MADAGASCAR MARINE CONSERVATION RESEARCH PROGRAMME

Nosy Be, Madagascar

MGM Phase 183 Science Report

June 2018 – September 2018

Kimberly Rogan
Antoine de Clippele Emma Rolls

Contents

Staff Members

Kimberly Rogan (KR)	Research Officer (RO)
Awena Sangster (AS)	Dive Officer (DO)
Lucie Bennett (LB)	Assistant Research Officer (ARO)
Charlie Jones (CJ)	Assistant Research Officer (ARO)
Tara Roberts (TR)	Assistant Research Officer (ARO)
Emma Rolls (ER)	Assistant Research Officer (ARO)
Antoine de Clippele (AD)	Assistant Research Officer (ARO)
Victor Tomboravo (VT)	Local Staff (LS)

1. Introduction

Madagascar is the world's fourth largest island. Located in the southwest Indian Ocean, 440km off the eastern coast of Africa and across the Mozambique Channel; it boasts over 5,000km of coastline with a coral reef system that extends approximately 3,540km (Jadot et. al, 2015, Cooke *et al*., 2000). Madagascar has the highest coral diversity in the Western Indian Ocean (WIO) region and reef fish diversity in the northwest region, comprising of approximately 576 species (McKenna and Allen, 2003). Madagascar is considered to be one of the world's most important biodiversity hotspots and it is crucial that it becomes a priority for conservation efforts as the endemism and diversity are under threat by human impact (Goodman and Benstead, 2005).

Madagascar has various fisheries, which include traditional small-scale fisheries, where fishermen use traditional wooden boats known as pirogues, to an industrial fleet that focuses on deep-sea and shrimp fishing (Jadot *et al*., 2015). Small-scale fishing target reef fish and invertebrates, which accounts for the majority of the annual catch estimate of 130,000 tons. Although certain species such as snappers and groupers are preferred, very few are considered inedible and therefore still fished from the reefs (Jadot *et al*., 2005). Targeting larger, predatory species can eventually lead to what is called a trophic cascade, where the abundance of prey species can increase and lead to a reduction in the quality of primary production (Wilson *et al*. 2010). Fisheries in Madagascar are poorly managed with the actual catch being underreported by up to 500% in past years (LeManach *et al*., 2012). Although the gap between reported catch and actual catch is decreasing, there is still approximately 40% underreported catch occurring each year (LeManach *et al*., 2012). A large percentage of the population in Madagascar rely on small-scale fishing as their base income, which makes the heavy overfishing of coral reefs a serious issue for marine ecosystems and future food security.

Coral reefs are delicate and complex ecosystems that are susceptible to natural and anthropogenic disturbances, which increase the risk of habitat loss for marine organisms. The majority of coral reef fish have close associations with coral reefs and some are even highly dependent on the benthic substrate (Wilson *et al*. 2001). Previous studies have indicated that coral reef fish assemblages have exhibited signs of a change in structure, which is causing a loss in biodiversity (Feary *et al*., 2007). The shift in fish communities suggests that there is a high reliance on coral reef habitat and adult fish population dynamics may be strongly affected by habitat recruitment. For example, although a certain fish species may not typically be associated with branching corals, they may begin to inhabit such areas if necessary (Feary *et al*., 2007). A serious long-term ecological impact of phase-shifts in coral reef environments includes the loss of invertebrate and fish species, and coral diversity (Jackson *et al*., 2001).

The limited body of environmental research of of marine organisms inhabiting Madagascar's waters is insufficient to estimate species richness; therefore it is important to continue research on the state of the coral reefs in the Nosy Vorona Passage(Goodman and Benstead, 2005)There are two marine protected areas (MPAs) in Madagascar and multiple locally managed marine areas (LMMAs), but only 2% of the coral reefs in Madagascar are located within those protected zones and the majority of fisheries are regarded as unsustainable (Goodman and Benstead, 2005).

Frontier Madagascar has been monitoring sites in Northwest Madagascar since 2010. Operating from the village of Ambalahonko, Nosy Be, Frontier uses trained staff members and volunteers to collect data on the marine fauna surrounding the Nosy Vorona Passage. This report discusses the research and conservation work undertaken by the Marine Conservation Research Team from June to September 2018.

1.1 Aims

The general aims of the Frontier Madagascar Marine Conservation Research Program are to research the health of coral reef ecosystems in Nosy Vorona Passage and to train volunteers in the scientific methods necessary to conduct surveys. Surveys on reef biodiversity include fish, nudibranch, invertebrate abundance, and benthic composition. Turtle surveys are also conducted at three sites to evaluate sex ratios in the region. As the state of the reefs is better understood, measures can be recommended, and conservations can be enacted. Regular beach cleans are also completed to document environmental pollution and to implement management strategies for proper litter disposal.

1.2 Objectives

There are various objectives, which must be completed to investigate the broad aims of the project:

Objective 1: To assess reef fish communities using underwater visual consensus (UVC) to build upon a long-term dataset of fish assemblages.

Objective 2: To assess the state of invertebrate species using UVC surveys and to build upon a long-term data set. The research will focus on *Diadema setosum*, a species of coral grazing urchin known to cause detrimental effects on reefs.

Objective 3: To assess the abundance and diversity of nudibranch species using UVC surveys and to build a long-term data set.

Objective 4: To monitor the benthic community composition using line intercept transects to use as a long-term data set.

Objective 5: To evaluate the sex ratio of hawksbill turtles in the Nosy Vorona Passage.

Objective 6: To assess the marine litter collected along the beach and in the mangroves near Frontier Madagascar Camp and to enact measures to reduce the quantity of litter.

2. Training

2.1 Briefing

Initial presentations on camp logistics, health and safety, dive operations, and the MGM project were delivered within the first week of the volunteers arriving on camp (table 1).

Table 1. Briefing sessions for new staff and volunteers conducted during Phase 183.

Briefing	Contents of the Talk
Introduction to Camp	An initial introduction to the facilities on camp and a presentation explaining procedures followed by a tour.
Health and Safety	Raising awareness of the potential health and safety risks that may be encountered during an expedition.
Dive Operations	Explanation of diving standards and practices followed by a tour around dive facilities and equipment.
Introduction to MGM	General introduction to the marine program including tour of the science hut and science resources. Explanation of aims, methodologies, and expected outputs for the projects.

2.2 Science Lectures

A number of lectures were given, and documentaries shown throughout phase 183 (table 2). Lectures and quizzes/tests used in previous phases were updated and new lectures were created to aid in learning. Conservation documentaries were also shown on occasion during this phase to encourage discussion amongst volunteers.

Table 2. Lectures and documentaries shown to volunteers during Phase 183.

Presentation/Documentary	Contents
Survey Methodology	Introduction and instruction of baseline survey protocol (BSP) used for coral reef research.
Schooling and Territorial Fish	Introduction of schooling and territorial fish species assessed during surveys.
Invertebrates	Introduction to invertebrate species assessed during surveys.
Benthic and Coral Biology	Introduction to benthic classes and coral formations assessed during surveys.
Nudibranchs	Information on nudibranchs and their biology, ecology, and identification of commonly found species.
Turtles	Information on turtle biology, ecology, conservation, and survey methods.
Chasing Coral	Documentary about ocean acidification and threats faced by coral reefs.
Project Manta	Documentary about Project Manta that reveals some of the manta ray's habits and the threats they face around the world.

