CORAL REEF RESILIENCE ASSESSMENT OF THE NOSY HARA MARINE PROTECTED AREA, NORTHWEST MADAGASCAR

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Acknowledgements

Contents

NOTE - This report follows a different format to facilitate communication of the main findings of the report to managers and non-technical readers. The **executive summary** *(section 1) and* **main discussion and findings** *(section 3) contain the primary findings. The detailed methods and results are presented in subsequent sections.*

1 Executive Summary

Coral reefs in the Nosy Hara Marine Park showed a high coral cover for the WIO, with levels of 34%, and a peak of 53%. Other important cover types were soft corals, being most abundant on outer wave-exposed sites, and macroalgae/cyanobacteria on sheltered inner sites. Overall, terrestrial influence is very high, which is the natural condition in the area, with low visibility levels for coral reefs, shallow reef bases, and evidence of high sediment influence on coral communities and in reef sediments. This inshore-offshore gradient is further strengthened by an exposure gradient, with offshore reefs being highly exposed to waves and the frequent cyclones that affect the area. Notwithstanding this gradient, coral reefs across the area are relatively homogeneous in their overall characteristics, with gradual differences in species, community structure and reef structure. *Acropora* was the dominant coral genus, followed closely by *Porites*, split equally among branching and massive species, reflecting a typical East African coral community. Algal communities are minor, with little macroalgae, except for the notable abundance of the filamentous alga *Enteromorpha*, and of the cyanobacterium *Lyngbya*. Both of these form thick mats of long filaments on some highly degraded inshore reefs where exposure to freshwater and/or terrestrial nutrients is high, and past disturbances may have opened space for them by killing off corals. They are indicators of a degraded state, preventing recovery to a coral-dominated state. Fish populations were highly impacted by fishing with almost no large carnivores or large herbivores, an overwhelming numerical dominance of planktivorous and benthic damselfish (Pomacentrids), and relatively low populations of herbivores.

Two major indicators of anthropogenic impact to the reefs were seen: a) an absence of large coral colonies and presence of dead coral/algal-covered surfaces suggesting moderate levels of coral mortality perhaps 4-10 years ago, and b) the depauperate fish populations, indicating high levels of fishing. The heavy fishing pressure is already known for the area, supplying the nearby market in Antsiranana/Diego, these surveys only confirm its impact underwater – the gradient of fishing pressure was clearly seen in the healthier fish populations on offshore less accessible reefs than inshore ones. The impacts to corals are more difficult to interpret, and may include mortality due to bleaching, which may have occurred at moderate levels and been undetected since the 1998 regional bleaching event until today, and physical damage from cyclones, of which there have been 5 direct hits in the last 11 years. It is likely that both of these have occurred to some degree, and their effects are combined. Corals show a gradient from most to least impacted from offshore to onshore – which is consistent with both factors, where cyclone and bleaching damage is highest on the exposed clear-water reefs, and lowest on the inner sheltered turbid reefs.

However, in spite of the evidence of recent mortality of corals there has been no shift in community structure away from *Acropora* dominance, thus the reefs are maintaining their state and function. At this level, the reefs are showing a good degree of resilience to the threats impacting them, however the highly depauperate fish communities are alarming, and may indicate the reefs may approach a point at which the benthic community may not be able to recover from future impacts if the full trophic structure of the reefs is not improved. Factors that appeared most important in maintaining the health of the reefs included the good connectivity and water exchange from local to subregional scales (e.g. to N. Mitsio and N. Be to the south), the adaptation of the coral communities to high-turbidity conditions that also screen corals from light stress during a bleaching event, and low levels of alteration of water quality from human activities (apart from enhancement of turbidity levels). Factors that scored most negatively in their contribution to reef health included the low fish and herbivore populations and impact of fishing.

