Madagascar Marine Research, Marodoka Report 2016

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1. Introduction

Operation Wallacea is a network of academics from European and North American universities, who design and implement biodiversity and conservation management research programs. Research is supported by students who join the program, to strengthen their CV or resume, gain course credit, or collect data for a dissertation or thesis. Academics benefit from funding for high quality fieldwork enabling them to publish papers in peer reviewed journals. This model enables the collection of large temporal and spatial datasets used for assessing the effectiveness of conservation management interventions.

The overall structure of this work is to bring academics and world leaders into the field to run small specialist research groups within the overall project framework. These groups consist of principle researchers, Ph.D. students, dissertation and thesis students and research assistant volunteers. The projects run over a 10 week period every summer (June - August). This format gives many advantages to field research, such as bringing together a wide variety of multidisciplinary field scientists into the same place with a central organization coordinating the research. Funding for the research is entirely based on volunteers, this ensures that projects can be run over prolonged periods and datasets can be built up over many years. The research is based on collecting data on the local ecosystems that can be channeled into high quality research publications and grant applications to establish examples of best practice conservation in the local communities.

Madagascar is a hotspot for unique, endemic wildlife. Because of this and the extreme degradation of its forest habitats over the years, conservation has been in full effect to help protect its threatened species. Unfortunately, this idea hasn't spread so much to the conservation of marine life. Proper management for marine ecosystems in Madagascar is in it's infancy, while overfishing still occurs on a daily basis in many locations.

Opwall has had a presence in Madagascar since 2011. In 2016, additional focus has been aimed towards the coral reefs located around the island of Nosy Be, off the northwest coast (Figure 1.1). The objective of this exploratory study is to assess the current health status of a section of reef just outside the Lokobe National Park borders, and to design an optimal reef monitoring strategy for future years.

Figure 1.1. Map of Nosy Be Madagascar showing the Operation Wallacea marine research site.

2. Sampling Design

The section of shallow, fringing reef located off the southern coast of Nosy Be was chosen for this study because of the immense fishing pressures it experiences on a daily basis and also for the close proximity to the neighboring MPA that belongs to Lokobe National Park which would allow for good comparisons in future studies.

Like the majority of reefs around the island, there aren't any properly marked dive sites. This made repeat sampling nearly impossible. Low-budget marker buoys were handmade and placed in ideal survey areas, but were constantly being misplaced or removed by the local fisherman. Random sampling, though not ideal, was the only option. The extent of degradation this reef has experienced has left it broken, patchy, and difficult to find continuous reef. Transects were laid randomly in areas with sufficient continuous reef (roughly 20m or more in length) and depths ranging from 1-11m depth. This study therefore represents a rapid ecological assessment designed to help define a future reef monitoring strategy for use by Opwall teams in 2017 and beyond.

3. Standardized Methodologies

In this study an array of standardized survey methods was used to assess coral reef ecosystem health and function, collecting data on the benthic, fish, and invertebrate communities. Survey teams were made up of university-level volunteers led by a member of the Operation Wallacea science team, trained in the data collection methods outlined below.

3.1 Benthic Habitat Surveys

While every reef is different, a healthy reef generally has a high percentage of hard (Scleractinian) corals and a low percentage of fleshy macroalgae (healthyreefs.org). These ratios help determine the current status of a reef while also identifying any phase shift or other patterns if monitored long term.

Benthic habitat surveys were performed using twenty-six 20m line intercept transects (English et al 1997) at depths ranging from 1-11m. Members of the benthic survey team collected data at 25cm intervals along the transect, recording data on benthic biotic or abiotic classification under the transect tape at that point (Exton 2013). All organisms and abiotic factors were identified using broad term categorization (e.g. live coral, dead coral, algae, soft coral, zoanthids, sand, etc.) following that of English et al (1997). Bivalves were excluded from this survey as they are not relevant when determining percent coral cover and are later included when surveying benthic invertebrates.

3.2 Fish Abundance and Diversity

Fish abundance has been significantly impacted by fishing pressures in many areas, which in turn affects ecosystem function as a whole (Exton 2013). Monitoring abundance and diversity allows for trends and patterns to eventually be recognized while providing insight to whether or not stricter management plans should be implemented.

For this, 23 replicate belt transects of 20m length (5m wide) were conducted at depths ranging from 1-11m. Ten minutes was taken to complete each transect, and each individual fish observed within the belt was identified to the family level. Care was taken to record individuals only once, and to incorporate both benthic and pelagic species into census data (Exton 2013).

3.3 Benthic Invertebrate Abundance

Many invertebrates are considered foundation species and a critical part of ecosystem health and function (geo.arizona.edu). For this semi-quantitative survey, 20m transects were repeated 12 times at varying depths ranging from 1-11m. A zigzag swim pattern was used to expand the survey area (2.5m on each side of the transect for a total width of 5m) (Andradi-Brown, Marine monitoring methods handbook). Organisms were identified using common names and extra care was taken to record any inconspicuous individuals.

