three sites evaluated, Ambatobe, Aihosa, and Ankarana, displayed contradictory tendencies to the rugosity theory.

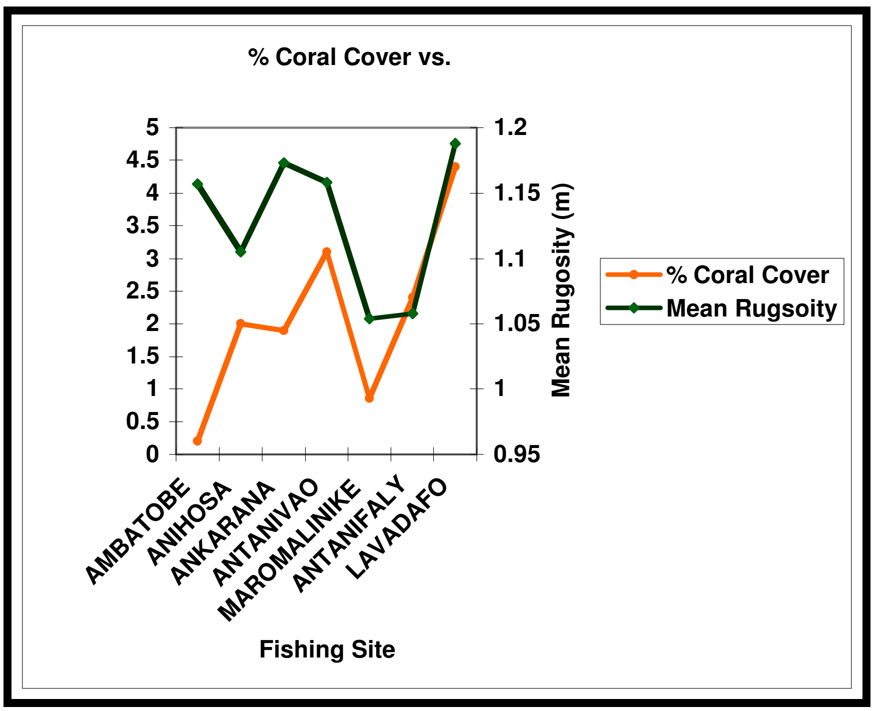


Figure 15: *Here, a graph comparing the relationship between % Coral Cover and Mean Rugosity. However, a direct relationship is not found in the first*

Rugosity is simply a measure of the roughness of a surface. It is not however, an accurate test of a reef flats benthic health. There is a slight correlation between rugosity and coral cover in four of the observed fishing sites. These sites include Antanivao, Maromalinike, Antanifaly, and

Lavadafo. However, because of this slight relationship between coral cover and rugosity, one can simply conclude that other factors, other than coral, are significant causes of high rugosity. One cause could simply be the presence of rubble and dead corals. In fact, rubble was found to be the most prominent benthic component on Beheloke's reef flat.

Mean Rugosity vs. Mean Octopus Abundance

Again, like the tenuous correlation between rugosity and coral cover, the same is seen in its relationship with octopus abundance. The same three sites, Ambatobe, Anihosa, and Ankarana, who display high rugosity and low octopus abundance, discredit the theory that high rugosity indicates high benthic health, providing an abundance of *O. cyanea*.

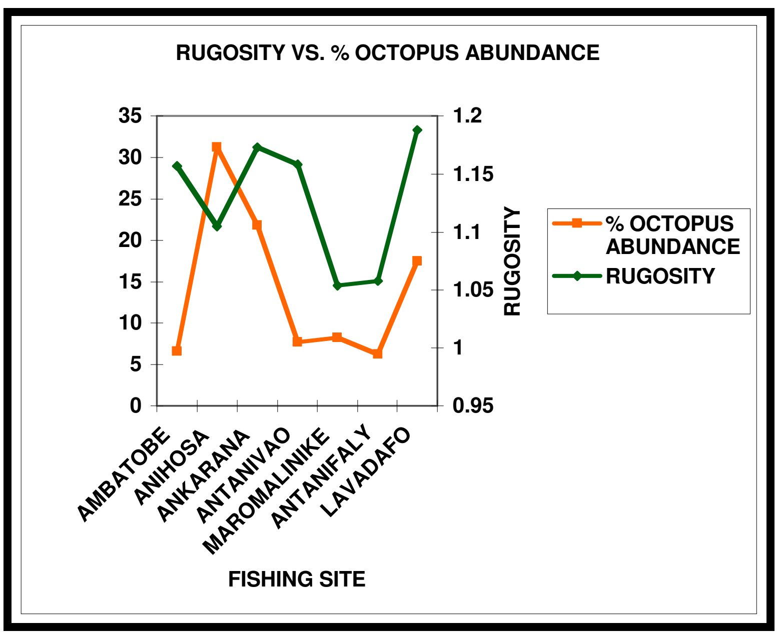


Figure 16*: Here, a graph illustrating the relationship between rugosity and the abundance of Octopus cyanea per fishing site. With the acception of Ambatobe, Anihosa, Ankarana, and Lavadafo, 3 out of the 7 sights display similar*