In terms of management recommendations, given the overall consistency in reef habitats throughout the Nosy Hara area, establishing a solid management regime throughout the area is important (covering fishing practices, reef and island use standards, monitoring and surveillance). Management interventions that are more targeted for individual reefs/islands can focus on the specific factors affecting them, as part of the overall mosaic of sites. Thus:

- Sites in the best condition – at Nosy Vaha, Nosy Hao, Lakandava, and Andavakalovo – are in a good state because of strong currents, exposure to waves and steeper slopes, and their inaccessibility. They are also of key importance in providing coral and other larvae for repopulating more impacted sites. These should be given full protection, to maintain their biodiversity and function as source reefs for other sites. As they are relatively inaccessible, full protection will not greatly affect fishing practices.

- Sites in intermediate condition – Agnahibe, Nosy Mbamaho, Nosy Hara Est, Ankarabo, Nosy Hao, Rejabora, Antsikoa – are in this state because they are generally accessible for fishing. They should be given clear 'wise use' protection status to minimize damage to them and at the same time maximize

benefits that can be obtained by fishing and other uses. This level of management should be established as the standard for the whole protected area.

- Sites in the poorest condition – Iavoloha, Andrivan'i Paul, Rameza, Ampasindava, Sandoz – have been degraded likely by a variety of conditions, such as bleaching, physical damage, overfishing, freshwater, nutrient supply or others. They are generally accessible for use and may face the most intense use, such as the fringing reef at Ampisandava. Management at these sites should include regulations for the intermediate sites, with additional measures to encourage rehabilitation. This may include, for example, removal of bioeroding sea urchins (such as at Ampisandava), clearing of macroalgae/cyanobacteria to facilitate coral recruitment, higher protection status for rotating portions of the reef/island area to promote recovery in patches over the years. Because of their importance in resource use, management interventions should be very carefully negotiated and discussed with resource users to minimize conflict and maximize compliance and effectiveness. Additionally, small scale management trials (e.g. of clearing macroalgae/cyanobacteria) could be initiated to explore different options for management.

2 Introduction

2.1 The study

This survey is conducted under the project "Building Resilience in Marine Protected Areas in Madagascar" of WWF Madagascar and the Western Indian Ocean. Its purpose is to provide information to ensure that climate change responses are integrated into Marine Protected Area design and management. A further purpose is to build capacity to undertake sound monitoring of coral reefs by partners. Specifically, the study objectives are:

1- To implement a bleaching and resilience rapid assessment protocol that meets the needs of MPA planning and implementation in Nosy Hara;

2- To assess the resistance of coral reefs in Nosy Hara to coral bleaching and climate change;

3- To assess the resilience of coral reefs in Nosy Hara and their ability to recover following a bleaching event;

4- To train Marine Protected Area managers and other partners in implementation of the resilience surveys; and

5- To make recommendations on zoning, design and management of coral reefs within the Marine Protected Area based on the survey findings.

This report contains answers to objectives 2, 3 and 5, while objective 4 was met through an initial training day on the surveys followed by ongoing training during implementation. Members of the survey team incorporated staff from the following partner organizations:

Organization	Survey team	Support/other
Madagascar National Park (ANGAP/MNP)	Razanakoto Ignace, Razafindratondra Samoel Firmin, Radison Jean Claude, Zavatra Jean Baptiste	Jaomanana, Randimbison Landisoa, Raspaul, Ralison Serge
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Conservation International (CI)		Tombolahy Lucie Monica, Rakotomandimby Dera

2.2 Reef resilience

Climate change is now recognized as one of the greatest threats to coral reefs worldwide. However to date reefs in NW Madagascar have been reported to have not suffered from bleaching impacts. Other factors that affect reefs in the region include natural ones from cyclones, terrestrial river/sediment influence and predator outbreaks such as crown of thorns seastars, and anthropogenic threats such as fishing, pollution and nutrient additions. These all affect the health of a coral reef. Reef health can be explained in terms of ecological resilience – i.e. its ability to resist threats and to recover to a healthy state when an impact does occur.

