Marine Conservation Project

Science Report, Phase 163

Nosy-Be, Madagascar

July 2016 – September 2016
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1 General Introduction

Coral reefs, which globally span ~527,072 km$^2$, maintain the highest levels of diversity among marine ecosystems containing thousands of fish, macro- and micro-invertebrate, megafauna, scleractinian corals and octocorals (Veron et al., 2009; Mora et al., 2005). Many of these immense and fragile ecosystems are in decline due to increasing environmental stressors, including rising ocean water temperatures, runoff and sedimentation, ocean acidification, overfishing and pollution (Hughes et al., 2003; Jackson et al., 2001). Such pressures change the structure of reefs, causing them to shift from a scleractinian-dominated state to an algal, seaweed, and sponge dominated state (Bellwood et al., 2004; Bell et al., 2013). Long-term ecological impacts of phase-shifts include loss of invertebrate, fish, and coral diversity and abundance (Jackson et al., 2001; Hughes, 1994; Bellwood et al., 2004), which in turn destabilises the coral reef ecosystems relied upon by many for subsistence and income (Costanza et al., 1997).

Madagascar, the fourth largest island in the world with over 5,000 km of coastline, supports extensive fringing reef systems, brackish and freshwater habitats, and shallow marine and pelagic environments (Cooke et al., 2003). Around 3,500 km of the coastline is fringed with scleractinian coral reefs, which are highly productive, dynamic and fragile ecosystems. With 55% of the population of Madagascar living on the coast, over half of the nation is reliant on fisheries, both for subsistence and income (Harris, 2011; Le Manach et al., 2012). Following a military backed coup in 2009, foreign aid was withdrawn and fish catch has largely gone unregulated and underreported by an estimated 40%, leading to poorly managed fish and invertebrate stocks and the continuing depletion of commercially important species, such as certain Holothurians (sea cucumbers) and large fish species (Narozanski et al., 2011; Le Manach et al., 2012). However, with a new president elected in January 2014, there is hope that conservation and protection of reef ecosystems will become an issue of importance. There are two fully decreed marine protected areas (MPA’s) in Madagascar and multiple locally managed marine areas (LMMA’s), however only 2% of the country’s coral reefs are located within protected zones and the majority of fisheries are regarded as unsustainable (Harris, 2011). Even with imposed area and fishing restrictions, there is little enforcement and the exploitation of many marine invertebrate and fish species continues to occur, leading to increased levels of bio-eroders such as sea urchins that contribute to overall reef decline (Bigot et al., 2003). Presently, much of Madagascar’s marine resources are depleted, leaving a legacy of reduced fisheries catch, and a continuing decline toward an unstable level of overall species abundance and diversity.

To further understand any anthropogenic effects on marine ecosystems, as well as to implement successful conservation measures, baseline data is required on a wide range of ecological and biological parameters. Detailed scientific data regarding fish assemblages, influential invertebrate species abundances, and coverage of benthic substrata are needed to understand processes of how all these organisms interact with each other and the ecosystem in which they survive. Frontier is a conservation NGO based in the United Kingdom that has worked out of the village of Ambalahonko on the island of Nosy Be in Northwest Madagascar since 2010. Trained scientists as well as volunteer research assistants have used baseline surveys to accumulate extensive data on fish and macro invertebrate assembles, as well as a preliminary assessment of seagrass diversity at sites within the Nosy Vorona Bight. As such this report aims to characterise adult and juvenile fish assemblages of
specific marine biotopes, examine abundance of echinoderms and opisthobranchs across different habitats, and quantify marine debris in beach areas surrounding Ambalahonko base camp.

**Study areas**

During Phase 162, fish and invertebrate assemblages were examined at several sites within the Nosy Vorona Bight in Northwest Madagascar (Table 1). Each site contained between one and three habitat types, and each habitat fell into three broad categories according the dominate substrate type present. Namely, coral, seagrass and sponge dominated. Coral dominated areas were further categorised into one of two groups (live or degraded coral) according to health status and benthic complexity/diversity giving a total of four distinct habitat types. This division was based on the results of Toor (2015), who previously assessed coral complexity and diversity at several sites within the region.

![Figure 1. Location map of sites surveyed off Nosy Be and Nosy Komba during Phase 162. NV = Nosy Vorona, TB = Three Brothers, And = Andrekareka, BP = Blue Pillars, MH = Mad Hatters, HR = Home Reef, Amp = Ampasipohy, DO = Doany, Amb = Ambalahonko, A51 = Area 51, BR = Black Rocks, Ant = Antafondro.](image-url)
Table 1: Description of the study sites surveyed in Phase 162: LC, healthiest reef classification; DC, degraded coral reef; Sg, seagrass-dominated; Sp, sponge-dominated habitat.

