

**MADAGASCAR MARINE CONSERVATION**

**Nosy Be, Madagascar**



**Phase 143 Science Report**  
July – September 2014

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## Table of Contents

1.0 Introduction .....	4
1.1 Aims .....	5
2.0 Methods .....	5
2.1 Study site .....	5
2.2 Survey methods .....	6
2.2.1 Benthic composition .....	7
2.2.2 Fish assemblages .....	7
2.2.3 Invertebrate assemblages .....	7
2.2.4 Opisthobranch assemblages.....	7
2.3 Statistical analysis .....	7
3.0 Results .....	8
3.1 Benthic composition.....	8
3.2 Invertebrate diversity and abundance .....	9
3.2.1 Site similarity.....	10
3.3 Fish diversity and abundance .....	12
3.3.1 Site similarity.....	12
3.4 Opisthobranch assemblages.....	14
3.5 New species records .....	15
4.0 Analysis of long term data sets.....	16
4.1 Benthic composition.....	16
4.2 Invertebrate abundance.....	17
4.3 Fish abundance .....	19
5.0 Discussion.....	20
5.1 Benthic composition.....	20
5.2 Invertebrate density and assemblages.....	21
5.3 Fish communities.....	21
5.4 Opisthobranch diversity and abundance.....	22
5.5 Long term data sets.....	22
5.5.1 Hard coral cover .....	22
5.5.2 Invertebrate assemblages .....	23
5.5.3 Fish diversity and abundance .....	23
6.0 Conclusion.....	24
7.0 Objectives for future study .....	24
8.0 References .....	25
9.0 Appendices .....	27

## 1.0 Introduction

Coral reefs are well known for being one of the most productive ecosystems on Earth upon which millions of people depend (Connell, 1978). Described as an essential ecological process and life support system necessary for human survival (IUCN, 1980), coral reefs provide ecological goods and services globally. However, despite being critical for the livelihood and nutrition of tens of millions of people (Salvat, 1992), these ecosystems are in worldwide decline owing to anthropogenic forces such as pollution, over harvesting and disease as well as climatic factors such as warming sea surface temperatures and ocean acidification (Bellwood *et al.*, 2004; Hodgson, 1999; Wilkinson, 2000). In many locations, these stressors are thought to have exceeded the regenerative capacity of the coral reefs, leading to severe shifts in species composition and subsequent ecological and economic losses (Bellwood *et al.*, 2004). By 2000, it was estimated that 27% of coral reefs worldwide had been lost due to human activities and the impacts of climate change (Wilkinson, 2000).

Despite the recommendation a decade ago that 20-30% of global marine habitats be protected, progress has been slow, with Marine Protected Areas (MPAs) often ineffective, failing to meet their objectives (McClanahan, 1999). This is particularly true of protected areas in developing countries where resources are scarce and the benefit of such management actions are not immediate to local stakeholders (McClanahan, 1999). In poverty stricken countries such as Madagascar, where families rely on coral reef ecosystems as a source of protein and income, management and regulation of the reefs and associated fishing pressures are few and far between (Westerman and Gardner, 2013).

With a coastline that stretches over 5000 km, Madagascar supports extensive fringing reefs systems, brackish and freshwater habitats, and shallow marine and pelagic environments (Cooke *et al.*, 2003). With such variable habitats, it is likely that the diversity of biota in Madagascar is far greater than that of other western Indian Ocean countries (Cooke *et al.*, 2003). For a number of reasons, these extensive fringing reefs have received little scientific attention (McKenna and Allen, 2005) and, despite the regional and global importance of Madagascar's tropical marine ecosystem, formal management is in its infancy with only 1% of the reefs included in no-take areas (McClanahan *et al.*, 2008). Inadequate resource management coupled with a rising population, increase in fishing effort and other anthropogenic stressors have resulted in chronic stress for large areas of the country's ecosystems (Harris *et al.*, 2010). Small-scale traditional fishers impose a large pressure on the marine environment, producing around 53% of the total marine fish catch (FAO, 2004); although international licences consistently granted to the EU allow commercial vessels to fish Madagascar's 200 NM coastal zone, targeting highly migratory tuna stocks which would be otherwise unexploited (WWF, 2012). The detrimental effects of overfishing have been well documented worldwide (Jackson *et al.*, 2001; Pauly *et al.*, 1998; Pauly and Thia-Eng, 1998), with negative direct and indirect consequences including the collapse of trophic food webs (Pauly *et al.*, 1998) and outbreaks of ecological pests such as the sea urchin *Diadema setosum* and the asteroid *Acanthaster planci* (McClanahan and Sharif, 1989; Webster and McMahan, 2002). In Madagascar, one of the world's poorest developing countries, the overwhelming reliance on small-scale fisheries for food security is exacerbated by the increasing coastal populations, with population doubling times of around 10-15 years (LeManach *et al.*, 2012). Further, a recent study has documented that overall catches from both commercial and small-scale fisheries in Madagascar have been declining for a number of years, suggesting that food insecurity may become a growing concern for coastal populations in the near future (LeManach *et al.*, 2012).

Ecological monitoring programmes in this area are therefore vital in order to provide accurate scientific data to local governments and management bodies, in an attempt to gain further information on the currently understudied marine resources which are critical to healthy ecosystem functioning, as well as the livelihood and nutrition of local stakeholders.

## 1.1 Aims

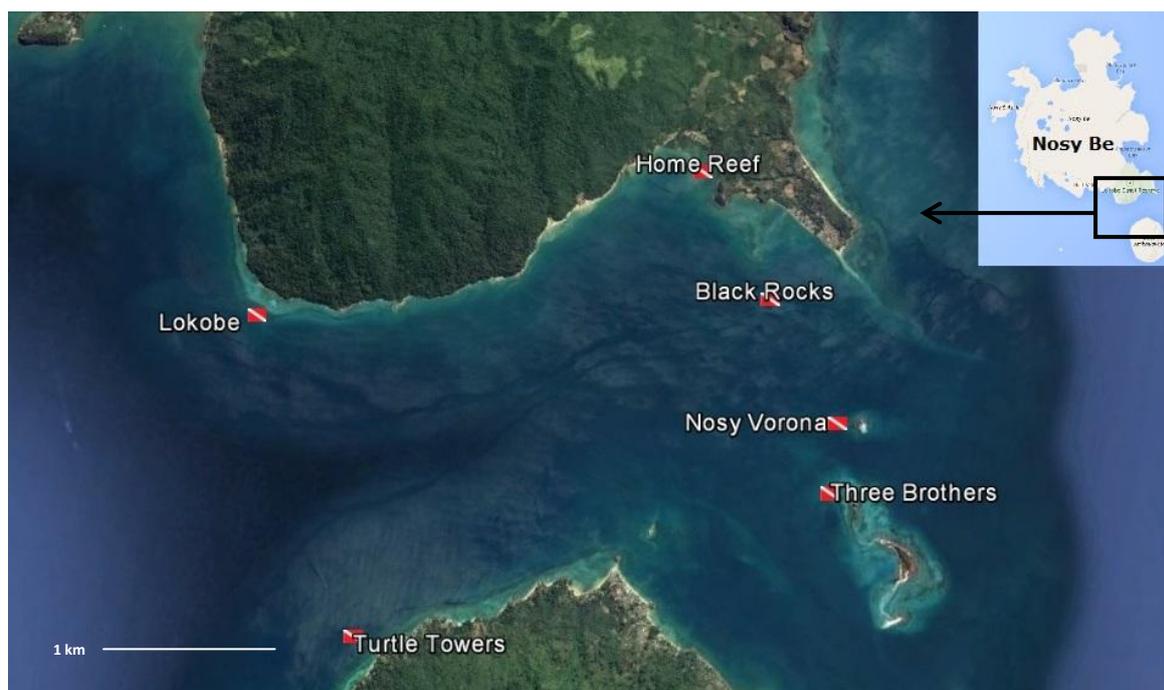
Frontier's marine conservation project has been based in the village of Ambalahonko, southeast Nosy Be, since 2011 undertaking long term monitoring programmes of the coral reef communities. By providing local management bodies with initial and on-going assessments of the status of coral reefs in this area, it is hoped that necessary management actions may be implemented in due course. This aim of this report is then to add to the growing database of information on the marine ecosystems in this area, including assessments of the benthic make-up, species abundances, and fish and macro-invertebrate assemblages. This report also adds additional species to the marine species inventory compiled for this area over the previous four years and summarises and compares previous data sets to examine any longer-term trends in the data collected in 2011, 2012, 2013 and 2014.

## 2.0 Methods

### 2.1 Study site

Ongoing research is conducted around the island of Nosy Be, northwest Madagascar (13°24'56 E, 48°17'50), situated within the Mozambique Channel. Nosy Be is characterised by varying marine habitats including extensive mangrove forests, fringing reefs and shallow continental shelf waters (Webster and McMahon, 2002). Due to its tropical location, Nosy Be experiences a wet season lasting approximately November to March and a dry season lasting approximately April to October. The heaviest rainfall is in January, where sedimentation from agriculture run off and deforested areas becomes a threat to the near shore coral reef systems (Jenkins, 1987).

Long term bio-monitoring is conducted at six sites within the Nosy Verona Bight (Figure 1). Within the Bight, water flow is controlled by wind, wave and tidal action. Tidal movement in the area is semi-diurnal and, due to the narrowing of the Mozambique Channel, spring tides range from a minimum of 0.1 m to a maximum of 4 m (Jenkins, 1987). Water temperatures range annually from approximately 27°C to 31°C.



**Figure 1.** Location map of the six survey sites situated within the Nosy Vorona Bight (Google Earth, 2014)

The sites represent various habitats and reef structures around the research centre based in the village of Ambalahonko (Table 1).

