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# Frontier Madagascar Environmental Research

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## REPORT 20

### Fish assemblage diversity and abundances in Diego Bay, Northern Madagascar: an interim report



**FRONTIER**  
FRONTIER - MADAGASCAR

2006

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## **Report 20**

### **Fish assemblage diversity and abundances in Diego Bay, Northern Madagascar: an interim report**

**Brown, L. F. , Fanning E**

**The Marine Sciences Institute,  
University of Toliara, Madagascar.**

**Frontier- Madagascar.  
The Institute Halieutique et des Sciences  
Marines (IHSM)  
Society for Environmental Exploration**

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Tel: +44 (0)20 7613 3061  
Fax: +44 (0)20 7613 2992  
E-mail: [research@frontier.ac.uk](mailto:research@frontier.ac.uk)  
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### **Frontier-Madagascar**

The Society for Environmental Exploration and The Institute Halieutique et des Sciences Marines (IHSM), part of the University of Toliara have been conducting collaborative research into environmental issues since 2000 under the title of Frontier Madagascar. Frontier Madagascar conducts research into biological diversity and resource utilisation of both marine and coastal terrestrial environments, of which one component is the Frontier Madagascar/Darwin Initiative: Madagascar Marine Biodiversity Training Programme.

Madagascar, the fourth largest Island on the planet 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 dependent 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 increasing pressure from unsustainable exploitation. Frontier-Madagascar carried out baseline survey work in the southwest coastal region of Toliara in an effort to provide biological and resource utilisation data for the preparation of sustainable management initiatives for the region.

### **Institute of Marine Sciences (IH.SM)**

The Institute Halieutique 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 postgraduate students. IHSM also provides consultations to government institutions, NGOs and individuals.

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### **Frontier-Madagascar Marine Research Programme (FM MRP)**

The Society for Environmental Exploration (SEE) and The Institute Halieutique et des Sciences Marines (IH.SM), part of the University of Toliara have been conducting collaborative research into environmental issues since 2000 under the title of Frontier-Madagascar. The Frontier-Madagascar Marine Research Programme conducts research into biological diversity and resource utilisation of both marine and coastal environments, which involves working directly with local stakeholders in the region.

## **FOR MORE INFORMATION**

Frontier -Madagascar  
BP41, Antsiranana, 201  
MADAGASCAR  
Tel/Fax: +261 (0) 20 82  
23117  
E-mail:  
[frontier@wanadoo.mg](mailto:frontier@wanadoo.mg)

Society for Environmental  
Exploration  
50-52 Rivington Street,  
London, EC2A 3QP. U.K.  
Tel: +44 (0) 20 7613 3061  
Fax: +44 (0) 20 7613 2992  
E-mail: [research@frontier.ac.uk](mailto:research@frontier.ac.uk)  
Internet: [www.frontier.ac.uk](http://www.frontier.ac.uk)

L'Insitute Halieutique et des  
Sciences Marine (IHSM)  
Zone Portuaire, BP 141,  
Tulear 601  
MADAGASCAR  
Tel: +261 (0) 20 94 43552  
Fax: +261 (0) 20 94 43434  
E-mail: [ihsm@wanadoo.mg](mailto:ihsm@wanadoo.mg)

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### **L'INSTITUT HALIEUTIQUE ET DES SCIENCES MARINE (IHSM)**

F-M Co-ordinators: Dr. Man Wai Rabenevanana  
Dr. Mara Edouard Remanevy

### **SOCIETY FOR ENVIRONMENTAL EXPLORATION (SEE)**

Managing Director: Mrs. Eibleis Fanning  
Programme Manager (Operations): Ms. Patricia Davies  
Programme Manager (Research): Mr Paul Rubio

### **FRONTIER-MADAGASCAR**

Project Co-ordinator: Mr. Philip Cowling  
Research Co-ordinator: Ms. Hannah Markham  
Assistant Research Co-ordinator: Ms. Lesley Brown  
Assistant Research Co-ordinator: Ms. Nikki Browne  
Assistant Research Co-ordinator: Mr. Stuart Higgs  
Assistant Research Co-ordinator: Mr. Mark Priest  
Mr. Jean-Piere Abel  
Mr. Nicholas  
Conservation Apprentice: Ms. Claire Greathead  
Dive Officer: Mr. Greg Williamson