<table>
<thead>
<tr>
<th>Site</th>
<th>GPS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nosy Vorona (LC, Sp, Sg)</td>
<td>13°25′30″ S, 48°21′46″ E</td>
<td>Fringing patchy reef formed around a small island. High live coral cover, patchy seagrass beds and large sponge-dominated habitat adjacent to reef. Little terrestrial influence, strong current, artisanal fishing pressure. Temperature range 270-310C.</td>
</tr>
<tr>
<td>Three Brothers (LC)</td>
<td>13°25′46″ S, 48°21′14″ E</td>
<td>Fringing mix of continuous and patchy reef formed around three distinct outcrops. High live coral cover, little terrestrial influence, moderate fishing pressure. Temperature range 27o-310C, weak current.</td>
</tr>
<tr>
<td>Andrekareka reef (LC, Sg)</td>
<td>13°26′48″ S, 48°20′09″ E</td>
<td>Very large (200 m x 40 m) continuous live coral fringing reef. High fishing pressure, some sedimentation, patchy seagrass beds proximal to small settlement with mixed species cover. Prone to anchor damage. Temperature range 27o-310C, moderate current.</td>
</tr>
<tr>
<td>Home reef (DC)</td>
<td>13°24′25″ S, 48°20′22″ E</td>
<td>Small, degraded reef, close proximity to settlement, freshwater runoff, heavy sedimentation, tops of coral can be exposed at extreme low tide. Some macro and turf algae, poor complexity. Heavy artisanal fishing pressure. Temperature range 27o-310C, weak to no current.</td>
</tr>
<tr>
<td>Mad Hatters (DC)</td>
<td>13°24′45″ S, 48°20′10″ E</td>
<td>Small, degraded, patchy reef with poor complexity. High fishing pressure, large levels of turf and macro algae. Close proximity to settlement, high levels of sedimentation. Temperature range 270-310C, weak to no current.</td>
</tr>
<tr>
<td>Ampasipohy (Unknown coral, Sg)</td>
<td>13°22′54″ S, 48°20′59″ E</td>
<td>Dense seagrass bed proximal to small coral reef, dominant species Thalassondendron ciliatum. Subject to strong currents/water movement on changing tides, temperature range 270-310C. Coral yet to be surveyed at this site.</td>
</tr>
<tr>
<td>Doany (Unknown coral, Sg)</td>
<td>13°23′59″ S, 48°21′19″ E</td>
<td>Patchy seagrass bed, shallow zone exposed at low tide, seagrass species cover variable, moderate fishing pressure, relatively little current, temperature range 270-310C.</td>
</tr>
<tr>
<td>Blue Pillars (LC, Sg)</td>
<td>13°27′06″ S, 48°19′39″ E</td>
<td>Large live coral reef, strong currents, extensive, dense seagrass bed, ca. 20 m wide, dominant species is T. ciliatum. Temperature range from 270-310C, moderate artisanal fishing pressure.</td>
</tr>
<tr>
<td>Antafondro (DC)</td>
<td>13°24′40″ S, 48°21′34″ E</td>
<td>Large, shallow degraded coral reef, close to human settlement. Expansive Acropora beds with large patches of dead coral, tops of coral can be exposed at extreme low tide. High artisanal fishing pressure, temperature range from 270-310C, occasionally exposed to strong current.</td>
</tr>
<tr>
<td>Black Rocks (DC)</td>
<td>13°24′52″ S, 48°20′21″ E</td>
<td>Moderate sized, shallow degraded coral reef with poor complexity in most parts. High fishing pressure, occasionally exposed to high current. Temperature range 270-310C</td>
</tr>
<tr>
<td>Area S1 (Sp)</td>
<td>13°25′27″ S, 48°20′71″ E</td>
<td>Large, deep (12-14 m) sponge-dominated area in channel between Nosy Komba and Nosy Be. Moderate fishing pressure. New site, yet to be characterised.</td>
</tr>
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2 A comparison of adult and juvenile fish assemblages between coral reef and seagrass habitats.

2.1 Introduction
Examining the interconnectivity and relationships between proximal habitats in many coral reef environments is vital to understanding the dynamics of coral reef fish assemblages (Wilson et al., 2010; Aguilar et al., 2014). Habitat selectivity and specificity is documented within many species, and is shaped by a variety of processes such as responses to predation, foraging efficiency or reproduction (Sutherland, 1996; Wilson et al., 2010). Species of fish within families Lutjanidae, Scaridae and Lethrinidae, have been shown in various locations to recruit to mangrove or seagrass ecosystems, undergoing ontogenic phase shifts where they migrate to coral reefs as sub-adults or adults (Bell and Westoby, 1986; Lecchini and Galzin, 2005; Nagelkerken et al., 2002; Wilson et al., 2010). In addition, the adults of many fish species, which are not directly associated with live coral, still spend part of their early life history closely associated with corals (Jones et al., 2004). Considering the decline of coral reefs and near shore habitats worldwide, this is cause for concern; the knock on effects of coral loss or mangrove removal will undoubtedly affect species that have habitat specific recruitment and directly utilise these habitats as adults or depend on those that do (Bellwood et al., 2002; Honda et al., 2013). Given the rate of environmental deterioration worldwide, coupled with unregulated fishing practices in developed and developing countries, it is not surprising that our marine ecosystems are experiencing unprecedented stress (Harris, 2011; Honda et al., 2013).

Previous studies have focused on the local interconnectivity of coral, algal, rubble and/or seagrass habitats and their importance at different scales (Dorensbosch et al., 2004; Wilson et al., 2010; Berkstrom et al., 2013). It is often suggested that the proximity of ‘nursery’ habitats to adjacent coral reefs plays a role in determining the species diversity and assemblages that are present (Baelde, 1990; Nagelkerken et al., 2002). While it is beyond the scope of this study to examine the complex ecological relationships and interconnectivity of habitats, the primary aim of this study was to examine the differences in adult and juvenile fish composition across a number of proximal habitats in Nosy Be, Madagascar. Furthermore, understanding the reliance of fish species on certain habitats is vital to ensure appropriate management and protection of marine resources (Wilson et al., 2010), especially in developing countries such as Madagascar, where reliance on natural resource extraction is in some places the only means of survival (Le Manach et al., 2012). Thus, the importance of habitat type for specific adult or juvenile fish species or families was assessed.