Although it is difficult to understand why Ambatobe, Anihosa, and Ankarana deviate from the expected relationship between rugosity and octopus abundance, further hypotheses can be made. For example, reasons for Ambatobe's deviation from the direct relationship between high rugosity and high octopus abundance may be a cause to its short distance from the village of Beheloke, 1.8 km. This negligible distance from the shoreline provides easy access to this fishing site, even during high tides.

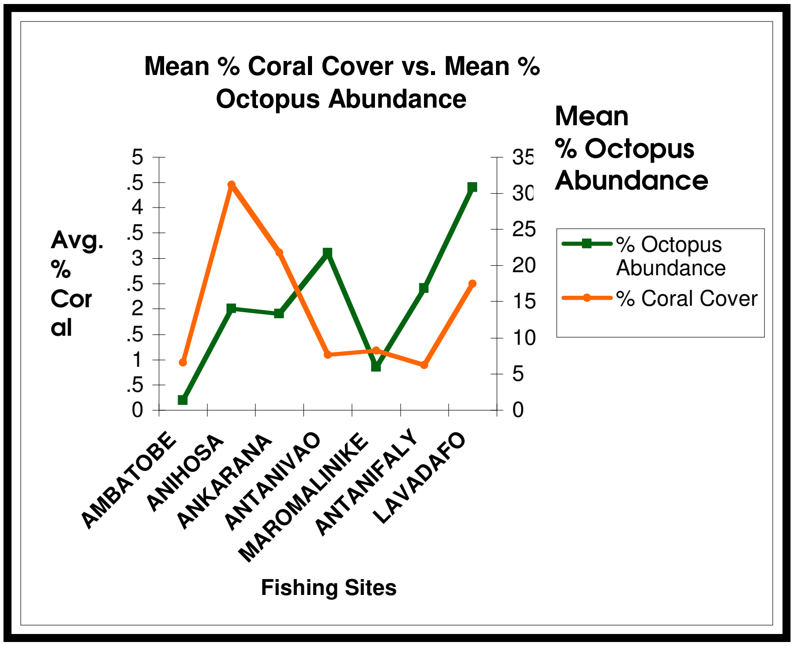
Understanding the reasons behind Anihosa and Ankarana's deviation was a little more difficult. Although it is impossible to know for sure, it is safe to assume that octopus abundance in these sites is a direct result of over-fishing, irrelevant to habitat degradation. As provided in *figure 5,* Anihosa was a site of high fishing pressures in October and November of 2010.

Mean Coral Cover vs. Mean Octopus Abundance

Unlike rugosity, coral cover proved to exist in a close relationship with the abundance of *Octopus cyanea*. Among the seven sites, with the exception of Antanivao and Lavadafo, which resulted in higher octopus abundance and lower coral cover, those that possessed a high percent coral cover also displayed high octopus abundance.

In the following graph, the similar behavior in trend lines indicates this direct relationship between abundance and co

Figure 17: *Here, a graph comparing the average coral cover of Beheloke's reef to the average abundance of*



In marine ecosystems, coral abundance represents positive benthic health of the reef flat. In Beheloke, as the health of the reef increases from site to site, the observed abundance rate of *O. cyanea* mirrors this increase directly. Over all, the strongest correlation of this study's data lies between this relationship between average coral cover and the abundance of *Octopus cyanea.*

A Comparison of Two Habitat Studies:

Beheloke vs. Blue Venture's Velondriake Protected Area

The data collected from the Beheloke study sites, which are not in protected areas, was compared with data from a similar study performed in Blue Venture's Velondriake protected area near Andavadoaka, 120 km north of Toliara, in November of 2010. It is important to note that the methods of these two studies were not the same.