#### Research Assistants:

Alex Douglas, Anthony Swinyard, James Bowyard, James Fisher, John Usherwood, John Macleod, Mark Priest, Ruth Frost, Karen Brinklow, Daniel Fry-Purver, Robert Wilson, Rosemary Bartlett, Samantha Cartwright, Christian Clough, James Dane, Julia Footnick, James Goldhawk, Jeanette Gray, Emily Marsden, Maiya Pina-Dacier, Andrew Silander, Harriet Thornton, Ruth Washbrook, Camilla Bourn, Andrew Williams, Elspeth Church, Hannah Gutteridge, Samuel Roberts, Claire Greathead, Danielle Walker, Robert Bentham, Oliver Holmes, Oliver Dean, Lindsey Elliot, Philip Whiting, Matthew Dolezal, Andrew Watkins, Dave Sproson, Robert Whittaker, Graham Fricker, Steven Roberts, Uyen Nguyen, Vanessa Fullerton, Natalie Simmons, Alison Palmer, Michelle Walker, Amy Briden.

#### IH.SM students:

Andrianarivo Rakotovao, Leandro Ralisadna & Yacinthe Razafimanimby

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<b>1. EXECUTIVE SUMMARY.....</b>	<b>7</b>
<b>LIST OF TABLES .....</b>	<b>8</b>
<b>TABLE OF FIGURES .....</b>	<b>8</b>
<b>2. INTRODUCTION.....</b>	<b>9</b>
<b>3. METHODS .....</b>	<b>12</b>
3.1. <i>Study site</i> .....	12
3.2 <i>UVC Methodology</i> .....	12
3.3 <i>Data Analysis</i> .....	13
<b>4. RESULTS.....</b>	<b>14</b>
4.1 <i>Biodiversity</i> .....	14
4.2 <i>Abundance &amp; Trophic Composition</i> .....	16
4.3 <i>Effect of Distance</i> .....	17
4.4 <i>Aspect and Depth</i> .....	17
<b>5. DISCUSSION .....</b>	<b>18</b>
<b>6. REFERENCES .....</b>	<b>21</b>

## **1. EXECUTIVE SUMMARY**

Frontier-Madagascar carried out underwater visual census (UVC) surveys within the Bay of Diego from March to November 2005 with the intention of highlighting areas of good biological character and health indicated by high biodiversity, healthy population sizes and the presence of keystone species. This is an area coming under increasing pressure from coastal developments to cope with an increasing tourist trade and population. This report is based on the first 9 months of survey work and highlights areas within the northern half of the bay with high fish abundance and biodiversity. Those inlets nearest the mouth of the bay were found to have the highest abundances and biodiversity. An impact on the reef fish assemblages of the bay is the proximity to Diego, which appears to have a negative effect on both the diversity and abundance. In all but one of the inlets, herbivorous fish were the most abundant. This could be indicative of poor health in the reef, via fishing pressures on larger piscivorous fish, or an abundance of algae through eutrophication. Further work is to be carried out on the southern shores of the bay in the next 6 months. This will allow Frontier-Madagascar to create a 'biomap' of the Diego Bay and give a clear answer on the health of the Diego bay and any areas that require protection or conservation.

## LIST OF TABLES

Table 1	Biodiversity (kg 100m <sup>3</sup> ) and abundance (sp 100m <sup>3</sup> ) for each family.	16
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## TABLE OF FIGURES

Figure 1	Large map of Madagascar	12
Figure 2	Northern shores of the Bay the inlets marked.	13
Figure 3	Biodiversity of fish surveyed within each bay inlet (kg 100m <sup>3</sup> )	17
Figure 4	Abundance of fish per inlet	17
Figure 5	Abundance and tropic composition of fish per inlet as per their biomass	18

## 2. INTRODUCTION

There have been numerous studies carried out worldwide on reef fish and their relationship with their environment (Jennings & Polunin 1996, Allen & Werner 2002, Graham *et al* 2005). Coral reefs are the most luxuriant and complex of all benthic communities (Duxbury & Duxbury 1999) covering only 280,000km<sup>2</sup>, less than 0.1% of the ocean (ReefBase); however, they are one of the main sources of protein for inhabitants of coastal areas. They are predominantly found in developing countries with little or no coastal management practices in place to protect these fragile environments and unfortunately as a result of this they are coming under increasing pressure. Studies of reef fish are increasingly used as indicators of reef health as they are highly conspicuous and easily identifiable animals that can be surveyed relatively easy with the use of SCUBA or snorkel (Ohman *et al* 1997). Numerous studies have looked at the effect of physical parameters such as exposure to wave action, temperature, benthic complexity and hard coral cover on their relative abundances and biomasses (Jones *et al* 2004). These have proved excellent in elaborating upon the whys and wherefores of tropical coral reef fish ecology (McClanahan 1997). Also increasingly investigated are anthropogenic impacts such as pollution and coastal development (Jennings *et al* 1999). These studies are important in highlighting concerns over increasing uncontrolled coastal development in developing countries as these have been shown to greatly impact coral reefs.