2.3 Practical Instruction

After introductory lectures and required dive training, in-water training for survey techniques and species identification begins. Identification for fish and invertebrate species, and benthic compositions are practiced using flash cards. After revision, standard computer quizzes (20 questions) and tests (30 questions) are given. Once they are passed, an in-water test takes place with a member of staff. All tests have a pass mark of 95% and once passed the volunteer may take part in surveying.

2.4 Dive Training

Volunteers must be qualified as PADI Advanced Open Water or higher to participate in surveys. Please see the dive report for all dive training undertaken during this phase.

3. Research Program

3.1 Biological Monitoring of Coral Reefs in the Nosy Vorona Passage

3.1.1 Introduction

Coral reefs around the world are being threatened by climate change and other human impacts. Approximately 30% of coral reefs have already suffered detrimental effects and by 2030 it is predicted that up to 60% of coral reefs may be lost (Hughes *et al*. 2003). Despite their importance, between 50 - 70% of all coral reefs are still under threat from anthropogenic pressures such as coral bleaching, rise in sea temperatures, overfishing, and damage from boat/fishing equipment, (Hoegh-Guldberg *et al*, 1990; Goreau 1992; Sebens 1994; Wilkinson and Buddemeier 1994). Since the pre-industrial era, surface air and sea surface temperatures have risen approximately 1°C. This raise in temperature is human induced and expected to reach 1.5°C in the near future (van Diemen *et al*, 2017). The rapid warming causes an extreme amount of stress on coral reefs and marine organisms, which causes a habitat range shift for most organisms (Hoffman and Parsons, 1997; Woodward, 1987). Sessile organisms, such as corals, are unable to relocate to more suitable conditions and are therefore left to suffer the consequences of a rapidly changing environment. Although coral reefs only cover about 0.5 – 1% of the world's oceans, they form the most diverse and productive ecosystems in the ocean (McAllister, 1991). It is estimated that 25% of all marine fish inhabit coral reefs and are therefore highly dependent on the benthos for survival (Dubinsky, 1990; McAllister, 1991). Conservation efforts are therefore vital to preserve existing coral species for the many services they provide in the face of such rapid environmental change and severe anthropogenic influences. Not only do coral reefs provide habitat for thousands of marine species, they contribute millions of dollars each year to ecotourism for snorkeling and diving (Spalding *et al*., 2017).

Population dynamics is an important branch of ecology for coral reefs that includes the study of short and long-term changes in a given population's size, structure and age distribution. By studying a population, an understanding of the ecological drivers behind the population can be established, this information is useful when assessing the vulnerability of a population to biotic and abiotic effects, as well as the long-term sustainability while under environmental stress (Verburg *et al*, 2002). Studies of population structures are usually completed over several years to establish an estimate of a species survivability and productivity for future growth (Kenkel *et al*, 2009; Chaloupka *et al*, 2008). Constant monitoring and surveillance of populations is becoming increasingly important to carry out to ensure the safety of a species when under external pressures such as anthropogenic induced climate change and pollution (Walther *et al*, 2002; Haward, 2018; Schmidt *et al*, 2017).

The populations in marine ecosystems, like coral reefs, need to be monitored due to their complex communities. Marine fish and invertebrate species play an essential role in food webs and nutrient cycling (McClanahan *et al*. 1999). In particular, marine macro invertebrates contribute to bioturbation and bioerosion of coral reefs, assisting in coral settlement (McClanahan *et al*. 1999). Bioturbation is a process in which sediments are reworked by animals or plants while bioerosion is the breakdown of hard ocean substrates. Some macro invertebrates that contribute to bioturbation are sea cucumbers as they defecate sediment grains. Mollusks such as clams contribute a large percentage to bioerosion as they burrow into corals. A rise in ocean temperatures combined with a higher ocean acidification and an increased amount of dissolved inorganic carbon will prevent the growth of some invertebrates (Caldeira and Wickett, 2003). The loss of invertebrate species, greatly reduces bioturbation on benthic substrates, causing a total loss of functionality of the ecosystem as a whole (Solan *et al*, 2004).

Other anthropogenic pressures can also affect the functionality of the coral reef. For example, our reliance on fisheries for food and resources places a strain on marine populations that live in areas such as Madagascar. This increased fishing pressure paired with other abiotic effects places marine species' populations at a higher risk of decline or extinction, with unregulated commercial fishing already causing a decrease in marine populations off the coast of Madagascar (Le Manach *et al*. 2012). A stable fish population is vital to maintain for both human livelihoods and to maximize ecosystem functionality throughout coral reefs.

In the present study, populations of reef fish, invertebrates, nudibranchs and benthic compositions are monitored to assess their population's long-term viability as well as resistance and resilience to increasing anthropogenic effects. This study aims to provide evidence of a decline in marine biodiversity in Nosy Vorona due to unsustainable anthropogenic activity and to make recommendations for sustainable management of the marine environment.

3.1.2 Survey Sites

During phase 183, fish, invertebrate, and nudibranch abundance and diversity, as well as benthic composition were sampled at four sites in the Nosy Vorona Passage, Nosy Be, NW Madagascar (figures 1 and 2). This area is surrounded by the fishing villages of Ambalahonko (pop. 100) and Antafondro (pop. 100), which are approximately 8km east of Hell-Ville. The area is characterized by fringing patch reefs and shallow continental shelf waters with depths reaching no more than 20m.

Figure 1. The island of Nosy Be, located northwest of mainland Madagascar.

Figure 2. The four survey sites in the Nosy Vorona Passage

Table 3. Description of the study sites surveyed in phase 183. Temperature ranges for all sites is between 27°–31° C.

Site	Depth Range (m)	GPS	Description
Home Reef	3.0-6.0	13 24’25” S 48 20’22” E	Small, degraded reef that is in close proximity to villages, which contribute to freshwater runoff and heavy sedimentation. Some macro and turf algae. Heavy fishing pressure. Weak to moderate current.
Three Brothers	3.0- 7.0	13 25’53” S 48 21’50” E	Fringing mix of continuous and patchy reef formed around three distinct outcrops. Moderate live coral cover, little terrestrial influence, and moderate fishing pressure. Weak to strong current.
Nosy Vorona	2.0- 10.0	13 25’30” S 48 21’46” E	Fringing patchy reef formed around a small island. Moderate live coral cover with extensive coral rubble and patchy sea grass beds. Little terrestrial influence, fishing pressure, and moderate to strong current.
Area 51	7.00-16.00	13 25’27” S 48 20’71” E	Large live coral and sponge site in the middle of the Vorona Passage. Typically, strong currents and often high sedimentation.