2.2 Methods
2.2.1 Survey method
To examine the differences adult and juvenile fish richness, diversity, and abundance between sites, underwater visual censuses (UVC) were undertaken at sites previously examined (Toor, 2015), (Table 2, Figure 1). This included eight sites and three distinct habitat types.
Table 2. Number of transects completed at each site during Phase 163. BP = Blue Pillars, NV = Nosy Vorona, TB = Three Brothers, And = Andrekareka, HR = Home Reef, MH = Mad Hatters, BR = Blackrocks, DO= Doany, ANT= Antafondro and A51 = Area 51.

<table>
<thead>
<tr>
<th>Site</th>
<th>Live Coral</th>
<th>Degraded Coral</th>
<th>Sponge</th>
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<tbody>
<tr>
<td>Site</td>
<td># Trans.</td>
<td>Site</td>
<td># Trans.</td>
</tr>
<tr>
<td>BP</td>
<td>5</td>
<td>BR</td>
<td>3</td>
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<tr>
<td>NV</td>
<td>8</td>
<td>HR</td>
<td>2</td>
</tr>
<tr>
<td>TB</td>
<td>6</td>
<td>MH</td>
<td>6</td>
</tr>
<tr>
<td>And</td>
<td>0</td>
<td>DO</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>ANT</td>
<td>4</td>
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At each location, divers selected a start point for each transect in pre-determined section of reef, then laid out the 50 x 5 m belt transect in a randomly chosen direction. This approach ensured that each section of the reef was covered, transects were independent of each other, and degree of randomness was included in the survey design. Each survey was carried out by two surveyors who identified fish to species level, recorded their abundance and whether they were adults or juveniles. The first surveyor recorded all of the faster swimming, agile fish that are likely to be disturbed by human presence, by swimming ahead of the second surveyor at a speed of approximately 15 min per transect to standardise survey effort. Then, the second surveyor returned along the same transect line counting the smaller territorial fish that are not as easily disturbed. To distinguish between adults and juveniles, the methods Wilson et al., 2010 were followed, where fish were separated based on colouration and patterns, or on body size (<25% of maximum adult total length). For simplicity, hereafter ‘adult’ is used to describe any individual which was not determined to be a juvenile, although it is recognised that there are life history stages in between the two. All fish surveys were undertaken within two hours of high tide to reduce variation between fish assemblages over different tidal ranges (Lee et al., 2014). In order to maintain consistent data collection between observers, all surveyors underwent a series of tests on all species identification both in water and on land before being permitted to survey. The sites surveyed, and the number of transects completed at each site are listed in Table 2.

To examine potential differences in adult and juvenile fish abundance between habitat types, an analysis of variance (ANOVA) was performed using R (R Core Team (2015)). Prior to analysis the data were square root transformed in order to reduce the effect of over abundant species and increase the importance of rare species, as well as to normalise the data. Homoscedasticity was checked using Levene’s test for homogeneity of variances. Following this, Tukey’s HDS test was used for pair
wise comparisons to separate significance. Furthermore, biodiversity was determined using the Shannon-Wiener Diversity Index for common fish families, and all species combined for each habitat type.

2.3 Results

A total of 6842 adult and juvenile fish were observed over a 3 month period, from July to September 2016, representing 28 families and 106 species. Of the total recorded individuals, 6182 were adults and 681 were juveniles.

There was a statistically significant difference in combined adult abundance between all habitat types except the LC-DC (p-value = 0.889) comparison (Figure 2). This was similar in combined juvenile abundance, with LC-DC (p-value = 0.965) not showing any statistical difference and not showing any statistical difference along with Sp-Sg (p-value = 0.968).

As was the case with the previous phase (162), when the analysis was performed separately on common families, statistically significant differences in abundance were found between habitat types. For example, the abundance of both adult and juvenile damsel fish was lower in Sp and Sg compared to the coral habitat types, which had no statistical difference between degraded and live coral. For adult butterflyfish, abundance was split into two groups with the coral habitats being significantly higher than the Sp and Sg habitats. There was no statistical difference in juvenile butterfly abundance across biotypes.

Adult wrasse showed a different pattern with LC showing the highest abundance followed by DC and Sp at intermediate levels and Sg the lowers abundance. Again there was no statistical difference between the coral habitats, while Sp and Sg were lower and grouped. The highest proportion of juvenile fish relative to adults was found in the Sg biotype (42.6 vs 57.4% respectively) followed by, LC, DC and Sp in descending order.

Live coral had the highest adult species richness with 76 fish species recorded, 8 fish taxa recorded and identified to family level, and a Shannon-Wiener Diversity Index of 2.83. For other habitat types, total diversity for adult fish in descending order was DC, Sp and then Sg. For individual common families, LC had the highest diversity, except for fusiliers and surgeon fish, where diversity was highest in Sp and DC respectively. Similarly, juvenile abundance and species richness was highest in LC, with 47 species and 4 additional families recorded. Diversity, however, was highest in Sg (2.28) with Sp following, then LC and DC with the lowest index scores. For adult fish, 20 species and 1 taxon were unique to coral-dominated habitat, regardless of health status (please see Appendices for full table). Eighteen species were unique to the live coral habitat, 3 species and 3 taxon were unique to degraded reef habitat, 2 species and 1 taxon were unique to seagrass, and 2 species and 1 taxon to sponge. For juvenile fish, 150 species were unique to coral-dominated habitat, regardless of health status (please see Appendices for full table). Fifteen species and 1 taxon were unique to the live coral habitat, 3 species and 1 taxon were unique to degraded reef habitat, 5 species and 1 taxon were unique to seagrass, and 2 species to sponge. A complete list of numbers of species recorded for each family across habitat types is displayed in Appendix Table 12. The three most dominant families in live coral and degraded were Pomacentridae (20 and 17 species), Labridae (19 and 11
species), and Chaetodontidae (10 species each). The most dominant families in seagrass and sponge were Pomacentridae (5 and 10 species) and Labridae (5 and 9 species respectively).