Madagascar, the world's fourth largest island, is one such developing country with little or no coastal management (Walker & Fanning 2003). It has over 6000km of coastline and approximately 2000km<sup>2</sup> of coral reefs (Gabrie *et al* 2000) within its waters; however, it is one of the poorest nations in the world with over 60% of its population living below the poverty line (UNDP 2005), and in coastal areas there is a real dependence on marine resources for income and food. There has traditionally been a large proportion of the population dependent on the sea for sustenance and income but recent political upheavals have seen migration of many inland dwellers towards the coast (Tulane 2005). This is putting increased pressure on already limited resources. Traditionally those tribes that lived by the ocean had their own taboos or 'fadys', which acted to restrict destructive practices on the fragile ecosystems (Cooke *et al* 2001). However expanding populations, migrations and fewer young people adhering to traditional methods (Brown 2005) means the surrounding reefs of Madagascar are becoming at risk of over fishing and pollution.

Despite the limited amount of research carried out in Madagascar to date (Walker & Fanning 2003) there are positive developments occurring such as the creation of marine protected areas. One such area is based in the Baie de Courier on the western side of the northern peninsula of Madagascar under the control of WWF and ANGAP, a Malagasy organisation that controls all of the terrestrial national parks of Madagascar. This as a result of research carried out by Conservation International (CI) in 2002 whereby with the aid of a small team of experts in corals, fish and invertebrates constructed a species list of over 1000 animals with at least 9 new coral species and 3 new fish species found

(CI 2002). These results and the new marine protected area have generated a lot of interest in the surrounding areas, including Diego Suarez, the nearest large settlement.

The Diego region is a popular area for tourists to visit due to its proximity to two nearby National Parks; Montagne d'Ambre and Ankarana, a well-served airport and a beach resort (Ramena). Additionally Diego is one of the world's oldest deep-water ports and therefore attracts visitors on cruise ships and yachts. As a result of this popularity Diego is rapidly developing to cater for an increasing population as well as increased tourism within the area. Much of this development is occurring along the southern shores of the Diego Bay. Diego Suarez is situated on a peninsula protruding into the Diego Bay, the world's second largest inlet and is surrounded on three sides by the bay. Being a seaport, Diego relies heavily on the ocean for much of its trade and income.