**Table 1.** Name, location, depth and description of each of the six survey sites

Site	Location	Depth range (m)	Description
Home Reef	13°24'25"S, 48°20'42"E	1.0 – 5.0	Shallow reef flat, subject to sedimentation from river run off and high fishing pressure
Black Rocks	13°24'48"S, 48°21'5"E	1.0 – 8.0	Fringing reef surrounding a rocky outcrop. Subject to exposure at extreme low tides. Current and wave energy pick up in the afternoon
Nosy Verona	13°25'30"S, 48°21'46"E	2.0 – 10.0	Fringing patchy reef formed around a small island in the Nosy Verona Bight. High tidal movement can result in strong currents
Three Brothers	13°25'51"S, 48°21'45"E	2.0 – 6.0	Fringing mix of continuous and patchy reef formed around three distinct outcrops in the Nosy Verona Bight.
Lokobe	13°25'36"S, 48°18'53"E	2.0 – 10.0	Dense continuous fringing reef in shallow waters to patchy reef in the deeper zones. Supposed Marine Reserve although little enforcement seen. Subject to high fishing pressure.
Turtle Towers	13°27'12"S, 48°19'27"E	3.0 – 10.0	Very large (200 m x 40 m) continuous fringing reef surrounding Nosy Komba, closest reef to the Nosy Tanikely MPA. Subject to fishing pressure and some sedimentation.

## 2.2 Survey methods

Surveying was undertaken at the six sites a minimum of ten times each between July and September 2014. In order to continue the collection of comparable data, survey methods were continued from the previous phase of study; the Active Search and Baseline Survey Protocol (BSP) methodologies. The Active Search method is less constrained than the BSP method and allows data to be collected when environmental conditions do not allow a transect line to be laid. It also facilitates data collection on shy, cryptic or fast swimming species which may be otherwise excluded from BSP transect surveys. This method involves three surveyors searching for a period of 30 minutes, one recording the species of vagile pelagic fish, one recording the species of less mobile territorial fish, and the other recording the species of macro-invertebrates; abundances of all individuals are estimated.

The BSP method of surveying allows concurrent information on the substrate, invertebrate and fish species assemblages to be collected. This technique involves laying an 80m transect line parallel to the shore along a constant bearing and depth, after which information is collected on a number of ecological facets (see below). To ensure accurate and consistent data collection, trained research assistants must pass both in-water and computer based tests on all fish, invertebrate and benthic species identification to an accuracy of 98% before undertaking any survey work.

### *2.2.1 Benthic composition*

Information on the benthos was collected using the Line Intercept Transect (LIT) method whereby measurements of the changes in coral morphology are taken along the entire length of the transect. Three 20m transects were completed, with a residual 10m gap between each transect. This method allows the determination of percentage cover of benthic communities over a given area as well as a relative abundance of different coral morphologies (Hill and Wilkinson, 2004). The substrate types were classified into a number of different categories (see Appendix 1).

### *2.2.2 Fish assemblages*

Surveys for fish were undertaken by two observers swimming one after the other along the transect line and collecting data in the first, second and third transect (0-20 m, 30-50 m and 60-80 m). Fish were surveyed in each 20 m transect within a visual 5 x 5 m box giving a total survey area of 500 m<sup>2</sup> per transect. All individual fish were recorded using a tally system and large schools were estimated to the nearest 10.

### *2.2.3 Invertebrate assemblages*

To obtain a measure of diversity and abundance for macro invertebrate species, trained observers swam along the pre-laid transect line of 20 m length in an 'S' shaped pattern to record any invertebrates observed 2.5 m either side of the transect line. This yields a total survey area of 100 m<sup>2</sup> per transect; as a rule three transects were carried out in one survey.

### *2.2.4 Opisthobranch assemblages*

To examine the diversity and distribution of opisthobranchs around the southeast Nosy Be area, surveys were undertaken a minimum of four times at each of the six aforementioned sites. Roaming surveys of the reef were undertaken by two to four observers using SCUBA equipment for a fixed duration of 30 minutes. When an individual was observed, the species was recorded as well as the size of the individual. Each opisthobranch was then photographed *in situ* to later confirm field identifications. In addition, the habitat type each individual was observed on was recorded as one of six categories: rocky reef (R), turf algae (TA), sand (S), coral rubble (CR), sessile organisms including sponges (S) and hard coral (HC).

## **2.3 Statistical analysis**

All data were initially analysed using Excel 2010 and SPSS V.21. All calculated averages are arithmetic means and all error bars displayed signify one standard error. To compare multiple means where data were normally distributed, an ANOVA was used followed by post hoc Tukey's tests to separate significance. Homogeneity of variances was tested using Levene's test; where data failed this test, non-parametric alternatives such as the Kruskal-Wallis test were used. To compare single means where all assumptions were met, a t-test was used. Alternatively, a non-parametric Mann-Whitney U test was utilised. To assess the

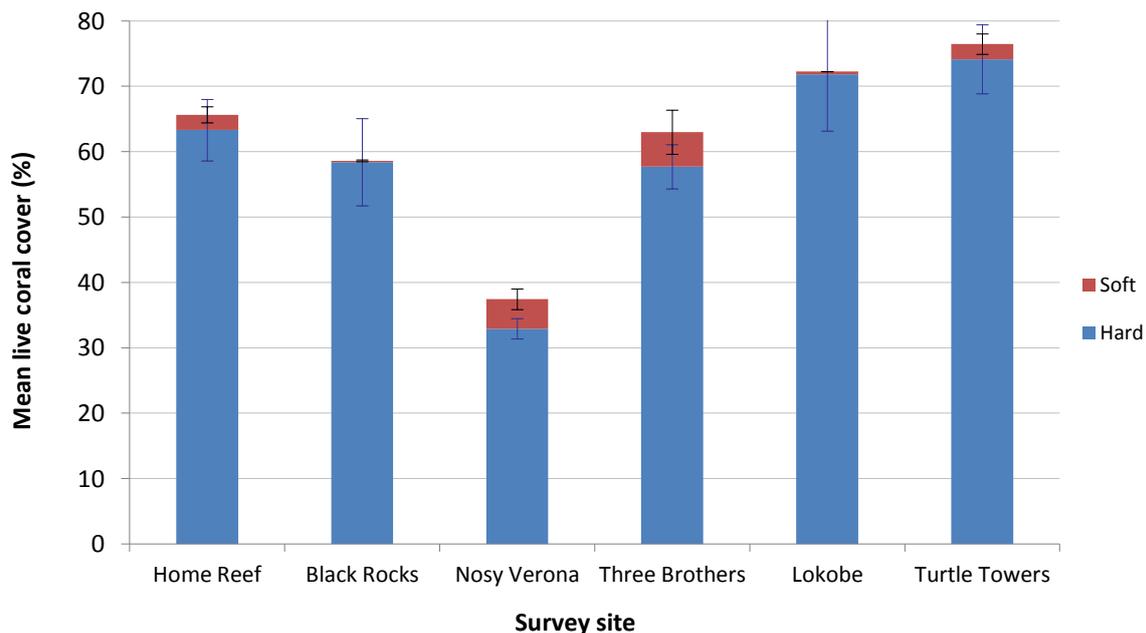
association between ecological variables, bivariate correlation was utilised in the form of the Spearman's Rank coefficient. To examine the differences between sites, Bray Curtis similarity plots and non-metric Multi-Dimensional Scaling (MDS) analysis was determined using PRIMER 6.0.

### 3.0 Results

#### 3.1 Benthic composition

For this period of study, the sites with the highest recorded Scleractinian hard coral cover were Turtle Towers and Lokobe with 74.1 % ( $\pm 5.3$ ) and 71.8 % ( $\pm 8.7$ ) respectively. The site with the lowest recorded hard coral cover was Nosy Verona with 32.9 % ( $\pm 1.5$ ) (Figure 2). Hard coral cover was significantly lower at Nosy Verona compared to Home Reef, Lokobe and Turtle Towers (ANOVA;  $F_{5, 25} = 9.6$ ,  $P = <0.01$  in all comparisons).

Additionally, soft coral cover made up a very small percent of the overall live coral cover with the greatest cover recorded at Three Brothers with 5.29 % ( $\pm 3.7$ ) and the lowest at Black Rocks with 0.21 % ( $\pm 0.16$ ) (Figure 2). Therefore, overall live coral cover was highest at Turtle Towers (76.4%) followed by Lokobe (72.5 %), although the variation between transects at Lokobe was high. Black Rocks and Lokobe experienced minimal soft coral cover of 0.21 % ( $\pm 0.14$ ) and 0.41% ( $\pm 0.26$ ) respectively.



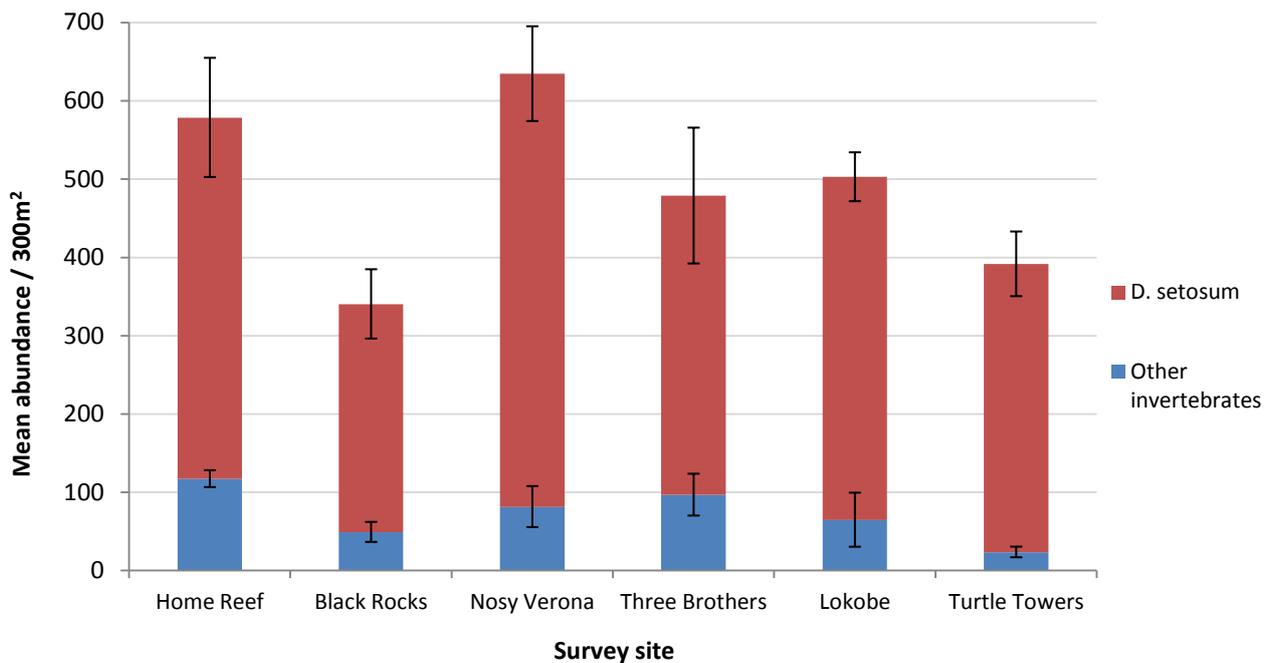
**Figure 2.** Mean percentage cover of live coral cover at each site showing the proportions of hard and soft coral.