2.4 Discussion

During Phase 163, the LC biotype had a similar overall adult species abundance to DC; however, species diversity, as measured via the Shannon-Wiener Diversity Index (SWDI), and total number of species recorded was higher in LC than all other biotypes demonstrating the importance of healthy coral reefs for fish diversity. A similar phenomenon was observed for juvenile fish, where total abundance was similar between the coral sites, and between Sp and Sg. However, Sg Shannon-Weiner diversity was highest overall with LC having only the 3rd highest SWDI. This shows the importance of Sg and Sp as habitats for juvenile fish before they migrate to coral reefs as adults.

LC still has a higher species richness and SWDI than DC which shows healthy coral is important for juveniles and adults. As the LC biotype is more diverse and complex in terms of hard coral species composition and cover (Toor, 2015), this is likely due to high species richness and abundance of coral associated species, including those in the family Pomacentridae, Chaetodontidae, and Labridae. Furthermore, many species within these families rely on scleractinian corals, particularly branching corals, for shelter, protection, and as a food source (Cole et al., 2008; Reese, 1981; Bozec et al., 2005). While this is true, many damselfish are algal grazers, and turf algae was observed in low abundance across live coral sites (4.34%) compared to degraded reef (16.05%) in the previous phase of research (Toor, 2015), and it’s possible that this family of fish may have a stronger preference for habitat than a high abundance of food sources.

Many wrasse feed upon small bivalves, decapods, gastropods, and algae, most of which are often in high abundances on many coral reefs and seagrass beds (Deady and Fives, 1995). In the present study, there was a higher abundance per transect and diversity of adult wrasse in LC habitats than in DC, Sg or Sp habitat types which raises questions surrounding the abundance of this families’ food source. To further elucidate the drivers behind differences in wrasse population size, an examination of bivalves, decapods and gastropods is required.

The exception in terms of adult biodiversity was fusiliers, where diversity was higher in the Sp biotype than any others. This may be a function of a variety of variables such as availability of food; however, both Sponge sites at Nosy Vorona and Area 51 are much deeper than any other sites surveyed. This may have been a significant contributing factor, as fusiliers often school in large groups, and may prefer to congregate in open water (Pers. Obs. Bloomfield 2016). Auster (2005) found that the scissortail fusilier, (Caesio caerulaurea), was successfully preyed upon while in shallow water or in close proximity to vertical reef faces. These locations appear to provide opportunity for predator ambush, and fewer escape routes for prey (Auster, 2005). Thus, fusiliers may display a behaviourally-mediated adaptation strategy that increases their chances of evading predators. This was supported by our data this phase, as higher diversity and abundance of fusiliers was observed in the deeper Sp habitat type (data not shown), supporting previous phases of research (Anderson, 2015; Bloomfield, 2015). Having said that, a similar abundance of fusiliers was observed in the LC habitat type (data not shown), although diversity there was lower (0.26 in Sp vs 0.10 in LC).
The diversity of adult and juvenile butterflyfish was highest in the LC biotype compared to all others. As this family is closely associated with, and relies upon coral assemblages, this finding is not unexpected, and further highlights the importance of coral reefs for maintaining fish biodiversity. Only juvenile butterflyfish were found in the Sg biotype, and it’s likely that species from this family undergo an ontogenic phase shift where they migrate to coral reefs as sub-adults or adults (Bell and Westoby, 1986; Lecchini and Galzin, 2005; Nagelkerken et al., 2002; Wilson et al., 2010). Thus, availability of the Sg biotype appears to be an important factor in the life history of many species.

Far fewer unique adult species were observed in the DC habitat type compared to LC (18 species vs. 3 species and 3 taxon respectively). Unique species to the coral habitats (LC-DC) included the commercially important white-spotted grouper, and studies on this species have shown that is it largely overexploited in Northwest Madagascar (Kirubasankar et al., 2013). The Chocolate Hind was the most common grouper species found this phase and recently this species has also been making up a high proportion of groupers in FAO fishing data. The Chocolate Hind has only recently begun to appear in FAO fishing data suggesting that populations of large more traditional grouper species is falling and fishers are moving to smaller species to make up their catches (Sadovy et al., 2013). The presence of larger, commercially and ecologically important species, such as groupers (Whitespotted in the present study), is dependent on the health of the reef, which promotes prey density (Beukers-Stewart et al., 2011). Healthier benthic substrates, including scleractinian corals, octocorals, porifera, and others, support a higher species richness by providing an array of resources, as well as a higher abundance, by providing increased overall resources and habitats (Chabanet et al., 1996). Higher overall species richness and abundance of corals, small fish, and invertebrates, support species in higher trophic levels and maintain stability throughout coral reef ecosystems and global marine systems (Wilson et al., 2010). This is also demonstrated by the exclusive presence of predatory triggerfish (moustache) within the LC biotype during Phase 163. The higher levels of species richness and abundance of adult fish in live coral demonstrates the interconnectivity of healthy, living substrates and fish diversity, and provides evidence of the importance of protecting substrates in order to conserve reef ecosystems as a whole. This highlights the importance of MPA’s and no-take zones, as well as fishing restrictions, limiting the more destructive methods of commercial and artisanal fisheries. Progress does appear to be occurring in northern Madagascar with the enforcement of MPA’s and marine reserves, however, with many developing countries the progress is slow and oftentimes unenforced (Rocliffe et al., 2014).

