Frontier Madagascar Environmental Research Series

REPORT 15

Science Summary

Frontier Madagascar Marine Research Program April – June 2007

Frontier Madagascar
2007

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Higgs SJ, Mrowicki R & Fanning E (Ed)

ANGAP

Association National pour la Gestion des Aires Protegees

The Society for Environmental Exploration

Frontier Madagascar
University of Antsiranana
Institue Halietique Sciences Marine (IHSM)

Society for Environmental Exploration

Antsiranana

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Frontier-Madagascar
Madagascar, the fourth largest islands in the world is renowned for its high biological and ecological diversity, characterised by its high abundance of endemic species. Madagascar is one of the poorest nations in the world and very dependant on the resources the natural environment provides. As a result conservation and development work is of paramount importance as efforts are made to preserve an environment under pressure from non-sustainable exploitation. Frontier Madagascar is in the process of carrying out baseline survey work in the northern tip of coastal Madagascar, the Antsiranana region, in an effort to provide biological and resource utilisation data for the preparation of sustainable management initiatives for the region.

Institut Halieutique et des Sciences Marines
The Institute Halieautique et des Sciences Marines (IHSM) is part of the University of Toliara in Madagascar, IHSM is a university centre of learning in the field of marine sciences and runs courses for both undergraduate and post graduate students. IHSM also provide consultations to government institutions, NGO's and individuals.

The Society for Environmental Exploration (SEE)
The Society is a non-profit making company limited by guarantee and was formed in 1989. The Society's objectives are to advance field research into environmental issues and implement practical projects contributing to the conservation of natural resources. Projects organised by The Society are joint initiatives developed in collaboration with national research agencies in co-operating countries.

Frontier Madagascar Coastal Research Programme (FMCRP)
The SEE and the IHSM have been conducting collaborative research into environmental issues since 2000 under the Frontier Madagascar banner,FMCRP. Frontier Madagascar conducts research into biological diversity and the resource utilisation of both marine and coastal terrestrial environments. Since moving to Diego Suarez in April 2004 the FMCRP has begun working in collaboration with the University of Antsiranana as well as the IHSM.

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EXECUTIVE SUMMARY

Frontier Madagascar moved to the Antsiranana province during April 2004, following 4 years of work in the South West region, based just outside Toliara. The program here was created from collaboration between the Society for Environmental Exploration, and the Institute Halietique Sciences Marine in order to use research assistants from across the world to gather baseline biological data on the marine ecosystem of Madagascar.

The move to Antsiranana has seen the continuation of this relationship and work outputs, principally gathering biological data on the Bay of Diego Suarez. The work program has also expanded to include some basic socio-economic work, exploring the resource usage of the region by the coastal villages. The last three months have further added to the data collected thus far, the techniques used, and the findings from which have been included in this report.

To date, as a result of the survey work and the casual observation of species by the staff members on the project, species lists have been created, of which the full list for fish and coral have been added to this report in the appendices. The lists detail 206 fish species, 171 corals, 31 algaes and 4 seagrasses. At the time of writing no species list has yet been created to document invertebrates but it is currently under compilation.

The species considered the rarest or most valuable on the lists in terms of their significance to conservation include Spotted Seahorse, Short Dragonfish, Green Sea Turtle, and migrating Humpback whales, all of which appear on the IUCN red list.

Locally important species, such as Ornate Lobster and Common Octopus, as well as entire families of organisms including Sea-cucumbers and certain fish such as Emperors, Snappers and Groupers are found within the bay and considered a valuable marine resource for the local people.

The area itself is potentially of great importance as it represents a merging of the two marine expanses in the area: the Indian Ocean and the Mozambique channel, both of which have been seen to exhibit differing biological characteristics and faunal composition. Further investigation of this area may well result in the discovery of higher biological value than is found in either of the bordering regions.

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1 INTRODUCTION AND OVERVIEW

1.1 Baie de Diego-Suarez and Manta Camp

Madagascar lies in the tropical West Indian Ocean, in the waters of the Southern Equatorial Current (SEC) forming part of the Agulhas large marine ecosystem (LME). This combined with its long coastline, large latitudinal range, east-west coasts and upstream location from eastern Africa potentially make for one of the most diverse marine areas in the region.

Studies conducted on the West Coast within both the Tulear and Nosy Be regions have identified high biodiversity, particularly with regard to fish populations. However, these sites are regarded as having suffered from relatively high levels of human activity. Biodiversity is generally greater in low anthropogenically impacted regions, thus additional areas within close proximity and under less stressful conditions would be expected to contain additional species. Furthermore, A Conservation International assessment of the Nosy Hara area in 2002 identified a greater number of endemic species in the northern region, and survey work within the Masoala region have identified high levels of biodiversity within the east coast. The close proximity of Diego-Suarez Bay suggests that species numbers may also be great, and could well be biologically distinct due to its location on the east coast as opposed to the west. Its location in the far north-east make it susceptible to influxes of species both from the African east coast and the Indian ocean making the area potentially one of the most biologically diverse in the country.

Diego Suarez Bay, in the north of the country, is the world's second largest natural inlet after Port Jackson, Australia. Its tropical climate causes seasonal variations in the bay's physical conditions. The austral winter (July to September) sees water temperatures drop to 23^{0}C, while temperatures can reach a maximum of 31ºC during the summer months of December to April. It is during this period that the majority of the 980mm of annual rainfall occurs with up to 350mm falling per month usually in short but intense localised storms (World Weather Information Service). During the austral winter strong onshore winds originating from the Indian Ocean continue for the majority of the dry season (April until November). These winds, known locally as 'Varatraz', cause the bay to experience considerable wave action given its enclosed nature, and can prove hazardous to small vessels operating within the bay.

The bay's large size relative to its seaward opening reduces water exchange and circulation, making it particularly susceptible to pollution. The absence of any major rivers entering the bay prevents large influxes of freshwater, sediment and land born pollutants. However its long coastline, and the presence of the regional capital, Diego-Suarez on a peninsula protruding into the centre of the bay, means it is still subject to the effects of terrestrial and particularly anthropogenic land use.

The benthic topography of the bay is characterised by a deep central section with an average depth of approximately 40m, extending from the opening of the bay to the north and to the west. The bays to the south and east of this section are all characterised by shallower topographies ranging from 20-10m.

The Baie de Diego-Suarez is open to the east, through which runs a deep-water channel that opens directly out into the Indian Ocean. It is an area of natural beauty, exuding a certain undiscovered charm unheard of by western standards, and is thus a unique area for survey work. It has been a deepwater port since the late nineteenth century but the perimeter of the bay is still somewhat untouched with pristine shorelines and undiscovered reefs. It is a privilege for us to be working in a region that is so attractive yet near to a major city with good communication and access. There is a lot of local interest in this region because of its proximity to other terrestrial protected areas such as Montagne D'Ambre, Orangea and the newly managed Montagne De Francaise.

Figure 1 illustrates the proximity of Manta base camp from the city of Diego-Suarez and the 11 study areas in which we have been working within during April - June. The camp is situated at an ideal location to the north-west of the bay opposite the village of Antsisikala (S 12°10.450 E 049°13.800). The site is extremely sheltered from the prevailing winds that are apparent in the dry season and has no restrictions on marine access at any state of the tide.

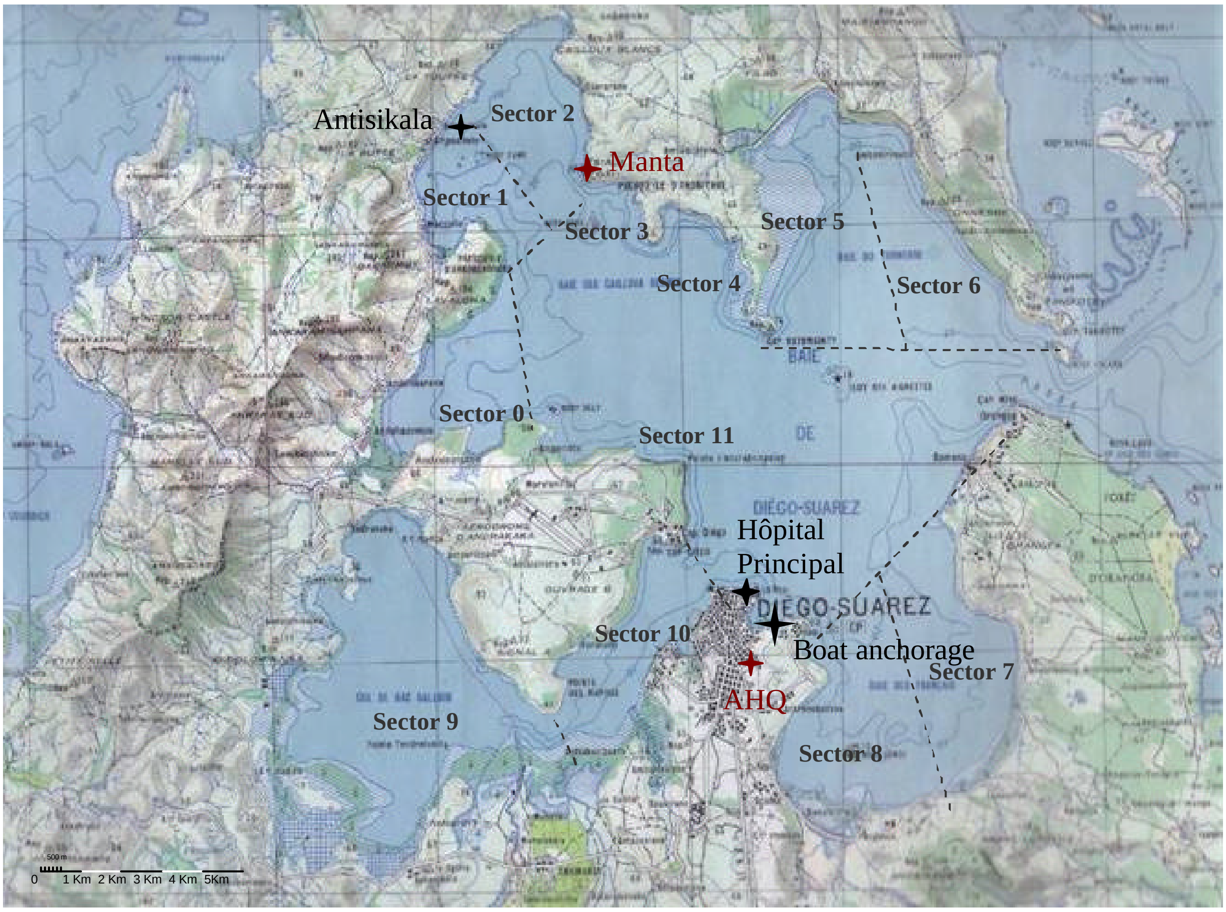

Figure 1. Map of the Baie de Diego-Suarez, displaying the 11 designated study areas in which the Frontier-Madagascar Marine Research Program (FMMRP) has been conducting research.

1.2 History and Rationale of Survey Program

The rationale for the survey program initiated in April 2005 stems directly from the affiliation of the Frontier-Madagascar Marine Research Program (FMMRP) program with SAGE, established in 2004, who were interested in identifying regions of the bay with particularly good reef systems. During the first year in which the Madagascar marine (MGM) program was based in the Baie de Diego-Suarez, the focus of the project was the biological assessment of the marine ecosystem. The initial analysis was completed in May 2006 and, following data analysis, we were able to produce habitat maps of the bay and detailed biological, physical and chemical analysis. Thus, in order to progress to the next step, it was necessary to begin assessing the socio-economic pressures on the bay. The two data sets can then be used in conjunction to develop management recommendations which promote ecosystem health and resource sustainability.

1.3 Frontier Madagascar Marine Research Program April – June 2007

1.3.1 Overview

Frontier Madagascar Marine Research Program (FMMRP) April – June 2007 consisted of 4 science staff, 2 dive staff, 2 local Malagasy staff, 1 Conservation Apprentice and 20 volunteer Research Assistants (RAs). Additionally, 1 Malagasy student from IH.SM joined the program for the duration of the phase. The main science objectives of the phase were achieved and two satellite camps were successfully conducted, the first based on the Mozambique Channel on the northwest coast of Madagascar, and the second in the Mer D'Emeraude on the northeast coast outside the Baie de Diego-Suarez. In terms of the socio-economic program, only a limited assessment of resource use in the bay was carried out; however, training of

Malagasy students and the continuation of English lessons contributed towards in-country capacity building and the maintenance of strong relationships with the local community.

1.3.2 Objectives

The overall aim of (FMMRP) April – June 2007 was the continuation of the biological assessment program to supplement information regarding temporal changes and enable the identification of changing ecological trends. Embedded within this was the need to begin focusing on the effective utilisation of the huge amount of information that the FMMRP has already collected, through the compilation and analysis of past RSP and BSP data. At the same time the expansion of the socio-economic program was to continue, in order to enable the assessment of fishing practices and pressures in greater detail and in areas of the bay that had not yet been visited. Thus, the scientific and socio-economic objectives for phase (FMMRP) April – June 2007 were as follows:

Scientific:

- To continue with Baseline Survey Protocol (BSP) surveys of the bay for improved temporal analysis;
- To continue the assessment of the algal/coral phase shift via Algal Quadrat (AQ) surveys;
- To conduct Coral Bleaching (CB) transects during the end of the warm rainy season period;
- To continue assessing the effects of sedimentation via sediment sampling and sieving;
- To continue testing water samples for important chemical parameters;
- To conduct a satellite camp in close proximity to the mouth of the bay in order to undertake scientific survey work in this area;
- To expand species lists by visiting sites close to and outside the mouth of the bay;
- To continue compiling previous RSP and BSP data in order to begin a more complex analysis.

Socio-economic:

- To continue to conduct socio-economic questionnaires within the bay;
- To expand our knowledge on the level of fishing and its impact within the bay;
- To maintain strong relations with local communities close to camp via the continuation of English lessons;
- To build stronger relations with communities further afield by conducting small workshops in schools in Diego-Suarez;
- To increase the capacity of local students for future marine conservation work;
- To maintain strong relations with IH.SM and the University of Diego, to incorporate the Natural Science Department.