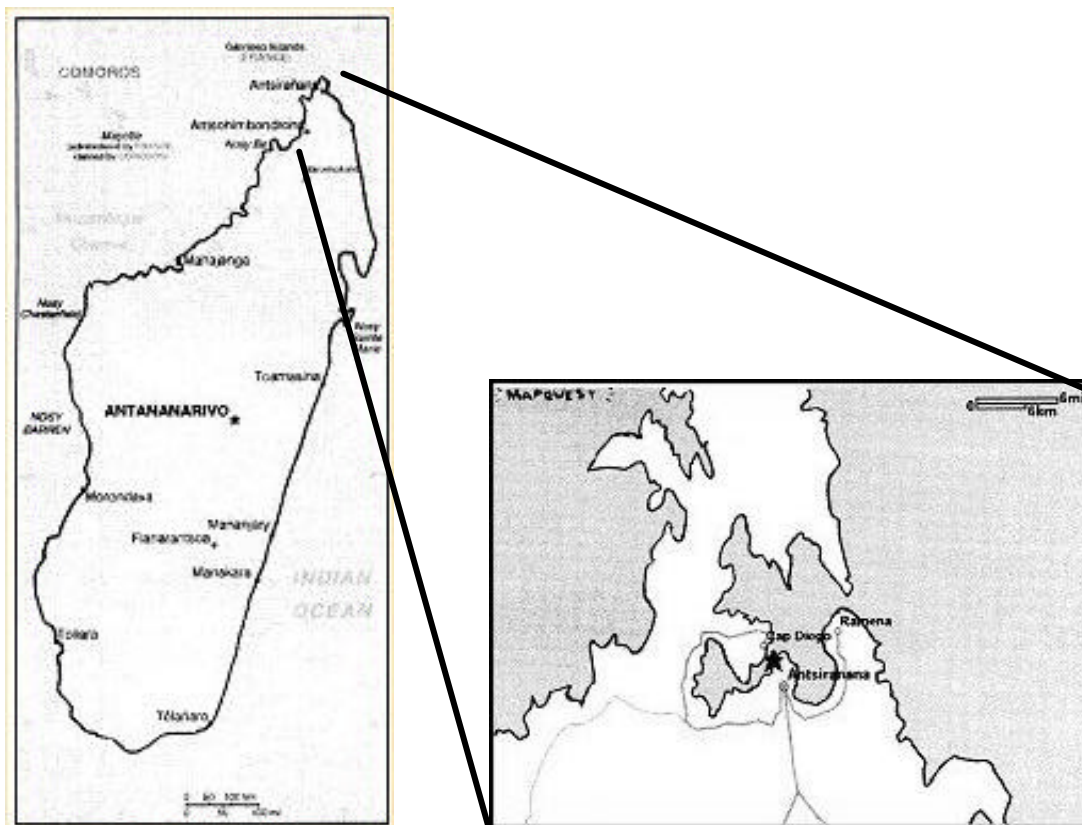


Figure 1: This map shows Madagascar with a closer view of the Diego region. The area to the west of Diego is the Baie de Courier, the newly set up marine protected area.

It was for this reason that the Frontier-Madagascar Marine Program was invited to the region by SAGE, a Malagasy organisation involved with development projects throughout Madagascar. The objective of the study was to carry out biological surveys in the bay to ascertain the health of the different ecosystems within the bay and to highlight any areas of concern or for future conservation.

Frontier-Madagascar, with the help of volunteer research assistants, has carried out extensive biological surveys within the Bay of Diego. The project was designed specifically to highlight areas with good biological character but also to highlight factors that are impacting on this marine environment. The use of standard UVC methods will allow this work to be compared to other marine surveys carried out both within Madagascar and worldwide either by Frontier or other agencies.

This report is concerned with data collected during the first 9 months of study within the northern shores of the bay on fish assemblages, most notably their biodiversity and abundances. This should be used in conjunction with the further work to be carried out over the coming months on the southern shores of the bay and additionally with the benthic and physical data also collected as part of these surveys to create a 'biomap' of the Diego Bay area.

### 3. METHODS

#### 3.1. Study site

This study was conducted on the northern shores of the Bay of Diego (12°10'S 049°15'E), Figure 2 shows a simple map of the area surveyed from March – December 2005. From initial Rapid Assessment it was found that the coral within the bay is largely fringing, not generally reaching below 8m. Baseline surveys were concentrated within this depth range with the use of SCUBA by trained volunteers. This use of unskilled volunteers allows groups to survey using relatively simple techniques and cover a large area over a short period of time.

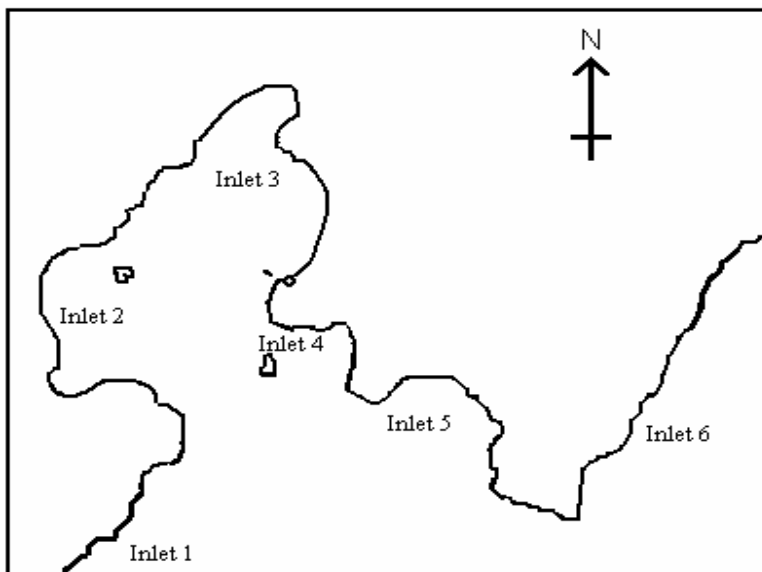


Figure 2: Map shows the separate inlets that were surveyed during this study. Diego is situated approximately 5km south of inlet 5 and the mouth of the bay is directly opposite inlet 6.

#### 3.2 UVC Methodology

The full UVC methodology is given in Markham *et al* (2005). The fish surveyor swims along a tape measure laid by a second diver, along the contour of the reef at a constant depth. UVC's were carried out at 0-2m, 6-8m and 8m+ chart datum depth. All fish of 17 families to enter into an imagined 5m<sup>3</sup> box to the left of the tape measure were recorded. Two surveys are carried out at every site consisting of 0-20m and 25-45m on the tape measure to allow comparisons between surveys. Over the period of the study the inlets were sampled at a minimum of 1km intervals. There were 58 sites and a total of 82 surveys were carried out at these sites over the period.