3.1.3 Methodology

Underwater visual consensus (UVC) surveys were conducted using SCUBA by qualified staff and volunteers. A minimum of three divers were necessary to complete a full survey. The roles involved different surveyors focused on schooling fish, territorial fish, invertebrates, and benthic (table 4). Transects were a total of 80 meters and divided into 20 meter sections with a 10 meter redundant area to reduce duplicate counts of fish (0-20m, 30-50m, 60-80m). Transects were placed randomly on the reef boundary for fringing reefs and across the reef for patch reefs. Random transects allow you to get a broader understanding of the different species and benthic compositions of the entire reef rather than focusing on one specific location on the reef. To ensure randomization, divers would snorkel towards the reef then descend once a part of the reef began. Schooling and territorial fish surveyors count the number of fish within a 5x5m box and total the number of species for the 60m transect. Invertebrate surveyors swim in a zigzag pattern along the transect searching for invertebrates and total the number of individuals. The benthic surveyor swims along the transect line recording composition including hard coral growth forms, soft coral, sand, rock, coral rubble, algae, hydroids, and zoanthids. The length of each category under the transect line is recorded Nudibranch surveys were conducted by active search and a quadrat. The total search time would last for 20 minutes and the timer would be stopped when a nudibranch was found. The 1m x 1m quadrat was placed over the substrate with the nudibranch in the middle. A photo was taken for identification later and the percent of benthic composition was counted. For the statistical analysis, an ANOVA and a two-way ANOVA were used. To verify conditions of ANOVA, the Shapiro test (normality), Levene tests and Fligner (homogeneity of variances) were used. When the conditions of ANOVA weren’t met, a nonparametric Kruskal-Wallis test was used. All statistics tests were run using Rstudio version 1.1.456 (Rstudio Team, 2015).

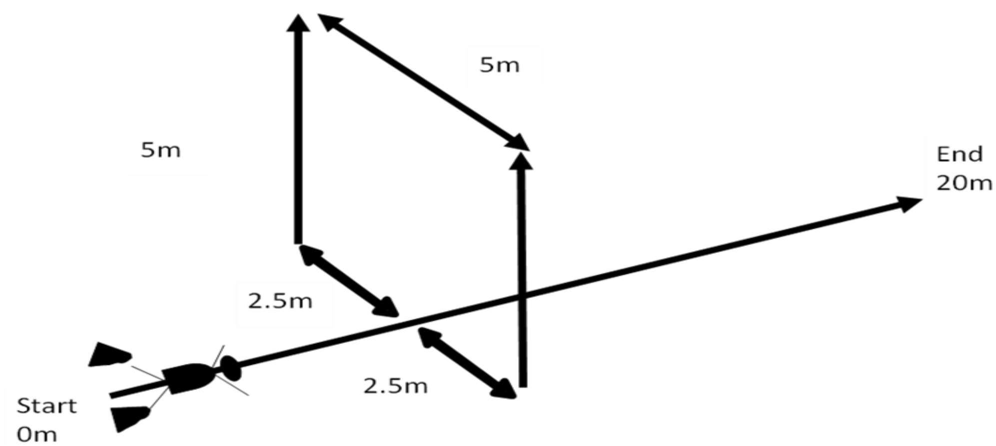

Figure 3. Procedure for UVC surveys of a 20m section of the transect. The surveyor records all fish observed in the box. The invertebrate surveyor will follow a similar procedure, except swim in zigzag formation to 2.5 meters on each side of the transect.

Table 4. The roles and responsibilities of each diver taking part in BSP surveying. Categories were split into schooling and territorial fish to make studying and surveying easier for the divers.

Position	Responsibilities
Territorial Fish Surveyor	Record all individual territorial fish species within a 5m area along the transect.
Schooling Fish Surveyor	Record all individual schooling fish species within a 5m area along the transect.
Invertebrate Surveyor	Swims in a zigzag pattern along the transect and records individual invertebrate species.
Benthic Surveyor	Record all coral formations and changes in substrate along the transect line.

3.1.4 Results

3.1.4.1 Assessment of Reef Fish Abundance and Diversity in Nosy Vorona Passage

Five surveys were conducted per site with a total of 1349, 6505, 2881 and 2887 fish recorded at Home Reef, Nosy Vorona, Three Brothers and Area 51 respectively. Although the average fish abundance varied at each site ($P<0.05$), a significant difference was only recorded in average fish abundance between Nosy Vorona and Home Reef ($P<0.05$). Fish abundance was highest at Nosy Vorona, with an average of 1,301 fish recorded per survey, with Home Reef only recording an average of 263.6 fish by comparison (figure 4). Similar trends in species and family richness were witnessed across the sites with an average of 185 species and 12.6 families recorded at Nosy Vorona and 114 species and 7.6 families at Home Reef (figures 5 and 6).

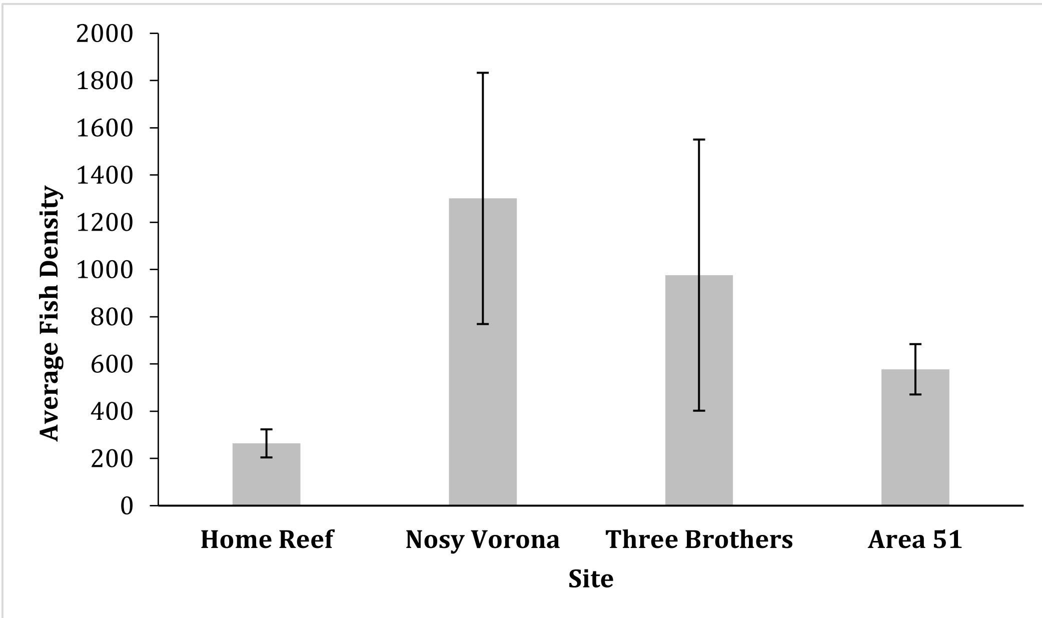

Figure 4. Average fish density at each site. Data collected across five 60 x 4 m transect locations per site.