The natural resilience of reefs is being undermined by stresses associated with human activities. These local pressures reduce the resilience of the system by undermining its ability to cope with additional stesses, such as from climate change. Increasingly, policy-makers, conservationists, scientists and the broader community are calling for management actions to restore and maintain the resilience of the coral reefs to climate change, and thus avoid worst-case scenarios.

The approach used in this study was developed by the IUCN Climate Change and Coral Reefs working group (http://cms.iucn.org/cccr), led by CORDIO East Africa, which has outlined a series of protocols to quantify basic resistance and resilience indicators for coral reef assessments. These methods are designed to assist management authorities in focusing management effort to priority areas.

2.3 The Nosy Hara area

Nosy Hara is located on the west coast of Madagascar in the province of Diania, just south of the northern tip, Cap d'Ambre and directly west of the town and large bay of Diego Garcia/Antsiranana. The coastline is similar to the more well-known Nosy Be area farther south, being a highly convoluted shoreline of large bays fringed by beach and mangroves, and with rivers draining the flat/rolling hills of the hinterland. The islands grouped around the main island of Nosy Hara are karst limestone (the tops of the islands have the typical 'tsingy' or eroded sharp limestone pillars typical of northern Madagascar). These are set on a broad shallow flat platform that extens out about 15 km from shore and is 20 km from north to south. The platform bears a series of small banks capped with coral reefs, and at its outer edge (about 5-10 m deep) is fringed by coral with a sharp drop to a sandy bottom most likely at about 20 m depth, which is part of the broad shelf that extends out from the west coast of Madagascar to variable distances, but about 20 km offshore.

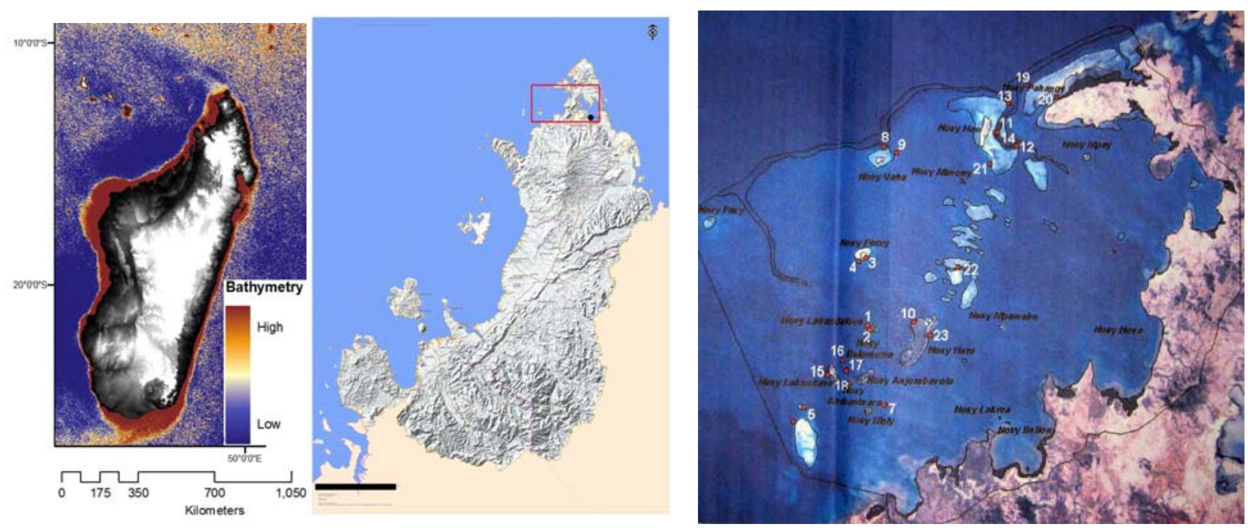
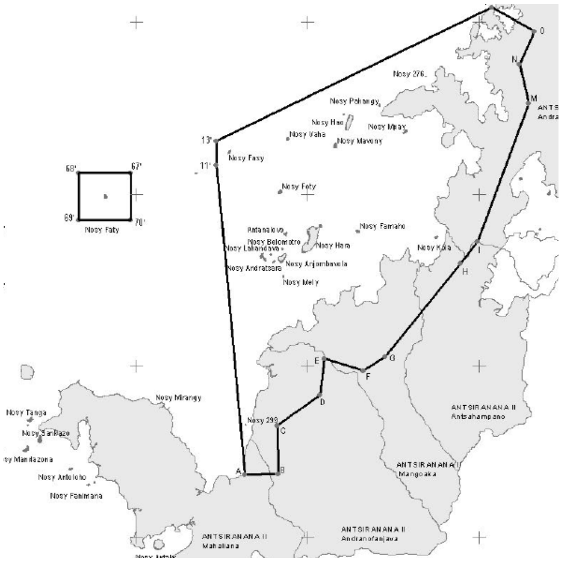