3.4 Growth Form Abundance

Stony corals are the ‘ecosystem architects’ of the marine world. The hard skeletons of these reef builders are what create the complexity needed to maintain the high levels of biodiversity associated with coral reefs (Gratwicke et al 2009). Each growth form has its own importance regarding ecosystem function, however, in terms of reef complexity, some coral growth forms contribute more than others. Colony morphology is not only driven by species, but also by light levels and temperature (Kaniewska et al 2009). Determining growth form abundance will provide insight on which key drivers are affecting reef complexity and set grounds for monitoring any change in future studies.

In this survey, corals were described using seven different growth forms that are recognized worldwide: A) mushroom corals, B) encrusting corals, C) foliose/laminar corals, D) branching corals, E) tabular corals, F) massive corals and G) submassive corals (Figure 3.4.1). 20m transects were laid at depths ranging from 1-11m. A QuadPod, which is a 1m x 1m quadrat with a fixed GoPro, was gently walked down the transect, hovering for 2-3 seconds at each meter to produce a still image of the reef. Images were selected based on quality and clarification. A total of 101 images were later analyzed using CPCe software (Coral Point Count w/Excel) where 100 data points were randomly, but uniformly, distributed over the image and growth forms were identified (Figure 3.4.2).

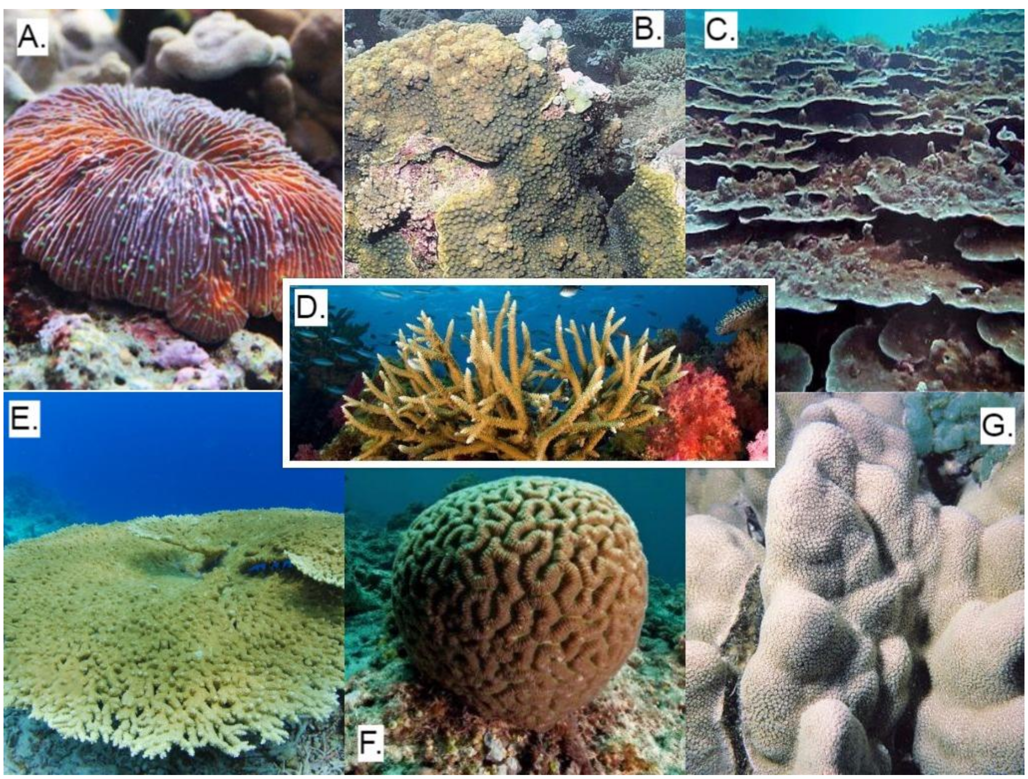

Figure 3.4.1. Coral morphologies: A) mushroom coral; B) encrusting coral; C) foliose/laminar coral; D) branching coral; E) tabular coral; F) brain coral; G) submassive coral.