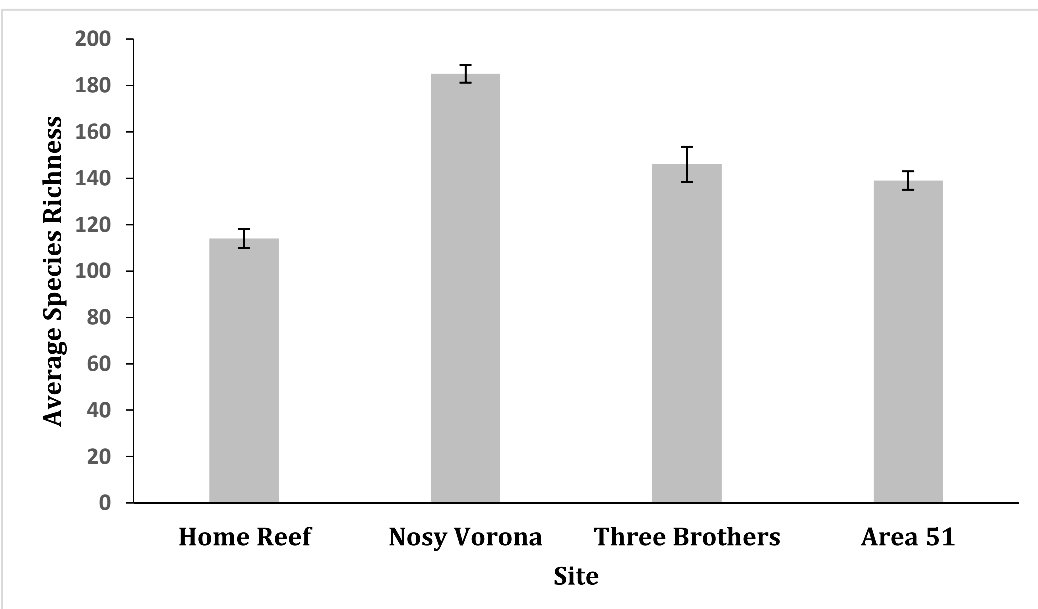

Figure 5. Fish species richness at each site. Data collected across five (5) 60 x 4 m transect locations per Site.

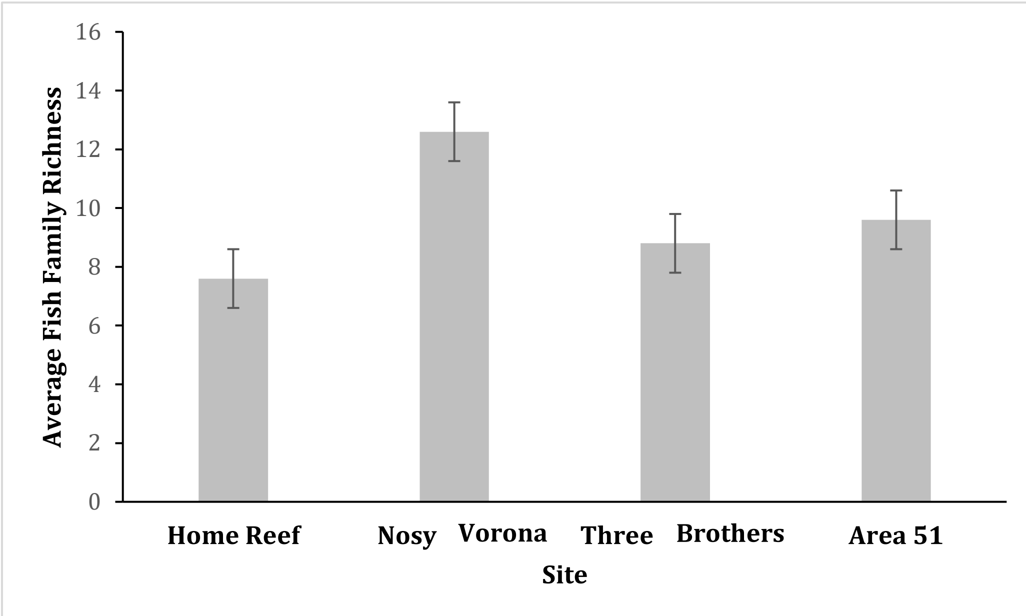

Figure 6. Average fish family richness at each site. Data collected across five 60m x 4 m transect locations per site.

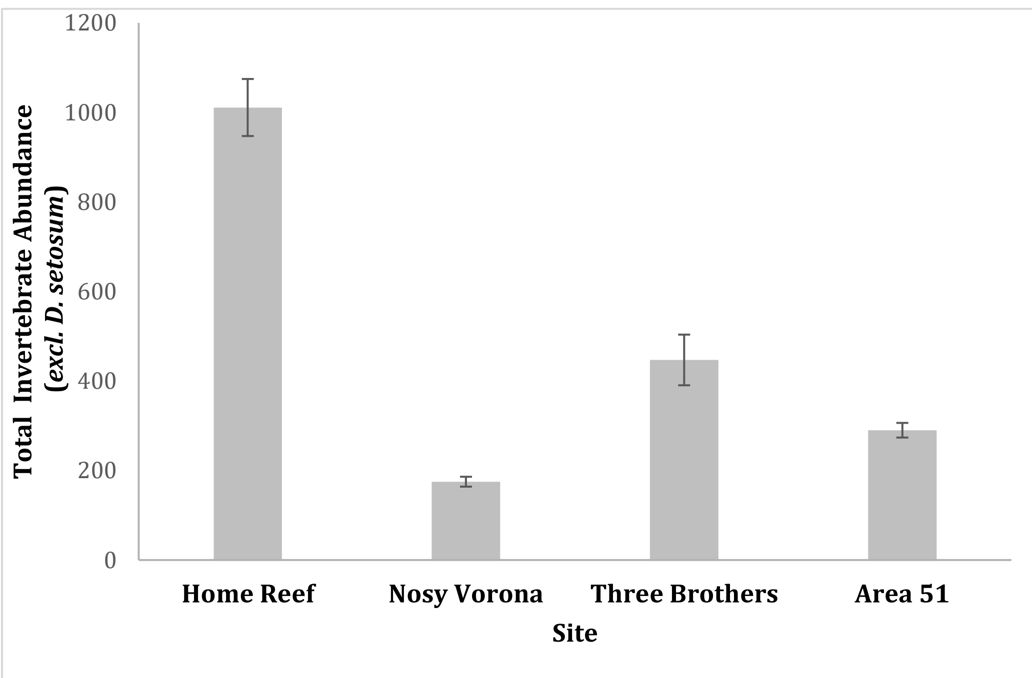

Figure 7. Total invertebrate abundance per site excluding family *D.setosum*. Data collected from five 60m x 5 m transect locations per site.

3.1.4.2 Assessment of Invertebrate Abundance and Diversity in Nosy Vorona Passage

No significant difference was observed in invertebrate species richness across survey sites, with the average number of species ranging from 6.8 at Home Reef and 9 at Nosy Vorona (P>0.05). There was however, a significantly higher total invertebrate abundance (excl. rate *D. setosum*) at Home Reef (figure 7). The invertebrate family *D.setosum* was excluded from total abundance data as each survey site recorded a significantly higher abundance of *D.setosum* than all other families documented. It was decided to have *D. setosum* separate from the other invertebrates as it would have caused a massive skew in the data if combined with all invertebrates.

Nosy Vorona recorded the highest *D.setosum* abundance, with an average total of 202.2 recorded within each 60m x 5m survey. It should be noted that, although a significantly higher abundance of *D.setosum* in comparison to other invertebrate families was recorded at each site, no significant difference was observed when comparing *D.setosum* abundance across each survey site (P>0.05).