Fig. 2.1 Left –map of Madagascar showing the continental shelf to about 100m depth in brown, noting the broader shelf on the west coast including in the northern part around Nosy Hara. Middle - the northern province of Diana, with Nosy Hara/Diego bay shown in the red box and Diego town by the black spot. The scale bar at the bottom represents 50 km. Right – the Nosy Hara group of island, platform and scattered shallow banks. The entire platfrom area, including the small island at the extreme left, is contained within the boundary of the Marine Protected Area of Nosy Hara.

Past surveys of the reefs of the Nosy Hara area have been conducted to provide baseline information for the protected area project, and justification for designating it as a Marine Protected Area.



2.3.1 Survey sites

Sixteen sampling sites were completed (fig. 2.1, Table 2.1). The depth of sampling was constrained by the reef topography, with the main area of coral growth mainly being shallow due to turbid water. This was selected for surveys, with transects being layed along the same contour of maximum coral growth.

Table 2.1. Sites surveyed in Nosy Hara in November-December 2008. Geographic coordinates, codes used in analyses and classification by depth, reef type, substrate rock type and exposure also shown.

Date	Site	Reefcode		Depth	Reeftype	Substrate	Exposure	Lat (S)	Long (E)
19-Nov	Andilana (Est Nosy Hara)	NHaraE	H01	5	Fringe	Karst	very low	12.12667	49.06611
19-Nov	Nosy Mbamaho	Mbam	H02	5	Slope	Reef	medium	12.23278	49.05944
20-Nov	Rameza	Ramz	H03	4	Bank	Reef	medium	12.29333	48.94694
20-Nov	Bejabora	Beja	H04	6	Bank	Reef	medium	12.26250	49.03306
21-Nov	Nosy Hao	Nhao	H05	4	Fringe	Reef	high		
21-Nov	Sandoz	Sand	H06	4	Fringe	Karst	medium	12.24778	49.00750
22-Nov	Ampasindava	Adav	H07	2	Fringe	Reef	low		
23-Nov	Antsakoa	Ants	H08	1	Fringe	Reef	low	12.25861	49.08694
23-Nov	Lakandava	Ldava	H09	5	Slope	Karst	high	12.26361	48.95861
24-Nov	Nosy Vaha	Nvaha	H10	8	Fringe	Reef	very high	12.12917	48.99250
24-Nov	Agnahibe	Agna	H11	1	Patch	Reef	medium	12.20056	49.02694
24-Nov	Andrivan'i Paul	Apaul	H12	4	Bank	Reef	medium	12.17444	49.08972
25-Nov	Andavakalovo	Alovo	H13	10	Slope	Karst	high		
25-Nov	Ankarabo	Anka	H14	8	Slope	Karst	high		
26-Nov	Passe Nosy Hao	PsNHao	H15	10	Patch	Reef	high	12.12667	49.06639
26-Nov	Iavoloha	Iavo	H16	5	Fringe	Karst	very low		