2 RESEARCH WORK PROGRAMME

2.1 Overview

The initial biological assessment of the Baie de Diego-Suarez was completed in May 2006 and therefore the aim of data collection was the assessment of temporal changes in benthic health, fish diversity and abundance and algal cover. Biological data collection in (FMMRP) April – June 2007 focused around the Baseline Survey Protocol (BSP) and Algal Quadrat (AQ) survey techniques. However, additional techniques designed to provide more in-depth data on specific components of the ecological status of the reefs were continued and have included sediment particle analysis, coral recruitment, water testing, and Coral Bleaching (CB) surveys. Additionally, a number of Reef Status Protocol (RSP) surveys were undertaken during satellite camps held in the Mozambique Channel and the Mer D'Emeraude, combined with timed snorkels to draw up preliminary species inventories.

Details of methods, results and conclusions for each of these are expanded below, and a summary of the outputs of the phase follows. However, the goals of the FMMRP are beginning to shift away from biological assessment of marine environments of the Baie de Diego-Suarez in order to incorporate socio-economic analysis.

2.2 Reef Status Protocol (RSP) Surveys

2.2.1 Introduction

The Reef Status Protocol (RSP) survey technique has been the earliest form of surveying employed in any new area of the bay. As the name suggests, these surveys are very quick and easy to perform, using a minimum amount of equipment and man power. However, the results generated allow us an insight into what to expect in any given area. They provide vital information in planning and coordinating the latter steps of the research and monitoring program. New survey forms generated in May 2006 allow a greater and more detailed amount of data collection dependant on the experience of the surveyors involved. Newly trained RAs are capable of assessing an area to the minimum standard required in order to achieve the aim of the survey. However, we have since found that on occasions when staff carry out dives, a greater amount of detail is obtained and hence changes have been made to accommodate differences in data quality. Once the data from the RSP has been fully analysed, we aim to produce a Reef Status Report for the Bay.

The bay has been segregated into 12 sectors, labelled 0-11 (see
Figure 1). This has allowed a more comprehensive and detailed spatial analysis of the region from which poor to good reef ecosystems can be identified. From the individual sector analysis, a mean assessment can be deduced for the bay as a whole. The completed RSP surveys are able to provide an overall view of the topography and health of all areas of the bay, thus enabling more comprehensive surveys to be carried out at the same locations.

To date, 145 RSP surveys have been conducted in the Baie de Diego-Suarez, which accounts for >95% of its total coastline. No RSP surveys were undertaken within the bay during (FMMRP) April – June 2007, although RSP data from previous phases have been compiled and a detailed analysis is currently underway. However, 12 RSP surveys were carried out during satellite camps in the Mozambique Channel (9), in week 6, and in the Mer D'Emeraude (3), in week 8. Upon visits to new areas, such surveys are ideal for enabling an initial rapid assessment of the marine environment in order to provide a general overview of the biological status of that site.

2.2.2 Materials and Methods

RSP surveys can be carried out using SCUBA or snorkel equipment, depending on the depth at the start of surveying. Two surveyors and a boat marshal are involved in the survey, their respective roles are as follows.

- The **navigator** is responsible for holding a straight course for the duration of the survey and collecting some in-water physical data. Upon entering the water, this person determines a bearing towards the shore and perpendicular to it. If diving, surveyors then descend to the seabed or to a maximum depth of 15 m, with the navigator carrying a Surface Marker Buoy (SMB). The navigator notes down the depth and temperature and takes a water sample for further analysis, before leading the survey along the bearing for 15 minutes or until the water becomes too shallow to continue.
- The **data recorder** swims alongside the navigator and records estimated quantitative data relating to the fish, coral, invertebrates and algae species for the survey area. This surveyor also notes down the physical parameters of the environment and draws a basic map of the survey area.
- The **boat marshal** remains on board the boat for the duration of the survey, with their primary role being diver safety. The boat marshal is responsible for recording information on the environment outside the water, which relates to the environment underwater. This information includes visible boat traffic, surface temperature and salinity, sea state, wind direction and strength, vertical visibility and cloud cover.

The data collected is analysed mainly for determining substrate type on an arbitrary scale (poor/average/good/high coverage) for the main benthic components including rock, sand, coral, silt, algae and sea grass. Species lists are compiled for fish and invertebrates encountered during the survey and average numbers are calculated in order to assess abundance values for each location.

2.2.3 Results

2.2.3.1 Baie de Diego-Suarez

The FMMRP science report for Jan - March outlines a preliminary analysis of the data from phases MGM064 and MGM071 (15 + 7 surveys), indicating a few ways in which it can be examined. A more complex analysis is being carried out, incorporating data for 51 RSP surveys conducted from phase MGM062 to MGM071; earlier RSP data was not included in the analysis, due to the change in the data recording protocol having resulted in pre April 2007 data not being easily comparable with the more recent data set. Some preliminary results are described here.

Table 1. The proportion of sites surveyed in different bay sectors displaying medium-high cover of coral, algae, seagrass, sand/silt and rubble substrata, as ascertained from RSP surveys undertaken between phases April – June and Jan – March 2007, along with the total numbers of sites surveyed.

Sector	Coral %	Algae%	Seagrass %	Sand/Silt %	Rubble %	Total Sites
0	66.7	0.0	0.0	33.3	0.0	3
1	0.0	0.0	50.0	100.0	0.0	2
2	0.0	0.0	25.0	100.0	25.0	4
3	60.0	0.0	60.0	100.0	40.0	5
5	100.0	0.0	0.0	0.0	0.0	1
8	0.0	100.0	100.0	100.0	0.0	4
9	23.5	35.3	23.5	100.0	17.6	17
10	25.0	25.0	0.0	100.0	25.0	4
11	75.0	75.0	0.0	100.0	25.0	4
NF	75.0	100.0	50.0	75.0	25.0	4
NH	100.0	0.0	0.0	33.3	0.0	3
						51

Table 1 displays data regarding the substrate characteristics of sites within each sector. Overall the majority of the sectors were deemed to have medium-high sand/silt cover, except those in sectors 0, 5 and the island sites NF and NH, which were mostly coral-dominated. Additionally, 36 of the sites were classified as sand-dominated habitats, whereas only 11 were classified as coral-dominated. Indeed, this reflects previous findings with regards to the distribution of coral cover within the Baie de Diego-Suarez.

High levels of algae and seagrass were encountered in sectors 8 (100.0% and 100.0% of sites) and NF (75.0% and 50.0% of sites). Sectors 8 and NF also harboured the greatest number of nutrient indicator algal species (2.50 ± 0.65 and 2.50 ± 0.29 species, ± SE, respectively). Fewest species of nutrient indicator algae were found at NH (0.33 ± 0.33 species). In the North West region of the bay, a relatively high proportion of the sites in sectors 1 and 3 had medium to high seagrass cover, but generally a low algae cover. Overall, 28 sites were classified as low vegetation sites, with only 11 and 6 being classified as algae- and seagrass-dominated, respectively.

There were no significant differences between sectors in terms of the number of fleshy and filamentous (Kruskal-Wallis H_{10}adj = 17.57, p = 0.063) or any other (Kruskal-Wallis H_{10}adj = 10.25, p = 0.419) species of macroalgae.

There was little variation in the number of fish families recorded in different sectors of the bay; diversity was, however, greatest in sector NH (7.67 ± 3.38 families) whilst being lowest in sector 9 (0.24 ± 0.12 families). Sectors 2 and 10 also displayed relatively low fish diversity (2.50 ± 1.19 and 2.75 ± 1.60 families, respectively). There was a significant difference between sectors in terms of the number of fish families encountered (Mood's median χ^2_9 = 25.22, p = 0.003), with sector 9 harbouring fewer than the other sectors.

Overall, significantly more fish families were encountered at coral-dominated sites than other types of site (Kruskal-Wallis H_2adj = 9.75, p = 0.008), yet the vegetation characteristics of sites did not appear to affect fish diversity.

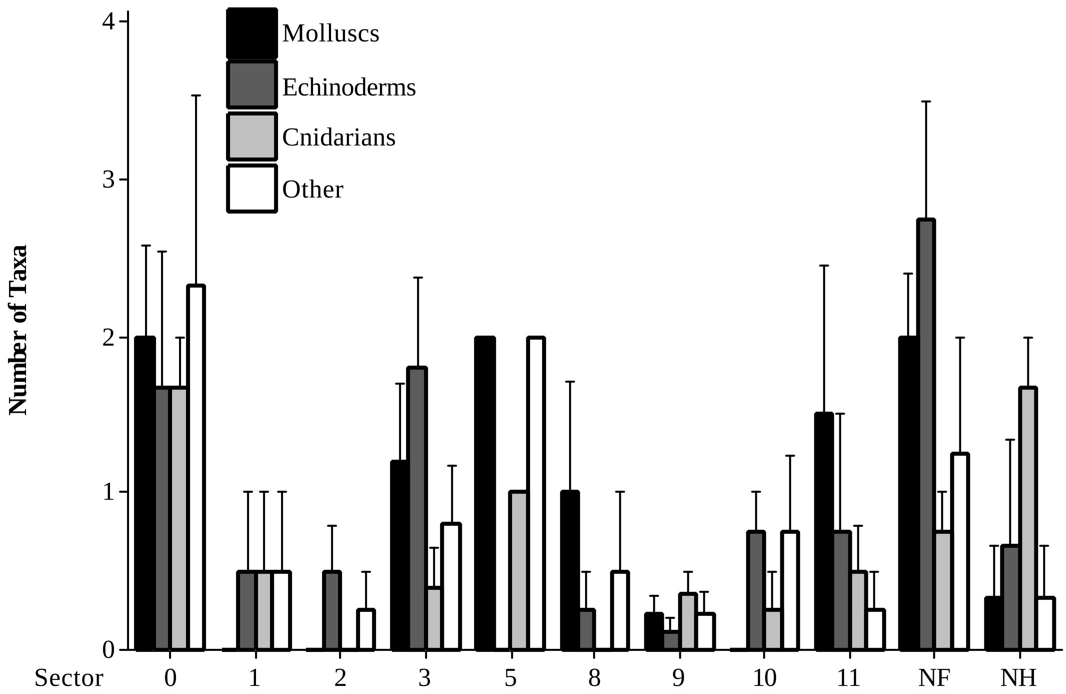

Figure 2. The mean number of invertebrate taxa within different phyla in each sector of the Baie de Diego-Suarez, as determined from RSP surveys carried out between phases MGM062 and MGM071. Error bars represent one standard error from the mean.

The diversity of invertebrates was highest in sectors 0 and NF (7.7 ± 2.3 and 6.8 ± 1.9 taxa, respectively), yet especially low in sectors 2 and 9 (0.8 ± 0.5 and 0.9 ± 0.3). There was a significant difference between sectors with regards to the number of invertebrate taxa encountered (Kruskal-Wallis H_{10}adj = 23.54, p = 0.009). Figure 2 displays variations in the numbers of taxa within various invertebrate phyla between different parts of the bay. No one phylum was recorded within all sectors, and there appears to be little spatial pattern in invertebrate community composition, as was hinted at in the previous analysis of RSP data. However, a significantly greater diversity of invertebrates (Kruskal-Wallis H_2adj = 14.99, p = 0.001) was present in coral-dominated sites (5.36 ± 0.91 taxa) than sand-dominated sites (1.67 ± 0.39 taxa). Site vegetation characteristics had no significant effect on invertebrate diversity (Kruskal-Wallis H_3adj = 2.04, p = 0.565).

Coral diversity, in terms of species richness, varied considerably around the bay (Figure 3) in ways that corroborate previous findings. The greatest number of species were recorded in sector 5 (16 hard and 3 soft coral species). Sectors 0, 1 and NF yielded moderately high coral species richness (12.0 ± 0.0, 9.0 ± 6.0 and 10.8 ± 3.8 species, respectively). Yet low coral diversity was encountered in sector 2 (1.8 ± 1.4 species), Sectors 9 and 10 (1.2 ± 0.5 and 1.8 ± 1.8 species, respectively) also exhibited low coral diversity. No coral was recorded in sector 8. In all sectors, except for sector 2, hard coral species outnumbered soft coral species, and the ratio of the abundance of the two types of coral remained fairly constant. Overall, there was no significant difference in coral species richness between different sectors (Mood's median χ^2_8 = 13.43, p = 0.098), and broad vegetation characteristics of each site had no effect on coral diversity (Kruskal-Wallis H_2adj = 3.44, p = 0.329).

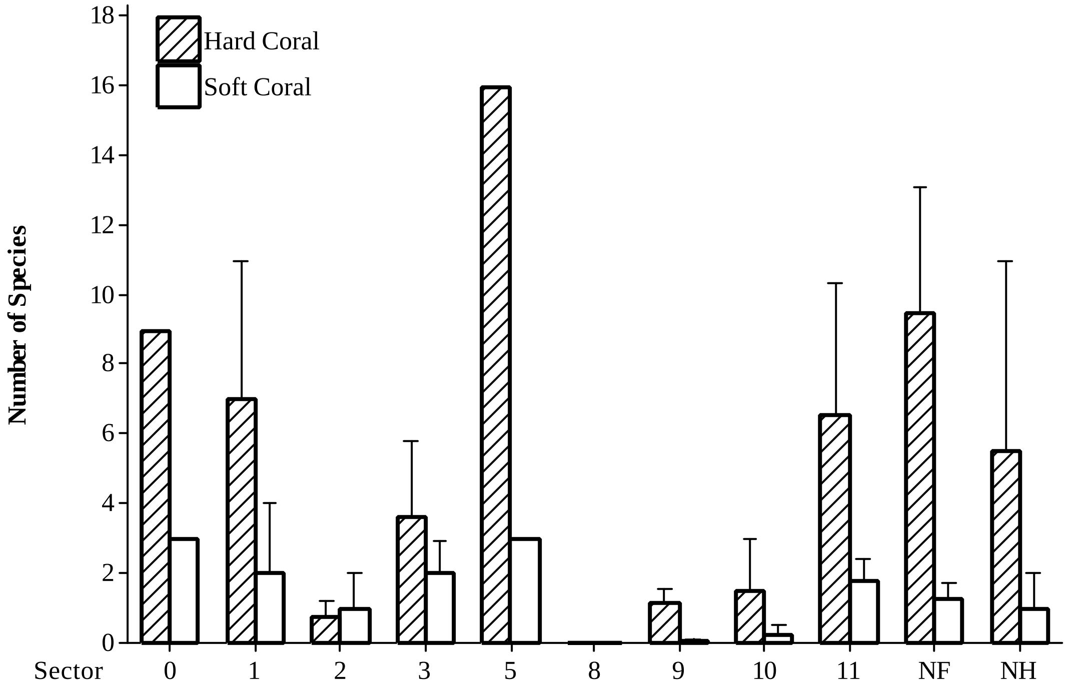

Figure 3. The mean number of species of hard and soft coral in different sectors of the Baie de Diego-Suarez, as determined from RSP surveys carried out between phases April 2006 and March 2007. Error bars represent one standard error from the mean.