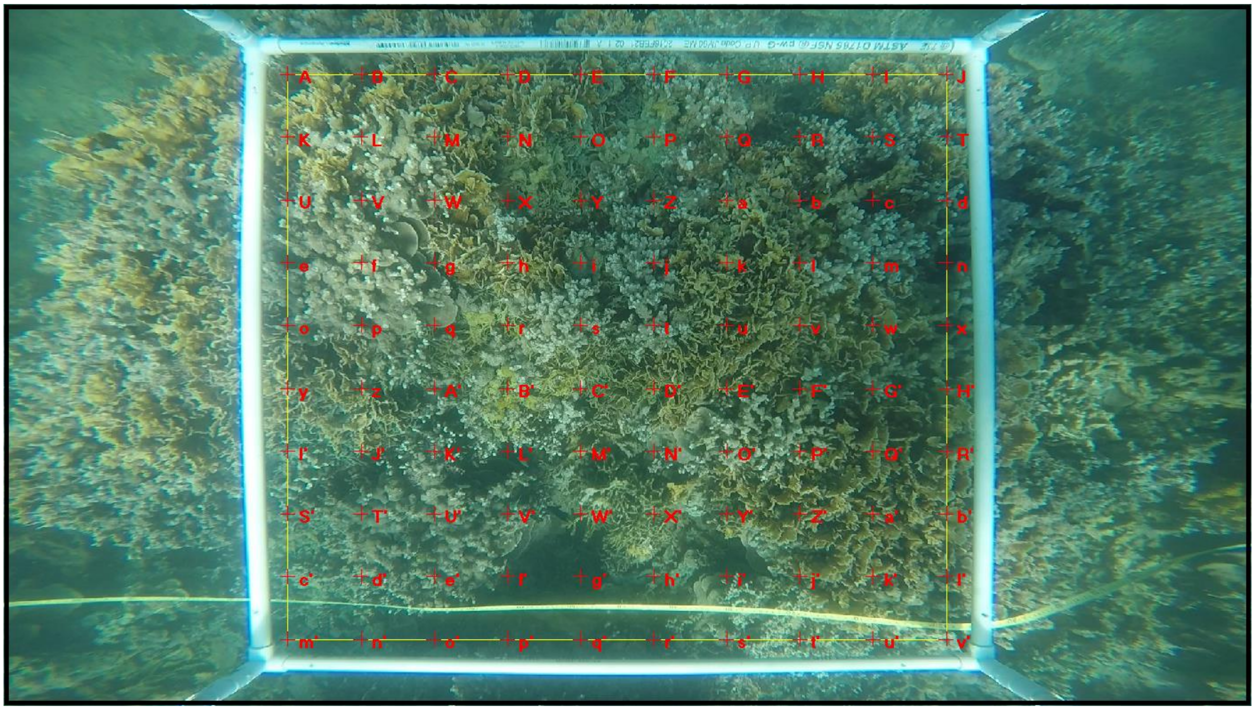

Figure 3.4.2. QuadPod image being analyzed using the the CPCe software.

4. Results and Discussion

4.1 Benthic Habitat Surveys

Benthic habitat data shows hard coral (scleractinian) to be the most abundant benthic category, averaging at 37% ±2.97, with percent cover of dead coral at 31% ±2.00. All other biotic benthic organisms, including macroalgae, barely cover 10% combined, suggesting little competition for coral recruitment. Sand made up 20% ±3.36, but this will largely be due to the patchy nature of the system being assessed (Figure 4.1.1).

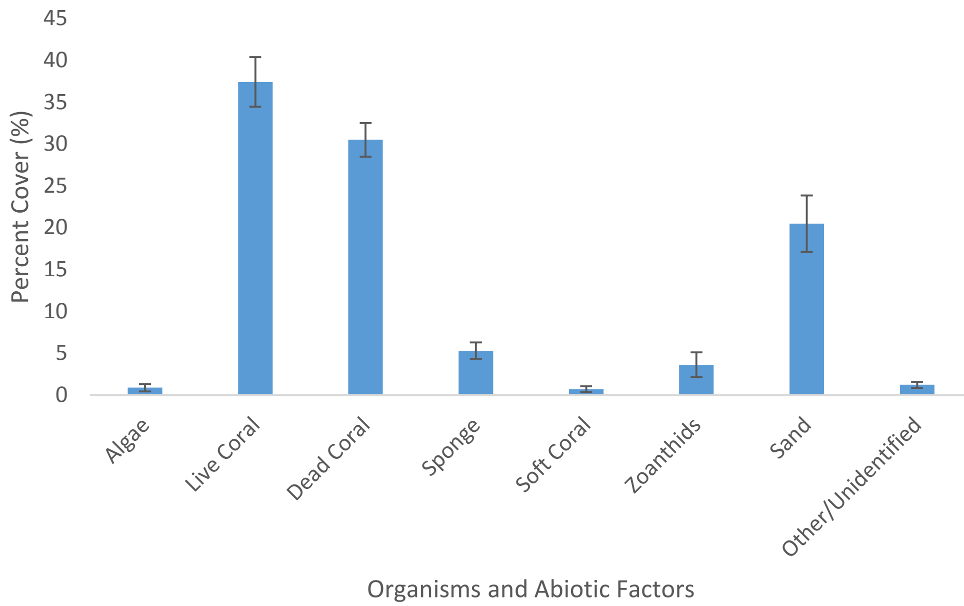

Figure 4.1.1. Benthic community structure. Data are mean values ±SE of all 26 replicate transects.