2.4 Overview of methods

The methods applied in this study were developed by the IUCN working group on Climate Change and Coral Reefs, specifically to examine the resilience of coral reefs to climate change (high seawater temperature). Several components of the reef ecosystem were measured at varying levels of detail, as follows:

1) Benthic cover – provides the main overall indicators of reef state, and particularly the balance between corals and algae. The method used was the Point Intercept Transect (PIT) for increased speed, but based on and compatible with the standard monitoring programmes in Madagascar that use Line Intercept Transects (LIT), using.

2) Fleshy algae – provides information on the main competitors to corals on degrading reefs. Fleshy algae cover (%) and height (cm) was estimated in $1m^2$ quadrats.

3) Coral community structure – provides an overview of the relative abundance of coral genera, and that are susceptible or resistant to coral bleaching. The abundance of all coral genera was estimated during field visits along a five-point scale from rare to dominant. Coral species diversity was also recorded for each site.

4) Coral size class distribution – provides detailed information on the demography and sizes of coral colonies, and can show indications of past impacts by the presence or not of large colonies. It includes sampling of recruitment and small corals in 1 m^2 quadrats, and larger corals in 25*1 m belt transects.

5) Coral threats – gives an indication of the current health of the coral community, and includes observations on coral bleaching, disease, and mortality, and presence of predators and threats such as crown of thorns stars.

6) Fish herbivores and other functional groups – fish exert primary control on the reef community, and on algae through herbivory, thus controlling competition between algae and corals. The numbers of fish in different functional groups, including herbivore functional groups, was measured in 50*5 m belt transects.

7) Resilience indicators – these are factors that affect the resistance of corals to bleaching and the resilience or recovery potential of the reef community. A broad range of indicators in different classes is measured, including of aspects in 1-6 above, but at less quantitative levels. The main classes of indicators are listed below:

Group	Factor	Explanation
Benthic Cover	Cover	Primary indicators of reef health, particularly of coral and algal dominance and competition.
Coral community	Current	Indicators of the current condition of the coral community, including recruitment, aspects of size class structure, condition, etc.
	Historic	Indicators of the historic condition of the coral community, including past impacts and recovery to date.
Ecological – reef community	Positive	Associates that are positive indicators of coral health – e.g. resident fish in branching corals, obligate feeders that don't harm corals.
	Negative	Assoiates that are negative indicators of coral health – e.g. boring organisms, encrusting sponges, etc.
	Herbivory	Health of the fish herbivore community
Physical	Substrate	Substrate health, critical for settlement and survival of young corals
	Cooling & flushing	Factors that cause mixing and cooling of water, which can reduce the high temperatures experienced by a reef
	Shading & screening	Factors that reduce light penetration in the water, thus reducing synergistic stress to corals from temperature and light.
	Acclimatization	Factors that cause high variability in environmental conditions, that promote acclimatization of corals to stress.
Connectivity	Larval source/sink	Size and spatial relationships of healthy coral communities and reefs from the local to regional scale.
	Transport	Transport of water between reefs
Anthropogenic	Water	Human impacts to water quality, that reduce the recovery ability of reefs and increase stress to corals
	Substrate	Human impacts to the reef substrate, that reduce the recovery ability of reefs and increase stress to corals
	Fishing	Degree of fishing and its impact on recovery ability of reefs.

3 Major findings

This section summarizes the main findings from the Detailed results (section 5), which can be read for greater understanding of the points mentioned here.

3.1 Overview

Coral reefs in the Nosy Hara Marine Park had an average coral cover of 34%, with highest levels at about 53%. At the main reef areas, corals were the dominant cover type, indicating healthy coral populations. The overall condition of reefs was consistent across the whole study area, with little effect of substrate type (karst island vs. reef platform), reef type (outer, fringing or banks) and depth. The degree of exposure to waves and rough conditions was the only factor that showed significant variation, with higher soft coral cover at reefs with high exposure and highest macroalgae cover on reefs with low exposure. This is typical for reefs, the high soft coral cover indicating high wave exposure, and high macroalgae closest to shore due to higher nutrient levels.