First of all, the Velondriake study used only 30 X 3 meter belt transects, as opposed to the 50 X 3 meter belt transects used in this study. In addition, Blue Ventures used 10 meter line intercept transects, while this study used 50 meter LIT's. In other words, the Beheloke study covered more surface area of the reef, evaluating a larger sample size. Furthermore, the study at Beheloke evaluated more sites than in Velondriake. Blue Ventures only evaluated 6 fishing sites, while this study evaluated 7.

Another slight difference between the two studies is found in rugosity measurement methods. In Velondriake, Blue Ventures used a tape measure to drape over the reef, as opposed to the heavy chain used at Beheloke. As a result, their evaluation of surface roughness may not have been as accurate as this study's. A heavy chain is a precise method of measuring rugosity because it does not move in the water and it easily follows the reef flat's contour. On the other hand, a tape measure is easily moved, as it will float in the water. Therefore, it is not an accurate device for such a unique measurement.

Mean Rugosity Comparison

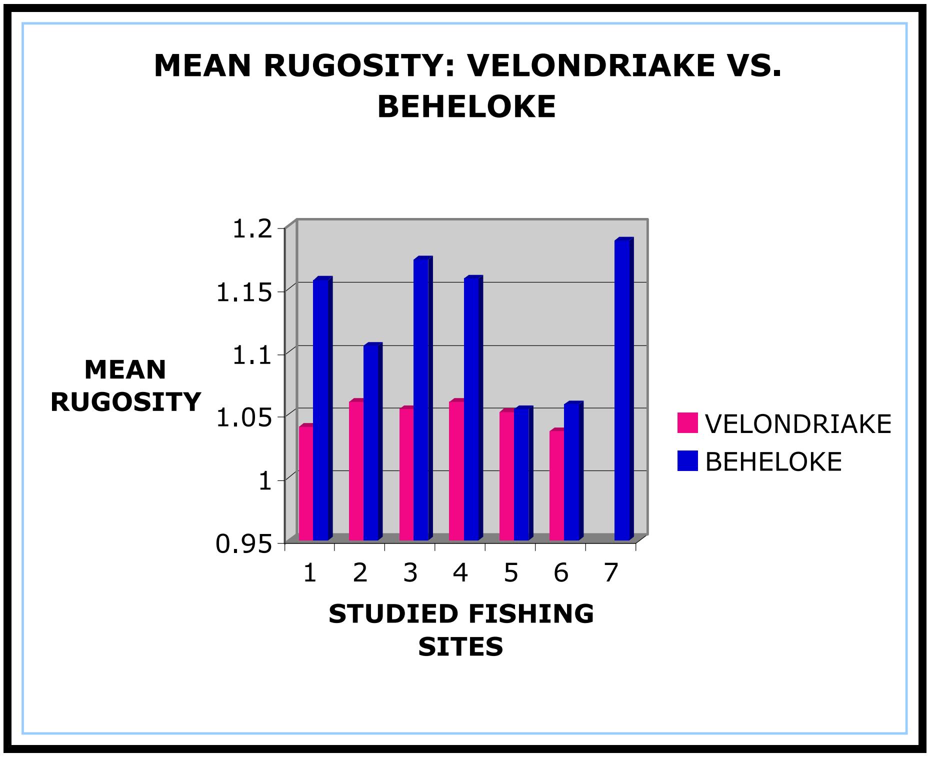


***Figure 18**: A graph displaying the comparison between rugosity*

Contradictory to the original hypothesis of this study, the rugosity measurements found in the Beheloke were all higher than those collected in Velondriake. In other words, the reef flat of a marine protected area was more degraded than that of Beheloke's. Reasons behind these curious results may be an outcome of a data collection error. As mentioned previously, the Velondriake rugosity methods may not have been as accurate as this study's. Another hypothesis suggests the presence of high anthropogenic influence North of Toliara, in the Andavadoaka region, while Beheloke is protected by its seclusion and low population size.

On the other hand, this data may suggest that the Velondriake MPA is not an effective shelter against reef-flat deterioration. However, this is not to say that a lower rugosity always indicates a lesser health on the reef flat. After comparing results concerning an estimated total coral cover between the two study sites, it is clear that Velondriake possesses a greater presence of coral. These results support the theory that a marine protected area will maintain a healthier reef system than a non-protected area.