Fish families recorded are *Pomacanthidae* (angelfish), *Sphyraenidae* (barracuda), *Chaetodontidae* (butterflyfish), *Lethrinidae* (emperor), *Balistidae* (triggerfish), *Caesionidae* (fusilier), *Mullidae* (goatfish), *Serranidae* (groupers), *Scombridae* (tunas and mackerels), *Scaridae* (parrotfish), *Siganidae* (rabbitfish), *Lutjanidae* (snappers), *Acanthuridae* (surgeonfish), *Haemulidae* (sweetlips), *Carangidae* (trevally), *Labridae*

(wrasse), *Pomacentridae* (damselfish). Fish were recorded according to their size within 2.5cm increments. Accuracy of fish length estimation was ensured by assessing volunteers using pieces of plastic of known lengths as per Jennings & Polunin (1996). Volunteers had to pass at least two assessments to ensure they were able to survey fish within an error margin of 15%.

### 3.3 Data Analysis

Fish lengths were converted to mass using weight:length relationships published on FishBase 2004. Where there was no recorded weight:length relationship the weight:length relationship for a fish of the same family and similar morphology was used.

Biodiversity was calculated from the fish abundances using the Shannon-Wiener diversity statistic shown below.

$$H' = -\sum p_i \ln p_i$$

Where  $p_i$  (the proportional abundance of the  $i$ th species) =  $\frac{n_i}{N}$

Abundance and biomass were calculated per 100m<sup>3</sup> to allow comparisons.

Correlation analysis was carried out for each site in relation to diversity and abundance to distance from the mouth of the bay and distance from Diego Suarez, thought to be the largest contributing factors to marine life within the bay.

A one-way ANOVA (unstacked) was carried out to observe differences between the inlets on biodiversity and abundance.

Fish were assigned to their trophic group of piscivore, invertivore, coralivore, herbivore, omnivore and detritivore. Compositions of trophic groups within each bay inlet were compared.

## 4. RESULTS

### 4.1 Biodiversity

Biodiversity of fish as per their Shannon-Wiener ( $H'$ ) figure for 100m<sup>3</sup> is shown in Table 1. Inlets 2 and 4 have the highest level of biodiversity with 1 and 3 the lowest. Inlets 5 and 6 are relatively the same with a figure of 2.59 and 2.9 respectively. A one-way ANOVA (unstacked) showed there to be significant difference between the inlets in biodiversity ( $p=0.013$ ,  $F=3.24$ ). Figure 3 shows the mean Shannon-Wiener for each bay inlet and illustrates the difference found in each bay.

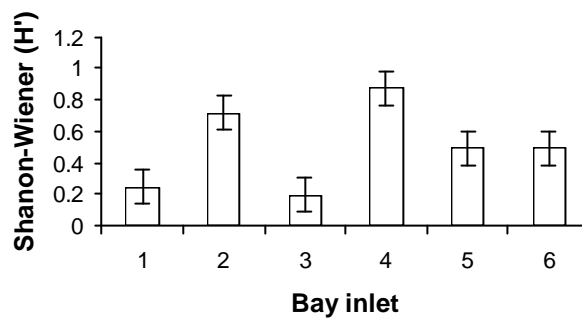


Figure 3: Biodiversity of fish surveyed within each bay inlet (Shannon-Wiener  $H'$ ). Fish Biodiversity was lowest in bay inlet 3. This inlet is the most sheltered bay in terms of wind exposure and is also the furthest from the mouth of the bay. Coral cover is low in this bay with visibility often reduced to just a couple of metres.

Table 1: Biomass (kg 100m<sup>3</sup>) and abundance (sp 100m<sup>3</sup>) for each family in their respective bay inlets.