4.2 Fish Abundance and Diversity

Although macroalgal growth is significantly low, it doesn't appear to be a result of high herbivore abundance, as populations of key herbivorous species (parrotfish, rabbitfish, surgeonfish, etc.) (Green et al 2009; Edwards et al 2013) are scarce. The damselfish (Pomacentridae) was found to be the most abundant of the herbivores and of all the species identified. Averaging at 94.74 individuals per 100m^2 (±5.65), the damselfish nearly quintuples the other families. Pomacentridae was removed from the figure to better display community structure. The larger herbivores, more commonly associated with maintaining a low algae to coral ratio, are the parrotfish (Scaridae), averaging 0.65/100 m^2 (±0.32); the rabbitfish (Siganidae), averaging 0.09/100 m^2 (±0.06); and the surgeonfish (Acanthuridae), averaging 1.65/100 m^2 (±0.66). Fusiliers (Caesionidae), a planktivorous species, were the second most abundant overall. This family is known for schooling in large numbers, so even though not present on every transect, average abundance remained relatively high at 15.52/100 m^2 (±4.48) (Figure 4.2.1).

Abundance isn't the only concern when looking at fish communities, but also diversity, especially when considering herbivores and their different functions (Burkepile et al 2008). Not all herbivores have the same eating habits or food preference. For example, most parrotfish are excavators/scrapers who primarily feed on turf algae and tend to scrape or even bite chunks out of the underlying substratum in the process (Green et al 2009; Edwards et al 2013). Species in the Acanthuridae and Siganidae families are primarily grazers/detritivores who feed on turf algae while leaving the basal structure intact and also on detritus (Green et al 2009). Browsers feed solely on macroalgae while also leaving the basal structure intact (Green et al 2009; Edwards et al 2013). Of all the fish identified in this study, only some rabbitfish and some parrotfish fall under this category. Damselfish, while more speciose than the other families, are in a category of their own due to their unique territorial, algal farming behaviors (Edwards et al 2013). Each of these functional groups play an important role in preventing coral-algal phase shifts which is why diversity is essential (Green et al 2009).

Biodiversity is the variability among living organisms in a particular region, and a simple biodiversity index can be calculated with the following formula (Blake 2009):

$$\frac{\text{Number of species}}{\text{Total number of organisms}} = \text{Biodiversity Index}$$

The closer the biodiversity index is to 1, the higher the biodiversity of the ecosystem is (Blake 2009). To better fit this study, the formula has been altered slightly, using 'Number of families' as the numerator instead of 'Number of species' and replacing 'Total number of organisms' with 'Average number of organisms per transect' since 23 transects were surveyed. Changing the numerator from 'species' to 'families' ultimately lowers the biodiversity index, but still provides insight on the level of biodiversity when taken into consideration.

$$\frac{\text{Number of families}}{\text{Average \# of organisms per transect}} = \text{Biodiversity Index}$$

Fish diversity in this area of coral reef is particularly low (BI=0.16), consisting primarily of small herbivores (66%) and lacking in the larger predatory (22%). Commercially valuable species only make up 2% of the identified population (Figure 4.2.2).