A Comparison of Average Coral Cover

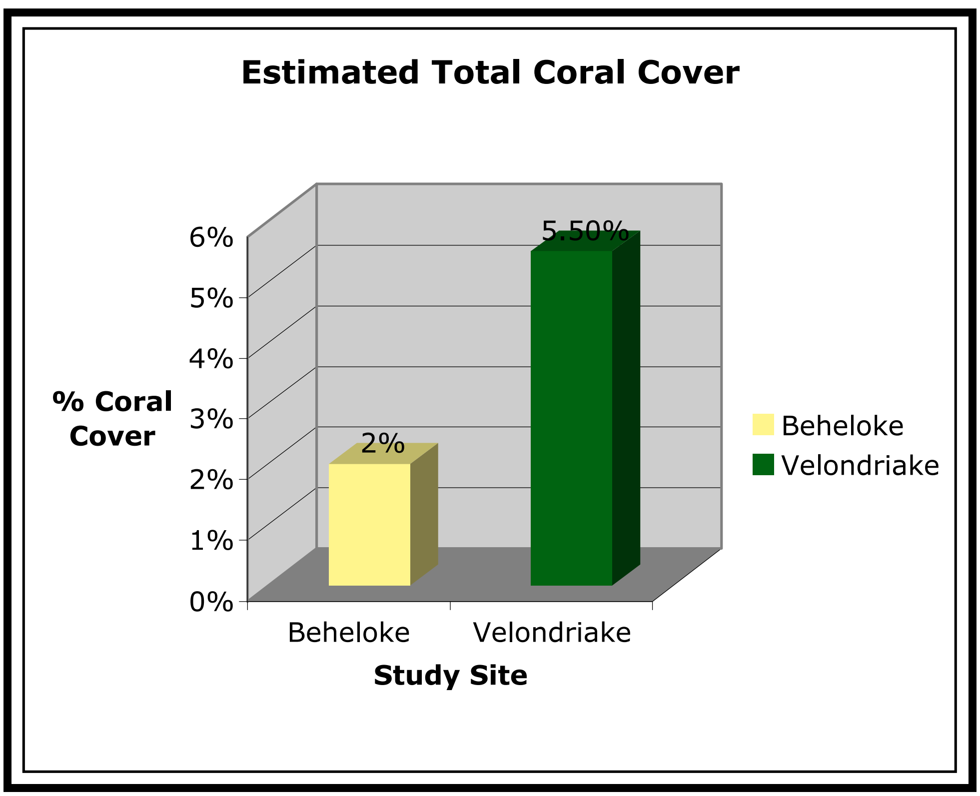


Figure 19: *A graph comparing an estimated total coral cover of the*

Unlike the low mean rugosity at Velondriake, the benthic cover does seem to be healthier than that of Beheloke. This contradicting data may suggest a period of previous reef degradation in the Velondriake zone. Nonetheless, the recently established MPA may have caused new coral growth; a regeneration of what once was.

Due to its slightly lower coral cover, Beheloke's benthic health may be suffering. However, further data suggests that the octopus hole abundance is significantly higher on the Beheloke reef flat.