The distribution of coral genera did not show any strong patterns across the study area, though diversity was highest at sites with greater depth and stronger currents/waves. *Acropora* is the dominant coral genus in Nosy Hara, followed by *Porites*. These are the two dominant genera on most western Indian Ocean reefs, and the presence of *Acropora* indicates either a low impact of past bleaching, or rapid recovery back to a rapidly growing/developing community. The absence of very large coral colonies, with over 70% of colonies being in the range of 21-160 cm, indicates a past mortality event. The abundance and size of both *Acropora* and *Porites* suggests that significant mortality has occurred in the area, but recovery is very rapid. Visual observation at multiple sites, with evidence of eroded skeletons now covered by algae and other invertebrates, suggests that a large proportion of the coral community has died at some point in the recent past. Recruitment of corals is reasonable in Nosy Hara, predominantly opportunistic broadcast spawning genera such as *Acropora* and *Seriatopora*. These observations suggest that mortality has been severe in the past, and could be from one or a combination of:

- A mass coral bleaching event – though no report has been made of widespread mortality in the last decade (e.g. Maharavo xxx, Webster xxx), it is possible that some mortality from the 1998 El Niño escaped detection, and also from smaller less known or publicized warm years since then;
- Cyclones are frequent in the area, passing directly overhead crossing from the east to the west, or moving through the Mozambique channel. High levels of broken corals could be from frequent physical disturbance, particularly on exposed reefs.

Algal populations were not extensive, except for a high abundance of the filamentous green alga *Enteromorpha* on some reefs. These reefs were apparently exposed to freshwater seepage from rainfall, channeled to the reefs through the porous karst rock framework. Similarly, thick beds of the filamentous cyanobacterium *Lyngbya* were found on similar reefs, and on sand beds at the deeper edge of coral growth particulary on platforms closest to shore (influenced by high nutrients from runoff). While herbivorous fish populations were low, there was not an over-abundance of fleshy algae such as *Dictyota, Sargassum, Turbinaria* and others.

Fish populations were dominated by damselfish, which are planktivorous and herbivorous. This is indicative of two things: a) the high planktivore numbers illustrate the high degree of water column productivity, due to high nutrients and turbid conditions fertilized at least partially by terrestrial runoff, and b) the high numbers of these small benthic herbivores can be indicative of low levels of predation, due to fishing of predators that would otherwise control the damselfish numbers. After damselfish, the herbivorous parrotfish and surgeonfish were most abundant. Snappers (lutjanids) are predatory and were fourth in abundance. The next predatory families were at very low abundances: the emperors (lethrinids), wrasses (labrids) and triggerfish (balistids), which feed on a variety of invertebrates and small fish. The absence of large high-value fish was particularly notable, with only 8 large excavators recorded at one site, and 4 humphead wrasse noted outside of transects at Nosy Vaha. Trends in fish populations were clearly affected by fishing, with the most diverse and abundant populations farther out from shore, at greater distances from the fishing villages and landing sites particularly in the south/central part of the area around Ampisandava.

The resilience indicators confirm the observations from the quantitative methods, noted above, in particular of good coral and fish populations on the outer reefs, particularly at Nosy Vaha, which experiences the least influence from turbid water and fishing, and at the deeper sites around the karst islands (Lakandava, Adavadalovo), where more complex topography and strong currents combine with good overall community development (of fish as well as corals). Poorest reef condition was noted for more inshore reefs due to restricted depth for coral growth (shallow bottom and high turbidity) and high fishing pressure. The most poorly rated indicator was the health of the herbivorous fish communities, with fishing also scoring very poorly.