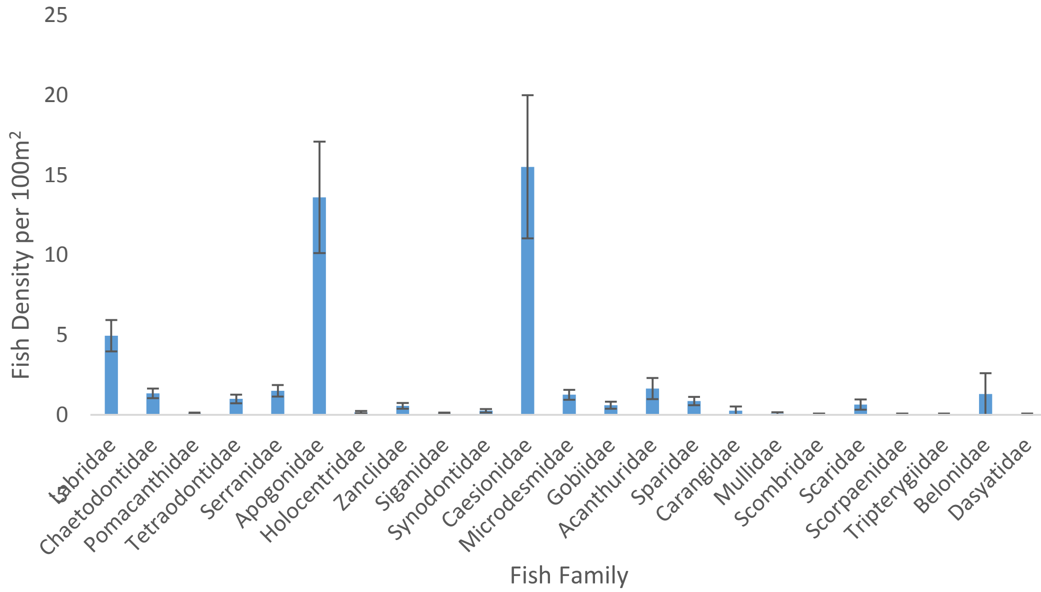

Figure 4.2.1. Average density per family per 100m^2. Pomacentridae was excluded from this graph to due to its disproportionate mean value to better display the overall community structure.

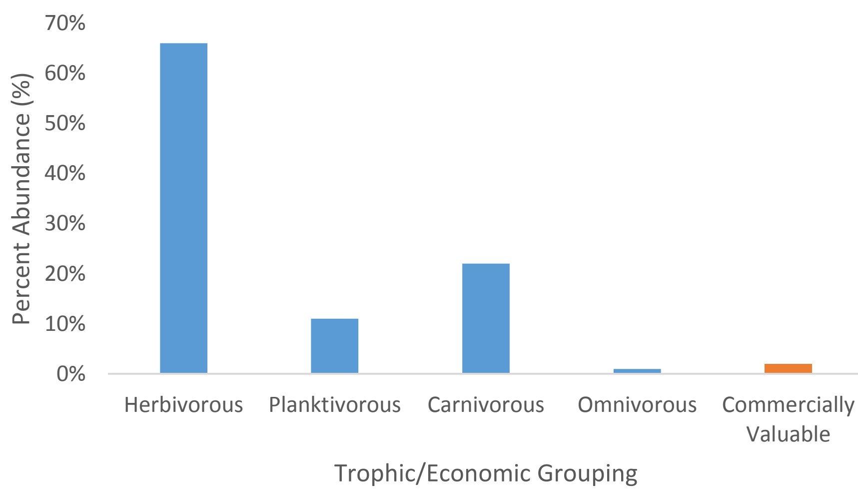

Figure 4.2.2. Total abundance as a percentage of the entire fish community when all replicate transects are combined. Unrelated to the previous, only 2% of the entire fish population is commercially valuable.

4.3 Benthic Invertebrate Abundance

Benthic invertebrates play an important role in maintaining a healthy trophic structure, acting as a valuable food source for many larger secondary consumers. Some inverts, like sea urchins, can also be considered habitat modifiers (geo.arizona.edu), in this case by limiting algal growth through grazing and promoting hard coral recruitment. The long-spined sea urchin (*Diadema spp*.) was by far the most abundant of all the invertebrates identified, averaging a density of $1.6/m^2$ (±0.14). The next most abundant, not even ¼ as dense as the long-spined sea urchin, is the cocks comb oyster (*Lopha cristagalli*) averaging a density of $0.27/m^2$ (±0.04) (Figure 4.3.1).

According to Rafel Coma et al (2011), coral cover can be directly related to urchin abundance. In this study that is not the case. Although urchin abundance is relatively high, figure 4.3.2 shows an R^2 value of only 0.0925, indicating no significant relationship between urchin density and coral cover. Although coral cover is low, it is possible that sea urchins are the main cause for low macroalgal levels, and coral cover is depressed for other reasons such as destructive fishing.

Sea cucumber density is not displayed on this graph since only 1 individual was observed within our survey parameters all season. However, this may be of concern since trepanging is very popular in Madagascar and Southeast Asia (Fishery and aquaculture country profiles 2008). 'Trepang' is Indonesian for sea cucumber, and 'trepanging' is the act of harvesting sea. Sea cucumber is considered a delicacy in the far east, awarded for its flavor-enhancing properties along with its reputation as a stimulant and aphrodisiac (Máñez et al 2010). The FAO states,

"Over-exploited trepang and shark stocks, whose production in tonnage and export value are much less important than shrimp, have not been the focus of specific management measures to reduce or counteract any over-exploitation." (Fishery and aquaculture country profiles 2008)

Perhaps the lack of management over these holothurians is the cause for their low numbers. This will be an area of focus in future studies.