Recorded algal cover was low across all sites. The greatest cover was recorded at Black Rocks with 5.2 % ( $\pm 3.8$ ), while none was recorded from Lokobe. All other sites contained 1.0% or less. Dead coral, defined as any substrate recorded as *Coral rubble* or *Recently killed coral*, varied significantly between sites (Kruskall-Wallis,  $df = 5$ ,  $P = 0.02$ ). Similar to the last phase of study, Turtle Towers again experienced the greatest percentage of dead coral with 13.2 % ( $\pm 3.2$ ). In contrast to last phase however, Nosy Verona was recorded to have the lowest cover of dead coral with only 3.3 % compared to 16.3 % recorded previously.

### 3.2 Invertebrate diversity and abundance

Species richness of invertebrates was taken from the Active Search, yielding a more comprehensive list of species observed at each site. Home Reef had the greatest diversity of invertebrates with 14.8 ( $\pm 0.5$ ) species observed per survey whereas Turtle Towers experienced the lowest (7.2 species  $\pm 0.5$ ).

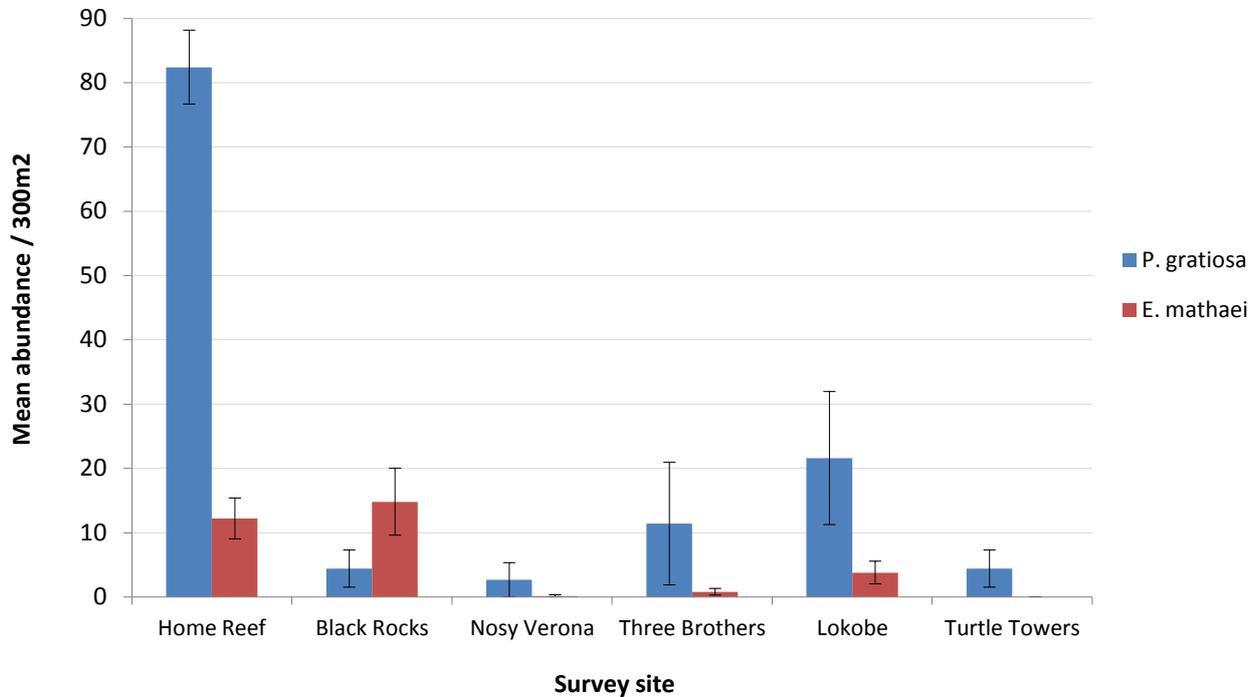
Similar to last phase, invertebrate abundance across all sites was dominated by the over-populous sea urchin *Diadema setosum* (Figure 3). Overall, Nosy Verona had the highest invertebrate abundance with an average of 605 ( $\pm 41$ ) individuals recorded per 300 m<sup>2</sup> however, *D. setosum* made up the majority of this count, with an average 553 ( $\pm 60$ ) individuals recorded per 300m<sup>2</sup> (= 18.4 10m<sup>2</sup>) (Figure 3). Pooling the *D. setosum* data for all sites results in a mean abundance of 13.8 ( $\pm 1.1$ ) urchins per 10m<sup>-2</sup> for this region. The lowest overall invertebrate count was recorded at Black Rocks with 340 ( $\pm 45$ ) individuals, although the difference was not statistically significant (ANOVA,  $F_{2, 25} = 2.27$ ,  $P = 0.07$ ). The exclusion of *D. setosum* from invertebrate analysis reveals that Home Reef experienced the highest abundance of other invertebrates, while Turtle Towers has the lowest abundance (117  $\pm 10$  and 23  $\pm 6$ , respectively).



**Figure 3.** Proportion of invertebrate abundance made up by *Diadema setosum* and other invertebrates

At Home Reef, the majority of other invertebrates recorded were the sea urchins *Parasalenia gratiosa* (82  $\pm$  5) and *Echinometra mathaei* (12  $\pm$  3). *E. mathaei* was found in highest abundance at Black Rocks with 15 individuals per 300m<sup>2</sup>, while at Turtle Towers this species was not recorded at all. A significant difference was found in the abundance of *P. gratiosa* across all sites (Kruskal-Wallis,  $df = 5$ ,  $P = <0.01$ ), and paired comparisons confirmed that abundance was significantly higher at Home Reef than all other sites (Mann-Whitney,  $Z < -2.61$ ,  $P = <0.01$  for all comparisons). Other invertebrates recorded include highly variable numbers of bi-valves at Nosy Verona (max  $n=128$ , min  $n=0$ ), Three Brothers (max  $n=127$ , min  $n=0$ ) and Lokobe (max  $n=139$ , min  $n=0$ ).

No correlation was found between the mean invertebrate abundance and live coral cover across all sites (Spearman's Rank,  $P= 0.69$ ).

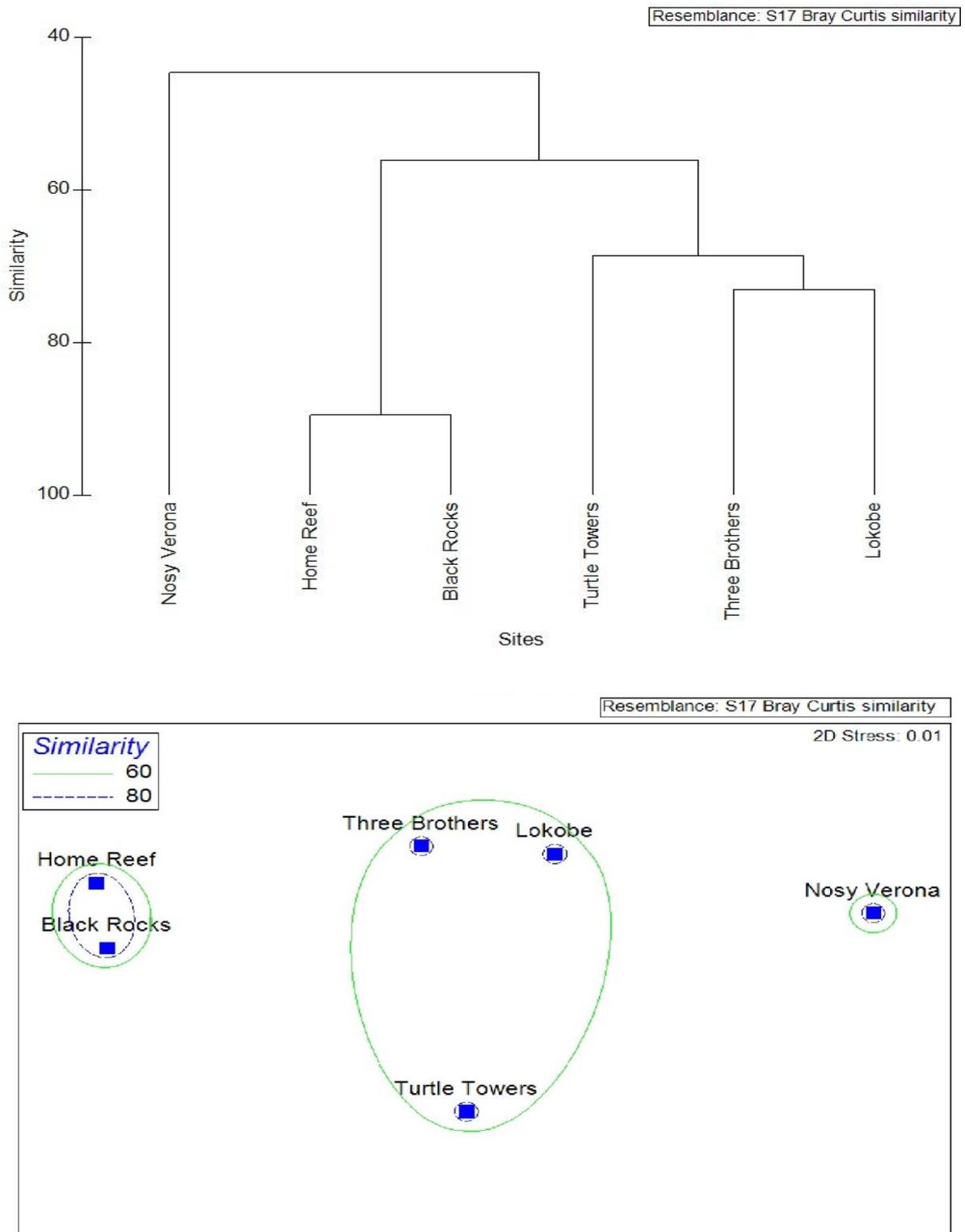


**Figure 4.** Abundance of the urchins *Parasalenia gratiosa* and *Echinometra mathaei* at all sites.

Crustaceans and cephalopods were both reported in extremely low numbers at all sites throughout the survey period with a maximum of two individuals recorded per site over all surveys. The ecological pest Crown of Thorns sea star, *Acanthaster planci*, was sighted on three occasions, twice at Nosy Verona and once at Lokobe. The two sightings at Nosy Verona may be the same individual; however photographs do not provide the detail required to confirm this.