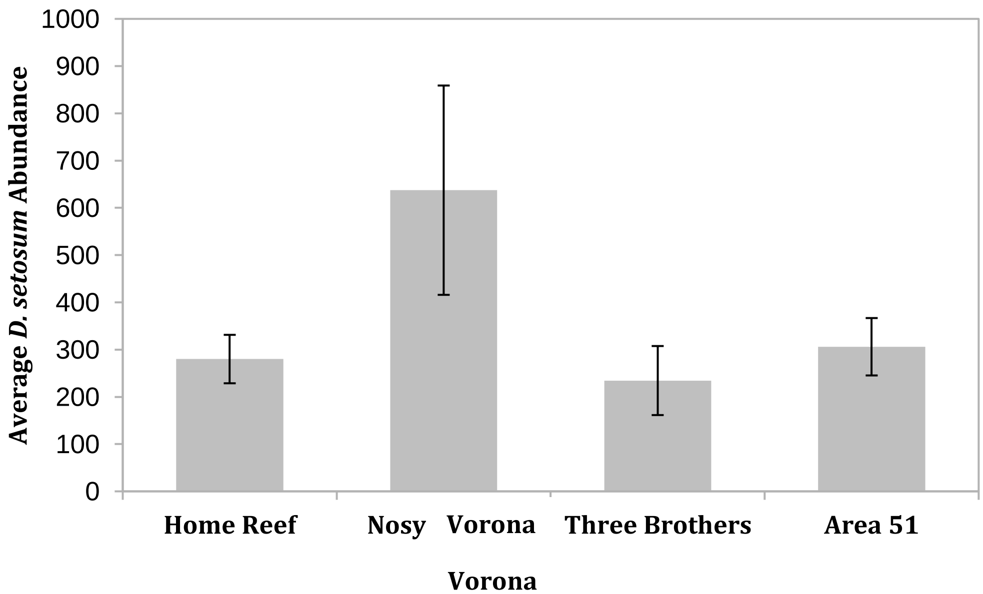

Figure 9. Average *D.setosum* abundance per site. Data collected from five 60m x 5m transect locations per site.

3.1.4.3 Assessment of Nudibranch Abundance and Diversity in Nosy Vorona Passage

A separate study of nudibranch abundance and species density was conducted across four survey sites, with the highest recorded abundance at Area 51 which had an average of 8.2 nudibranchs per transect. A significant difference was found to exist between nudibranch abundance at Area 51 and each additional site (p values; Home Reef P<0.001, Vorona P<0.001 and Three Brothers P<0.05). There was no significant difference in nudibranch abundance between Home Reef and Vorona (P>0.05), and Home Reef and Three Brothers (P>0.05).

In total, 68% of nudibranchs were recorded on dead coral or coral rubble with algal cover substrate. The remaining nudibranchs recorded were found to prefer a sand (10%), sponge (21%) or hard coral (1%) substrate. No significant difference in species richness was found across a comparison of the four sites (P>0.05).

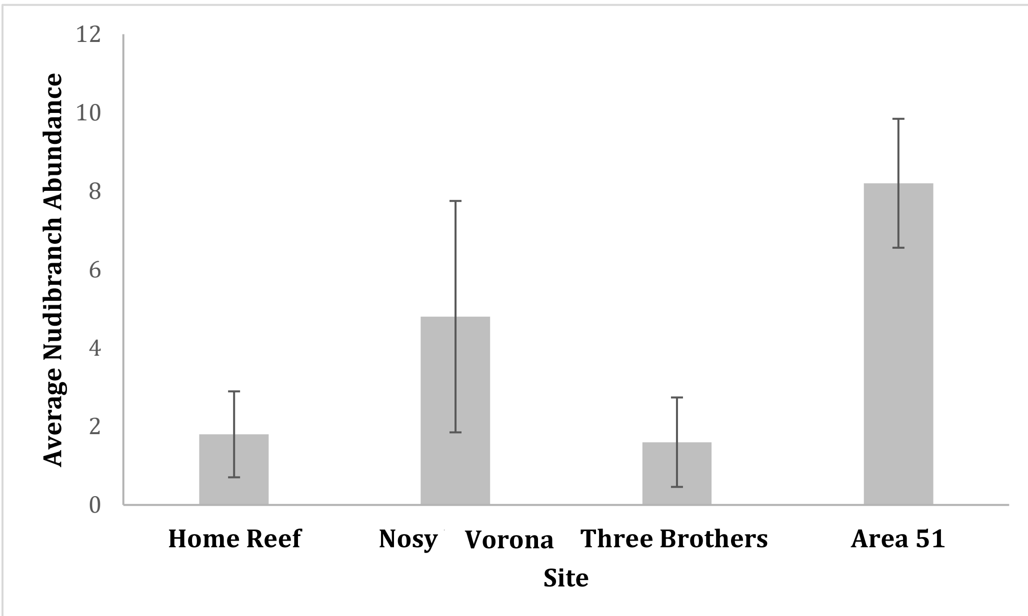

Figure 10. Average Nudibranch abundance per site. Data collected from five 60 x 5 m transect locations per site.

3.1.4.4 Documentation of Benthic Morphology in Nosy Vorona Passage

No significant difference was found between benthic morphology at each site (p values; hard coral 0.49 algae 0.28 rubble 0.067 soft coral 0.19)[1]. Figure 11 illustrates that hard coral was the dominant living coral morphology across each site, with Nosy Vorona exhibiting the highest percentage cover at 38% hard coral. Nosy Vorona also held the lowest coverage of algal and rubble coverage at 3.7 and 5.2% respectively. In comparison, Home Reef consisted of 42% algal and rubble cover and less than 35% living coral cover[2]. Nosy Vorona, Area 51 and Three Brothers each recorded 13 different species across living benthic compositions where 11 compositions were recorded at Home Reef. Nosy Vorona, Area 51 and Three Brothers each recorded 13 different species across living benthic compositions where 11 compositions were recorded at Home Reef.

[1] It should be noted that statistical analysis was carried out on average hard coral, soft coral, algal and rubble cover for each site only, as these benthic categories were considered the most significant indictors of reef health.

[2] ‘Living Coral’ cover encompasses hard corals, soft corals, sponges, anemones, hydroids, and zoanthids.