Previous studies undertaken by Frontier Madagascar have recorded proportions of up to 95% juvenile fish in a seagrass habitat. Seagrass consistently has a high proportion of juvenile fish assemblages and it is possible that a previous phase (154), with an exceptionally high proportion of 94.9 to 5.1% of juveniles to adults, may have been a seasonal affect that aligns with the reproductive season of various fishes.

The present study found a 57.4 - 42.6% proportion of adults to juveniles in Sg. This was the highest proportion of juveniles in any biotype studied. This finding supports the popular theory that seagrass habitats are ecologically important nursery areas for juvenile fish (Nagelkerken et al., 2002). Seasonality of juvenile recruitment, and thus changes in juvenile abundance due to varying habitat structure, food availability, and reproductive complexity have been demonstrated in various habitat types (including seagrass) for many species (Garcia-Rubies and Macpherson 1995; Laegdsgaard and Johnson 1995; Victor 1986). Prolonged and consistent monitoring of juvenile fish assemblages and
seagrass mapping will help to clarify this finding. The present study utilised 3 months worth of survey data, and found a 54.7 – 42.6 % proportion of adults to juveniles in Sg. As previously mentioned, juvenile abundance was similar between some sites, while species composition and thus richness varied between habitat types. For example juvenile butterflyfish and wrasse (except for cigar wrasse) were found exclusively in coral-dominated (LC and DC) or LC biotypes, and (adult and) juvenile footballer demoiselles were only recorded in the Sg habitat. This is possibly due to protection from predation, availability of food sources, and habitat preference (Bell and Westoby, 1986). Furthermore, similar proportions of juvenile fish were observed in the DC habitat type compared to LC during the current phase. Interestingly, there is some existing evidence to suggest that many Indo-Pacific reef fish do not distinguish between live and partially degraded coral during settlement, and some preferred to settle on degraded coral (Feary et al., 2007). Further investigation is required to determine whether shifts from live coral specialists to coral generalists has occurred on some reefs in the Nosy Be area.

Limitations

In this study there were a number of limitations and other contributing factors which undoubtedly play a role in influencing the fish assemblages of marine habitats other than the gross benthic cover, for example, seagrass leaf density and species coverage may influence fish abundance at a location (Hyndes et al. 2003). Furthermore, it is likely that nocturnal species migrate to seagrass habitats overnight (Robblee and Zieman 1984); however, underwater visual censuses were only undertaken diurnally for logistical purposes, therefore, these species and their affinity to different habitats will have been missed. It is also recognised that many fish species have an intermediate life stage, which may have an associated habitat not recorded in this study. In addition, efforts which focus on particular characteristics of seagrass beds, such as differing leaf density or biomass, will further explore the habitat preferences of juvenile and adult fish on a fine scale. There may also be limitations due to human error as some individuals may have been missed on surveys, suggesting that abundance may be higher than actually reported as well as some individuals being misidentified.

3 Comparison of echinoderm and opisthobranch abundance and diversity between habitat types

1.1. Introduction

Macro invertebrates can play a vital role in the food webs of marine ecosystems, as well as contributing to bio-turbation and bio-erosion of coral reefs, the latter of which can have an effect on successful coral settlement (Bak, 1993). The phylum Echinodermata consists of the classes Echinoidea (sea urchins), Asteroidea (sea stars), and Holothuroidea (sea cucumbers), as well as Crinoidea (feather stars) and Ophiuroidea (brittle stars) with over 6,000 reef dwelling species critical in the functionality and stability of coral reef ecosystems (Stella et al., 2010). The symbiotic relationships of these invertebrate families with scleractinian corals, sponge, soft coral, sand, algae and seagrass directly and indirectly affect the overall health of reefs. In fact, 51 species of echinoderms are known to associate with scleractinian corals through direct consumption, as a habitat to live on or inside of, or for mating (Stella et al., 2010). This causes a negative feedback loop
with the loss of scleractinian corals, which increases the pressure for competition between
echinoderms for resources, which degrades the scleractinian corals even further (Stella et al. 2010; Dumas, 2007). Only 12 echinoderm species are known corallivores, however, with outbreaks of
highly destructive species such as the asteroidean, Acanthaster planci (crown of thorns starfish), the
damage can still be expansive (Stella et al., 2010).