### 3.2.1 Site similarity

Bray-Curtis similarity plots were generated to visually explore the similarities of invertebrate diversity and abundance across all sites. To obtain a more robust analysis, all invertebrate data were pooled for January to September, 2014. The sites which have the greatest similarity are Home Reef and Black Rocks with a resemblance of 89%, followed by Three Brothers and Lokobe (73%). Nosy Verona is dissimilar to all other sites in terms of overall invertebrate assemblage (Figure 5).



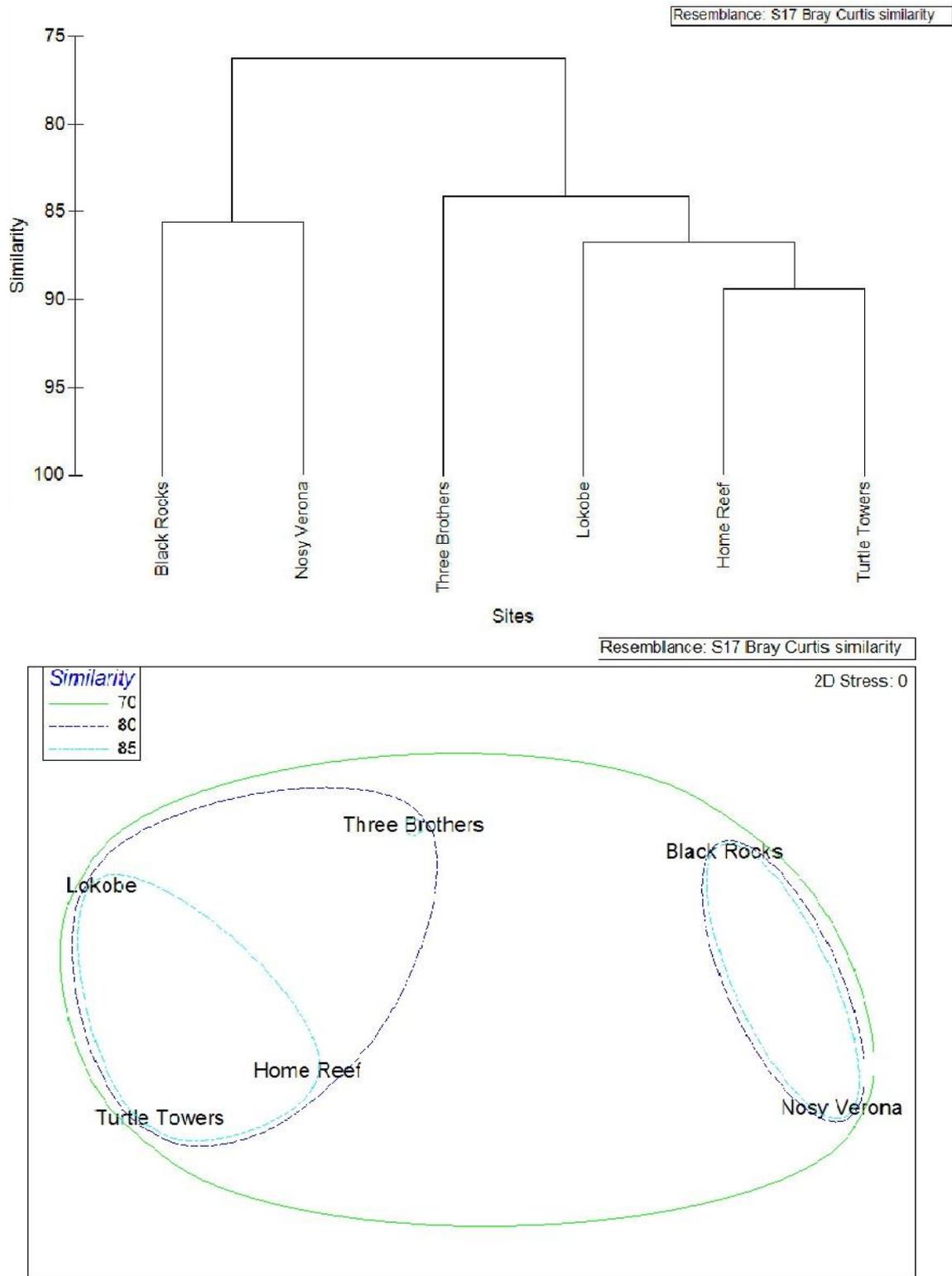
**Figure 5.** (a) Dendrogram for hierarchical clustering of all sites surveyed from January to September 2014, using group average linking of Bray-Curtis coefficient and (b) MDS analysis and similarly clusters of all sites.

### 3.3 Fish diversity and abundance

Analysis of the Active Search data together with the BSP data yielded a more comprehensive list of species diversity across all sites. The data indicates that Lokobe has the highest overall species diversity, with a mean of 46.5 ( $\pm 1.0$ ) fish species observed per survey. Black Rocks, Turtle Towers and Three Brothers were all marginally lower with 43 to 44 species observed per survey. In comparison, the site with the lowest fish diversity was Nosy Verona with 28.6 ( $\pm 0.9$ ). Analysis of the fish abundance data collected using the Active Search method returned broad and highly variable results and therefore will not be included in this report. Overall, the highest mean fish abundance recorded using the BSP method was Nosy Verona with 412 ( $\pm 59$ ) individuals per 1500 m<sup>2</sup> survey. This finding is consistent with data collected over the previous 6 months of study. The lowest mean fish abundance was observed at Turtle Towers with 257 ( $\pm 46$ ) individuals reported per 1500 m<sup>2</sup>, although no significant difference was found between mean fish abundance across all sites (ANOVA;  $F_{2, 25} = 0.79$ ,  $P = 0.56$ ).

#### 3.3.1 Site similarity

Bray-Curtis similarity and resemblance plots illustrate that all sites have at least 70% similarity to each other in terms of fish species richness and abundance. Interestingly, Turtle Towers was found to have a similarly high resemblance with both Home Reef (89%) and Lokobe (88%). As a group, Black Rocks and Nosy Verona were most similar compared to the remaining sites (Figure 6).



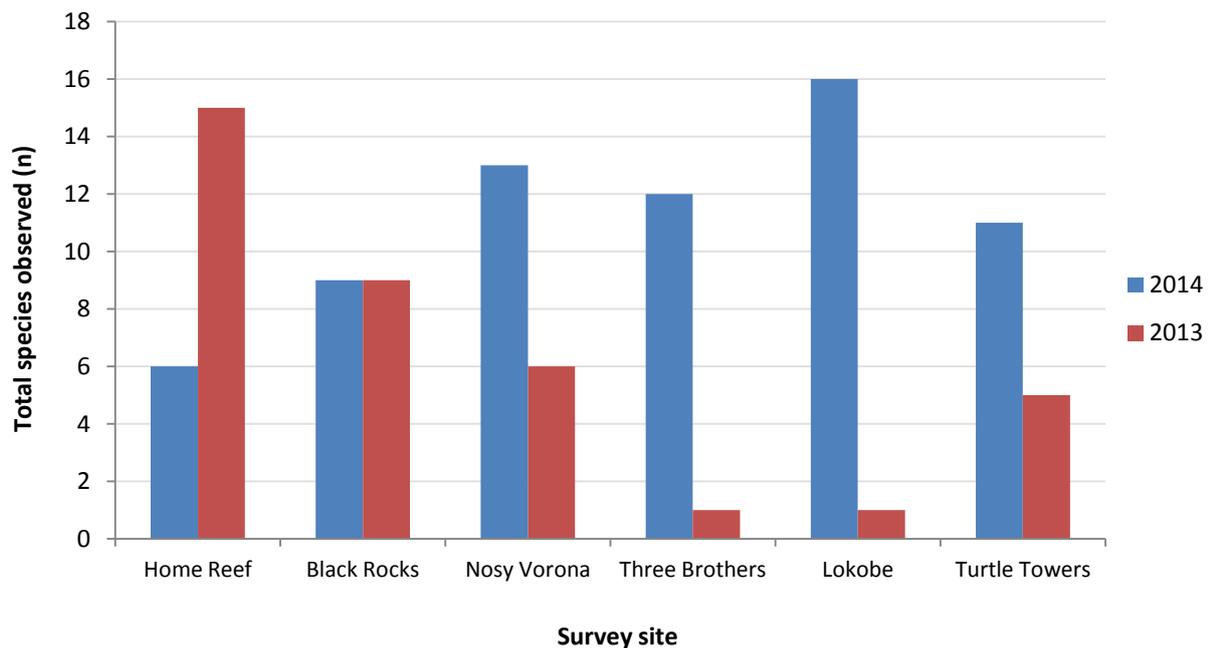
**Figure 6.** (a) Dendrogram for hierarchical clustering of all sites based on fish assemblages recorded from January to September 2014, using group average linking of Bray-Curtis coefficient and (b) MDS analysis and similarly clusters of all sites.