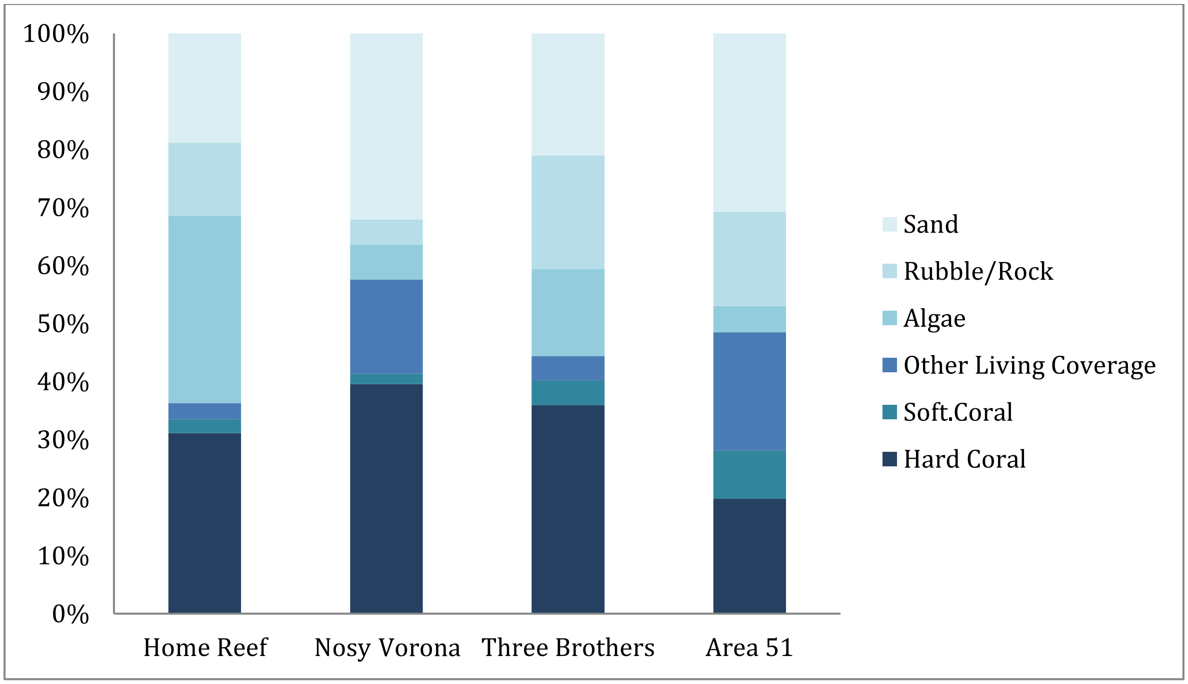

Figure 11. Average percentage cover of benthic morphology across 3 surveys at Home Reef and Nosy Vorona and 4 surveys at Three Brothers and Area 51.

3.1.5 Discussion

Fish and invertebrate community structures, and benthic composition in a coral reef ecosystem can act as an indicator of overall reef health. Home Reef had the lowest average fish species and family richness, which can possibly be due to the benthic substrate consisting with a large percentage of algae, which does not provide sufficient habitat for reef fish. Larger fish such as parrotfish and triggerfish graze on healthy reefs, which may be a reason why they are not in high abundance at our survey sites. Other fish such as the blue green chromis (*Chromis viridis*) use tabular corals as their habitat since it provides protection from larger predators. Nosy Vorona had the highest average fish species and family richness but the lowest total and average invertebrate abundance. Although previous studies indicate *D. setosum* on coral reefs occur at high abundance at reefs low in predators, the echinoid was most abundant at Vorona despite the high quantity of fish species and families present (Larsson *et al*., 2010). This could be due to the high percentage of coral rubble/rock cover, which can indicate that the health of Vorona's reef may already be in decline. There are sections at Vorona that show signs of bleached coral and areas where the coral is already dead and covered in algae. Home Reef had the highest average invertebrate abundance in comparison to the other three sites. All sites were fairly similar when comparing average invertebrate species richness, as the most common species found at each site were the echinoid (e.g. *P.gratiosa*), holothuroids (e.g. *H. atra*, and *H. edulis*), bivalves, and nudibranchs. Although nudibranchs were recorded at each site, they were found at a significantly higher abundance at Area 51 favouring substrates such as coral rubble, sand, and algal cover.

The lack of large predatory fish on the reef's frontier survey suggest these reefs are not very healthy which has resulted in dead coral patches and high sea urchin populations. These cause of these issues are not certain but may be as a result of overfishing. This pressure can become a major stressor on the reefs as loss of predators can cause inter- and intra- specific competitive interactions, such as sea urchin populations, in this case *D. setosum*, dominating coral reefs (Larsson *et al*., 2010). Previous studies have shown that when sea urchin predators such as Balistidae and Labridae show signs of decreasing populations, it gives an opportunity for sea urchin grazers to increase greatly in numbers (Hamilton & Caselle, 2015). When sea urchin populations become too high, they create areas known as "urchin barrens", characterized by destructive grazing of living and dead coral (Larsson *et al*., 2010). Urchin barrens have significant implications for ecological processes on coral reefs, as they represent areas of low productivity and diversity (Valentine & Johnson, 2005).

There are currently two strategies that have been put into use globally to help prevent coral reefs from suffering the consequences of urchin barrens. The first is to alleviate fishing pressures from the reefs to allow for sea urchin predators to increase their population numbers. The other is called the "Sea Urchin Reduction" method, which requires sea urchins to be removed by hand (Larsson *et al*., 2010). For this, divers use a knife to quickly kill the urchin and it is removed from the reef. It is a relatively safe method if divers receive proper training. While sea urchin reduction removes the problem immediately, it does not solve the issue of creating a long-term healthy ecosystem. For conservation purposes, managing fishing practices would be the most beneficial to the overall health of the reefs.

Further biological monitoring of coral reefs is vital now more than ever to understand any patterns or changes in the marine ecosystem. With climate change and overfishing as serious threats to the health of reefs globally, continuous studies of fish assemblages, invertebrate abundance and diversity, and benthic composition are essential in implementing conservation and management strategies. Monitoring the fishing practices around Nosy Be could prevent further urchin barrens of the coral reefs around that area. Future research would also involve seeing how the species composition of fish is affected by substrate type, and reef health (disease, bleaching, algal blooms).

3.2 Marine Litter

3.2.1 Introduction

Over the past 50 years, plastic pollution, has become an increasing concern due to plastics' longevity and detrimental impact on marine life (Derraik, 2002). Plastics contribute 60-80% of all marine debris with equipment from fishing, ship traffic, deliberate littering, or careless handling of waste being top contributors (Derraik, 2002). Plastic bags, synthetic rope, fishing nets, and other plastic materials may last up to decades in the ocean and although they are typically lightweight and buoyant, they can end up on the seabed and become ingested or entangle wildlife (Wolfe, 1987). Litter also washes up on beaches, making shorelines aesthetically unappealing and reducing the value of these resources from a recreational perspective (Ryan and Swanepoel, 1996). In villages such as Ambalahonko, deliberate littering typically ends up in the surrounding mangroves and in nearby reefs (Rogan *et al.,* 2018).

Beach cleans are effective ways to have a positive impact on the immediate environment and to assess potential sources of pollution, so management efforts can be implemented to ensure the proper disposal of non-biodegradable litter. With the knowledge Frontier obtains from conducting beach cleans, efforts can be made to ensure proper disposal of biodegradable and non-biodegradable litter as well as community involvement to educate about the threats of litter in the ocean, especially with mangroves and coral reefs being major ecosystems for the village of Ambalahonko.

3.2.2 Methodology

Beach cleans were typically completed twice per week, with one on the right and left side of the Frontier camp (figure 12). Cleans usually lasted about 30 to 45 minutes. Staff and volunteers split to the right of camp, past Ambalahonko (village transect, approx. 200m) or to the left of camp (control transect, approx. 500m). The control transect is not in close proximity to the village and so the litter collected here is not likely to be from the villagers but marine litter. All litter was collected between the mangrove roots and the tree line. For each piece of litter, the type and zone (mangrove roots, sand/rocks, and trees) in which it was collected was recorded. Upon collection, litter was sorted into burnable and non-burnable bags to dispose of properly after the beach cleans. Unfortunately, there is no "green" way of disposing of rubbish so plastics, fabrics, papers, and things that can be burned are all taken to the burn pit on camp, which is the method locals use. Metals, glass, and electronics are non-burnable and are kept separately to be taken into a facility in Hellville. Plastic bottles were stored on camp for the potential of reusing for other projects.