2.2.3.2 Satellite Camps

Figure 4 shows the broad richness of corals, fish and invertebrates as ascertained from RSP surveys in the Mozambique Channel (base camp GPS: S 12°06.034', E 049°12.372') and Mer d'Emeraude (base camp GPS: S 12°12.830', E 049°21.951') carried out in phase (FMRP) April – June 2007. A greater number of coral genera (11.3 ± 2.5) and invertebrate taxa (7.3 ± 1.4) were encountered in the Mozambique Channel than the Mer d'Emeraude (0.7 ± 0.3 and 4.0 ± 0.0, respectively); additionally, these values closely reflect the highest values for these two groups within the Baie de Diego-Suarez (see previous). Fish family diversity was greater in the Mer d'Emeraude than the Mozambique Channel (11.3 ± 2.6 and 6.0 ± 1.5 families, respectively), although this difference was not statistically significant (Kruskal-Wallis H_1adj = 2.80, p = 0.094). The number of fish families recorded on RSP surveys at the former location was greater than the numbers encountered in the Baie de Diego-Suarez (see previous).

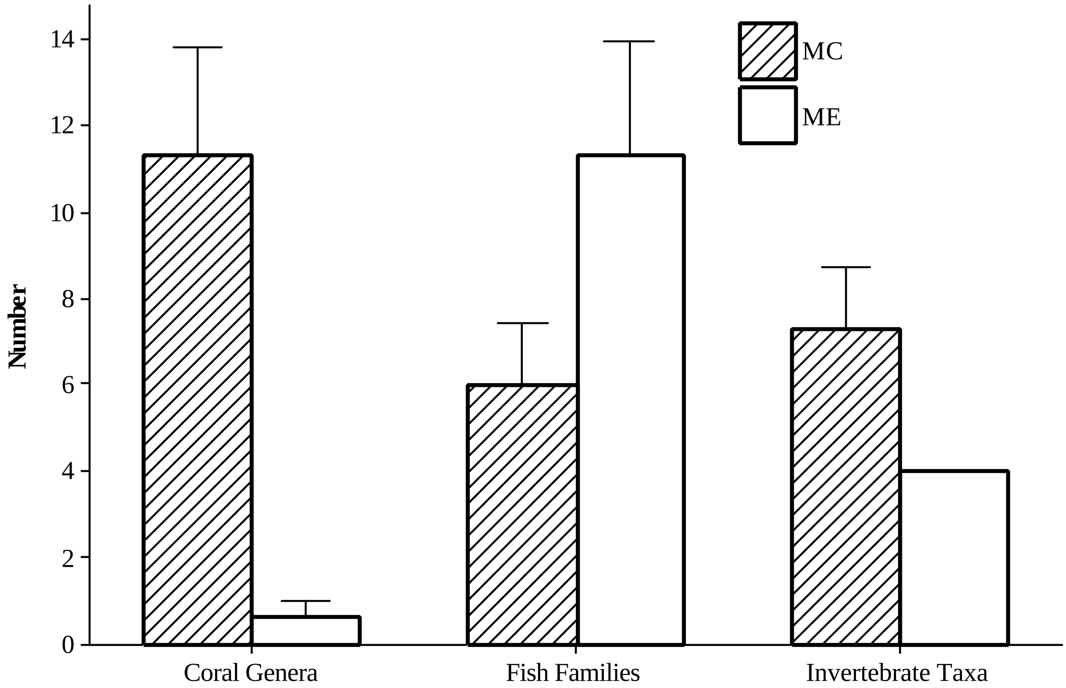

Figure 4. The mean number of coral genus, fish families and invertebrate taxa recorded on RSP surveys during satellite camps in the Mozambique Channel (MC; 9 surveys) and Mer d'Emeraude (ME; 3 surveys) during (FMRP) April – June 2007. Error bars represent one standard error from the mean.

2.2.4 Discussion

2.2.4.1 The Bay of Diego Suarez

The high levels of algae and seagrass encountered in sectors 8 and NF may be reflective of nutrient input into the water from Diego-Suarez and the village of Antsisikala, respectively. NH showed the fewest indicator algae species (0.33 ± 0.33 species), which is to be expected, it being far from potential sources of nutrient input and being moderately exposed to the open ocean.

Whilst no significant differences were detected within the sectors with regard to the fleshy or filamentous algal species, it should be noted that the small number of surveys carried out reduces the reliability of wider conclusions about environmental characteristics within each of the sectors, especially when considering the highly patchy nature of subtidal habitats within the bay.

The fish data recorded for fish families and distribution shows a significant difference throughout the bay, which, whilst reflecting changes in vegetation and other environmental factors detailed throughout the report, may also be subject to a number of other factors. Most notable is the likelihood of visibility effecting the results as this was a massively variable factor throughout the bay during the survey period, the nature of the census and the highly mobile habits of the fish make the technique's efficiency quite varied through differing visibilities.

With regard to the invertebrate data collection, it should be noted that in sand dominated sites any invertebrates present are likely to be buried under the substrate and therefore will not be recorded using this survey technique, so core samples should be taken if the data is to be used to draw comparisons.

The high level of coral species richness found in sector 5 was remarkable compared to the values given for the other sectors, and whilst it may be a true representation of the area it should be noted that this data is the product of a single survey and so is possibly an inaccurate representative of the site. As well as the sector 5, sectors 0,1, and NF also showed moderately high levels of species diversity, highlighting them as area that could benefit from additional, more detailed research. The relatively low coral diversity of sectors 2, 9 and

10 could possibly be attributed to their proximity to human settlements, the effects of which may prove to have significant input on the biology of the bay following further investigation.

2.2.4.2 The Mozambique Channel

The Mozambique Channel is renowned for its ichthyofaunal diversity, and the surveys undertaken in the Mer d'Emeraude represented the interior of this extensive, shallow lagoon, whereas greatest species diversity is likely to be found outside the reef wall. Therefore the position of the survey in the Mer d'Emeraude will explain much of the difference in the diversity data of corals (or something like this just to clarify the point). On the other hand,

Preliminary species inventories for corals, fish and invertebrates were also drawn up for the Mozambique Channel satellite camp (see Appendix I - III), assisting with the achievement of the FMMRP objective of expanding ichthyofaunal species lists for this area of northern Madagascar. It is hoped that areas outside of the Baie de Diego-Suarez, such as the channel and the Mer d'Emeraude, can be visited more frequently in future phases so as to acquire more knowledge of the marine ecology of these regions and gain greater understanding of the factors governing species distributions via comparison with findings from the bay itself.

2.2.5 Conclusions

RSP surveys began in the bay on our arrival in April 2005. Survey work in May-September was limited to the north western corner of the Bay due to weather conditions preventing access to sectors further afield. During these initial three months sectors 1-4 were surveyed. October 2005 coincided with the end of the windy season and hence allowed project work to extend east and south. Sectors 5, 7 and 8 were completed, and survey work in sector 0 began. RSP data within the remaining sectors (6, 9, 10, and 11) was since collected and has been incorporated into the analysis to complete the initial assessment.

The data taken from RSPs forms the preliminary assessment on reef health within the bay. This is followed by a comprehensive analysis conducted during the Baseline Survey Protocol (BSP), detailed below. However, the Reef Status assessment of the entire bay has allowed areas to be quickly identified in terms of their biodiversity, whether excellent, moderate or poor. To date, over 70 km of the coastline of the bay has been successfully surveyed. The data has enabled us not only to identify areas of good coral or sea grass cover for example, but has also enabled the effective elimination of unsuitable areas from future surveys, such as areas consisting purely of sand, thus saving time and money to be concentrated on certain areas. Thus the technique has been deemed to be of a low resource use and can be carried out effectively by non-specialist volunteers, therefore reducing time for science training.

Although all RSP data collected to date has now been collated into a usable format to enable a more complete, comprehensive analysis, only a preliminary analysis has so far been carried out, with some of the findings mentioned above. To complete the analysis, both univariate and multivariate statistics shall be invoked to a greater extent to determine significant patterns that arise in biological and physical characteristics. When available, the application of Geographical Information Systems (GIS) software will be used to allow such patterns to be visualised in a more accessible way, and to aid in the characterisation of the different habitats of the Baie de Diego-Suarez. Unfortunately, the pre- April 2006 data does not incorporate the same level of detail as the data collected since the revision of the RSP survey forms, and so cannot be included in a great deal of this more detailed analysis.

The analysis of the RSP data so far, despite its low resolution in comparison with that obtained from BSP surveys, has allowed some useful conclusions to be drawn and, additionally, highlights potential directions in which the examination of the data can proceed further. The initial ecological mapping of the bay has now been completed, and so further surveying by the RSP technique within the bay is unlikely; however it will still serve as a useful tool for rapid biological assessment upon visiting new areas outside of the bay.

The next section deals with the details of the BSP survey technique and draws conclusions from the results to date. However, it should be noted that the BSP data verifies findings taken from RSP surveys indicating that although the technique is not quantified and is often carried out by non-specialists, the data is accurate.

2.3 Baseline Survey Protocol (BSP) Surveys

2.3.1 Introduction

The primary method of surveying biodiversity during (FMRP) April – June 2007, as with previous phases, was a compilation of a number of well-known survey techniques into a standardised procedure, the Baseline Survey Protocol (BSP). The resulting technique aimed at providing data on the basic benthic coverage, Underwater Visual Census (UVC) fish data, frequency of indicator invertebrates present, and a detailed account of the physical and environmental conditions of the site, thus allowing all aspects of the marine environment to be directly related to each other at known locations. The technique not only aims at producing sound biological data, but also providing potential explanations for reef health status. In addition, by combining the techniques into one comprehensive method, it is easier for the RAs to fully comprehend and appreciate the relevance of the data they help to collate.

2.3.2 Materials and Methods

The BSP is a four-person survey technique which can be carried out at a variety of depths using either SCUBA or snorkel equipment as appropriate. Previously locations that have been assessed using the RSP are chosen. During previous phases, sites that presented both high and low ecological value were surveyed in order to produce an overall assessment of the bay. In addition, previous sites were resurveyed at different depths for the development of habitat maps based on three contour gradients, less than 2 m, 2 – 6 m and 6.5 – 12 m below chart datum.

All surveyors enter the water and actively begin the survey at the same time, each collecting a different data field to be compiled after the dive. The four roles for a SCUBA survey are detailed below. Similar procedures are followed for snorkel surveys.

- The **physical surveyor** is in charge of the operation once the team is in the water. Their first responsibility is to ensure the safety of all participants, and secondly that the survey is carried out correctly. At the start of the survey, they decide the origin of the transect. This location will be at a pre-determined depth and will follow a bearing parallel to the shore along a depth contour.

Table 2. Physical parameters recorded by the physical surveyor at different points on the transect line during a Baseline Survey Protocol (BSP) survey. ✓ = data recorded; **-** = data not recorded.

Physical Parameter	Distance along Transect (m)			
	0	20	25	45
Depth	✓	✓	✓	✓
Temperature	✓	✓	✓	✓
Visibility	✓	✓	✓	✓
Rugosity	-	✓	-	✓
Salinity (water sample)	✓	-	-	-

- The **fish surveyor** is responsible for recording the size and frequency of fish encountered within a belt transect zone along the tape measure laid out by the physical diver.

Table 3. Common names and latin names of fish families surveyed during Baseline Survey Protocol (BSP) surveys.

Common Name	Family Name
Angelfish	*Pomacentridae*
Butterflyfish	*Chaetodontidae*
Damselfish	*Pomacanthidae*
Emperors	*Lethrinidae*
Fusiliers	*Caesionidae*
Goatfish	*Mullidae*
Groupers	*Serranidae*
Moray Eels	*Muraenidae*
Parrotfish	*Scaridae*

Rabbitfish	*Siganidae*
Snappers	*Lutjanidae*
Spinecheeks	*Nemipteridae*
Sweetlips	*Haemulidae*
Triggerfish	*Balistidae*
Wrasse	*Labridae*

- The **benthic surveyor** travels along the transect line looking directly under the tape measure and recording the benthos underneath at 1 cm intervals.

- The **algae and invertebrates** surveyor is responsible for recording details of the invertebrate populations of the survey area, and generating an algal species list which compliments the quantitative data recorded by the benthic surveyor.

Table 4. Invertebrate indicator species recorded during Baseline Survey Protocol (BSP) surveys.

Invertebrate Indicator Species
Diadema Urchins
Lobsters
Sea Cucumbers
Banded Coral Shrimp
Pencil Urchins
Jellyfish
Crown of Thorns
Gastropods
Bivalves / Giant Clams

- A **boat marshal** is also appointed for BSP dive surveys. They remain on board the boat for the duration of the survey as a matter of diver safety. The boat marshal is responsible for recording information on the environment outside the water, as this can have implications for the environment underwater.

Whilst underwater on a SCUBA survey, the surveyors will be coupled together as recommended by the buddy diving system, with the fish and physical divers being together at the front of the survey. This allows the fish surveyor a chance to observe the fish populations along the line before they are disturbed by the presence of the divers. The benthic, algae and invertebrates' surveyors follow along the line after a short wait to allow any sediment disturbed during the survey to settle again, increasing the visibility. In total the survey should take approximately 30-40 minutes, enabling surveyors to traverse the line at a speed suitable to gather an accurate picture of the habitat.

2.3.3 Results

As with the RSP data, the input and analysis of this huge dataset is still underway, and the continued collection of data in subsequent phases shall further enhance the elucidation of temporal patterns within the bay. This section of the report deals with the data collected from April to June, 2007, and draws a preliminary analysis has been used to draw out some key patterns.

Preliminary analysis of the data collected in (FMRP) April – June 2007reveals similar patterns to what has previously been established, although again it must be borne in mind that any conclusions that can be drawn from it are shrouded in uncertainty due to the unrepresentatively small size of the dataset in question, which is unlikely to accurately represent the environment.