At all sites, the majority of fish recorded belong to the territorial Pomacentridae family (damselfish), comprising a minimum 62% composition of the fish assemblage at Home Reef to a maximum of 85% of the assemblage at Black Rocks. In comparison, when grouped together, predatory teleosts including members of

the Serranidae (groupers), Lutjanidae (emperors), Acanthuridae (surgeons), Lethrinidae (snappers) and Carangidae (trevallies) comprised an average of 3.8% of each assemblage. Turtle Towers had the highest percentage of predatory fish whereas Home Reef had the lowest ( $6.4\% \pm 0.0$  and  $2.3\% \pm 0.2$  respectively). No relationship was observed between live coral cover and overall fish abundance across all sites (Spearman's Rank  $P= 0.49$ ).

### 3.4 Opisthobranch assemblages

During this study, 27 opisthobranch surveys were undertaken which resulted in a total of 176 opisthobranchs recorded from 37 species. Of these, 32 species were of the order Nudibranchia, three of the Sacoglossa and three Cephalaspidea. An overall mean of  $4 (\pm 0.3)$  species were observed per survey throughout the study period with a mean of  $6.4 (\pm 0.5)$  individuals observed per survey. Species diversity was highest at Lokobe with a total of 16 species recorded, while Home Reef returned the lowest diversity of 6 species. In the previous study, 142 individuals were recorded with approximately 27 confirmed species. However, there are large differences in the species diversity observed at each site almost certainly related to differences in sampling effort (Figure 7). For example in 2013, Three Brothers and Lokobe were only surveyed once, while Home Reef was surveyed nine times. Consequently, results from the previous study are of relatively little use to compare inter-site differences.

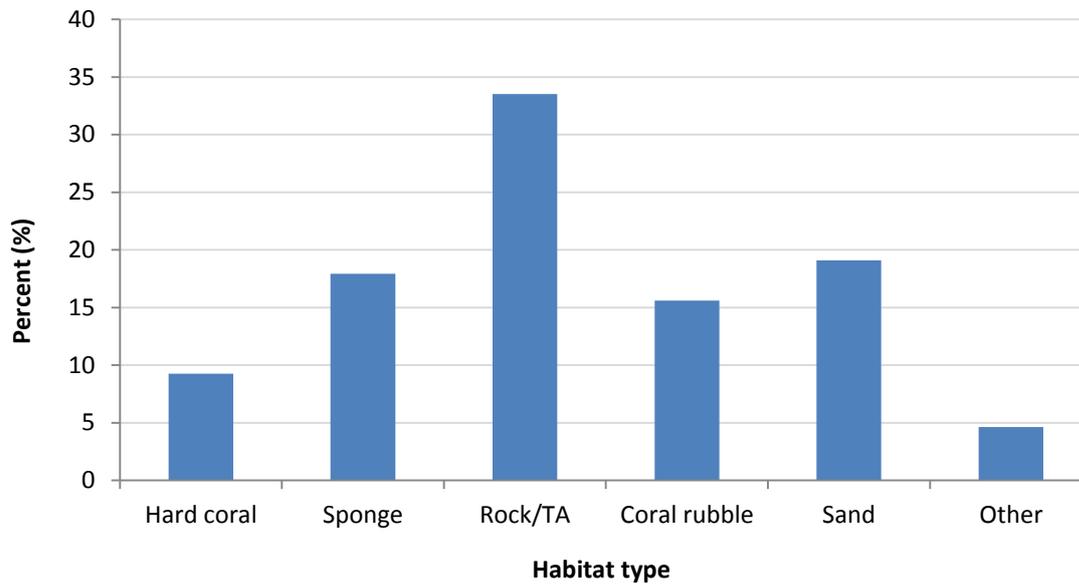


**Figure 7.** Comparison of total opisthobranch species observed at each site in 2013 and 2014

Previously, opisthobranchs have been surveyed sporadically at the same sites for a period of approximately six months in the latter half of 2013. During this time, 24 surveys were carried out following somewhat comparable methodologies to those undertaken in the current study. A combined table listing a comprehensive list of confirmed species sighted to date has been compiled (see Appendix 2)

*In situ* observations confirmed with photographs were used to identify the habitat type utilised by each opisthobranch at the time of observation. The highest number of individuals ( $n= 58$ ; 33%) were observed on

rocky substrate, often covered in filamentous turf algae (TA). Following this, 19% of individuals ( $n= 33$ ) were observed on sand. Combining sessile organisms (hard coral and sponge) yields a total of 27% of individuals ( $n= 47$ ) found in association with a possible food source (Figure 8).



**Figure 8.** Percentage composition of opisthobranch species recorded on different substrate types

Across all sites, the majority of opisthobranchs ( $n= 85$ , 49%) observed were in the ‘medium’ size bracket, 21 – 40 mm in length. Following this, 27% of opisthobranchs were classified as ‘large’ (41-70 mm) while five individuals were classed as ‘very large’ (>70 mm) (Table 2).

**Table 2.** Size frequency data of opisthobranchs with different categories and corresponding lengths in mm

Categories	Size (mm)	Number (n)
Very small	0-10	6
Small	11 - 20	31
Medium	21 - 40	85
Large	41 - 70	48
Very large	>70	5

### 3.5 New species records

A number of new species have been photographed and positively identified during this study phase to add to the growing inventory of marine species for this area. The IUCN status for each has been investigated and listed below (Table 3).

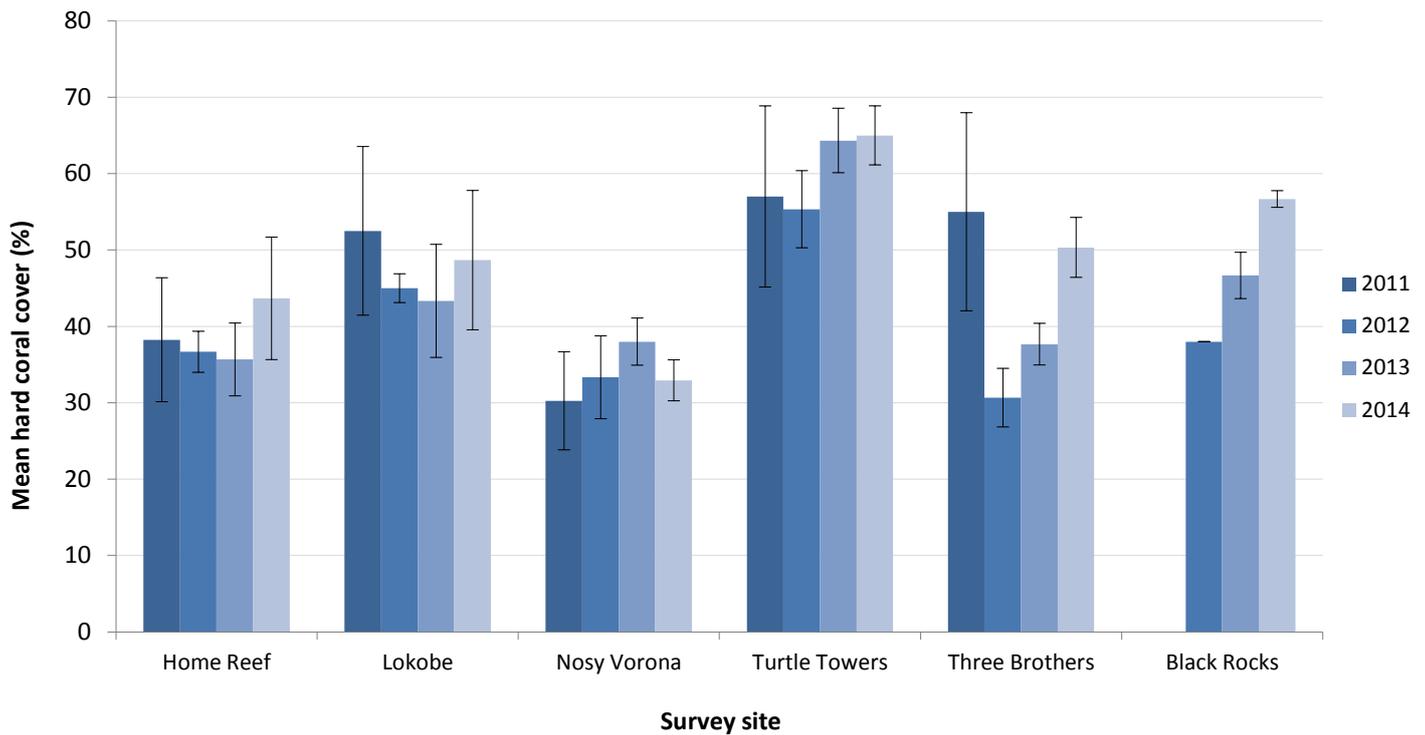
**Table 3.** List of all new species sighted and positively identified in this study period with associated IUCN status.

Common Name	Species name	IUCN status
<b>Fish and eels</b>		
Broom filefish	<i>Amanses scopus</i>	Not assessed
Common helmet gurnard	<i>Dactyloptena orientalis</i>	Not assessed
Geometric moray	<i>Siderea grisea</i>	Not assessed
Humphead wrasse	<i>Cheilinus undulatus</i>	Endangered
Paddletail snapper	<i>Lutjanus gibbus</i>	Not assessed
Robust ghost pipefish	<i>Solenostomus cyanopterus</i>	Not assessed
Slender pipefish	<i>Trachyhamphus longirostris</i>	Not assessed
Snowflake moray	<i>Echidna nebulosa</i>	Not assessed
<b>Invertebrates</b>		
Berry's bobtail squid	<i>Euprymna berryi</i>	Data-deficient
Curryfish sea cucumber	<i>Stichopus hermanni</i>	Vulnerable (pop <sup>n</sup> . decreasing)
Lined sea hare	<i>Stylocheilus striatus</i>	Not assessed
Old club sea star	<i>Mithrodia clavigera</i>	Not assessed
Seven armed sea star	<i>Luidia maculata</i>	Not assessed
Striated locust lobster	<i>Scyllarus martensii</i>	Least Concern
Whorl-spine urchin	<i>Prinocidaris verticillata</i>	Not assessed

## 4.0 Analysis of long term data sets

### 4.1 Benthic composition

To permit analysis of the data over a longer time period, the mean hard coral cover reported for each study period from 2011, 2012 and 2013 was compared with that for each study period thus far for 2014 (Figure 9). The results do not indicate a clear trend across all sites; instead, hard coral cover appears to fluctuate. Statistical analysis of the pooled data for each of the four years concludes a significant difference in hard coral cover between Home Reef and Turtle Towers (Mann-Whitney,  $Z=-2.30$ ,  $P= 0.02$ ), and also Nosy Verona and Turtle Towers (Mann-Whitney,  $Z= -2.03$ ,  $P= 0.02$ ). The only site with significant differences between years was at Three Brothers, where hard coral cover differed significantly between 2011 and 2012, and between 2012 and 2014 (ANOVA,  $F_2, 7=6.81$ ,  $P= 0.02$  and  $0.04$  respectively). The overall mean hard coral cover across all sites for this region is 45.1%.