		No. of species in genus	Mean number of species per transect						Biomass – kg per 100m <sup>3</sup>					
			1	2	3	4	5	6	1	2	3	4	5	6
Angelfish	<i>Pomacanthidae</i>	3	1.29	0.33	0	0.06	0.63	0.95	1.34	0.35	0	0.06	0.65	0.99
Barracuda	<i>Sphyraenidae</i>	3	0	0	0	0	0	0	0	0	0	0	0	0
Butterflyfish	<i>Chaetodonidae</i>	14	0.86	1.50	1.20	2.00	2.13	2.60	0.47	0.83	0.66	1.10	1.17	1.43
Damsel	<i>Pomacentridae</i>	24	17.00	36.83	17.15	17.44	91.00	36.05	10.98	23.80	11.08	9.03	58.80	23.29
Emperor	<i>Lethrinidae</i>	6	0	0.33	0.70	0.56	1.25	0.20	0	0.10	0.20	0.16	0.36	0.06
Fusilier	<i>Caesonidae</i>	1	0.36	0.67	0.20	0	0	7.50	0.12	0.22	0.07	0	0	2.47
Goatfish	<i>Mullidae</i>	6	0	0	0.85	0	0	0.25	0	0	0.22	0	0	0.06
Grouper	<i>Serranidae</i>	5	0.36	0	0.40	0.25	0	0.25	0.08	0	0.09	0.06	0	0.06
Parrotfish	<i>Scaridae</i>	9	1.29	1.33	0.05	0.13	0.38	1.10	0.32	0.33	0.01	0.03	0.09	0.27
Rabbitfish	<i>Siganidae</i>	3	1.57	0	0	0	0	0	0.40	0	0	0	0	0
Snapper	<i>Lutjanidae</i>	5	0.71	0	1.30	0.56	0	0.15	0.25	0	0.45	0.19	0	0.05
Surgeonfish	<i>Acanthuridae</i>	8	2.64	2.00	1.45	0.13	0.75	1.70	2.11	1.60	1.16	0.10	0.60	1.36
Sweetlips	<i>Haemulidae</i>	5	0.64	0.33	0	0.44	0	0.75	0.15	0.08	0	0.10	0	0.17
Trevally	<i>Carangidae</i>	4	0.07	0	0	0	0	0.05	0.03	0	0	0	0	0.02
Triggerfish	<i>Balistidae</i>	4	0	0	0	0.06	0	0.05	0	0	0	0.02	0	0.01
Tuna and Mackerel	<i>Scombridae</i>	2	0	0	0	0	0	0	0	0	0	0	0	0
Wrasse	<i>Labridae</i>	13	1.64	38.83	0.10	0.94	4.13	5.05	0.44	10.38	0.03	0.25	1.10	1.35
<b>Total</b>		<b>115</b>	<b>28.43</b>	<b>82.17</b>	<b>23.40</b>	<b>22.56</b>	<b>100.25</b>	<b>56.65</b>	<b>16.68</b>	<b>37.67</b>	<b>13.96</b>	<b>11.11</b>	<b>62.77</b>	<b>31.61</b>

## 4.2 Abundance & Trophic Composition

Overall abundance of fish species, recorded as biomass of fish per 100m<sup>3</sup> is also shown in Table 1 for each fish family surveyed. Abundance as individuals per transect (species richness) for each inlet is shown in Figure 4 and by biomass for each inlet is shown in Figure 5. A one-way ANOVA (unstacked) shows there to be a significant difference in abundance (biomass) between the inlets ( $p=0.001$ ,  $F=4.94$ ).

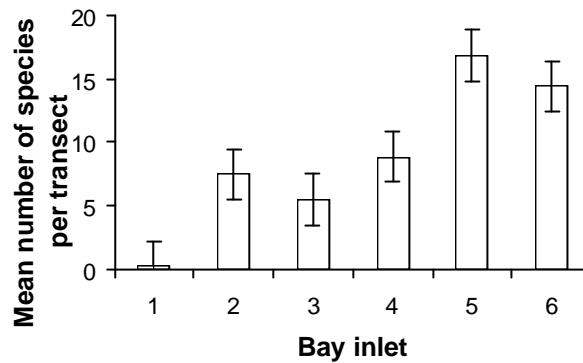


Figure 4: Abundance (species richness) of fish per inlet as measured by number of species encountered per survey.