The structural complexity of marine habitats depends on the species that live within microhabitats. Sessile animals that form the substrata of different biotopes compete with each other for space, largely based on life form, colonial or solitary, with different phyla of animals gaining success in certain areas (Jackson, 1997). Colonial species, including scleractinian corals, tend to dominate reef space, excluding solitary growth forms, such as many sponge species, forcing them to colonize areas off of the reef crest (Jackson, 1997). In sponge-dominated habitats, usually at greater depths than scleractinian corals, species are able to exclude most colonial corals even without direct contact by excreting allelochemical defences (Porter and Targett, 1988; Stella et al., 2010). With climate change affecting sea-water temperatures and consequently many marine flora and fauna, is possible that reef structure may change irreversibly, shifting towards more sponge dominated reefs (Bell et al., 2013). Warmer water temperatures, causing a higher acidity level and an increase in dissolved inorganic carbon, prevent the growth of calcifying organisms including scleractinian corals, crustose coraline algae, and some invertebrates (Caldeira & Wickett, 2003; Raven et al., 2005; Schneider and Erez, 2006; Anthony et al., 2008; Jokiel et al., 2008). Historical evidence suggests that many sponge species, while still affected by climate change, are more resilient to warmer water temperatures and ocean acidification (Bell et al., 2013). With the current state of coral reefs and continuing degradation it is possible that sponge dominated reefs may once again emerge (Bell et al., 2013).

Distinct from both scleractinian coral and sponge-dominated biotopes, seagrass beds provide a unique habitat and are regarded as ecologically important nurseries for many macro-invertebrate species (Boström et al., 2006). Seagrass beds with high levels of biomass provide shelter and different nutrient sources through the consumption of leaf tissue and of epiphytes that cover the leaves of many seagrass species that macro-invertebrates are unable to find in other marine microhabitats (Boström and Mattila, 1999; Attrill, et al. 2000). The difference in structure between these biotopes promotes a difference in echinoderm diversity due to different spatial niches and food resources and possibly less interspecific competition (Pante et al., 2006).

Opisthobranchs, from the subclass Opisthobranchia, are gastropods with internal shells, external shells, or no shell, that largely feed on sponges and macro algae both of which can be distributed across multiple marine biotopes (Faulkner and Ghiselin, 1983; Bell et al., 2013). As opisthobranchs may consume coral and/or sponges, they are able to influence coral reef structure, and in turn could be largely affected by coral reef loss and degradation through bleaching events and anthropogenic effects (Ziegler et al., 2014). They largely rely on chemoreceptors (rhinophores) that are highly sensitive to source food and mates, (Puyana, 2002) and many species leave chemically rich slime trails that are used to find prey as well as avoid predators (Puyana, 2002). Many chemicals that are used by opisthobranchs as a defence mechanism are sourced from other organisms upon consumption (Puyana, 2002). Due to sensitivity in chemoreceptors to changes in water quality, opisthobranchs are regarded as influential indicators of reef health according to their diversity and abundance.
This study aimed to examine echinoderm and opisthobranch abundance, species richness and diversity between biotopes. With many echinoderms playing influential roles in the stability or degradation of many coral reef ecosystems, it is key to assess the prevalence of destructive species and their potential impacts on reefs in the area. This study was carried out through the use of underwater visual censuses (UVC) to record the total number of Asteroidea, Echinoidea, Holothuroidea and Opisthobranchs, in live coral, degraded coral, sponge, and seagrass habitats.

3.1 Methods

3.1.1 Study location

Three different habitat types were selected which occur in the waters surrounding the south west of Nosy Be, Madagascar; coral, seagrass and sponge-dominated. Coral dominated habitats were further categorised into two groups, Live Coral and Degraded Coral, according to general health and complexity (Toor 2015, Table 5). Fishing pressure around the island is high, although only from artisanal fishers and spear fishers who also collect sea cucumbers.

Table 5. Number of transects completed at each site during Phase 163. NV = Nosy Vorona, BP = Blue Pillars, TB = Three Brothers, And = Andrekareka, BR = Black Rocks, HR = Home Reef, MH = Mad Hatters, and A51 = Area 51.

<table>
<thead>
<tr>
<th>Site</th>
<th># Trans.</th>
<th>Site</th>
<th># Trans.</th>
<th>Site</th>
<th># Trans.</th>
<th>Site</th>
<th># Trans.</th>
</tr>
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<tbody>
<tr>
<td>NV</td>
<td>18</td>
<td>MH</td>
<td>0</td>
<td>And</td>
<td>0</td>
<td>NV</td>
<td>0</td>
</tr>
<tr>
<td>BP</td>
<td>6</td>
<td>BR</td>
<td>3</td>
<td></td>
<td></td>
<td>A51</td>
<td>3</td>
</tr>
<tr>
<td>TB</td>
<td>5</td>
<td>HR</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>And</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>Total</td>
<td>3</td>
<td>Total</td>
<td>0</td>
<td>Total</td>
<td>3</td>
</tr>
</tbody>
</table>

3.1.2 Survey methods

To examine the species richness, diversity and abundances of echinoids and opisthobranchs, a 25 m transect line was laid parallel to the shore at a constant depth. After the transect line was laid, the first observer slowly swam back to the beginning, recording any echinoids, holothurians and asteroids that were observed within 1 m either side of the transect line. At the same time, the second observer would follow behind and survey for opisthobranchs, again searching 1 m either side of the line. When possible, a photograph was taken of each opisthobranch to aid identification at a later stage. If this was not possible, a detailed description of the animal was recorded. To maintain
consistency in search effort, each survey typically lasted between 15 – 20 min. The total number of combined transects for each site is listed in Table 5.

To examine differences in the abundance of species for each class of organism across live coral, degraded coral, sponge, and seagrass habitats, an analysis of variance (ANOVA) was performed using R (R Core Team (2015)). Prior to analysis data was square root transformed to normalise the data and increase the importance of rare species. Homoscedasticity was checked using Levene’s test for homogeneity of variances. Following this, Tukey’s HSD test was used for pair wise comparisons to separate significance. Due to the overabundance of the echinoderm, D. setosum, recordings of this species were removed for a comparative analysis. Furthermore, biodiversity was determined using the Shannon-Wiener Diversity Index for classes separately, and all species combined for each habitat type.