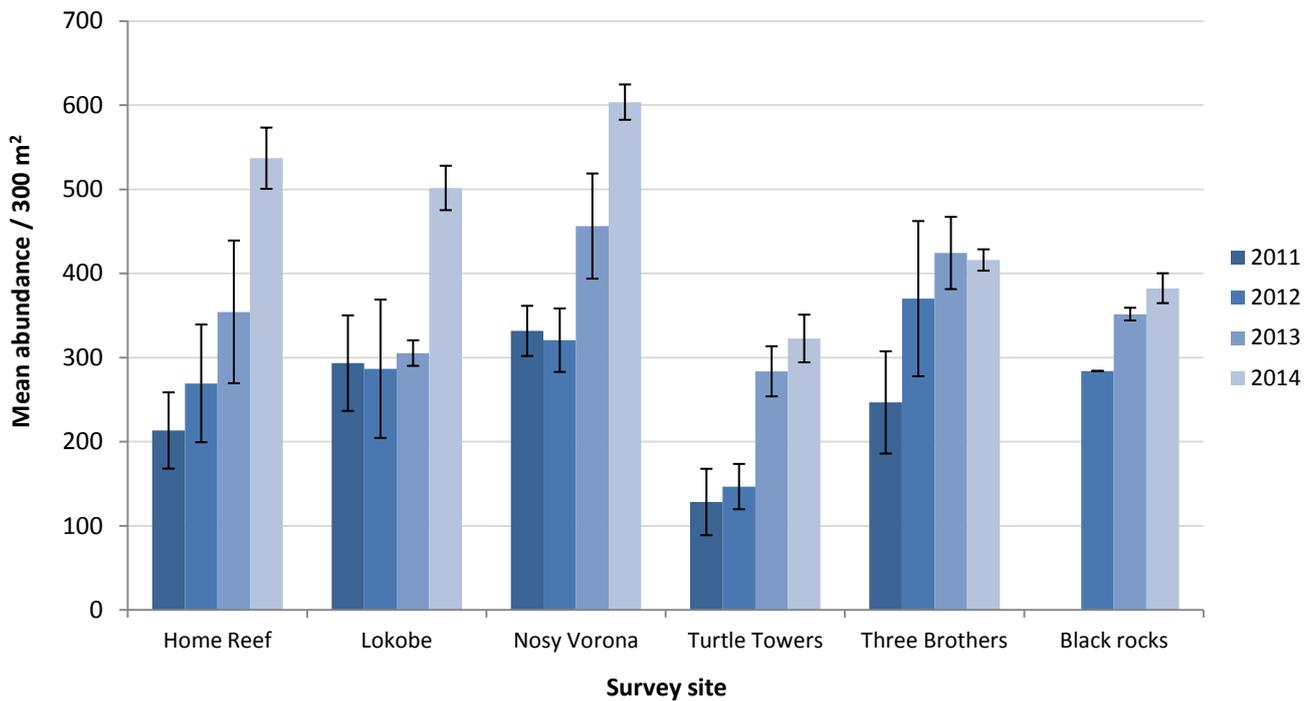


**Figure 9.** Compiled data for 2011 - 2014 comparing mean percentage hard coral cover at each site

Dead coral cover, defined as any substrate recorded as *Coral Rubble* or *Recently Killed Coral*, was also examined for this period. Results were highly variable however and show marked differences between phases and years for each site; therefore, no trends are apparent in the data.

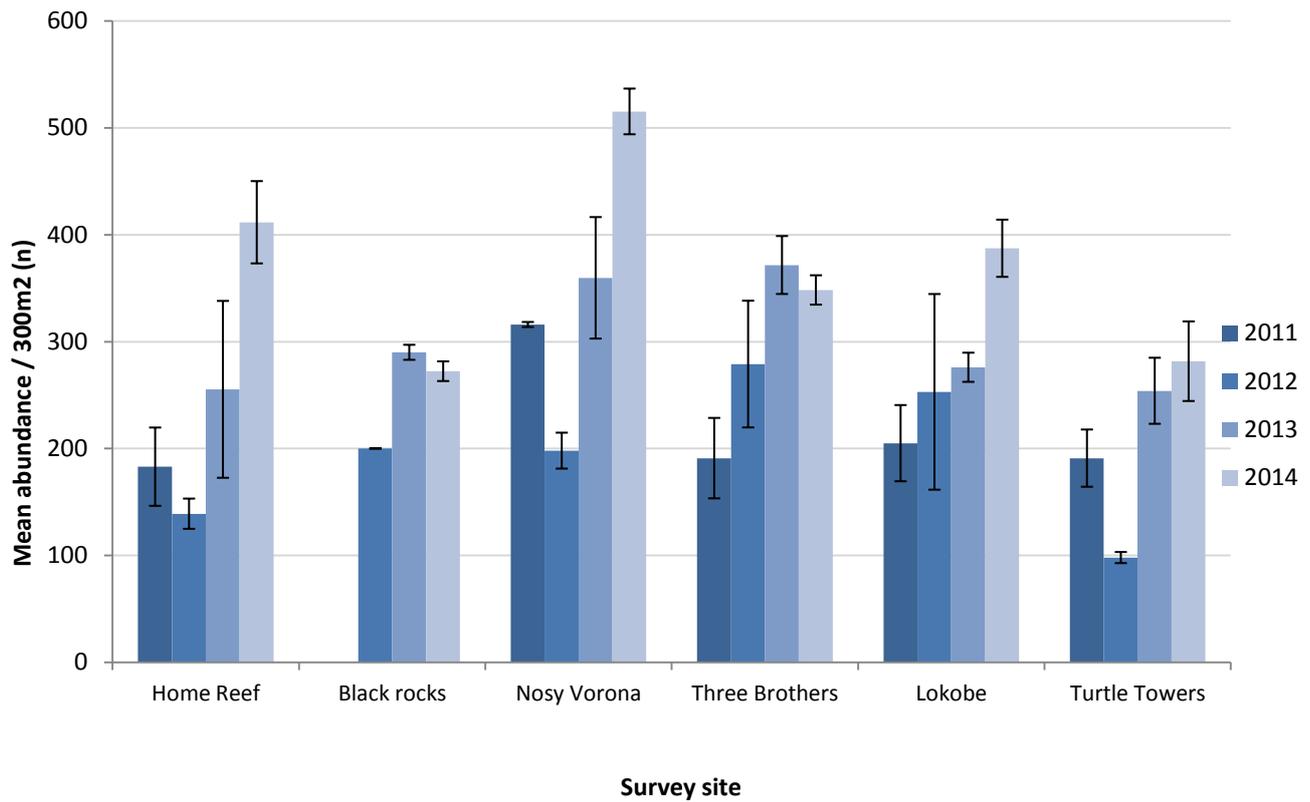
## 4.2 Invertebrate abundance

Examining the long term data suggests a general increase in the abundance of invertebrates at Home Reef, with the mean abundance reported for this study well over double the average count for 2011 (561 individuals compared to 213). The invertebrate abundance at Lokobe appears to remain stable for 2011-2012 with around 300 individuals per year, although a marked increase can be seen in 2014, with a mean of 501 individuals recorded per 300 m<sup>2</sup> survey (Figure 10). However, no significant differences were found between invertebrate abundance across all sites between 2011 and 2014 (Kruskal-Wallis, all comparisons  $P > 0.05$ ).



**Figure 10.** Compiled data for 2011 - 2014 comparing mean invertebrate abundance at each site

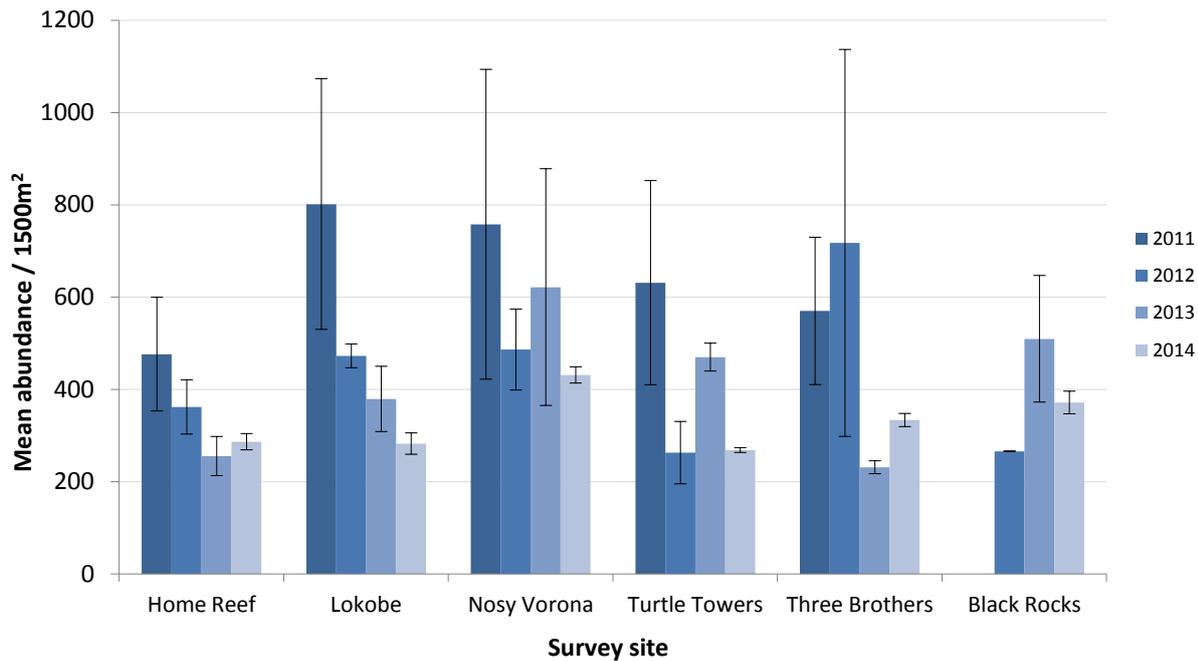
Throughout the years, it is clear that the sea urchin *Diadema setosum* has been the dominant individual in all surveys. To gain a better understanding of the possible increase in abundance of this urchin alone, data on *D. setosum* were extracted from all surveys. Not surprisingly, the data show a general trend of an increasing abundance of *D. setosum* over the survey period, particularly at Home Reef, Nosy Verona, Lokobe and Turtle Towers. At the other two sites, abundance in 2014 appears to have marginally dropped, although previous to this large increases can be observed (Figure 11). Paired comparisons of the data pooled by years shows that there has been a significant increase in *D. setosum* at Nosy Verona (Kruskal-Wallis,  $df= 3$ ,  $P= 0.04$ ) and at Turtle Towers ( $df= 3$ ,  $P= 0.03$ ).