Figure 12. Village (red) and Control (yellow) transect locations. Frontier base camp is located between the two transects. The village transect was approximately 200m in length, falling directly adjacent to Ambalahonko Village, the control transect was the stretch with no direct link to either Ambalahonko village to the west or Antafondro village to the east.

3.2.3 Results

A total of 25 beach cleans were conducted within phase 183 with a total of 3,532 individual pieces of marine litter collected from the upper tree line, substrate and lower mangrove roots. Approximately 64% of all litter was collected from the transect adjacent to the village, which was found to be significantly higher than the other transects ($P<0.01$).

Soft plastics (18%), hard plastics (12%) and food wrapper (11%) accounted for the greatest proportion of litter on the village transect, whereas soft plastics (13%), hard plastics (27%) and fabric/clothing (10%) accounted for the greatest proportion of litter on the control transect. A significantly higher amount of litter was collected from the upper tree line in both the village ($P<0.001$) and control transect ($P<0.001$). No significant difference was found between the quantity of litter collected from the substrate and mangrove roots ($P>0.05$).

3.2.4 Discussion

Plastic items, including bags and bottles, were the most common type of litter found along the beach, which is consistent with previous published works (Santos *et al.*, 2008). As part of the village transect is directly in front of Ambalahonko, it can explain why there is such a higher percentage of debris found compared to the control transect. There are several reasons that can lead to the large quantities of litter found on the beach. First, the lack of litter collection and processing facilities near

Ambalahonko gives locals almost no other alternative to dispose of their waste and there are no alternatives to single use plastics locally available. There is also a lack of education about the impacts of anthropogenic litter on beaches and in the oceans. The interest shown by local children to help with Frontier beach cleans highlights an opportunity to engage further with the community on environmental awareness and conservation activities. In the future, it would be important to involve the community more by having large beach cleans where locals can join Frontier regularly. We will also begin to educate them more with the community project on the effects of plastics in the ocean, we can hope that it will encourage them to dispose of waste properly.

3.3 Hawksbill Turtle Survey

3.3.1 Introduction

Madagascar is home to five of seven species of sea turtles including the critically endangered hawksbill, *Eretmochelys imbricata* (Hays *et al*., 2010). Madagascar hosts important nesting and foraging populations, and it is estimated that approximately 15,000 turtles are caught annually for domestic use and international trade (Hays *et al*., 2010). Sea turtles face many threats including hunting, habitat destruction, marine ecosystem disruption, and by-catch in artisanal and commercial fishing gear, but the main threat to turtle populations is climate change (Hays *et al*., 2003). All species of sea turtles exhibit what is called temperature dependent sex determination (TSD) (Hays *et al*., 2010). Sea turtle populations, which are already under threat, have begun to exhibit skewed sex ratios towards the female sex that is produced at higher temperatures (Hays *et al*., 2010), therefore climate change may induce the production of single-sex generations and ultimately extinction (Hays *et al*., 2003). Conducting research on hawksbill turtle populations around the Nosy Vorona Passage will allow for a better understanding of the abundance, behaviour, and sex ratios, which can help in future conservation efforts. We are hopeful that if we get reliable results in the future that we will be able to share our work with other conservation organizations, the local community and with local governments.

3.3.2 Methodology

Snorkel surveys were conducted at Home Reef, Nosy Vorona, and Three Brothers for 45 minutes each using active search methods with a minimum of two snorkelers per team. Sites were determined in coordination with the BSP reef surveys. Once reef structure was spotted, surveyors would swim in the area of for 45 minutes. One surveyor collected data via a dive slate while the other took photographs using a variety of underwater action cameras, preferably GoPro. Before their first survey, volunteers would be briefed on each category on the dive slate. Photos of the turtle need to be taken on each side of their face as this is where the identifiable features are found. The photos are then sorted by date and site to later be used on the IS3 Pattern Program. Dive slates have categories for species, sex, size, behaviour, features, interaction with snorkelers, number of vessels, and vessel distance. Behaviors included swimming, resting, and eating. Size of the carapace was estimated in categories beginning with less than 60cm and ending with greater than 100cm. Categories in between those sizes were grouped in intervals of 10cm (60-70cm, 70-80cm, etc.).

3.3.3 Results

Data from the Phase 183 Turtle Identification project were combined with that of Phase 182, for a total of 20 turtles recorded across 19 surveys. Of these surveys, 11 were conducted at Home Reef, four at Nosy Vorona and four at Three Brothers. A greater number of surveys are required at the sites Nosy Vorona and Three Brothers to obtain any statistical significance in relations to turtle abundance at each site. Home Reef is the closest site to camp and is a short swim away whereas the other sites require a 15-minute boat ride. At the other sites, if there are not enough surveyors to have a reef monitoring team and a turtle survey team then no turtle surveys will be conducted on that day. The amount of surveys at each site is highly reliant upon the number of volunteers available.

All recorded turtles were hawksbill, of which 85% were female. Behaviors observed included locomotion and feeding. Most of the turtles were found on the reef itself while few were found swimming out towards the open water. A photographic log of each sighting has been recorded however no discernable features were noted on the majority of individuals. There are currently not enough photographs to create a catalogue as yet, however, further surveys and photographs will continue next phase that will hopefully allow us to begin creating a catalogue. They are all currently sorted by site and date. Once enough photos are collected, we will begin using the IS3 Pattern Program to identify individuals and determine if they travel between the sites.

3.3.4 Discussion

There needs to be significantly more data to support the idea that climate change may be affecting the sex ratios of hawksbill turtles in Madagascar. Surveys will continue into the next phase with further detail of turtles observed. While over the past few months, the majority of hawksbill turtles spotted have been female, which supports climate change skewing ratios to be more female dominant, it is still too early in the research to make any conclusions about turtle populations in the Nosy Vorona Passage. Since all turtles spotted have been hawksbill, the main focus of continued surveys will be noting the sex of any turtles, although behaviour and features such as damaged shells will be documented as well.

4. Proposed Research Plan for Phase 184

- Continue long-term biomonitoring of the coral reefs in the area (fish, invertebrate, nudibranch, and benthic).
- Continue beach cleans on each side of camp and extend to the village of Antafondro and involve the community more through education and large beach cleans.
- Turtle surveys will continue to focus on the skew of sex ratios as well as using photo identification to create a catalogue of individuals.
- Reconstruction and building of new Fish Aggregation Devices (FAD) and surveys will begin at each of the FAD's to determine if they are successful and beneficial for the villages.

5. References

Caldeira K. and Wickett M. (2003). Oceanography: Anthropogenic Carbon and Ocean pH. *Nature*, 425, 365-370.

Campbell, B., Hanich, Q., and Delisle, A. (2016). Not just a passing FAD: Insights from the use of artisanal fish aggregation devices for food security in Kiribati. *Ocean and Coastal Management*, 119, 38-44.

Chaloupka M., Kamezaki N. and Limpus C. (2008). Is climate change affecting the population dynamics of the endangered Pacific loggerhead sea turtle?, *Journal of Experimental Marine Biology and Ecology*, 356, 136-143.