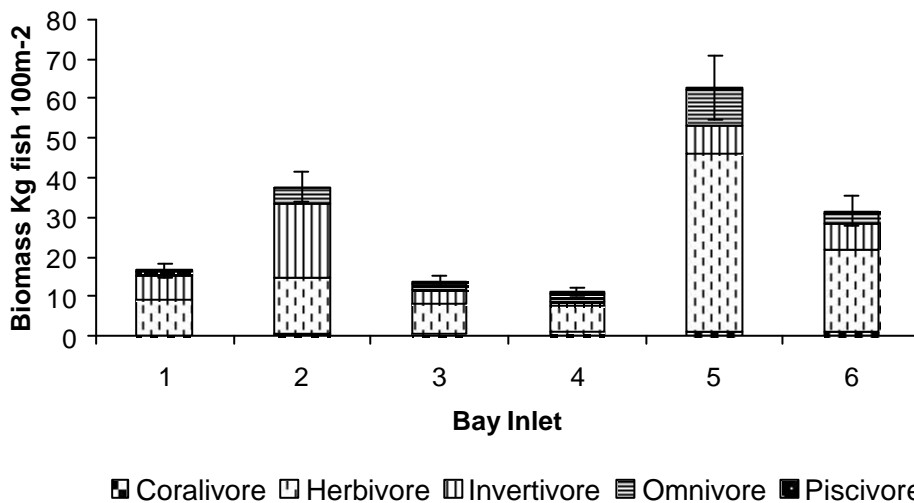


Figure 5: Abundance and Trophic Composition of fish per inlet as per their biomass calculated from published length:weight relationships. Inlet 5 also has the highest biomass compared to the other inlets. Herbivorous fish were by far the most abundant trophic group in all except bay inlet 2. Second most abundant were the invertivorous fish. Coralivores and piscivores were not particularly common at any point within the bay.

All fish were assigned to one of five trophic groups; coralivore, piscivore, omnivore or herbivore. Figure 5 also shows the overall biomass of each trophic group within each bay inlet.

Herbivorous fish were abundant in all inlets, with inlet 5 showing the highest biomass per 100m<sup>3</sup>. Invertivore fish were the second most abundant trophic group within the bay of Diego. Inlet 2 was the only inlet where herbivorous fish were not the most abundant, with invertivore fish being the largest group by biomass. Levels of coralivores, piscivores and omnivores were low throughout the inlets surveyed. Surprisingly, those bays with high levels of hard coral cover did not appear to have significantly higher numbers of coralivores compared to the other inlets. Hard coral cover increases towards the mouth of the bay at inlet 6 (Markham *et al* 2005), and whilst there is a corresponding rise in coralivores in inlets 4, 5 and 6 this is small in comparison with the herbivorous and invertivore fish.

### **4.3 Effect of Distance**

A correlation analysis of site abundance (biomass) and distance from the mouth of Diego Bay showed a significant relationship between the two variables (Pearsons= -0.441, p=0.001). Additionally there was a significant relationship between distance from Diego and the abundance (biomass) of fish within the bay (Pearsons= -0.313, p=0.017).

A further correlation analysis looked at biodiversity (Shanon-Wiener H') and found a significant relationship between biodiversity levels and distance from the mouth of the bay (Pearsons= -0.447, p<0.001). Additionally, biodiversity is related to the distance from Diego, with a statistically significant relationship (Pearsons= -0.493, p<0.001).

### **4.4 Aspect and Depth**

A look at aspect of the reef showed there to be no significance on either abundance (p>0.01) or biodiversity (0.01). In addition, depth did not appear to have any significant effect on either abundance (p>0.01) or diversity (p>0.01).

## 5. DISCUSSION

The bay inlets were viewed separately for the purpose of this study as each bay inlet appears to have very different characteristics with respect to aspect, exposure to wind, current, inflow of water, depth, benthic cover and anthropogenic impacts. From the results above it is clear that there is a significant difference between the inlets in biodiversity, species richness, fish abundance and trophic composition. Often some species of fish are only found within a very localised area, such that some inlets have an abundance of one species that is not encountered anywhere else within the bay, for example *Siganidae* are only found in inlet 1, and *Mullidae* only in inlets 3 and 6.

Unsurprisingly, distance from the mouth of the bay has a significant effect on both the abundance of fish, and also on the diversity of fish. The further away from the bay mouth the lower the abundances and diversity of the fish. Inlet 6 is directly opposite the mouth of the bay and local fishermen claim this to be one of the best parts of the bay to fish in. This is one of the few areas of the bay where large apex predators such as sharks have been observed indicating sufficient prey for these predators to subsist on.

The city of Diego appears to have a negative affect on fish abundances and diversity within the bay. This is a large city within a developing country that has little regulation of pollution and sewage seepage into the surrounding waters. The city is located on a peninsula projecting into the bay of Diego. In the northern shores of the bay there is little human habitation with just 4 small villages, each populated by less than 200 people. The majority of human habitation is based in the southern reaches of the bay.

Given the distance of the inlets from Diego (approximately 6-12km) it is hardly surprising that such anthropogenic activities can have such an impact. However, compounding this is the relatively low influx of seawater through the narrow mouth of the bay. It should therefore be expected that those areas near the mouth of the bay on the southern shores should also show higher diversity and abundances than those near to Diego. There is however more human habitation within this area, such as the village of Ramena, which could impact the fish assemblages of this area. In essence the bay is a partially closed system with little mixing or influx of water from the open ocean, therefore any anthropogenic activities will have a far greater impact than would be expected in a fully open system.