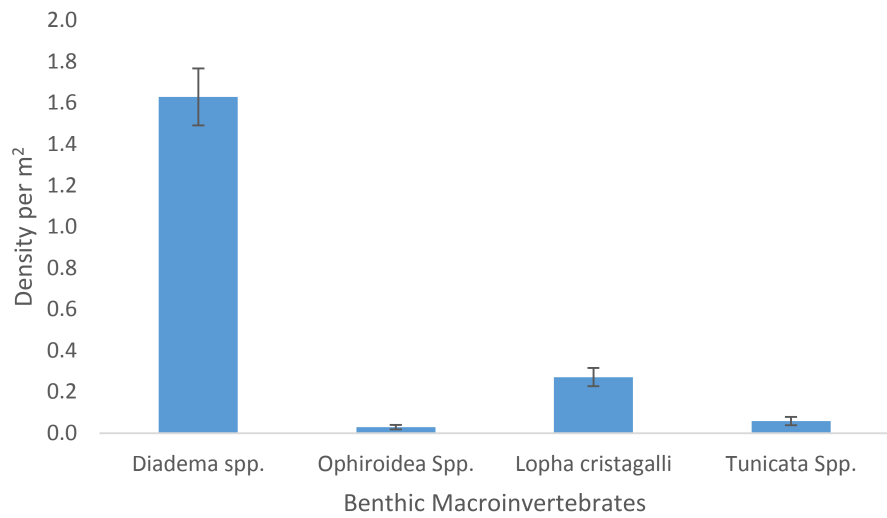

Figure 4.3.1. Benthic invertebrate abundance per m^2. Excluding all organisms averaging <0.02/m^2.

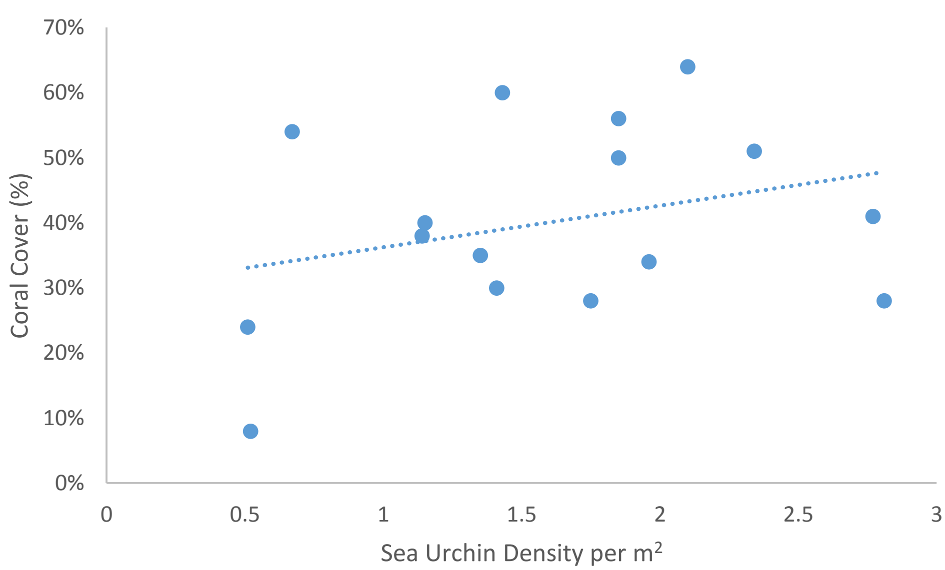

Figure 4.3.2. Correlation between coral cover and sea urchin density. ($y = 0.0639x + 0.2984$; R^2=0.0925)

4.4 Growth Form Abundance

The physical complexity of a reef is directly dependent on the composition and abundance of different coral growth forms, and is the key driver for maintaining high biodiversity (Gratwicke et al 2005; Graham et al 2006). Complexity and resilience varies between growth forms. For example, 'massive' coral species like brain corals (Figure 3.4.1) have very low complexity, but are generally resilient, stable structures. More complex corals, like branching corals, tend to be less resilient and more short-lived, especially in areas of destructive fishing (Gratwicke et al 2005).

For the area studied in this survey, complexity is very low. This section of reef is dominated primarily by submassive corals (μ=29.78 ±1.99; 30% cover) (Figure 4.4.1) which are only slightly more complex than massive corals (μ=0.03 ±0.02; 0% cover), but fairly resilient. More complex corals such as branching (μ=0.81 ±0.28; 1% cover), foliose (μ=2.71 ±0.55), and tabular (μ=0 ±0.00) were almost nonexistent. This again, suggests that complexity isn't very high which is a likely culprit to the overall low biodiversity.