Cooke, A., O Ratomahenina., E Ranaivoson and H. Razafindrainibe. (2000). Madagascar. In Sheppard, C.R.C (Eds). *Seas at the Millennium: An Environmental Evaluation*. pp. 113-131. Pergamon, Amterdam.

Derraik, J. (2002). The pollution of the marine environment by plastic debris; a review. *Marine Pollution Bulletin*. 44(9), 842-852.

Dubinsky Z. (1990) Coral reefs. Ecosystems of the World 25, *Elsevier*, 550pp.

Goreau T. (1992) Bleaching and reef community change in Jamaica: 1951-1991, *American Zoologist*, 32, 683-95.

Goodman, S. M. and Benstead, J. P. (2005). Updated estimates of biotic diversity and endemism in Madagascar. *Oryx*, 39, 73-77.

Hall E., Muller E., Goulet T., Bellworthy J., Ritchie K. and Fine M. (2018). Eutrophication may compromise the resilience of the Red Sea coral Stylophora pistillata to global change, *Marine Pollution Bulletin*, 131, 701–711.

Hamilton, S. Caselle, J. (2015) Exploitation and recovery of a sea urchin predator has implications for the resilience of southern California kelp forest, *Proceedings of the Royal Society B: Biological Sciences*, 282(1799),

Haward M. (2018). Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. *Nature communications*, 9.

Hays, G. Fossette, S., Katselidis, K. Schofield, G., and Gravenor, M. (2010). Breeding Periodicity for Male Sea Turtles, Operational Sex Ratios, and Implications in the Face of Climate Change. *Conservation Biology*, 24(6). pp 1636-1643.

Hoegh-Guldberg O., Mumby P., Hooten A., Steneck R., Greenfield P., Gomez E., Harvell C., Sale P., Edwards A., Caldeira K., Knowlton N., Eakin C., Iglesias-Prieto R., Muthiga N., Bradbury R., Dubi A., Hatziolos M. (1990). Coral Reefs Under Rapid Climate Change and Ocean Acidification, *Science*, 318, 1737-1742.

Hoffman A. and Parsons P. (1997). *Extreme Environmental Change and Evolution*. Cambridge, Cambridge University Press.

Jackson, J. B., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J., and Warner, R. (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science*, 293: 629- 638.

Jadot, C., Darling, E.S. and A. Brenier. (2015). Madagascar: A Baseline Assessment of Coral Reef Fisheries. *Wildlife Conservation Society*, Bronx NY USA.

Kenkel N., Hendrie M. and Bella I. (2009). A long-term study of Pinus banksiana population dynamics, *Journal of Vegetation Science*, 8, 241-254.

Lamb J., Willis B., Fiorenza E., Couch C., Howard R., Rader D., True J., Kelly L., Ahmad A., Jompa J. and Harvell C. (2018). Plastic waste associated with disease on coral reefs, *Science*, 359, 460-462.

Larsson, J., Henriksson, O., and Grahn, M. (2010). Population Genetic Structure and Connectivity of the Abundance Sea Urchin, Diadema setosum around Unguja Island (Zanzibar). *Western Indian Ocean J. Mar. Sci.*, 9(2), pp 165-174.

Le Manach F., Gough C., Harris A., Humber F., Harper S. and Zeller D. (2012). Unreported fishing, hungry people and political turmoil: the recipe for a food security crisis in Madagascar. *Marine Policy*, 36, 218-225

Le Manach F., Gough C., Humber F., Harper S. and Zeller, D. (2011). Reconstruction of total marine fisheries catches for Madagascar (1950-2008), *Fisheries Centre*, 4, 21-37.

McAllister D. (1991). What is the status of the world's coral reef fishes?, *Sea Wind*, 5, 14–18.

McClanahan T., Hendrick V., Rodrigues M. and Polunin N. (1999). Varying responses of herbivorous and invertebrate-feeding fishes to macroalgal reduction on a coral reef. *Coral Reefs*, 18, 195-203.

McKenna S.A. and G.R Allen. (2003). A Rapid Marine Biodiversity Assessment of Northwest Madagascar. *Bulletin of the Rapid Assessment Program 31*, Conservation International, Washington, DC.

Rogan, K., deClippele, A., and Rolls, E. (2018) Frontier Madagascar 182 Science Report.

Rilov, G. and Benayahu, Y. (2002). Rehabilitation of coral reef fish communities: the importance of artificial reef relief to recruitment rates. *Bulletin of Marine Science*, 70, 185-197.

RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

Santos, I, R., Friedrich, C, A., Ivar do Sul, J, A. (2008) Marine debris contamination along undeveloped tropical beaches from northeast Brazil. Environmental Monitoring Assessment.

Sebens K. (1994). Biodiversity of coral reefs: what are we losing and why?. *American Zoologist*, 34, 115-33.

Smith S. (1978). Coral reef area and the contributions of reefs to processes and resources of the world's oceans. *Nature*, 273, 225–6.

Solan M., Cardinale B., Downing A., Engelhardt K., Ruesink J. and Srivastava D. (2004). Extinction and Ecosystem Function in the Marine Benthos. *Science*, 306, 1177-1180.

Spalding, M. Burke, L. Wood, S. Ashpole, J. Hutchison, J. zu Ermgassen, P. (2017) Mapping the global value and distribution of coral reef tourism, *Marine Policy*, 82, 104-113

Valentine, J. Johnson, C. (2005) Persistence of sea urchins (*Heliocidaris erythogramma*) barrens on the east coast of Tasmania: inhibition of macroalgal recovery in the absence of high densities of sea urchins, *Botanica Marina*, 48(2)

van Diemen, Renee & Ferrat, Marion & Pathak, Minal & Portugal Pereira, Joana & Shukla, Priyadarshi & Skea, Jim & Slade, Raphael. (2017). The Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report Cycle, 2015 - 2022: Cities and Mitigation.

Verburg P., Soepboer W., Veldkamp A., Limpiada R., Espaldon V. and Mastura S. (2002). Modeling the Spatial Dynamics of Regional Land Use: The CLUE-S Model. *Environmental Management*, 30, 391-405.

Walther G., Post E., Convey P., Menzel A., Parmesan C., Trevor J., Beebee C., Fromentin J., Hoegh-Guldberg O. and Bairlein F. (2002). Ecological responses to recent climate change. *Nature*, 416, 389-395.

Wilkinson C. and Buddemeier W. (1994). *Global climate change and coral reefs: implications for people and reefs. Report of the UNEPIOC-ASPEI-IUCN Global Task Team on the Implications of Climate Change on Coral Reefs*. 124 pp. IUCN, Gland, Switzerland.

Wilson, S. K., Depczynski, M., Fisher, R., Holmes, T, H., O'Leary, R, A., and Tinkler, P. (2001) Habitat Associations of Juvenile Fish at Ningaloo Reef, Western Australia: The Importance of Coral and Algae. PLOS ONE 6(1).

Woodward F. (1987). *Climate and Plant Distribution*. Cambridge, Cambridge University Press.

Worm B. and Duffy J. (2003). Biodiversity, productivity and stability in real food webs. *Trends in Ecology and Evolution*, 18, 628-632.