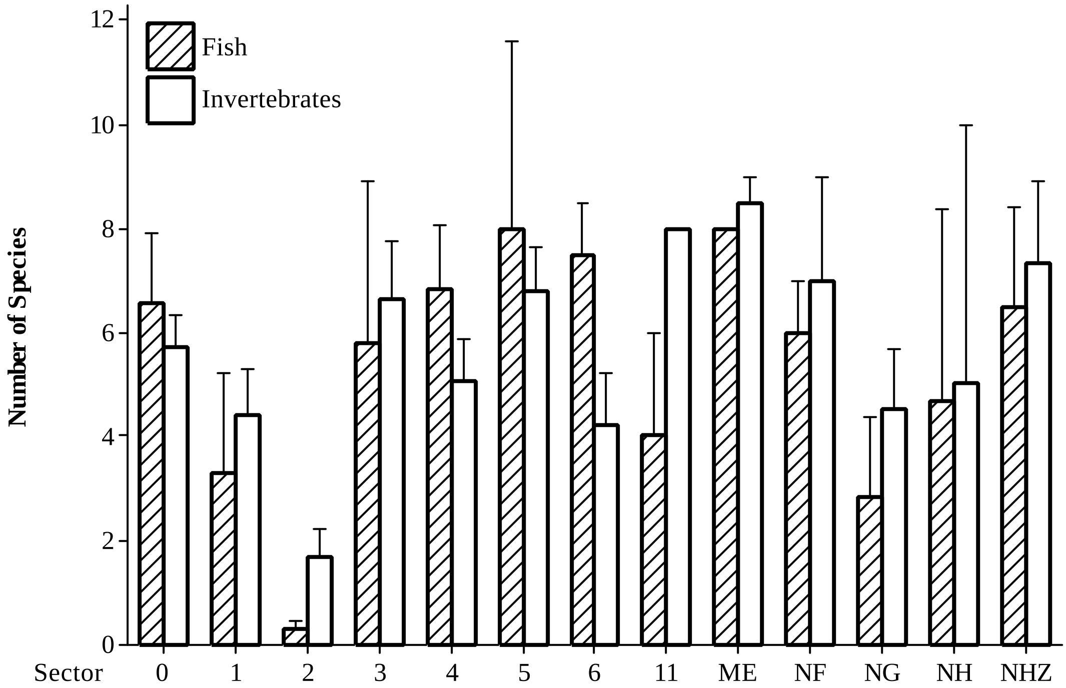

Figure 5. The mean numbers of fish and invertebrate species recorded on BSP surveys within different sectors of the Baie de Diego-Suarez during (FMRP) April – June 2007 (sector ME is located outside of the bay). Error bars represent one standard error from the mean.

Figure 5 shows that the number of fish species encountered was highest in sectors 5 and 6, near the mouth of the bay (8.0 ± 3.6 and 7.5 ± 1.0 species, respectively). A similarly high number of species were also recorded on a BSP survey within the Mer d'Emeraude (8 species), outside of the bay. Other sectors of the bay exhibited moderate fish diversities, yet the lowest recorded numbers of species were in sectors 1, 2 and NG (3.3 ± 1.9, 0.3 ± 0.1 and 2.8 ± 1.5 species, respectively).

The highest invertebrate diversity was recorded in the Mer d'Emeraude (8.5 ± 0.5 species) and, within the bay, in sectors 11 and NHZ (8.0 ± 0.0 and 7.3 ± 1.6 species, respectively).

Within the bay itself, highest algal diversity was recorded in sectors 0 and 1 (3.5 ± 0.6 and 4.2 ± 0.9 species, respectively), whilst relatively few algal species were recorded in sector 2 (1.4 ± 0.3 species). Seagrass species richness was greatest in sector 2 (1.7 ± 0.5 species), and moderately high outside the mouth of the bay, in sector NHZ and in the Mer d'Emeraude (1.5 ± 0.7 and 1.5 ± 0.5 species, respectively).

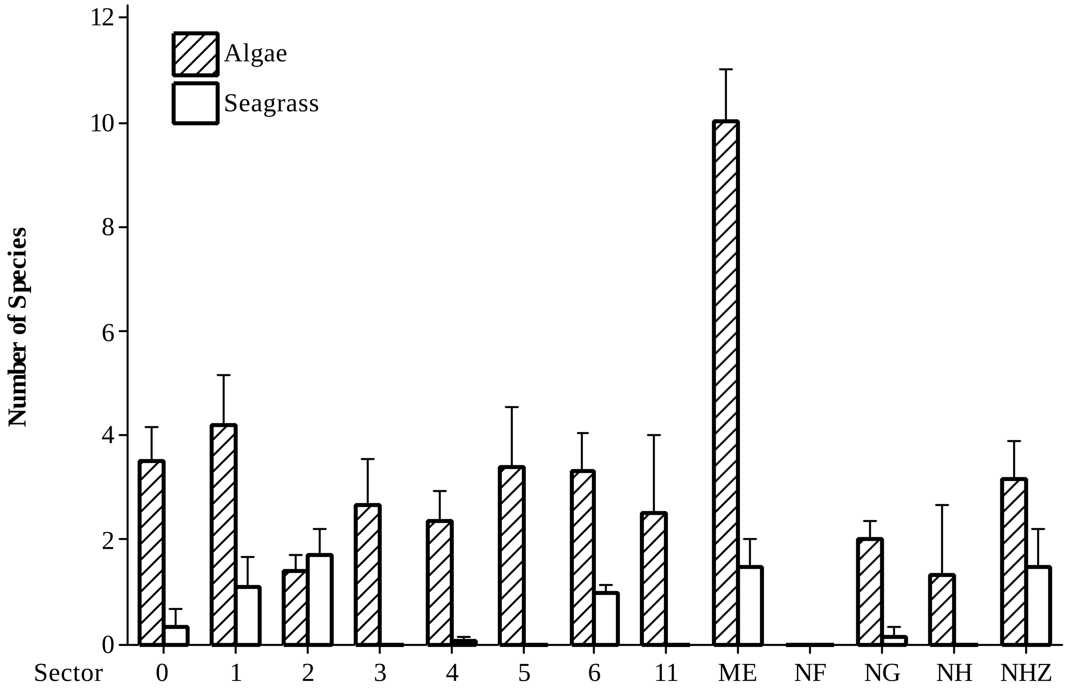

Figure 6. The mean number of species of algae and seagrass recorded on BSP surveys within different sectors of the Baie de Diego-Suarez during (FMRP) April – June 2007 (sector ME is located outside of the bay). Error bars represent one standard error from the mean.

2.3.4 Discussion

The high level of fish species encountered in sectors 5 and 6 is possibly related to the healthiest reef systems being located in those areas, which is perhaps in turn related to a greater level of oceanic exposure relative to terrestrial input. The appearance in the data set of low numbers in sectors 1,2 and NG have probably been brought about by the influence of the high levels of terrestrial input detrimental to aquatic ecosystems and lower influx of more pelagic species found in the area due to its sheltered location at the back of the bay.

Invertebrate diversity does not seem to correspond with that of fish, and there is little recognisable pattern with regards to this ecological group. As this comparison of broad species diversity does not incorporate differences in community compositions, further detailed analysis is required to see how diverse invertebrate assemblages differ around the bay and other areas.

As has been previously revealed, algal species diversity was greatest outside the mouth of the bay, in the Mer d'Emeraude (10.0 ± 1.0 species), perhaps relating to greatest exposure to open oceanic conditions and a higher level of environmental disturbance reducing the likelihood of the dominance of a small number of species. The high algal diversity of sectors 0 and 1 are likely induced as a result of them being situated in the sheltered northwest region of the bay. This pattern could reflect the high levels of terrestrial nutrient input promoting a greater proliferation of marine vegetation. However, this does not support previous findings (see Frontier Internal Report Series).

The distribution of sea grass reflects some of the patterns of macroalgae, although this relationship cannot be ascertained with confidence due to the unreliable nature of such a small, variable dataset.

Overall, in terms of fish and marine plant species, there appears to be two main regions exhibiting relatively high diversity – near or outside the mouth of the bay, especially in the Mer d'Emeraude, and in the northwest interior of the bay itself, around sectors 1 and 2. The distribution of invertebrates seems to follow a more independent pattern, perhaps relating more to proximity to anthropogenic influence from Diego-Suarez than to proximity to the mouth of the bay. It is hoped that further work in 2007 can compound these findings, following integration of datasets arising from the year 2007 as a whole and a more detailed analysis.

2.3.5 Conclusions

As mentioned, the most useful conclusions about the status of the marine ecosystems of the Baie de Diego-Suarez can be drawn from examining the BSP data from all phases to date, either as a whole or on a year-by-year basis. Examination of data gathered within a single phase only allows a limited number and level of complexity of ecological patterns to be identified and gives unclear, unreliable and potentially misleading answers. The preliminary analysis of the data from (FMMRP) April – June 2007 provided some valuable information, which partly corroborated conclusions that have been formed previously. Before results can be extrapolated from this data however, it is necessary to complete the entry and examination of the wider BSP dataset to produce as accurate, reliable and useful results as possible. This shall also pave the way for more complex analysis via univariate and multivariate statistical methodologies and GIS techniques. An integrated examination of pre-(FMMRP) Jan – March 2007 BSP data is underway; once the data for March to December have been gathered, this shall form another dataset in its own right to be analysed fully and related to the findings for the previous year. It is suggested that a similar approach is followed for subsequent BSP surveys in the Baie de Diego-Suarez, enabling a more structured, long-term temporal analysis of ecological patterns. The preliminary analysis of the (FMMRP) April – June 2007 data has provided valuable information and partly corroborates previous conclusions. However it is necessary to complete the analysis of the whole BSP data set to enable useful, accurate and reliable conclusions to be drawn.

2.4 Algal Quadrat (AQ) Surveys

2.4.1 Introduction

The algal/coral phase shift is a term used to describe the delicate balance between the level of coral and algae within reef ecosystems. A healthy reef ecosystem is characterised by a high coral cover and low algal abundance, dependant on stable physical conditions. These include sea surface temperatures, salinity, irradiance levels, and dissolved nutrients. Any values of such parameters outside certain ranges will lead to deterioration of coral health, abundance and diversity. During such periods, algal cover will increase, suffocating corals and preventing successful coral recruitment.

Algal and coral cover is quantified within the BSP survey technique. However, in order to assess algal cover in direct relation to coral cover, a quadrat survey methodology was devised in October 2005. The modified survey technique also takes into account the level of coral recruitment, determined by the number of small hard stony corals found within the quadrate, and the level of deposited sediment. The latter factor used in conjunction with suspended sediment will determine the effects of sedimentation on the coral/algal equilibrium. The methodology was improved upon in April 2006 in order to allow future statistical analysis of the results. During the phase RAs carried out both algal methodologies at survey sites in order to allow a direct comparison of the results gained from each of the techniques. This will ensure that data from phases prior to 062 can also be analysed in a similar manner. However, from July 2006 onwards, only the second Algal Quadrat (AQ) survey methodology was used.

2.4.2 Materials and Methods

A 50 m transect is deployed parallel to the shore at a depth contour 1-1.5 m above chart datum. At the start of the transect, the surveyor records the initial bearing, water temperature, depth and visibility. A 50×50 cm quadrat divided into 10×10 cm sections by wires is placed to the right of the transect at 5 m intervals, commencing at 0 m and finishing at 45 m. Each time, the quadrat is laid with its bottom left-hand corner adjacent to the appropriate mark on the transect line. The percentage cover within each 10×10 cm section for coral, algae and sea grass is recorded, identifying to species level if possible. The relief (height difference between the lowest and highest points of the quadrat), number of small stony corals < 2 cm, and the percentage sediment cover are also noted down for each quadrat. At the end of the transect, the surveyor re-records the temperature, depth and horizontal visibility.

2.4.3 Results

At the time of writing the results have not yet been analysed.

2.4.4 Discussion

Both of the aforementioned AQ survey techniques were able to gather a large quantity of data, although analysis of the results is not yet completed. The combined data will form the basis for the spatial and temporal assessment of algal cover in the Baie de Diego-Suarez.

2.4.5 Conclusions

This survey technique was introduced to the (FMMRP) science programme in October 2005. Initial surveys carried out were to be used as preliminary studies in order to assess the efficiency of the technique and the success at which RAs were able to record the necessary data. Data collection during February 2006 was carried out effectively. The technique was further modified in April 2006 to allow quantification and statistical analysis of the result. Following the completion of the data analysis we will be able to draw important conclusions into the relationship between algae and coral, how sediment load may be affecting this relationship and, more specifically, which algal species thrive in varying conditions. In addition, comparison of data between program phases will provide information on temporal patterns within the bay.

Furthermore, we hope to confirm which sectors are potentially suffering from eutrophication using indicator species of algae, thus backing up chemical analysis of the water samples. Both data sets will then be used to verify and explain the health status of reef ecosystems within the individual sectors of the bay as determined by the RSP and BSP surveys.

2.5 Water Analysis

2.5.1 Introduction

Water testing was introduced October 2005. The introduction of a water testing program allows us to evaluate the chemical status of the bay thereby highlighting any areas of significant chemical content. Reef ecosystem health is reliant on stable nutrient levels within the water column. Important nutrients include phosphates, nitrates, nitrites and ammonia as well as carbonate levels which indicate the hardness of the water. Any increase in nutrient concentrations, particularly phosphates and nitrates, indicates eutrophication, a condition which pre-empts algal blooms. Thus testing water samples taken from sites within all sectors of the Baie de Diego-Suarez may provide explanations for the current health status at said locations.

2.5.2 Materials and Methods

Water sampling was integrated into the RSP and BSP survey techniques, both on the surface and at depth (see above). The boat marshal was responsible for taking a sample using a 50 ml container on which several tests were to be performed. A sealed contained was taken down by the physical baseline surveyor, and a sample taken at the start of the transect before commencement of the survey. On return to base camp, the water was tested using standard salt water aquarium test kits manufactured by Nutrafin. Essentially each test was performed using 5 ml of the water sample to which the corresponding chemical was added as directed by the accompanying instructions. Nutrient levels were determined by a graduated colour change after a pre-designated period of time. In addition, the pH and salinity of water samples were measured to determine differences in these parameters within the bay.