**Figure 11.** Compiled data for 2011 - 2014 comparing mean abundance of *Diadema setosum* at each site

### 4.3 Fish abundance

When examining the long-term data set, recorded fish abundance across all sites are highly variable. These data exhibit a general trend of decreasing fish stocks, particularly at Lokobe which shows a significant decrease in fish abundance during the study period (Kruskal-Wallis,  $df= 3$ ,  $P= 0.02$ ). However, analysis of this data must be cautious due to the large variances exhibited over the data set (Figure 12). When all sites were pooled to compare the overall difference in abundance within the Nosy Verona Bight since 2011, no statistical significance was found (Kruskal- Wallis,  $df = 5$ ,  $P= 0.51$ ).



**Figure 12.** Compiled data for 2011 - 2014 comparing mean fish abundance per 1500 m<sup>2</sup> survey at each site

## 5.0 Discussion

### 5.1 Benthic composition

Overall, the recorded benthic composition for this phase varied markedly from that recorded last phase. Sites such as Lokobe and Home Reef are reported to have nearly double the average hard coral cover than was reported three months previously (see Dobinson, 2014). Differences of this scale are unlikely to be evidence of rapidly growing Scleractinian cover, and are more likely a result of the variance inherent with re-surveying random transects. This is an issue that is currently being addressed with the implementation of permanent transect markers at each site. This will help to ensure that the differences in results between two survey periods can be attributed to environmental change, rather than variances in the sample set (Hill and Wilkinson, 2004).

Live coral cover remains high, with an overall mean of 61% across all sites. This continues to exceed the global reported average of 33% in 1999 (Hodgson, 1999) and continues to suggest that the coral reefs in this area are in good health.

Low algal cover was again reported across all sites, with most experiencing 1.0% or less. This minimal result is consistent with the findings of the previous phase where low macroalgal cover was recorded at all sites. For this study period, July – September, rainfall is low if not absent in the Nosy Be region, and therefore any nutrient rich runoff which may be deposited on the near-shore reefs is largely reduced. Turf algae, however, is prominent at all sites, predominantly in the form of algal gardens growing on recently killed long branching *Acropora* spp., which are ‘farmed’ by territorial pomacentrids (pers. obs). In Tanzania, algal farming by pomacentrids has been shown to affect the local fish faunal abundance, species richness and community composition (Bergman *et al.*, 2001). Further, a link has recently been demonstrated between this farming behaviour and the prevalence and occurrence of coral disease, whereby greater occurrence of Black Band Disease was found inside damsel fish territories than out (Casey *et al.*, 2014). Coral disease in the Nosy

Be area has been anecdotally reported, although the exact pathogens have not been confirmed; therefore future studies would benefit from examining the occurrence of any disease, and the possible relationship with pomacentrid algal farms.

## 5.2 Invertebrate density and assemblages

Similar to the previous phase, *Diadema setosum* dominated the invertebrate assemblages at all sites. An overall mean of 13.8 individuals 10 per m<sup>2</sup> is comparable to estimates of this urchin in other areas. Around the Mitsio Islands for example, which are generally considered to be in good health, *D. setosum* abundance is reported at approximately 14 individuals per m<sup>2</sup> (WCS, 2011).

Site resemblance analysis suggests that Home Reef and Black Rocks are the most similar in terms of invertebrate diversity and abundance. These two sites are geographically proximate to one another, situated less than 500m apart; therefore little change would be expected in the abundance of less mobile and slow moving organisms such as holothurians, echinoderms and asteroids. Further, both sites are susceptible to hand gleaning of invertebrates at low tide when most of the reef and its inhabitants are exposed. That Nosy Verona is dissimilar to other sites is frequently noted anecdotally, and may be due to the location of the site in the middle of the Nosy Verona Bight. Here, current movement and therefore flushing times are thought to be highest, which may increase the chance of encounter with planktonic invertebrate larvae.

The sightings of the ecological pest Crown of Thorns sea star, *Acanthaster planci*, are noteworthy as this species has been sighted on only a handful of occasions historically. The only official record of this sea star is from Black Rocks in March 2013, although there may have been other unreported sightings. Population outbreaks in this species have been attributed to a number of factors, namely a decline in predator populations through collecting or overfishing practices (Birkeland and Lucas, 1990). Historically, *A. planci* is known to have caused major damage to large scale reef systems, and has been a particular problem on the Great Barrier Reef, Australia (Kenchington, 1978).

## 5.3 Fish communities

As expected, fish abundance reported during this phase was relatively similar to that reported during April-June, with Nosy Verona experiencing the highest overall abundance again. Nosy Verona is situated in the middle of the Nosy Verona Bight and, as such, is subject to high water movement and current flow, particularly on the full moon. Although artisanal fishing does occur, the small island is predominantly uninhabited although a light house is present along with a small house, which suggests anthropogenic stressors to the reef are minimal. Further, although not quantified, the reef structure at Nosy Verona exhibits greater complexity than other sites such as Black Rocks or Home Reef, thereby potentially offering more ecological niches to be filled by different species and reducing predation through greater availability of shelter (Almany, 2004).

The mean species richness of fish reported across all sites was 40, which is markedly higher than the WIO regional average of 28 species (WCS, 2011), and is comparable to that of the Mitsio Islands, north-west Madagascar (45 species). Regional comparisons of abundance cannot be made at this point as the biomass (kg/ha) has not yet been determined for these sites.

Analysis of site similarity revealed that all sites are at least 70% similar to one another in terms of fish diversity and abundance. This is not surprising as all of the survey sites are located within approximately 5

NM of each other, and are all situated within the Nosy Verona Bight. That Turtle Towers and Home Reef are the most similar is surprising, as these habitats are the most geographically isolated from one other, and are

markedly different in structural complexity. This apparent resemblance may therefore be inaccurate due to limitations of sampling, low numbers of replicates, or attributable to the patchy nature and distribution of many fish species which may not reflect the true fish assemblages.

## 5.4 Opisthobranch diversity and abundance

In this study, 37 species were recorded, 14 of which were not previously recorded and as such are new records for the species inventory. The previous study also recorded six species that have not been observed during this study phase. As most opisthobranchs exist in low densities and are ephemeral in nature, short collecting or observational trips will likely yield only a fraction of the total fauna in the environment (Willan and Coleman, 1984). It is therefore likely that additional surveys will continue to uncover additional species. Further, many individuals are small, inherently cryptic or well-camouflaged, while others are nocturnally active; therefore many species may have been easily overlooked (Miller, 1962).

Lokobe was found to have the highest species diversity, with at least one new species recorded on each dive. This reef is located on the south eastern point of Nosy Be, and is often subject to strong easterly currents and high water flow, potentially increasing the chance of encounter by planktonic opisthobranch larvae. Further, as documented, the hard coral cover at Lokobe is exceptionally high – a feature which would initially suggest a lower diversity of nudibranchs (pers obs.); however at approximately 7 m the dense coral reef gives way to patchy sand habitat which extends to at least 13 m. Current flow is highest in this deeper channel, which is dominated by patchy coral bommies, sand, and large sponges and is where the majority of the individuals were observed.

Many opisthobranchs were found on rocky reef or reef habitat covered in filamentous turf algae; while a lower number were recorded to be in association with their potential prey (corals or sponges). These results are comparable to a recent study in Thailand, which reported that the majority of nudibranchs were found on coral rubble (39%) or sand (28%), while less than 25% were associated with sessile organisms (Chavanich *et al.* 2013). This may indicate that opisthobranchs do not always reside on their food habitat; rather, they use the prey substrate to feed upon and then move to reside on the rocky reef. Due to the comparatively low numbers of observations of many species, it was not feasible to separate the habitat use by each species. Therefore, perhaps further data collection will reveal inter-species differences.

## 5.5 Long term data sets

### 5.5.1 Hard coral cover

The variance exhibited in the long term data make it difficult to draw meaningful conclusions from each site. No clear trend can be observed, and it may be that the variance exhibited suggests a limitation of the survey method that has been utilised over the years. However, pooling all data from each site across the four years yields a much larger data set where it is hoped that such discrepancies will be averaged out. In this case, the data yield a long term average of 45% hard coral cover for this area. This is considerably higher than the Western Indian Ocean (WIO) regional average of 31.1% (WCS, 2011), and may be attributed to the relatively remote location of many of the sites, resulting in comparatively minimal anthropogenic stressors. Although artisanal fishing pressure is high, the damage to corals is likely limited at most sites as the fishing vessels, small wooden *pirogues*, are man-powered and do not use anchors on the reefs (pers. obs.). Further,

commercial tourism companies do not operate in the area; as such, impacts from recreational SCUBA diving are non-existent, with the exception of Turtle Towers which does experience diving pressure from SCUBA operators.