3.2 Results

A total of 2376 echinoderms, 86 holothurians, 32 asteroideans and 16 opisthobranchs were recorded over a three month period during phase 162. Of the 2376 echinoids recorded, 2376 individuals were the echinoid Diadema setosum, while the remaining individuals were comprised of four separate species.

Table 6. Mean (±SE) abundance per transect of echinoid, holothurian and asteroid species across habitat types. LC = live coral, DC = degraded coral, Sg = seagrass, Sp = sponge. Superscripts denote statistical significance. Superscripts denote statistical significance.

<table>
<thead>
<tr>
<th></th>
<th>LC</th>
<th>DC</th>
<th>Sg</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echinoids, minus D. setosum</td>
<td>4.65 ± 1.3</td>
<td></td>
<td></td>
<td>0.00 ± 0.0</td>
</tr>
<tr>
<td>D. setosum</td>
<td>67.90 ± 9.9</td>
<td></td>
<td></td>
<td>139.33 ± 11.0</td>
</tr>
<tr>
<td>Echinoids (total)</td>
<td>81.93 ± 6.2</td>
<td></td>
<td>139.33 ± 11.0</td>
<td></td>
</tr>
<tr>
<td>Holothurians</td>
<td>2.96 ± 0.3</td>
<td>2.33 ± 0.1</td>
<td>4.3 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Asteroids</td>
<td>1.10 ± 0.2</td>
<td></td>
<td>0.6 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>Opisthobranchs</td>
<td>0.55 ± 0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Total number of invertebrate species recorded in each habitat type during Phase 163. LC = live coral, DC = degraded coral, Sg = seagrass, Sp = sponge.

<table>
<thead>
<tr>
<th></th>
<th>LC</th>
<th>DC</th>
<th>Sg</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echinoids</td>
<td>10</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Holothurians</td>
<td>10</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Asteroids</td>
<td>8</td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
Unfortunately due to issues with surveying this phase (163), the total number of invertebrate species recorded, is much less than the previous phase (162), where a total of 14,066 echinoderms, 147 holothurians, 74 asteroideans and 85 opisthobranchs were recorded across all four of the habitat types.

The data from this phase will be combined with the data from the next phase (164), before conclusions can be drawn on the above results. That said, it is expected that this will follow a similar pattern to the data in phase 162 where LC, DC and Sp habitats had a similarly high abundance of echinoids (while Sg was significantly lower) and for holothurians and asteroids, abundance was significantly higher in the Sp habitat compared to all others. For opisthobranchs, there was only a single significant difference being between LC and Sg. The habitat LC had the greatest number of species for all invertebrate classes, except for opisthobranchs, where DC had a higher number of individual species and family representatives (Frontier Madagascar phase 162 report).

### 4 Collection and analysis of marine debris from coastal areas proximal to Nosy Be base camp

#### 4.1 Introduction

Marine debris, especially plastic debris, have become ubiquitous in marine environments and are a source of global concern due to their longevity and impact on marine organisms (Derraik, 2002). An extensive review of published research has shown that between 60 - 80% of all marine debris is plastic, and sources of plastic pollution are varied, but include equipment from fishers/fishing fleets, other ship traffic, including container ships, deliberate littering or careless handling of waste (Derraik, 2002). Proximity to industrialised areas, suburban areas and river mouths, and our over-reliance on ‘disposable’ products are also significant contributing factors to the amount of marine debris observed in a given area (Derraik, 2002).

Impacts from marine debris are varied, but affect many species globally. Direct deleterious effects may be caused by macro or micro plastics, and may occur as a result of ingestion, exposure to toxic substances adsorbed to plastic surfaces, or entanglement (Derraik, 2002; Wright et al., 2013). As such, discarded or accidentally released fishing equipment, such as nets that continue to ‘ghost fish’ and indiscriminately kill organisms for an extended period of time are also of ecological concern. Indirect ecological consequences have also been documented, through the introduction of foreign or invasive species attached to drifting debris (Derraik, 2002).

Collection of marine debris is one of the most effective ways to have a meaningful positive environmental impact, and assess potential sources of environmental pollution so that management strategies can be implemented that aim to curb input of non-biodegradable items. As such, Frontier Madagascar regularly undertake beach cleans, and the following is a summary of items collected, a discussion of potential sources of marine debris, and suggestions for management strategies that may reduce the amount of marine debris in the area surrounding Ambalahonko.

<table>
<thead>
<tr>
<th>Opisthobranchs</th>
<th>16</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>44</td>
<td>4</td>
</tr>
</tbody>
</table>
4.2 Methods
Beach cleans were typically undertaken twice per week, approximately one hour either side of low tide. Volunteers and staff would venture to the right of camp (or sometimes as far as the border of Lokobe National Reserve) passing Ambalahonko village and a small stream, or left to Black Rocks (and occasionally as far as Antafondro, Figure 1), collecting debris as they go between the water and tree line. For each piece of debris, the type and zone in which it was collected was recorded (sand, mangrove, tree line). Upon collection, debris was sorted into flammable and non-flammable items for burning, or storage respectively. During Phase 163, a total of 15 collections took place to the left, and 14 took place to the right of base camp.