2.5.3 Results

This section presents the results from March through until June, at the time of writing the most recent results are currently being analysed and their publication will follow shortly.

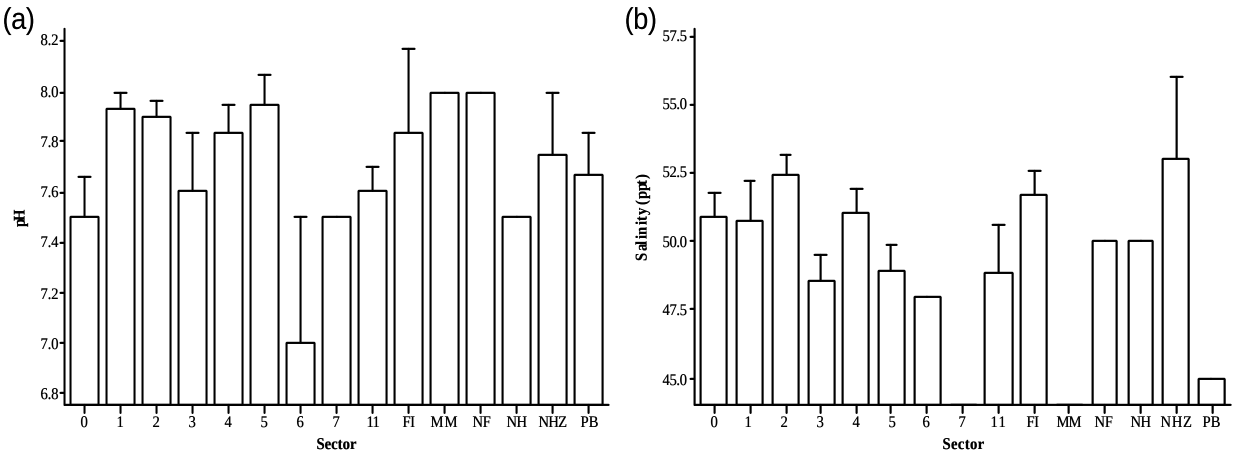

Figure 7. The mean (a) pH and (b) salinity as ascertained from chemical analysis of water samples obtained from different sectors within the Baie de Diego-Suarez during phases Jan – June 2007 (sector PB is situated outside of the mouth of the bay). Error bars represent one standard error from the mean.

The mean pH levels ranged from 7.00 (sector 6) to 8.00 (sectors MM and NF); excluding sector 6, the lowest pH was recorded in sectors 0, 7 and NH (Figure 7).

Mean salinity within the bay ranged from 48.00 ppt (sector 6) to 53.00 (sector NHZ); salinity was moderately high next to islands close to the mouth of the bay (FI and NHZ), overall, there seems to be no clear pattern as to the spatial variation in salinity levels around the bay.

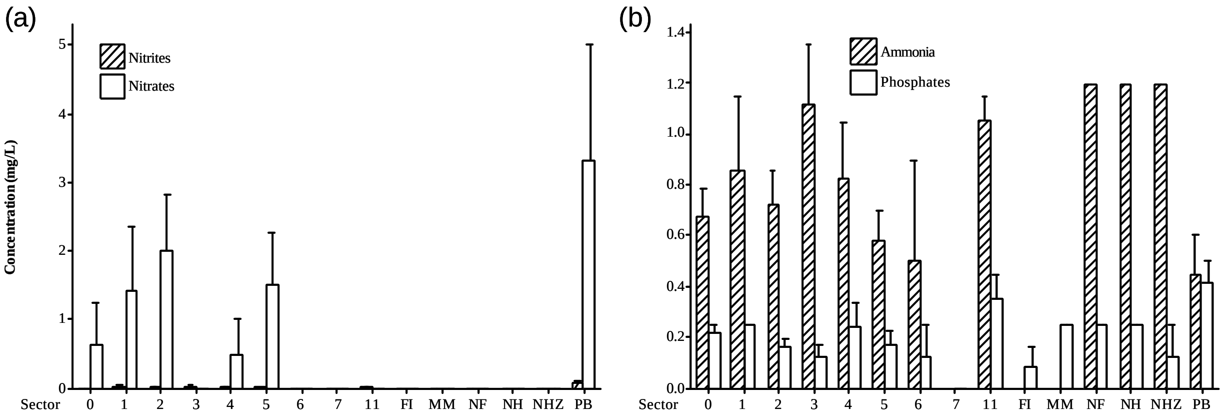

Figure 8. The mean concentrations of (a) nitrites and nitrates and (b) ammonia and phosphates as ascertained from chemical analysis of water samples obtained from different sectors within the Baie de Diego-Suarez from Jan until June 2007. Error bars represent one standard error from the mean.

Figure 8 displays the spatial variations in nutrient levels around the bay. Nitrite levels were often below the detectable limits of the equipment used for measuring them. However, relatively elevated nitrite concentrations were encountered in sectors 1-5, in the northern section of the bay; this also corresponded with high nitrate levels, especially in sectors 2 and 5 (2.00 ± 0.82 and 1.50 ± 0.76 mg/l, respectively).

Table 5. The mean pH and concentrations of nitrates, ammonia and phosphates in the Baie de Diego-Suarez as ascertained from chemical testing of water samples collected between phases October 2005 and June 2007.

Phase	pH	Nutrient Levels (mg/l)		
		Nitrates	Ammonia	Phosphates
MGM054	7.73	0.19	0.10	0.25
MGM061	7.96	0.14	0.10	0.25
MGM062	8.01	1.38	0.07	0.11

MGM063	8.03	-	0.08	-
MGM064	7.97	1.67	0.34	0.18
MGM071	7.66	1.08	0.57	0.17
MGM072	7.85	0.76	0.94	0.24

As with nitrites and nitrates, ammonia and phosphate levels varied widely, with ammonia concentrations being substantially greater than phosphate concentrations at all sites. In the northern section of the bay, concentrations seemed to peak around sectors 3 and 4, and became progressively lower nearer to the mouth of the bay. Conversely, the highest ammonia concentrations (1.20 ± 0.0 mg/l) were encountered at sites next to bay islands (sectors NF, NH and NHZ).

2.5.4 Discussion

Data from previous phases has revealed sector 7 as exhibiting a relatively acidic marine environment (7.0), perhaps relating to its proximity to areas of human settlement. However, these more recent results do not correspond with earlier findings that pH levels are depressed in areas with supposedly greater anthropogenic impact. The reduced pH in sectors 6 and 7 might reflect their greater exposure to the open ocean. Mean salinity within the bay ranged from 48.00 ppt (sector 6) to 53.00 (sector NHZ); salinity was moderately high next to islands close to the mouth of the bay (FI and NHZ), perhaps relating to the low levels of potential terrestrial input at these sites. Overall, however, there seems to be no clear pattern as to the spatial variation in salinity levels around the bay. Additionally, this variation does not correspond with that ascertained from previous date. It seems that such chemical parameters in the bay fluctuate widely as a result of the complex geophysical characteristics of the Baie de Diego-Suarez and its high coastline to volume ratio, exacerbating the influence of terrestrial input that the marine environment experiences.

Unfortunately, little sampling was done in the southern portion of the bay, therefore it is difficult to draw comparisons between the two areas in terms of nutrient concentrations. The concentration of nitrates in sector PB, outside the mouth of the bay, was high (3.33 ± 1.67 mg/l), which can be explained by its proximity to the mouth of a large river.

Only one sample was taken in each of these areas and so the conclusions to be drawn for these sectors are somewhat unreliable. The high phosphate concentrations for sector PB (0.45 ± 0.15 mg/l) can be attributed to river input. Within the bay itself, the lack of a clear pattern may be due to a combination of the limited resolution of the water testing equipment and some environmental synchronicity between widespread regions of the bay.

Examination of general water testing data on a temporal basis reveals a number of patterns. Firstly, there are seasonal fluctuations in chemical parameters within the bay due to changes in rainfall and subsequent terrestrial freshwater input between the warm, dry season and the hot, rainy season. For example, mean pH levels in the bay can be seen to peak slightly during the dry season, whereas phosphate levels decreased at this time. Secondly, a number of longer term trends are becoming apparent. Ammonia concentrations appear to be increasing over time, as do nitrate concentrations, which also exhibited a slight peak in the dry season.

2.5.5 Conclusions

Water testing can provide potential explanations to patterns in the marine flora and fauna, and thus is an important component of the ecological survey program in the Baie de Diego-Suarez. Continuous sampling since October 2005 enables the identification of variations in water quality both on a temporal and spatial scale. At present only limited conclusions can be made due to incomplete data sets. This problem will be reduced with continued testing in future phases in order to either verify current results or discern temporal patterns which may as yet be unclear. Furthermore, nutrient concentrations are difficult to evaluate to high levels of accuracy given the equipment used to measure them, and higher resolution spatiotemporal variations are mostly indiscernible.

It is still possible to draw a number of broad conclusions from the water testing data at the current time. Overall, it can be seen that chemical parameters within the Baie de Diego-Suarez fluctuate widely on both spatial and temporal scales, due to a combination of seasonal variations in terrestrial input and the geophysical characteristics of the bay that result in a high edge to volume ratio. Additionally, long-term data collection has shown that concentrations of nitrates and ammonia appear to be increasing, whereas phosphate levels have remained relatively stable. However, as of yet, there is no clear idea as to what factors govern the chemical environment of the bay, and the relative extent to which each operates.

2.6 Sediment Analysis

2.6.1 Introduction

High levels of sediment in the water are the result of construction activities and land clearance resulting in high surface runoff. Heavy sedimentation adversely affects coral reproduction, growth and recruitment by limiting light availability. This results in reduced coral diversity and abundance within a particular site and will have knock-on effects upon fish and invertebrate communities. Sedimentation levels are determined from both suspended sediment and deposited sediment parameters. Suspended sediment is quantified as a measure of visibility which is recorded during the RSP, BSP and AQ survey techniques. In addition, the line intercept transect (LIT) method of recording data, undertaken during benthic surveys, quantifies deposited sediment.

Sediment traps may also be deployed in order to obtain a more reliable quantification method. These provide a non-destructive, time-integrated sample of the sediment from the water column. However, sediment traps were not deployed between October 2006 and Jan 2007 due to the high number of traps that have been lost, resulting in an inefficient survey technique.

Sediment samples taken from sites can be used to determine the relative proportions of particles of different grain sizes. Areas which contain a greater proportion of fine sediment are generally characterised by poor visibility, hence this is an additional variable in the assessment of reef health. Undertaken via the graduated sieving of sediment samples collected during BSP surveys, this technique has proven to be a reliable method of carrying out a relatively detailed sediment analysis and has so far been able to provide an additional data set for sites.

2.6.2 Materials and Methods

Algae and invertebrate surveyors, during BSP surveys, collected 100 ml sediment samples at the start of each transect. The samples were then sieved and separated into four graduations based on particle diameter (2 mm, 1 mm, 0.5 mm and 0.25 mm). Each fraction was then completely dried and weighed in order to determine the ratios of the amounts of sediment of particle sizes found at each survey site.

2.6.3 Results

The results for phases MGM071 and MGM072 are presented here.

Figure 9 displays the sediment particle size compositions for different sectors. Particle size fractions are not split evenly throughout the sectors, or even within a single sector. The middle range particle sizes, coloured green and blue in figure 9 show the smallest variation in relative percentage throughout the data set, with the other two size ranges varying considerably more between the different sectors. Changes between the two data sets also vary considerably between the sectors, most notable are the relatively small changes found in sector 4 compared to the much larger differences between the data for sector 5.

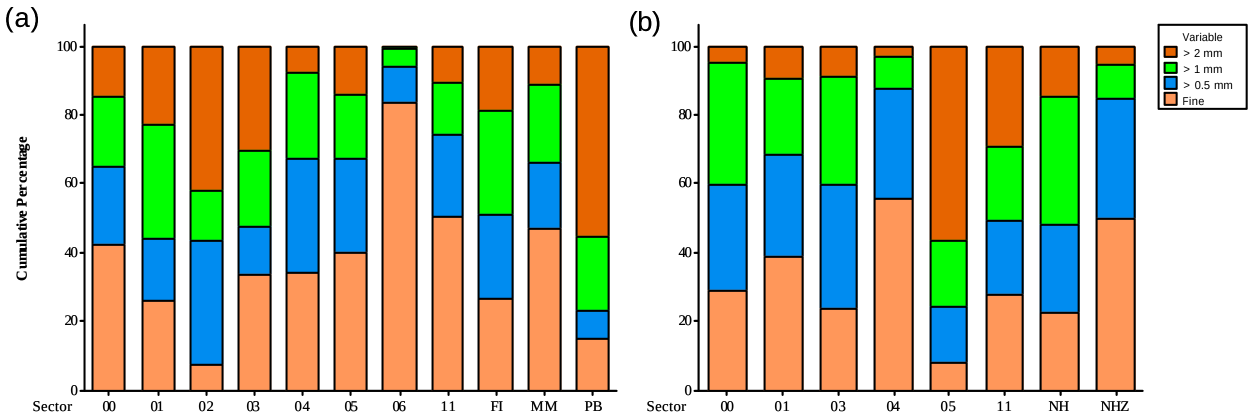

Figure 9. The cumulative percentages, in terms of dry mass, of different particle sizes for sediment samples obtained from different sectors within the Baie de Diego-Suarez during phases (a) MGM071 (sector PB is situated outside the mouth of the bay) and (b) MGM072.

2.6.4 Discussion

Particle size fractions were not as evenly spread as they appeared at the end of December 2006, which is probably due to reduced wind and, subsequently, lower wave and current action acting to redistribute sediment particles during the calm, rainy season. Additionally, increased rain during phase Jan 2007 will have led to greater input and settling of finer sediment particles from terrestrial sources. During Jan 2007, samples from sector 2 contained notably larger particle sizes. The northern area of sector 2 contains an extensive mangrove system which may act to trap fine sediment before it is able to enter the bay through terrestrial input. On the other hand, sediment particle size in sector 6 was considerably smaller than in the rest of the bay, which may be due to its relatively sheltered location near the bay mouth. Thus, there appears to be an overall increase in sediment particle size towards the back of the bay, away from the open ocean.