Many studies have shown there to be a direct link between hard coral cover and reef fish assemblage mass and diversity (Chabanet *et al* 1997). Much of the coral within the bay is of a fringing nature and little coral is found below 8m, a relatively shallow depth compared to coral growth elsewhere in Madagascar (Walker *et al* 2003). Beyond the fringing coral there is little growth with the predominant sediment fine sand or silt. On windy days the visibility within the bay can be affected greatly. Additionally, the mouth of the bay is narrow and based on the eastern side of the bay. For 9 months of the year the wind predominantly comes from the southeast which allows some influx of water through the mouth although this does mean some inlets such as 3 have very little water movement. The wind swings round and comes predominantly from the north during the

remaining 3 months which could impact the degree of mixing with open ocean water. Given the partially closed system recruitment of both coral and fish is likely to be much lower than in an open ocean system.

Salinity changed dramatically in the bay during the survey period. At the outset of the project salinity was generally 18-20ppt with this rising to 33ppt during November. The project commenced in March, the end of the rainy season and continued on to December, the end of the windy season and during this time there was little rainfall. It is likely this lack of rainfall and mixing with open ocean water caused this salinity to rise. Generally one would expect salinity levels of around 34ppt in a normal open ocean reef system however the fish within this bay are able to tolerate much lower levels of salinity. Whilst this is not surprising as often many of these fish associate with mangroves during juvenile stages it may explain somewhat the limited biomass and abundance of fish as salinity is a well-known limiting factor of coral growth. It is possible the recent location of the large private salinity plant may be having some effect on the salinity of the bay. However, information regarding the salinity plant is sparse at present as it is a privately owned company and Frontier-Madagascar do not have permission to survey within the inlet where it is based. The plant is visible from the aeroplanes landing at Diego airport and the water within the inlet is a murky brown colour. The plant is most likely having some form of impact on the reef fish and coral of the bay given its location and size. Further studies however can only be carried out once permission is granted from the owners.

Neither aspect nor depth appear to play a major role in the biodiversity or abundance of fish within the bay, however this could likely be due to the choice of site at present. The sites have until now been chosen non-randomly, and were instead chosen as good examples of coral coverage and fish abundances for that inlet. Frontier-Madagascar is at present attempting to obtain survey data at 1km intervals along the coastline of the bay. This study is based on one survey at each site which is not necessarily at the same depth. It is the intention of the study to survey at least 3 times at each site at 3 depths 2, 6 and >7m. Whilst this is relatively shallow compared to other similar style studies there is little or no coral found below depths of 8m therefore it would be a waste of resources to survey areas where it is known there is little marine life. Although depth was not a significant factor in the biodiversity or abundance of fish assemblages, with further sampling this may become significant as more surveys are carried out.

A species list of fish found within the bay was constructed based on sightings during UVC surveys, rapid assessment surveys (Markham *et al* 2005) and recreational snorkelling. However there are a number of fish on this list that have as yet not been encountered on a survey. This could be explained in that each survey only covers an area of 100m<sup>3</sup>. Our initial rapid assessments covered much larger areas (750-1500m<sup>2</sup>) and allowed us to generate simple biomaps of the individual characteristics of the inlets. These were used extensively to select areas to concentrate our initial surveys. The intensive baseline UVC method used is an excellent means of assessing the health of an area, and allows comparison of one area with another, but without additional work such as rapid assessment, the true diversity and complexity of an area could be missed due to the limited area covered in each survey.

The intended future work of Frontier-Madagascar within the Bay of Diego is to continue its current survey work of fish abundances and biomass and to extend this to the southern shores of the bay. Initial assessments, using rapid assessment methodology (Markham *et al* 2005) shows there to be very little live coral in the south, with the predominant benthic coverage consisting of seagrass beds. Whilst seagrass beds are an important ecosystem for fish recruitment, the visibility in the southern inlets is very poor making surveying difficult. There is also the added factor of anthropogenic impacts in the south which could prove to have far bigger impacts on those southern ecosystems than anthropogenic influences in the north. An interesting addition to this study would be to survey immediately outside the mouth of the bay. Here the impacts affecting the fauna of the bay would still be in effect but here with an open system of mixing it would be apparent just how much is limiting the growth of coral and fish within the Bay of Diego. Few studies exist of bay systems and this work could add immensely to this field of coral reef ecology.

Upon completion of this project within the Diego Bay it will be possible to further investigate relations between hard coral cover, fishing intensities, physical parameters such as salinity, visibility, temperature and benthic complexity on the biomass and abundance of reef fish found within the bay. This should enable us to fulfil our initial objective, which was to assess the health of the bay of Diego and highlight any areas in need of protection and conservation.

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