4.3 Results
During phase 163, a total of 5169 pieces of marine debris were collected from sand, mangrove and tree areas along the coastline proximal to Ambalahonko base camp. Over 1133 pieces were collected from mangrove areas, 813 from sandy areas and 801 pieces from the treeline furthest from the water. The most common items found throughout the phase were assorted plastics (Bags, bottles etc.), metals and glass (Figure 6). Unidentifiable plastic objects were also recorded but were removed from the dataset as recorded objects were significantly higher than all other materials in both left (n=1675) and right (n= 795) of beach camp. Significantly higher amounts of fabric, glass, crockery, batteries and paper were found to the right of camp.

![Figure 6](image-url)

*Figure 6.* Total number of pieces collected for each debris type during beach cleans to either the left or right of Ambalahonko base camp.

4.4 Discussion
Consistent with previously published works, plastic items were the most common type of debris collected, and many were smaller fragments of unidentified origin and unknown age (Derraik, 2002; Santos et al., 2008). Other plastic items frequently collected, such as plastic bags, bottles and
confectionary wrappers have an origin that is most likely local, from the villages of Ambalahonko or Antafondro. Incidence of this type of debris may have been high due to a variety of contributing factors. For example, a lack of education about the impacts of marine debris, a lack of litter collection and processing facilities, and a current lack of alternatives to the use of such items. As such, Environmental Awareness Days that focus the impacts of marine debris, the introduction of waste bags and containers that are frequently collected and disposed of in the most environmentally safe way possible (for a developing country where resources are limited), involvement of local communities in beach cleans, and a discussion about possible alternatives to the use of plastic products may be an excellent starting point for raising awareness and eventually reducing marine debris of this nature. For the longer term, like most countries, a general move away from reliance on single use plastic items is absolutely essential. This also holds true for batteries, which were frequently collected and are especially toxic. Some progress could be made if funding was available to buy small solar panels that could then in turn charge reusable batteries.

Of less ecological concern are other items collected such as paper/cardboard, organics and metals. For the most part, these substances will degrade over time, and most are not especially harmful when ingested. For this reason future work on reducing marine debris should primarily focus on plastic items.

**Limitations**

Basic data on macro-debris is collected during each beach clean. More detailed information on the exact location of debris collection would assist in determining the source of pollution (i.e. result can be related to ocean currents, proximity to rivers etc.). Furthermore, a more in-depth study/collection that investigates the presence and abundance of micro-plastic would be interesting, and a first for this area. The implementation of a BTEC or other personal project utilising planned transects, where the results are mapped on a fine scale in different areas surrounding camp would achieve this.

**5 Additional objectives of future work**

Future aims continue to include surveying Lokobe and Tanikely Marine Reserves, for seagrass species mapping and assessment of fish assemblages, or assessment of fish assemblages respectively. Invertebrate surveys would also be interesting and insightful. Acquisition of permission to survey in the reserve is still being processed with the possibility of approval still some time away.

A higher focus will be placed on seagrass mapping at established sites during Phase 164 to assess seasonal and other variation in cover and diversity. Some monitoring in seagrass habitats did occur during Phases 162 and 163, however the dataset is not large enough to analyse in isolation, so it will be added to the next phase. Adult and juvenile fish assemblages will continue to be examined among the different habitats to further assess differences between habitats. Surveys of adult and juvenile fish in fringing mangroves around the village of Ambalahonko will be instigated if feasible (dependent on volunteer numbers). More focus will be placed on surveying fish assemblages in sponge habitats, as this is a unique habitat type that was surveyed for the first time in phase 162, and has not yet been explored in great depth. As such, fish assemblages will be assessed off Nosy Vorona and in Area 51 next phase.
To better understand habitat preferences of juvenile fish species, we will begin a study investigating habitat associations between juvenile fish and substrate type. For each juvenile fish encountered, the benthic substrate it is associated with will be identified to species level. Then the presence and abundance of preferred benthic substrate types/species will then be quantified across habitat types in an effort to understand the fine-scale relationship coral species and juvenile diversity, and more broadly, between biotype and fish abundance diversity.

Coral genera surveys will be carried out at survey sites throughout the Nosy Vorona bight. However, this will be dependent on the availability of camera equipment and GPS units.

To gain a better understanding of fishing pressure, and other anthropogenic factors that affect coral reef health, a scoping socio-economic study will be instigated in Nosy Be.

6 Reference List


Veron, J., Hoegh-Guldberg, O., Lenton, T., Lough, J., Obura, D., Pearce-Kelly, P., Sheppard, C., Spalding, M., Stafford-Smith,


7 Appendices

Table 8. Unique adult species recorded only in coral-dominated, live coral, degraded coral, seagrass or sponge habitats.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degraded Coral</td>
<td>Butterflyfish: Saddleback, Vagabond, Copper Sweeper, Wrasse: Axispot Hogfish.</td>
</tr>
<tr>
<td>Seagrass</td>
<td>Sweetlips: Oriental, Lizardfish, Wrasse: Cigar, Orangesocket, Rabbitfish: Dusky, Barracuda: Yellowfin</td>
</tr>
<tr>
<td>Sponge</td>
<td>Butterflyfish: Longfin Bannerfish, Puffers: Spotted Toby.</td>
</tr>
</tbody>
</table>

Table 9. Unique Juvenile species recorded only in coral-dominated, live coral, degraded coral, seagrass or sponge habitats.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Species</th>
</tr>
</thead>
</table>