### 5.5.2 *Invertebrate assemblages*

The apparent and marked increase of *Diadema setosum* across all sites is concerning, as there are very few natural predators, and currently, this species is not consumed locally nor is it of any economic value (pers. obs). Sea urchins are predominantly herbivorous; however also feed on other substrate including juvenile corals and as such play an important role in the bio-erosion of coral reefs (Glynn, 1988). Hence, at appropriate densities, sea urchins can have a beneficial role in the coral reef ecosystem, preventing the growth of macroalgae and subsequently providing space for settlement of coral recruits. However, at high densities urchins can have a negative effect on the overall calcium carbonate budget of coral reefs (Wen-Qui, 2014), and reduce the post settlement survival rates of coral recruits (O'Leary *et al.*, 2013). In order to examine the relationship and possible cause of the increasing populations, the relative abundance of their major predators, triggerfish (Balistidae) (McClanahan and Sharif, 1989), were pooled into their respective years. However, the numbers of these fish were so low that no possible conclusions could be drawn. Further, it has been suggested that the use of belt transects to count predatory fish such as the *Balistidae* are relatively inaccurate and exhibit high variation (McClanahan, 1998); therefore these data were not included. The low numbers recorded since 2011 however may suggest that, rather than a continued decrease of the abundance of triggerfish and other predatory fish, these reefs have experienced a low population of the predators for some time before survey work began. This has likely facilitated the increasing population of sea urchins following spawning events with little or no predatory pressures. *Diadema setosum* are highly fecund, free-spawning echinoderms and have a long larval period, allowing dispersal between distant sites (Uthicke *et al.*, 2009). The removal of their finfish predators from these sites may have resulted in an outbreak of the species, which has the potential to cause shifts in species compositions, potentially affecting the rates of ecological processes such as bio-erosion (Wen-Qui, 2014) and productivity (Carpenter, 1985).

If the abundance of *Diadema setosum* continues to increase, human intervention may be a necessary and beneficial management option. Previously, research has documented that an 85% reduction in sea urchin populations on a heavily fished reef system resulted in increases of fleshy algae and estimated finfish wet weights, particularly parrotfish and wrasse. The fleshy algae were later replaced by hard coral, likely as a result of increased herbivory (McClanahan *et al.*, 2000). This experiment was trialled in Kenya, where urchin populations were documented at approximately 30 per 10 m<sup>2</sup>. In this area of Nosy Be however, the maximum density of *D. setosum* recorded was 18 per 10 m<sup>2</sup>; therefore such management options are likely not yet a necessity.

### 5.5.3 *Fish diversity and abundance*

High variability characterises the fish abundance data, particularly in 2011 and 2012 and, when all sites were pooled into years, no statistical difference in abundance of fish within the Nosy Verona Bight was found between all years. However, the significant decrease of fish abundance at Lokobe over the four year survey period should not be discredited. Lokobe is a strict terrestrial reserve where fishing is forbidden within a 200 m boundary of the mean low water mark, punishable with a 200,000 Malagasy Ariary fine. This law however is relaxed, infrequently adhered to, and almost certainly never punished. During this survey period at least one, to a maximum of four, fishing *pirogues* were noted on 80% of all surveys. On one occasion, up to 15 *pirogues* were observed fishing parallel to one another in the deeper channel of Lokobe; such is the lack of enforcement.

The large variation seen at Three Brothers in 2012 can be attributed to an apparently large school of Fusiliers numbering 3700 individuals in one survey. When this outlier is removed, the fish abundance for 2012 nearly matches that of 2013. Whether the apparent decrease at all sites since 2011 is one of merit is not clear, however the data should not be ignored. Management of indiscriminate fishing practices at all sites is a necessity, including banning the use of mosquito nets to fish for juveniles in the mangrove roots and along the shore at low tide. This practice removes juveniles from the ecosystem, causing a collapse of the reproductive cycle and subsequent loss of spawning stock to the environment.

## 6.0 Conclusion

The results of this study phase coupled with the analysis of long term data sets reveals a number of concerning trends which exemplify the growing need for basic fisheries management actions. With a few exceptions, overall fish abundance appears to be declining across most sites with predatory teleost counts at times comprising a negligible amount of the overall fish counts. Instead, the dominant teleosts are territorial herbivorous fish which farm algal gardens on recently killed coral branches, diminishing the opportunity for recovery and increasing the susceptibility to disease and other pathogens.

Further, *Diadema setosum* numbers continue to increase likely due to a lack of predatory pressure in the larval and subadult phase as a result of reduced predator numbers. This again highlights the need for fisheries management in some form, be it gear restrictions, minimum landing sizes or no-take reserves. Recently, large red marker buoys were implemented to denote the boundaries of the Lokobe marine reserve, inside which, large boats are now not permitted to travel and fishing is not to occur. Predictably, fishing activity has already been observed inside the boundary, and boats are frequently seen traveling inside to save fuel and time. Although these buoys are certainly a step in the right direction, without routine monitoring supported by actual enforcement, the regulations will remain unheeded.

Evidence that no-take areas are effective is overwhelming, with numerous examples documenting an increase in average size, density, abundance and biomass of previously heavily fished species (Lester *et al.*, 2009; Roberts and Hawkins, 1997; Russ and Alcala, 1996). A prime example of this lies within the Nosy Tanikely MPA, located within 5 NM of the research center which supports healthy biomasses of groupers, jacks, trevallies, snappers and parrotfish (pers. obs). If the management of Lokobe were to uphold the same protections, in time the benefits could be substantial with the potential of biomass spillover to nearby sites (Russ and Alcala, 2010), particularly with two protected areas in close proximity to one other.

## 7.0 Objectives for future study

During the next phase of research (October – December 2014), a number of new surveys will be undertaken in order to examine different ecological relationships and potentially map new habitats. The BSP method will be disassembled to create separate surveys which will facilitate a greater number replicates and therefore produce more scientifically robust data. Other changes will include;

- Mapping and ecological studies of the seagrass beds in the area. This will include initial species identifications, and creating an initial inventory of the fauna present.
- Surveying invertebrates along different depth, and therefore habitat, gradients at the current survey sites.
- Surveys of fish will be stratified by habitat use, i.e. habitats such as seagrass, live coral, coral rubble and unvegetated habitat will be surveyed to determine differences in fish compositions.

- Implementing permanent transect markers at the current survey sites in order to standardize future surveys and allow for more meaningful replication.
- Trialling the use of photo quadrats and computer software analysis as a method of surveying the substrate.

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## 9.0 Appendices

### Appendix 1

Categories used to classify benthic type:

Hard Coral	Other substrate	Abiotic
Long branching	Soft coral	Coral rubble
Short branching	Seagrass	Recently Killed Coral
Digitate	Turf algae	Sand
Tabular	Macro algae	Silt
Foliose	Anemone	Rock
Laminar	Zooanthids	
Columnar	Hydrozoans	
Sub-massive	Sponge	
Massive		
Encrusting		

**Appendix 2**

List of all opisthobranch species recorded to date around the southeast of Nosy Be. The asterisk denotes those species recorded in 2013 that were not observed in this study.

<b>Family</b>	<b>Species name</b>	<b>Authority</b>
<b>Aglajidae</b>	<i>Chelidonura electra</i>	Rudman, 1970
	<i>Chelidonura punctata</i>	Eliot, 1903
	<i>Philinopsis pilsbryi</i>	Eliot, 1909
<b>Arminidae</b>	<i>Dermatobranchus albus</i>	Eliot, 1904
	<i>Dermatobranchus</i> sp.	-
<b>Bornellidae</b>	<i>Bornella anguilla</i>	Johnson, 1984
<b>Chromodorididae</b>	<i>Chromodoris africana</i>	Rudman, 1982
	<i>Chromodoris albo pustulosa complex</i>	Rudman, 1987
	<i>Chromodoris annulata</i>	Eliot, 1904
	<i>Chromodoris</i> cf. <i>elizabethina</i>	Bergh, 1877
	<i>Chromodoris fidelis</i>	Kelaart, 1858
	<i>Chromodoris hamiltoni</i> *	Rudman, 1977
	<i>Doris</i> sp. (unidentified)	-
	<i>Glossodoris cincta</i> *	Bergh, 1888
	<i>Glossodoris hikuereensis</i> *	Pruvot-Fol, 1954
	<i>Glossodoris symmetrica</i> *	Rudman, 1990
	<i>Goniobranchus geometrica</i>	Risbec, 1928
	<i>Hypselodoris infucata</i>	Rüppell & Leuckart, 1831
	<i>Hypselodoris maculosa</i>	Pease, 1871
	<i>Hypselodoris whitei</i>	Adams & Reeve, 1850
	<i>Risbecia pulchella</i>	Ruppell & Leuckart, 1828
	<b>Discodorididae</b>	<i>Discodoris boholiensis</i> *
<i>Halgerda</i> cf. <i>elegans</i>		Bergh, 1905
<i>Halgerda tessellata</i>		Bergh, 1880
<i>Jorunna funebris</i>		Kelaart, 1858
<i>Taringa caudata</i>		Farran, 1905
<b>Facelinidae</b>	<i>Pteraeolidia ianthina</i>	Angas, 1864
<b>Flabellinidae</b>	<i>Flabellina bicolor</i>	Kelaart, 1858
<b>Glaucidae</b>	<i>Moridilla brockii</i>	Bergh, 1888
<b>Phylliididae</b>	<i>Phyllid</i> sp.	
	<i>Phyllidia</i> cf. <i>alyta</i>	Yonow, 1996
	<i>Phyllidia marindica</i>	Yonow & Hayward, 1991
	<i>Phyllidiella lizae</i>	Brunckhorst, 1993
	<i>Phyllidiella pustuloisa</i>	Cuvier, 1804
	<i>Phyllidiella varicosa</i>	Lamarck, 1801
	<i>Phyllidiella zeylanica</i>	Kelaart, 1859
<b>Plakobranchidae</b> ( <b>Sacoglossa</b> )	<i>Elysia ornate</i>	Swainson, 1840
	<i>Elysia virgate</i>	Bergh, 1888
	<i>Plakobranchus ocellatus</i>	van Hasselt, 1824
<b>Tritoniidae</b>	<i>Marionia levis</i> *	Eliot, 1904