The sediment samples from April – June 2007 are characterised by a comparatively larger proportion of medium (0.5 – 2 mm) sized particles and fewer small particles. Stronger winds and rougher seas during this phase may have acted to re-suspend finer particles, explaining this trend. As an exception, sector 4 contained a greater proportion of finer sediment particles than in the previous phase, although this may reflect the patchy nature of the substrate within this region and the insufficient resolution of the sampling technique to accommodate this variability. Sediment samples from sector 5 were particularly orientated towards large particle sizes, which are to be expected, due to its highly exposed location opposite the mouth of the bay; the same conclusion might be drawn for sector PB in Jan 2007, situated outside the mouth of the bay.

2.6.5 Conclusions

Sediment trap collection proved to be far more difficult than previously anticipated and hence data collection and analysis for this method has been limited. Until a new more efficient method of relocating the traps is found, no more will be deployed. On the other hand, sieving of sediment samples, which began in April 2006, has proven to be a simple yet effective method in which to further assess benthic cover and provide additional potential explanations for patterns in reef health, although its limitations in accuracy and resolution must be taken into account. Since sediment sampling began over a year ago, it has been evident that there is a great deal of variation in sediment characteristics throughout the bay, and seasonal variations in sediment particle size distribution are now apparent. Continued sampling and more detailed analysis is required to compound these initial findings and determine the key factors governing sediment characteristics within the bay, as well as to relate this to the results of the biological monitoring program.

2.7 Species Lists

2.7.1 Introduction

Much of the earlier phases of the MGM project in the Baie de Diego-Suarez involved the production and expansion of species lists to provide a foundation for subsequent surveying and monitoring. Since then, the lists have continued to grow as unrecorded species are identified, and staff has taken on more of a central role in verifying sightings. However, the expansion of species lists forms only a secondary objective of a project.

As mentioned, Between April and June 2007, satellite camps were undertaken to carry out preliminary surveys in the Mozambique Channel and the Mer d'Emeraude. This presented a valuable opportunity to expand MGM species lists and initiate some form of comparison of species compositions of marine ecosystems between areas inside and outside the bay.

2.7.2 Materials and Methods

The species lists of the MGM program have been produced mostly through opportunistic sightings during survey and recreational dives, snorkels and practice sessions. Species are normally only added to the list following photographic evidence. Unfortunately, due to the opportunistic nature of some of the sightings, photos are not always available and hence verification of some species is still awaited. Under these circumstances, repeat sightings or a positive identification by a suitably qualified surveyor (staff member) is required.

2.7.3 Fish Species List

Until recently amongst the scientific community, the list of confirmed fish species for Madagascar has been far from complete, with little work on the subject having been carried out. Additionally, to date, there have been no comparative studies of the northern and southern fish populations of Madagascar. The Rapid Marine Biodiversity Assessment Report published in 2005 by Conservation International (CI) and FAO added greatly to this list, but already we have found several additional, but as of yet unconfirmed, species within the Baie de Diego-Suarez.

The fish species list for the Baie de Diego-Suarez, as it stands at the end of June 2007, contains 203 fish that have been positively identified by our in-field experts (see Appendix I). No further species were added to the list during the phase. Additionally, there are approximately 20 other species still awaiting identification to species level, which will be promptly added upon verification. This number has increased steadily since the list was first compiled in April 2005. Appendix III provides a fish species inventory compiled during the satellite camp in the Mozambique Channel.

The rapid assessment report completed by CI in 2002 detailing the North Madagascar region includes around 400 fish species, incorporating a list of every species observed during the rapid assessment surveys as well as all other species that were discovered in a "comprehensive search of the relevant literature". It can be assumed that the FMMRP species list produced is a fairly comprehensive guide to the species of the area, as it is unlikely that all 400 species are found within the Baie de Diego-Suarez. The number of species identified by Frontier that were not listed in the CI reports from their assessments is still to be confirmed.

2.7.4 Coral Species List

To date, 173 species of coral within 65 coral genera have been recorded by our survey teams, with the full list held in Appendix II (all species mentioned within these lists can be photographically verified). This number is by no means complete. No further species were added to the list for the bay. A coral species inventory for the Mozambique Channel satellite camp is provided in Appendix II.

2.7.5 Invertebrate Species List

Although FMMRP surveying methods require surveyors to be able to identify a number of invertebrate taxa most of the animals need not be identified to species level and there are even some that need not be identified past class level. Additionally, the FMMRP has not yet attempted the production of a comprehensive species list of invertebrates that exist in the Baie de Diego-Suarez. It is hoped that the compilation of an invertebrate species inventory can be initiated in July 2007.

2.7.6 Conclusions

The collection of a complete species list for the bay is constructive, with the information being valuable for both scientific and political purposes, for providing key species to justify conservation measures. However, to achieve fully comprehensive lists, highly experienced surveyors are required, focussing solely on particular species. Such data collection does not fit within the current capacity of Frontier or, more crucially, our current objectives. Other projects such as the rapid assessment carried out by CI fulfil these objectives. As a result, the production of a complete species list has not been a specific priority. Species lists are being accumulated in order to support the data that is gathered to fulfil our objectives of training and providing spatial information on reef health. Therefore the lists should be viewed with the following drawbacks in mind:

- They include species who only inhabit the upper 15 m of the water column, whereas a great deal of tropical reef species may be found at greater depths;
- A species normally may not be confirmed and added to the list until an adequate photograph has been taken in order to verify its presence;
- Species lists alone do not aid in the explanation of complex reef ecosystem patterns.

We are very much aware that there are still plenty of unidentified species within the bay itself and, even more so, outside it. Future phases shall see the continuation of the expansion of species lists through opportunistic sightings, with this remaining as a secondary objective of the project.

3 COMMUNITY WORK AND PUBLIC AWARENESS

3.1 Overview

The socio-economic side to marine conservation is as important as the assessment of the biological parameters. On our arrival in Diego Bay we established contacts with the local village Antsisikala, located directly opposite Manta Camp. Two years on, these contacts have built into good working relationships following the implementation of weekly English lessons and the initial introductory workshop held in April 2005.

This phase the main focus was on increasing public awareness of marine conservation through the PADI Aware Scheme. In addition, we invited 2 students from the University of Diego and 2 students IHSM students to attend the RA program in order to begin expanding the capacity of students in the region.

3.2 Community Work Programme

English lessons have been running in the nearby village of Antsisikala every Saturday and are attended by villagers, staff members and research assistants. This phase we have attended 9 Malagasy lessons which have been conducted by SH, RM and TN. Previous to April 2006, improvements in the Malagasy students' English was relatively slow with much repetition required in the lesson plans. However, April 2006 saw the start of a new teaching placement scheme within Frontier-Madagascar, the first of whom was placed in Antsisikala. The addition of a permanent English teacher has resulted in a vast improvement in students' English skills.

No educational workshops were undertaken during April 2007, although a project proposal has been submitted to the PADI AWARE grant scheme, which shall enable the FMMRP to conduct a further series of workshops in local communities.

3.3 University Students

MGM has maintained strong communications with IH.SM based in Toliara from whom we received three students in July 2005. In Jan 2007, two students from Toliara joined in the RA program, participating in both the dive training and the science lectures; one student (AJ) remained with the program for an extra 3 months, leaving in July 2007. AJ successfully completed the PADI Open Water Diver course, and became a qualified algae and invertebrates surveyor. A written report and a presentation on the research with the FMMRP are course requirements of the IH.SM students.

No students were received from the University of Diego April – June 2007. It is hoped that further phases can accommodate more students from the university, including those from the Natural Sciences department as well as the Anglo-American department.

3.4 Conclusions

The English lessons in Antsisikala have proved to be a popular sideline to the science program and act as a means of cultural exchange with both parties gaining a lot from the experience. However, we have now formed a strong basis for establishing the socio-economic work programme and having gained the trust of local villagers. We have been received well into the local community and have begun expanding the programme to incorporate research into fisheries, local resource use and community awareness programmes that involve surrounding villagers, migrating fishermen and the inhabitants of Diego.

Since the arrival of Frontier in the region, we have formed close links to a number of local businesses and people of importance in the Diego community. Hence people are becoming increasingly aware of our presence and the nature of our work in the bay. Local people are often very interested to hear what work we are doing, which was proved again during the three workshops in October 2006. In March 2007, the large workshop held in Diego aimed at stakeholders in the region turned out to be a great success and it is an important step in process of turning the Baie de Diego-Suarez into a Marine Protected Area.

The attendance of Malagasy students in the RA program is an important aspect of the project as this aspect contributes to the in-country capacity-building objectives of the FMMRP.

4.0 RECOMMENDATIONS

The work carried out to date in the Bay of Diego Suarez is part of an ongoing research and monitoring program that first began work in April 2005. The project's original goals to create a map of the biological diversity and distribution of species throughout the bay, accompanied by a full list of species from all taxa encountered during the initial surveying, were completed at the beginning of 2007. Since then the project began looking more at the need of the local people and at their level of dependence on the bay as a resource, as well as continuing the survey techniques originally employed as a monitoring technique to maintain the accuracy of the information and detect any temporal changes to aid in predicting future events.

Some work has been done in exploring the potential for a protected area to be established in the bay, and a separate report (The Bay de Diego Suarez Management Proposal, Browne N.B. Markham H.) details these findings. Additional research will need to be carried out before any plans to impose protection on the bay can be put into place however, with notable effort on the economic and social consequences of these actions.

Biologically speaking, within the bay, the research program would do well to continue monitoring the status of the bay using the existing techniques, as well as exploring new research methodologies. The possibility to relocate some or the entire program to a new location outside the bay exists, and should be explored in more detail, in order to maintain an active relationship with ANGAP and SAGE, the governing bodies of conservation in Madagascar.

5.0 APPENDICES

APPENDIX I. FISH SPECIES LIST

The following table lists all of the fish species that have been positively identified by the Frontier-Madagascar Marine Research Program within the Baie de Diego-Suarez.

Common Name		Latin Name		
Family	Species	Family	Genus	Species
Shark	Whale Shark	*Rhincodontidae*	*Rhincodon*	*Typus*
Ray	Blackspotted Electric Ray	*Torpedinidae*	*Torpedo*	*fuscomaculata*
Ray	Bluespotted Ribbontail Ray	*Dasyatidae*	*Taeniura*	*lymma*
Ray	Giant Reef Ray	*Dasyatidae*	*Taeniura*	*melanospilos*
Ray	Bluespotted Stingray	*Dasyatidae*	*Dasyatis*	*kuhlii*
Ray	Honeycomb Stingray	*Dasyatidae*	*Himantura*	*uarnak*
Ray	Spotted Eagle Ray	*Myliobatidae*	*Aetobatus*	*narinari*
Ray	Manta Ray	*Mobulidae*	*Manta*	*birostris*
Moray Eel	Snowflake Moray	*Muraenidae*	*Echidna*	*nebulosa*
Moray Eel	Zebra Moray	*Muraenidae*	*Gymnomuraena*	*zebra*
Moray Eel	Giant Moray	*Muraenidae*	*Gymnothorax*	*javanicus*
Moray Eel	Undulated Moray	*Muraenidae*	*Gymnothorax*	*undulatus*
Moray Eel	Black-Blotched Moray	*Muraenidae*	*Gymnothorax*	*permistus*
Moray Eel	Geometric Moray	*Muraenidae*	*Siderea*	*grisea*
Eel Catfish	Striped Catfish	*Plotosidae*	*Plotosus*	*lineatus*
Lizardfish	Sand Lizardfish	*Synodontidae*	*Synodus*	*dermatogenys*
Halfbeaks	Spotted Halfbeak	*Hemirhamphidae*	*Hemiramphus*	*far*
Squirrelfish	Bloodspot Squirrelfish	*Holocentridae*	*Neoniphon*	*sammara*
Squirrelfish	Crown Squirrelfish	*Holocentridae*	*Sargocentron*	*diadema*
Squirrelfish	Long-jawed Squirrelfish	*Holocentridae*	*Sargocentron*	*spiniferum*
Trumpetfish	Trumpetfish	*Aulostomidae*	*Aulostomus*	*chinensis*
Cornetfish	Cornetfish	*Fistulariidae*	*Fistularia*	*commersonii*
Shrimpfish	Shrimpfish	*Centriscidae*	*Aeoliscus*	*strigatus*
Dragonfish	Short Dragonfish	*Pegasidae*	*Eurypegasus*	*draconis*
Seahorse	Spotted Seahorse	*Syngnathdiae*	*Hippocampus*	*kuda*
Flathead	Fringelip Flathead	*Platycephalidae*	*Thysanophrys*	*otaitensis*
Scorpionfish	Lionfish	*Scorpaenidae*	*Pterois*	*volitans / miles ?*
Grouper	Chocolate Hind	*Serranidae*	*Cephalopholis*	*boenak*
Grouper	Whitespotted Grouper	*Serranidae*	*Epinephelus*	*caeruleopunctatus*
Grouper	Malabar Grouper	*Serranidae*	*Epinephelus*	*malabricus*
Grouper	Saddleback Coralgrouper	*Serranidae*	*Plectropomus*	*laevis*
Soapfish	Sixstripe Soapfish	*Serranidae*	*Grammistes*	*sexlineatus*
Hawkfish	Freckled Hawkfish	*Cirrhitidae*	*Paracirrhites*	*forsteri*
Hawkfish	Pixy Hawkfish	*Cirrhitidae*	*Cirrhitichthys*	*oxycephalus*
Cardinalfish	Reef-flat Cardinalfish	*Apogonidae*	*Apogon*	*taeniophorus*
Cardinalfish	Ring-tailed Cardinalfish	*Apogonidae*	*Apogon*	*aureus*
Cardinalfish	Five-lined Cardinalfish	*Apogonidae*	*Cheilodipterus*	*quinquelineatus*
Cardinalfish	Lined Cardinalfish	*Apogonidae*	*Cheilodipterus*	*artus*
Cardinalfish	Orange-lined Cardinalfish	*Apogonidae*	*Archamia*	*fucata*
Mojarra	Blacktip Mojarra	*Gerreidae*	*Gerres*	*acinaces*
Remora	Sharksucker	*Echeneidae*	*Echenesis*	*naucrates*
Trevally	Bar Jack	*Carangidae*	*Carangoides*	*orthogrammus*
Trevally	Golden Trevally	*Carangidae*	*Gnathanodon*	*speciosus*
Trevally	Bluefin Trevally	*Carangidae*	*Caranx*	*melampygus*
Trevally	Bigeye Trevally	*Carangidae*	*Caranx*	*sexfasciatus*