A Comparison of Octopus Hole Abundance

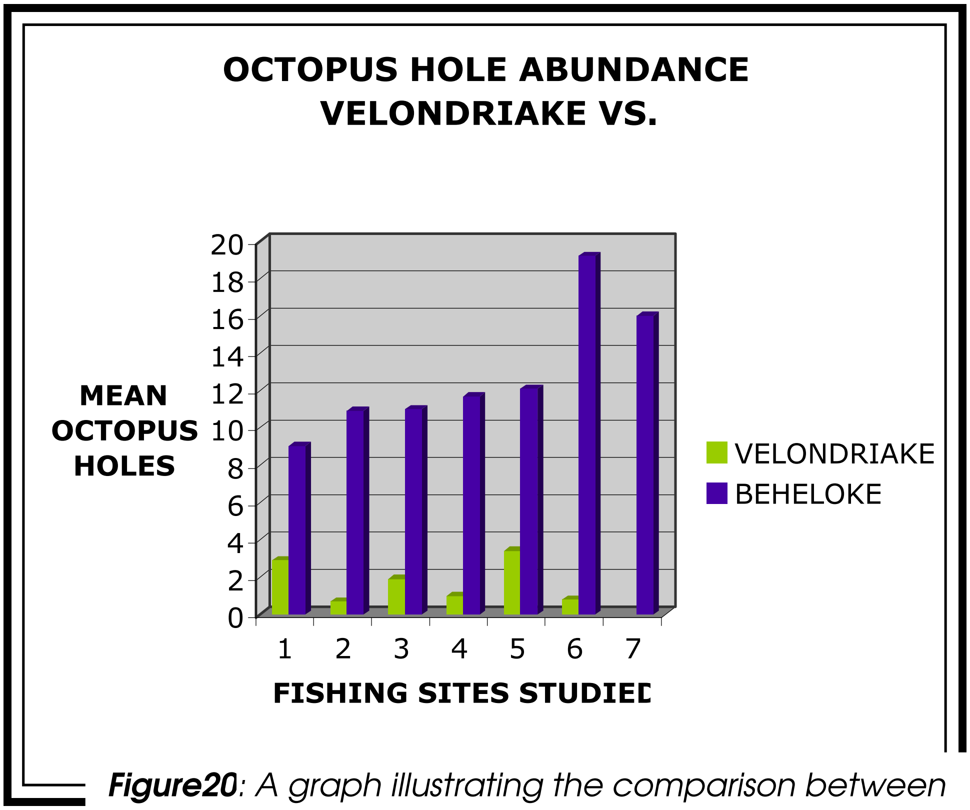


Figure20: *A graph illustrating the comparison between Octopus hole abundance data collected at the*

Deviating from the theoretical correlation between healthy coral cover and octopus abundance, the Velondriake study yielded significantly less *Octopus cyanea* holes than Beheloke. The unusual nature of these results may have been a cause of methodical differences between the two studies. For example, a larger sample size of octopus shelters was evaluated at Beheloke. As a result, a larger sample size was used.

Another important methodical error to note is the presence of observer biases. Different fishermen were used as guides for the study in the Velondriake zone than at Beheloke, which may have resulted in varying capabilities in identifying octopus shelters. A minute difference between the two studies, such as this, is enough to have caused this significant deviation between the two sites.

From a strictly objective standpoint, Velondriake's low rugosity suggests that the reef flat offers less shelter for *Octopus cyanea*, provided that low rugosity indicates reef degradation. Even though a higher percent coral cover was collected at Velondriake, the results suggest that reef flat deterioration is occurring, yielding a limited range of octopus shelters available. Although these results indicate that Velondriake's coral reef system is healthy, it is safe to conclude that anthropogenic activity, like fishing and reef gleaning, is contributing to reef degradation and is providing less shelter for *Octopus cyanea*.

Discussion Overview

Beheloke's data provides no definitive conclusions on the relationships between rugosity, reef health, abundance and an MPA's ability to increase octopus populations. But, for purposes of this study, extrapolations can be made. Firstly, trends of mean rugosity and mean coral cover on the reef flat is certainly linked octopus abundance in Beheloke. As discussed earlier, increased rugosity measurements indicate reef deterioration, habitat loss, and ultimately a lower abundance of *Octopus cyanea.*

Furthermore, it is clear from the comparative analysis, Beheloke vs. Velondriake, that Beheloke's reef is less deteriorated and provides more shelter to *Octopus cyanea.* Although Velondriake possesses a higher percent coral cover, based on its low rugosity, anthropogenic pressures must be stronger in Andavadoaka, than in the isolated countryside near Beheloke.

The question now remains, how effective is an MPA's ability to conserve marine ecosystems. The data of this study illustrates that MPA's preserve the health of marine species such as corals, but prove to be less effective in deterring activity promoting reef deterioration. Unfortunately for *Octopus cyanea*, marine protected areas and closure periods seem to have little effect on its abundance. However, because the Velondriake data was collected in November, one month before the national fishing closure, the resulting habitat degradation observed may have been skewed, representing increased fishing pressures prior to the reefs protection.

As this study was the first of its kind in Beheloke, no conclusions on the effectiveness of MPA's on marine ecosystems can be made. Not enough data, at either Beheloke or Velondriake, has been collected concerning the relationship between *Octopus cyanea's* habitat and an MPA's influence on abundance.

Conclusion

As overfishing continues in Southwest Madagascar, it is important to implement effective management programs. However, comprehensive data is vital to create such a program. Again, the data collected in Beheloke and the Velondriake is not conclusive. Nonetheless, it can provide us with a foundation for scientific inquiry. The importance lies among the questions that this study has sparked: How has over-fishing affected the barrier reef of Southwest Madagascar? What are the effects of such degradation on the abundance of *Octopus cyanea?* What is the effectiveness of a marine protected area? And most of all, how can we begin manage these issues? To answer these questions, further studies concerning *Octopus cyanea's* habitat and the direct effects of "No-Take-Zones" on octopus populations are vital. As future scrutiny continues, an accurate understanding of the consequences of overfishing, the abilities of an MPA, and the overall effects of habitat degradation on *Octopus cyanea* populations in Southwest Madagascar will be revealed.

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