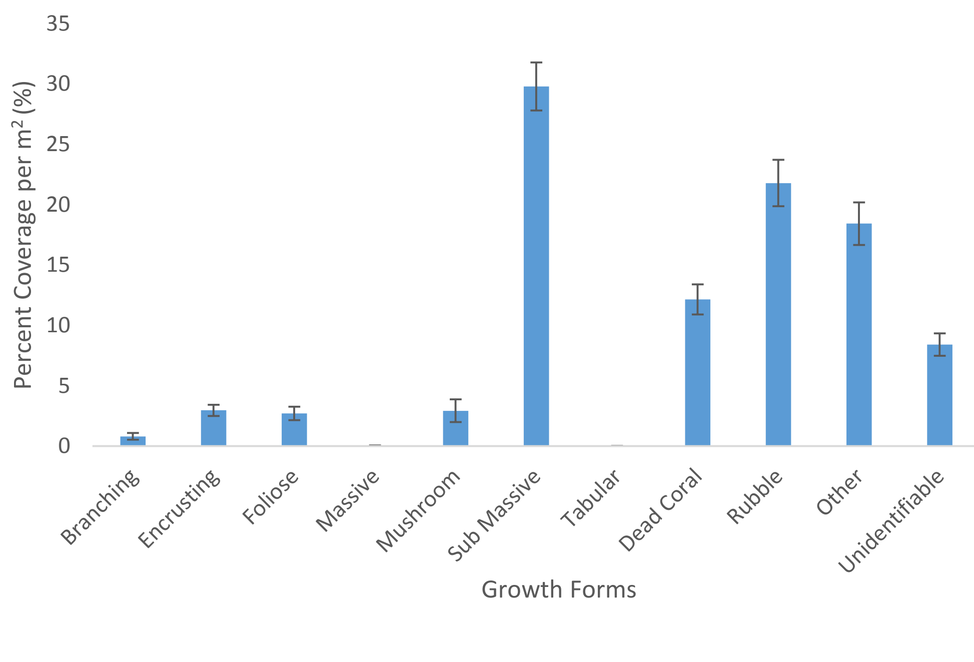

Figure 4.4.1. Growth form abundance. Data are mean values ±SE of all 101 images.

5. Conclusion

Understanding the current status of the reef is only step one in implementing proper conservation management. Macroalgae is a common competitor for suitable substrate on tropical reefs and can negatively affect coral reef resilience when in unfavorable ratios (Green et al 2009). Key factors that help control algal communities are not only herbivore abundance, but also herbivore diversity (Green et al 2009; Edwards et al 2013). Although macroalgal cover is low, likely as a result of the echinoid populations, herbivore abundance and diversity is quite low, potentially rendering the reef vulnerable to an algal dominated phase shift.

Low biodiversity could be caused by a variety of factors; one being lack of structural complexity as indicated by the lack of branching coral growth forms. With minimal algal coverage, one would assume that hard coral cover would proliferate. So, why hasn't it? From visual observations only, I believe that the coral population has likely been suppressed by sedimentation due to the silty nature of the ocean floor, and also the immense amount of destructive fishing that occurs in this area.

The traditional fishing method of Malagasy fishermen is dragging a net along the ocean floor from a canoe carved out of a tree trunk. The FAO states,

"Not much emphasis have been laid on the management of traditional fisheries as these are regulated like individual fishing…" (Fishery and aquaculture country profiles 2008).

This method, that 60,000+ employed fisherman use, would quickly demolish any of those fragile complex coral structures (branching, foliose, etc.) that would typically provide diverse habitats and maximize niche availability (Fishery and aquaculture country profiles 2008; Alvarez-Filip et al 2009).

In figure 4.4.1 'Dead coral' and 'Rubble' are separated. Dead coral that is still attached to the reef is labeled as 'Dead coral'. Broken pieces of coral (dead or dying) are considered 'Rubble'. This differentiation is ideal when estimating suitable substrates for juvenile coral recruitment as rubble is unstable and unsuitable for coral recruitment (Green et al 2009). This differentiation also provides some insight as to likely cause of death. In theory, rubble is likely created by ruinous physical disturbances such as destructive fishing or hurricanes, while dead coral is likely a result of a less destructive but still fatal disturbance such as water temperature or ocean acidification. As you can see in the figure, rubble exceeds dead coral almost 2:1 suggesting that destructive disturbances are the most common cause of coral fatalities, contributing to the low structural complexity and overall low biodiversity in the area.

6. Future Monitoring Approach

A main goal of this study was to lay down the framework for a longer term monitoring strategy to be utilized in future years. Aside from a few minor exceptions that will be improved upon, this goal was successfully achieved. Apart from a couple necessary deviations, we plan to mirror the methods described in Operation Wallacea's Marine Monitoring Methods Handbook and Stereo-Video-System (SVS) User Manual to produce more standardized data between sites.

6.1 General Regulations

One thing that will greatly improve this data when both collecting and analyzing, is having properly marked dive sites. This would deliver much more regulated data, increase efficiency during collection, and allow for comparison between sites.

Ideally, survey depths would be regulated as well. However, because this area is so shallow and continuous reef was difficult to come by, regulating survey depth would have drastically decreased the number of replicates. Perhaps with some more exploration, a nearby deeper reef will be discovered, where regulating depth will seem less restrictive and more productive.