Snapper	Bluelined Snapper	*Lutjanidae*	*Lutjanus*	*kasmira*
Snapper	Bluestriped Snapper	*Lutjanidae*	*Lutjanus*	*notatus*
Snapper	Onespot Snapper	*Lutjanidae*	*Lutjanus*	*monostigmata*
Snapper	Humpback Snapper	*Lutjanidae*	*Lutjanus*	*gibbus*
Snapper	Red Snapper	*Lutjanidae*	*Lutjanus*	*bohar*
Snapper	River Snapper	*Lutjanidae*	*Lutjanus*	*argentimaculatus*
Fusilier	Scissor-tailed Fusilier	*Caesionidae*	*Caesio*	*caerulaurea*
Fusilier	Ruddy Fusilier	*Caesionidae*	*Pterocaesio*	*pisang*
Sweetlips	Slatey Sweetlips	*Haemulidae*	*Diagramma*	*pictum*
Sweetlips	Whitebarred Sweetlips	*Haemulidae*	*Plectorhinchus*	*playfairi*
Sweetlips	Black Sweetlips	*Haemulidae*	*Plectorhinchus*	*sordidus*
Sweetlips	Blackspotted Sweetlips	*Haemulidae*	*Plectorhinchus*	*gaterinus*
Sweetlips	Gold-spotted Sweetlips	*Haemulidae*	*Plectorhinchus*	*flavomaculatus*
Spinecheek	Arabian Spinecheek	*Nemipteridae*	*Scolopsis*	*ghanam*
Spinecheek	Thumbprint Spinecheek	*Nemipteridae*	*Scolopsis*	*bimaculatus*
Spinecheek	Whitecheek Monocle Bream	*Nemipteridae*	*Scolopsis*	*vosmeri*
Sea Bream	Doublebar Bream	*Sparidae*	*Acanthopagrus*	*bifasciatus*
Sea Bream	Yellowfin Bream	*Sparidae*	*Rhabdosargus*	*sarba*
Emperor	Bigeye Emperor	*Lethrinidae*	*Monotaxis*	*grandoculis*
Emperor	Blackspot Emperor	*Lethrinidae*	*Lethrinus*	*harak*
Emperor	Sky Emperor	*Lethrinidae*	*Lethrinus*	*mahsena*
Emperor	Spangled Emperor	*Lethrinidae*	*Lethrinus*	*nebulosus*
Goatfish	Yellowstripe Goatfish	*Mullidae*	*Mulloidichthys*	*flavolineatus*
Goatfish	Dash-and-dot Goatfish	*Mullidae*	*Parupeneus*	*barberinus*
Goatfish	Indian Goatfish	*Mullidae*	*Parupeneus*	*indicus*
Goatfish	Whitesaddle Goatfish	*Mullidae*	*Parupeneus*	*poryphyreus*
Goatfish	Rosy Goatfish	*Mullidae*	*Parupeneus*	*rubescens*
Goatfish	Blackstriped Goatfish	*Mullidae*	*Upeneus*	*tragula*
Sweeper	Copper Sweeper	*Pempheridae*	*Pempheris*	*oualensis*
Rudderfish	Highfin Rudderfish	*Kyphosidae*	*Kyphosus*	*cinerascens*
Spadefish	Longfin Spadefish	*Ephippidae*	*Platax*	*teira*
Mono	Mono	*Monodactylus*	*Monodactylus*	*argenteus*
Butterflyfish	Lined Butterflyfish	*Chaetodontidae*	*Chaetodon*	*lineolatus*
Butterflyfish	Black-backed Butterflyfish	*Chaetodontidae*	*Chaetodon*	*melannotus*
Butterflyfish	Vagabond Butterflyfish	*Chaetodontidae*	*Chaetodon*	*vagabundus*
Butterflyfish	Threadfin Butterflyfish	*Chaetodontidae*	*Chaetodon*	*auriga*
Butterflyfish	Bennett's Butterflyfish	*Chaetodontidae*	*Chaetodon*	*bennetti*
Butterflyfish	Zanzibar Butterflyfish	*Chaetodontidae*	*Chaetodon*	*zanzibariensis*
Butterflyfish	Klein's Butterflyfish	*Chaetodontidae*	*Chaetodon*	*kleinii*
Butterflyfish	Yellowhead Butterflyfish	*Chaetodontidae*	*Chaetodon*	*xanthocephalus*
Butterflyfish	Racoon Butterflyfish	*Chaetodontidae*	*Chaetodon*	*lunula*
Butterflyfish	Spotted Butterflyfish	*Chaetodontidae*	*Chaetodon*	*guttatissimus*
Butterflyfish	Redfin Butterflyfish	*Chaetodontidae*	*Chaetodon*	*trifasciatus*
Butterflyfish	Meyer's Butterflyfish	*Chaetodontidae*	*Chaetodon*	*meyeri*
Butterflyfish	Chevronned Butterflyfish	*Chaetodontidae*	*Chaetodon*	*trifascialis*
Butterflyfish	Longfin Bannerfish	*Chaetodontidae*	*Heniochus*	*acuminatus*
Butterflyfish	Longnose Bannefish	*Chaetodontidae*	*Heniochus*	*monoceros*
Butterflyfish	Longnose Butterflyfish	*Chaetodontidae*	*Forcipiger*	*flavissimus*
Angelfish	African Pygmy Angelfish	*Pomacanthidae*	*Centropyge*	*acanthops*
Angelfish	Many-spined Angelfish	*Pomacanthidae*	*Centropyge*	*multispinis*
Angelfish	Ear-spot Angelfish	*Pomacanthidae*	*Pomacanthus*	*chrysurus*
Angelfish	Semicircle Angelfish	*Pomacanthidae*	*Pomacanthus*	*semicirculatus*
Angelfish	Emperor Angelfish	*Pomacanthidae*	*Pomacanthus*	*imperator*
Damselfish	Indo-pacific Sergeant	*Pomacentridae*	*Abudefduf*	*vaigiensis*
Damselfish	Scissor-tail Sergeant	*Pomacentridae*	*Abudefduf*	*sexfasciatus*
Damselfish	Natal Sergeant	*Pomacentridae*	*Abudefduf*	*natalensis*

Damselfish	Black-spot Sergeant	*Pomacentridae*	*Abudefduf*	*sordidus*
Damselfish	Banded Sergeant	*Pomacentridae*	*Abudefduf*	*septemfasciatus*
Damselfish	False-eye Sergeant	*Pomacentridae*	*Abudefduf*	*sparoides*
Damselfish	Skunk Anemonefish	*Pomacentridae*	*Amphiprion*	*akallopisos*
Damselfish	Madagascar Anemonefish	*Pomacentridae*	*Amphiprion*	*latifasciatus*
Damselfish	Jewel Damsel	*Pomacentridae*	*Plectroglyphidodon*	*lacrymatus*
Damselfish	White-belly Damsel	*Pomacentridae*	*Amblyglyphidodon*	*curacao*
Damselfish	Twotone Chromis	*Pomacentridae*	*Chromis*	*dimidiata*
Damselfish	Humbug Dascyllus	*Pomacentridae*	*Dascyllus*	*aruanus*
Damselfish	Three-spot Dascyllus	*Pomacentridae*	*Dascyllus*	*trimaculatus*
Damselfish	Indian Dascyllus	*Pomacentridae*	*Dascyllus*	*carneus*
Damselfish	Black Damsel	*Pomacentridae*	*Neoglyphidodon*	*melas*
Damselfish	Regal Demoiselle	*Pomacentridae*	*Neopomacentrus*	*cyanomos*
Damselfish	Yellowtail Demoiselle	*Pomacentridae*	*Neopomacentrus*	*azysron*
Damselfish	Caerulean Damsel	*Pomacentridae*	*Pomacentrus*	*caeruleus*
Damselfish	Blue Damsel	*Pomacentridae*	*Pomacentrus*	*pavo*
Damselfish	Sulphur Damsel	*Pomacentridae*	*Pomacentrus*	*sulfureus*
Damselfish	Threeline Damsel	*Pomacentridae*	*Pomacentrus*	*trilineatus*
Wrasse	Diana's Hogfish	*Labridae*	*Bodianus*	*anthoides*
Wrasse	Axilspot Hogfish	*Labridae*	*Bodianus*	*axillaris*
Wrasse	Red-banded Wrasse	*Labridae*	*Cheilinus*	*fasciatus*
Wrasse	Tripletail Wrasse	*Labridae*	*Cheilinus*	*trilobatus*
Wrasse	Floral Wrasse	*Labridae*	*Cheilinus*	*chlorourus*
Wrasse	Slingjaw wrase	*Labridae*	*Epibulus*	*insidiator*
Wrasse	Dragon Wrasse	*Labridae*	*Novaculichthys*	*taeniourus*
Wrasse	Goldstripe Wrasse	*Labridae*	*Halichoeres*	*zeylonicus*
Wrasse	Clown Coris	*Labridae*	*Coris*	*aygula*
Wrasse	Queen Coris	*Labridae*	*Coris*	*frerei*
Wrasse	Spottail Coris	*Labridae*	*Coris*	*caudimacula*
Wrasse	Checkerboard Wrasse	*Labridae*	*Halichoeres*	*hortulanus*
Wrasse	Zigzag Wrasse	*Labridae*	*Halichoeres*	*scapularis*
Wrasse	Barred Thicklip Wrasse	*Labridae*	*Hemigymnus*	*fasciatus*
Wrasse	Blackedge Thicklip Wrasse	*Labridae*	*Hemigymnus*	*melapterus*
Wrasse	Cigar Wrasse	*Labridae*	*Cheilio*	*inermis*
Wrasse	Indian Ocean Bird Wrasse	*Labridae*	*Gomphosus*	*caeruleus*
Wrasse	Three-ribbon Wrasse	*Labridae*	*Stethojulis*	*strigiventer*
Wrasse	Bluelined Wrasse	*Labridae*	*Stethojulis*	*albovittata*
Wrasse	Goldbar Wrasse	*Labridae*	*Thalassoma*	*hebracium*
Wrasse	Crescent Wrasse	*Labridae*	*Thalassoma*	*lunare*
Wrasse	Sixbar Wrasse	*Labridae*	*Thalassoma*	*hardwicke*
Wrasse	Christmas Wrasse	*Labridae*	*Thalassoma*	*trilobatum*
Wrasse	Bicolor Cleaner Wrasse	*Labridae*	*Labroides*	*bicolor*
Wrasse	Bluestreak Cleaner Wrasse	*Labridae*	*Labroides*	*dimidiatus*
Parrotfish	Bicolor Parrotfish	*Scaridae*	*Cetoscarus*	*bicolor*
Parrotfish	Indian Ocean Steephead Parrotfish	*Scaridae*	*Chlorurus*	*strongylocephalus*
Parrotfish	Redlip Parrotfish	*Scaridae*	*Scarus*	*rubroviolaceus*
Parrotfish	Bluebarred Parrotfish	*Scaridae*	*Scarus*	*ghobban*
Parrotfish	Bullethead Parrotfish	*Scaridae*	*Chlorurus*	*sordidus*
Parrotfish	Bridled Parrotfish	*Scaridae*	*Scarus*	*frenatus*
Parrotfish	Swarthy Parrotfish	*Scaridae*	*Scarus*	*niger*
Parrotfish	Tricolor Parrotfish	*Scaridae*	*Scarus*	*tricolor*
Parrotfish	Saddled Parrotfish	*Scaridae*	*Chlorurus*	*cyanascens*
Parrotfish	Black Crescent Parrotfish	*Scaridae*	*Chlorurus*	*atrilunula*
Parrotfish	Dusky-capped Parrotfish	*Scaridae*	*Scarus*	*scaber*
Parrotfish	Russell's Parrotfish	*Scaridae*	*Scarus*	*russelli*
Parrotfish	Indian Ocean Longnose Parrotfish	*Scaridae*	*Hipposcarus*	*harid*