6.2 Benthic Habitat Surveys

Overall, the methods outlined for the benthic habitat surveys worked well. One change to make would be to mirror the same taxa and non-living components as suggested in Opwall's Marine Monitoring Methods Handbook. This would include the addition of all benthic invertebrates aside from hard coral, soft coral, and sponges, and the addition of rock and silt, as these were both present but not categorized as such.

6.3 Fish Abundance and Diversity

The methods in place for the fish abundance and diversity surveys worked well, especially with the limiting resources. However, there is always much room for human error and inconsistency when using the underwater visual census (UVC) method. To minimize this in future years, we will be introducing stereo-video-system (SVS) surveys. Not only will SVS greatly improve accuracy and accountability when counting and identifying individuals, but it also calculates fish biomass. This will be a huge step up from the UVC method used previously. Methods will mirror those of Opwall's Stereo-Video-System (SVS) User Manual.

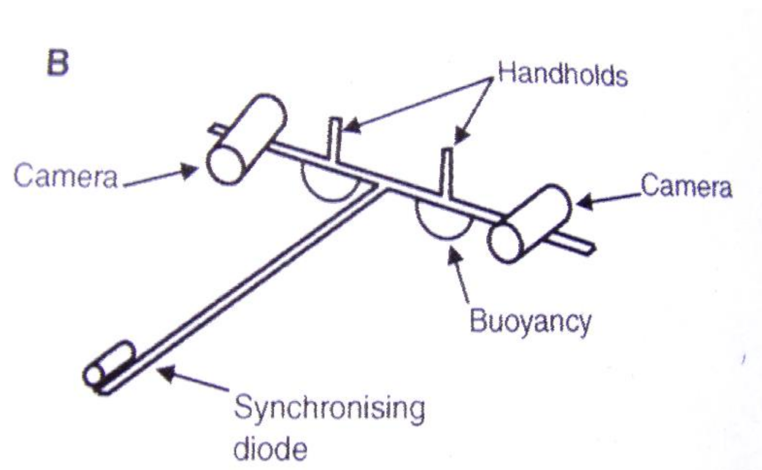

Figure 6.3.1. The stereo-video apparatus uses two cameras mounted on either side of the aluminum bar with a central diode extending in front of the cameras used to synchronize the video footage during analysis (Exton 2013).

6.4 Benthic Invertebrate Abundance

Benthic invertebrate abundance surveying methods followed closely already to those described in Opwall's Handbook. The only contrast was length and width of the belt transects. Instead of 2m x 50m transects totaling 100m^2, we used 5m x 20m transect also totaling 100m^2 to accommodate the patchy nature of the reef. This will remain the same in future studies.

6.5 Growth Form Abundance

The QuadPod was an experimental survey used to calculate coral growth form abundance. It was great in theory, however, there were some setbacks to this apparatus. To fit the entire 1m x 1m quadrat in frame, the GoPro had to be fixed relatively far from the base. This disrupted the clarity of the images, rendering a large portion of the images useless. Of the 520 images taken with the QuadPod, only 101 were clear enough to analyze properly. Much time and energy can be saved by sticking with the line intercept method used in the benthic habitat surveys, which also has the ability to calculate coral growth form abundance.

6.6 3D Reef Modeling

A new 3D reef modeling technique designed by Oxford University and Operation Wallacea will be implemented on site. This method to construct and analyze digital representations of coral reef structures is said to be cost and time effective, and accurate with less than 3% variation, even when analyzed by someone with no computer programming ability. This survey can replace the growth form abundance surveys using the QuadPod, allowing us to much more accurately measure structural complexity along with rugosity (Young et al 2017).

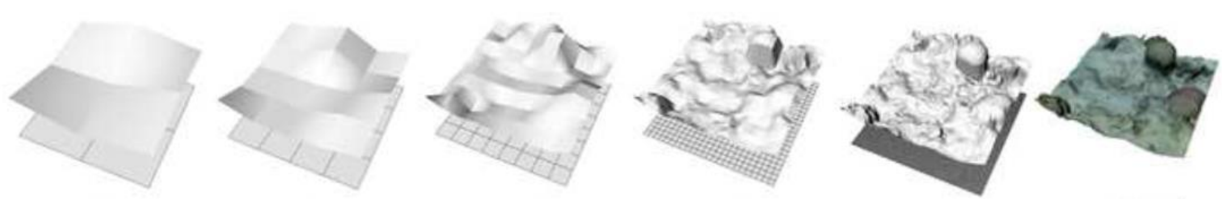

Figure 6.6.1. Demonstration of the program processes for the 3D reef modeling software.

7. Closing

Overall, this study has helped gain an understanding of the general status of the reef, identified key issues that will need to be closely monitored, while laying the groundwork for a long-term monitoring strategy to be implemented. The approach taken will continually develop, resulting in an optimal reef monitoring strategy for future years.

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