Barracuda	Great Barracuda	*Sphyraenidae*	*Sphyraena*	*barracuda*
Barracuda	Blackfin Barracuda	*Sphyraenidae*	*Sphyraena*	*qenie*
Barracuda	Yellowtail Barracuda	*Sphyraenidae*	*Sphyraena*	*flavicauda*
Sandperch	Speckled Sandperch	*Pinguipedidae*	*Parapercis*	*hexophthalma*
Blenny	Cleaner Mimic	*Blenniidae*	*Aspidontus*	*taeniatus*
Blenny	Scale Eating Fangblenny	*Blenniidae*	*Plagiotremus*	*tapeinosoma*
Blenny	Mozambique Fangblenny	*Blenniidae*	*Meiacanthus*	*mossambicus*
Blenny	Bluestriped Fangblenny	*Blenniidae*	*Plagiotremus*	*rhinorhynchus*
Dartfish	Blackfin Dartfish	*Microdesmidae*	*Ptereleotris*	*evides*
Moorish Idol	Moorish Idol	*Zanclidae*	*Zanclus*	*cornutus*
Surgeonfish	Desjardin's Sailfin Tang	*Acanthuridae*	*Zebrasoma*	*desjardinii*
Surgeonfish	Brushtail Tang	*Acanthuridae*	*Zebrasoma*	*scopas*
Surgeonfish	Convict Surgeonfish	*Acanthuridae*	*Acanthurus*	*triostegus*
Surgeonfish	Powder-blue Surgeonfish	*Acanthuridae*	*Acanthurus*	*leucosternon*
Surgeonfish	Striped Surgeonfish	*Acanthuridae*	*Acanthurus*	*lineatus*
Surgeonfish	Yellowfin Surgeonfish	*Acanthuridae*	*Acanthurus*	*xanthopterus*
Surgeonfish	Lietenant Surgeonfish	*Acanthuridae*	*Acanthurus*	*tennenti*
Surgeonfish	Striped Bristletooth	*Acanthuridae*	*Ctenochaetus*	*binotatus*
Surgeonfish	Goldring Britletooth	*Acanthuridae*	*Ctenochaetus*	*strigosus*
Surgeonfish	Bluespined Unicornfish	*Acanthuridae*	*Naso*	*vlamingi*
Surgeonfish	Spotted Unicornfish	*Acanthuridae*	*Naso*	*brevirostris*
Rabbitfish	Forktail Rabbitfish	*Siganidae*	*Siganus*	*argenteus*
Rabbitfish	Dusky Rabbitfish	*Siganidae*	*Siganus*	*fuscescens*
Rabbitfish	Stellate Rabbitfish	*Siganidae*	*Siganus*	*stellatus*
Mackerel	Striped Mackerel	*Scombridae*	*Rastrelliger*	*kanagurta*
Triggerfish	Rippled Triggerfish	*Balistidae*	*Pseudobalistes*	*fuscus*
Triggerfish	Halfmoon Triggerfish	*Balistidae*	*Sufflamen*	*chrysopterus*
Triggerfish	Orangestriped Triggerfish	*Balistidae*	*Balistapus*	*undulatus*
Triggerfish	Moustache Triggerfish	*Balistidae*	*Balistoides*	*viridescens*
Triggerfish	Picassofish	*Balistidae*	*Rhinecanthus*	*assasi*
Filefish	Broom Filefish	*Monocanthidae*	*Amanses*	*scopas*
Filefish	Wire-net Filefish	*Monocanthidae*	*Cantherhines*	*pardalis*
Filefish	Specktacled Filefish	*Monocanthidae*	*Cantherhines*	*fronticintus*
Filefish	Longnose Filefish	*Monocanthidae*	*Oxymonacanthus*	*longirostris*
Filefish	Scribbled Filefish	*Monocanthidae*	*Aluterus*	*scriptus*
Filefish	Blacksaddle Mimic	*Monocanthidae*	*Paraluteres*	*prionurus*
Trunkfish	Yellow Boxfish	*Ostraciidae*	*Ostracion*	*cubicus*
Trunkfish	Longhorn Cowfish	*Ostraciidae*	*Lactoria*	*cornuta*
Pufferfish	Black-saddled Toby	*Tetraodontidae*	*Canthigaster*	*valentini*
Pufferfish	Bennett's Toby	*Tetraodontidae*	*Canthigaster*	*bennetti*
Pufferfish	Star Puffer	*Tetraodontidae*	*Arothron*	*stellatus*
Pufferfish	Map Puffer	*Tetraodontidae*	*Arothron*	*mappa*
Pufferfish	Immaculate Puffer	*Tetraodontidae*	*Arothron*	*immaculatus*
Pufferfish	Whitespotted Puffer	*Tetraodontidae*	*Arothron*	*hispidus*
Porcupinefish	Porcupinefish	*Diodontidae*	*Diodon*	*hystrix*
Porcupinefish	Black Blotched Porupinefish	*Diodontidae*	*Diodon*	*liturosus*

APPENDIX II. CORAL SPECIES LIST

The following table lists all of the coral species that have been positively identified within the Frontier-Madagascar Marine Research Program.

Family	Genus	Species
Pocilloporidae	*Pocillopora*	*damicornis*
Pocilloporidae	*Pocillopora*	*verrucosa*
Pocilloporidae	*Pocillopora*	*indiania*
Pocilloporidae	*Pocillopora*	*eydouxi*
Pocilloporidae	*Seritopora*	*hystrix*
Pocilloporidae	*Stylophora*	*pistulata*
Acroporidae	*Montipora*	*aequitebulata*
Acroporidae	*Montipora*	*floweri*
Acroporidae	*Montipora*	*monasteriata*
Acroporidae	*Montipora*	*verrocosa*
Acroporidae	*Acropora*	*palifera*
Acroporidae	*Acropora*	*formosa*
Acroporidae	*Acropora*	*robusta*
Acroporidae	*Acropora*	*valenciennesi*
Acroporidae	*Acropora*	*austera*
Acroporidae	*Acropora*	*copiosa*
Acroporidae	*Acropora*	*yongei*
Acroporidae	*Acropora*	*hycinthus*
Acroporidae	*Acropora*	*arabensis*
Acroporidae	*Acropora*	*globiceps*
Acroporidae	*Acropora*	*humilis*
Acroporidae	*Acropora*	*monticulosa*
Acroporidae	*Acropora*	*gemmifera*
Acroporidae	*Acropora*	*digitifera*
Acroporidae	*Acropora*	*pulchra*
Acroporidae	*Acropora*	*latistella*
Acroporidae	*Acropora*	*tenuis*
Acroporidae	*Acropora*	*loripes*
Acroporidae	*Acropora*	*appressa*
Acroporidae	*Acropora*	*nasuta*
Acroporidae	*Acropora*	*longicyathus*
Acroporidae	*Acropora*	*samoensis*
Acroporidae	*Astreopora*	*listeri*
Acroporidae	*Astreopora*	*suggesta*
Acroporidae	*Astreopora*	*myriophthalma*
Poritidae	*Porites*	*solida*
Poritidae	*Porites*	*lobata*
Poritidae	*Porites*	*lutea*
Poritidae	*Porites*	*annae*
Poritidae	*Porites*	*rus*
Fungiidae	*Herpolitha*	*limax*

Oculinidae	*Galaxea*	*fascicularis*
Oculinidae	*Galaxea*	*astreata*
Meandrinidae	*Ctenella*	*chagius*
Pectiniidae	*Pectinia*	*lactuca*
Pectiniidae	*Oxypora*	*lacera*
Pectiniidae	*Mycedium*	*elephantotus*
Pectiniidae	*Echinophyllia*	*aspera*
Pectiniidae	*Echinophyllia*	*echinata*
Mussidae	*Cynarina*	*lacrymalis*
Mussidae	*Lobophyllia*	*corymbosa*
Mussidae	*Lobophyllia*	*hemprichii*
Mussidae	*Symphillia*	*recta*
Mussidae	*Symphillia*	*radians*
Mussidae	*Symphillia*	*valenciennesii*
Mussidae	*Acanthastrea*	*echinata*
Mussidae	*Acanthastrea*	*brevis*
Merulinidae	*Hydnophora*	*exesa*
Merulinidae	*Hydnophora*	*microconos*
Merulinidae	*Merulina*	*sabricula*
Merulinidae	*Merulina*	*ampliata*
Faviidae	*Caulastrea*	*furcata*
Faviidae	*Barbattoia*	*amicorum*
Faviidae	*Favia*	*matthai*
Faviidae	*Favia*	*speciosa*
Faviidae	*Favia*	*helianthoides*
Faviidae	*Favia*	*truncatus*
Faviidae	*Favia*	*pallida*
Faviidae	*Favia*	*favus*
Faviidae	*Favia*	*lizardensis*
Faviidae	*Echinopora*	*forskaliana*
Euphyllidae	*Euphyllia*	*ancora*
Euphyllidae	*Plerogyra*	*sinuosa*
Euphyllidae	*Physogyra*	*lichtensteini*
Dendrophylliidae	*Turbinaria*	*frondens*
Dendrophylliidae	*Turbinaria*	*mesenteria*
Dendrophylliidae	*Turbinaria*	*irregularis*
Dendrophylliidae	*Turbinaria*	*stellulata*

Dendrophylliidae	*Turbastrea*	
Dendrophylliidae	*Heteropsammia*	*cochlea*
Milliporidae	*Millipora*	Branching sp
Milliporidae	*Millipora*	Encrusting sp
Milliporidae	*Millipora*	Plate sp
Tubiporidae	*Tubipora*	*musica*
Alcyoniidae	*Lobophyton*	*crassum*
Alcyoniidae	*Sarcophyton*	*glaucum*
Alcyoniidae	*Sarcophyton*	*trocheliophorum*
Alcyoniidae	*Sarcophyton*	*crassocaule*
Alcyoniidae	*Sinularia*	*sp*
Nephtheidae	*Lemnalia*	*sp*
Nephtheidae	*Paralemnalia*	*sp*
Nephtheidae	*Nepthea*	*sp*
Nephtheidae	*Dendronephthya*	*sp*
Plexauridae	*Stereosoma*	*sp*
Plexauridae	*Anthelia*	*glauca*
Xeniidae	*Xenia*	*crassa*
Xeniidae	*Heteroxenia*	*fuscensens*
Ellisellidae	Whip corals	
Poritidae	*Porites*	*attanuata*
Poritidae	*Porites*	*cylindrica*
Poritidae	*Porites*	*negrosensis*
Poritidae	*Porites*	*profundus*
Poritidae	*Goniopora*	*pendulus*
Poritidae	*Goniopora*	*djiboutiensis*
Poritidae	*Goniopora*	*stokesi*
Poritidae	*Goniopora*	*lobata*
Poritidae	*Goniopora*	*somaliensis*
Poritidae	*Goniopora*	*albiconus*
Poritidae	*Goniopora*	*minor*
Poritidae	*Alveopora*	*allingi*
Poritidae	*Alveopora*	*fenestrata*
Poritidae	*Alveopora*	*daedalea*
Poritidae	*Alveopora*	*tizardi*
Siderastreidae	*Cosinaraea*	*monile*
Siderastreidae	*Cosinaraea*	*columna*
Siderastreidae	*Cosinaraea*	*crassa*

Siderastreidae	*Horastrea*	*indica*
Siderastreidae	*Siderastrea*	*savignyana*
Siderastreidae	*Psammocora*	*contigua*
Siderastreidae	*Psammocora*	*obtusangula*
Siderastreidae	*Psammocora*	*superficialis*
Siderastreidae	*Psammocora*	*nierstraszi*
Agariciidae	*Pavona*	*cactus*
Agariciidae	*Pavona*	*frondifera*
Agariciidae	*Pavona*	*varians*
Agariciidae	*Pavona*	*decussata*
Agariciidae	*Pavona*	*venosa*
Agariciidae	*Gardineroseris*	*planulata*
Agariciidae	*Coeloseris*	*mayeri*
Fungiidae	*Fungia*	*klunzinigeri*
Fungiidae	*Fungia*	*fungites*
Fungiidae	*Fungia*	*concinna*
Fungiidae	*Fungia*	*repanda*
Fungiidae	*Fungia*	*scabra*
Fungiidae	*Herpolitha*	*weberi*
Faviidae	*Favia*	*veroni*
Faviidae	*Favia*	*maritima*
Faviidae	*Favities*	*pentagona*
Faviidae	*Favities*	*spinosa*
Faviidae	*Favities*	*chinensis*
Faviidae	*Favities*	*halicorna*
Faviidae	*Favities*	*abdita*
Faviidae	*Favities*	*vasta*
Faviidae	*Favities*	*flexuosa*
Faviidae	*Leptastrea*	*purpurea*
Faviidae	*Gonastrea*	*minuta*
Faviidae	*Gonastrea*	*peresi*
Faviidae	*Gonastrea*	*aspera*
Faviidae	*Gonastrea*	*peresi*
Faviidae	*Gonastrea*	*pectinata*
Faviidae	*Gonastrea*	*edwardsi*
Faviidae	*Platygyra*	*pini*
Faviidae	*Platygyra*	*crosslandi*
Faviidae	*Platygyra*	*ryukyuensis*
Faviidae	*Platygyra*	*sinensis*
Faviidae	*Platygyra*	*acuta*
Faviidae	*Platygyra*	*daedalea*
Faviidae	*Platygyra*	*lamellina*

Faviidae	*Oulophyllia*	*crispa*
Faviidae	*Leptoria*	*phrygia*
Faviidae	*Montastrea*	*serageldini*
Faviidae	*Montastrea*	*curta*
Faviidae	*Montastrea*	*annuligera*
Faviidae	*Plesiastrea*	*devantieri*
Faviidae	*Diploastrea*	*heliopora*
Faviidae	*Cyphastrea*	*serailia*
Faviidae	*Cyphastrea*	*chaladium*
Faviidae	*Cyphastrea*	*microphthalma*
Faviidae	*Echinopora*	*lamellosa*
Faviidae	*Echinopora*	*hirsutissima*
Pennatulacea	Sea pens	

APPENDIX III. PRELIMINARY SPECIES INVENTORIES FOR MOZAMBIQUE CHANNEL

The following table lists all the species/taxa recorded on preliminary surveys during a satellite camp in the Mozambique Channel in phase MGM072.

Coral Species	**Fish Species**	**Algae Species**	**Invertebrate Taxa**
Acropora digitifera	*Acanthurus xanthopterus*	*Colpomenia sp.*	Banded cleaner shrimp
Acropora latistella	*Canthigaster valentin*	*Dictyota sp.*	Bivalve
Acropora nasuta	*Chaetodon falcula*	*Eucheuma sp.*	Cuttlefish
Astreopora sp.	*Chaetodon lineolatus*	*Halimeda sp.*	Feather star
Coscinarea sp.	*Chaetodon lunula*	*Lobophora sp.*	Giant clam
Dendrophyllia sp.	*Chaetodon trifasciatus*	*Neomeris sp.*	Hydrozoan
Favia lizardensis	*Chaetodon vagabundus*	*Padina sp.*	Lobster
Favia speciosa	*Chaetodon zanzibariensis*	*Udotea sp.*	Nudibranch
Favites abdita	*Cheilinus fasciatus*	(Green filamentous)	Pin cushion star
Favites flexuosa	*Chromis viridis*	(Blue-green algae)	Sea anemone
Fungia sp.	*Ctenochaetus strigosus*		Sea cucumber
Galaxea sp.	*Dascyllus aruanus*		Sea squirt
Gonastrea sp.	*Epibulus insidiator*		Shrimp
Gonipora sp.	*Heniochus acuminatus*		Triton shell
Herpolitha limax	*Neoglyphidodon melas*		Tube worm
Herpolitha weberi	*Neopomacentrus cyanomos*		
Lemnalia sp.	*Neopomacentrus fuliginosus*		
Lobophyllia corymbosa	*Parapeneus barberinus*		
Merulina sp.	*Pomacanthus chrysurus*		
Pachyseris sp.	*Pomacanthus semicirculatus*		
Pavona cactus	*Pomacentrus caeruleus*		
Platygyra sinesis	*Pomacentrus sulfureus*		
Pocillopora damicornis	*Pseudanthias squamipinnis*		
Pocillopora verrucosa	*Taeniura lymma*		
Porites sollida	*Zanclus cornatus*		
Sarcophyton sp.	*Zebrasoma desjardinii*		
Seriatopora hystrix			
Sinularia sp.			
Stylophora pistulata			
Symphillia recta			
Xenia sp.			