The resilience indicators also identify some key patterns among factors affecting coral bleaching. These are a) that turbid water, though a limit on reef development over time, protects corals from bleaching, hence the presence of some of the best coral communities on inshore sites, and b) that cooling/flushing factors did not appear to protect the deeper/high-current reefs from mortality, but recovery has been robust due to good conditions for coral recruitment and growth.

The main controlling factors of reefs in the area appear to be:

- high turbidity, caused by high levels of rainfall and river/surface runoff from land. The high turbidity is likely due to a mixture of both natural and anthropogenic influences that cannot be distinguished in this study. The effect of high turbidity is two-fold:

    a. reef depths were very shallow, as light levels decreased rapidly, and inshore coral growth stopped by 5 m depth, while offshore there were corals down to 20 m. In this sense, high turbidity is a limiting influence on corals, and is stronger inshore than offshore. However it is also the case that most substrate in the area is quite shallow, except for deeper slopes around the karst islands, the outer reef slope.

    b. Screening of sunlight by turbidity can protect corals from bleaching, and the low apparent levels of historic mortality, compared to other parts of East Africa, suggests protection of corals in the area by turbid waters. It was also apparent that dead coral surfaces, perhaps due to bleaching in the past 5-10 years were more apparent on offshore reefs where waters are clearer, and less apparent on inshore more turbid reefs.

- reef complexity combined with currents and water exchange – the steeper slopes at the edge of the platform and around high islands, combined with stronger currents around them and from wave energy, enables greater complexity and diversity of corals, though not necessarily higher cover/abundance.

The outer reef at Nosy Vaha stood out as the healthiest site, by its high coral cover on the tops of buttresses and good fish populations, including the only humphead wrasses (*Cheilinus undulatus*) seen in the entire survey. Other sites that rated highly did so due to a range of factors being favourable, not just one.

At the lower end of the scale, sites that showed poor health were characterized by two main types of conditions: poor habitat, being meainly flat expanses of coral on banks/platforms with high sand cover (Agnahibe, Andrivapaul and Rameza) and dominance by the filamentous algae *Enteromorpha* and/or the cyanobacteria *Lyngbya* (Iavolova, Rameza).

An important issue to consider for the area is the possibility of a mass mortality of corals in the past. Observations suggests that there has been some mortality, with dead coral skeletons present, though relatively highly eroded and overgrown with a variety of algal and invertebrate types.

3.2 Major threats

3.2.1 Coral bleaching

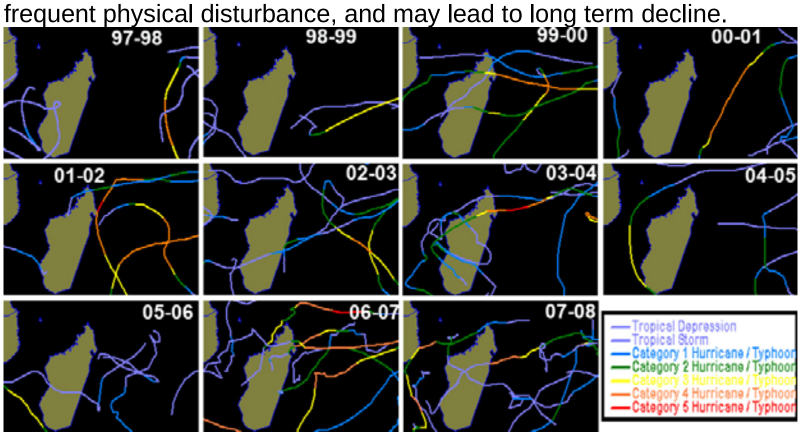
To date, no major mortality related to coral bleaching has been reported for the northwest region (Maharavo pers. comm.., Webster and McMahon 2005), though it is possible that it did occur at some locations, whether during the 1998 region-wide bleaching event or a smaller more recent one. Other possibilities are the influence of cyclones, of which there have been 2 major ones in the last decade.

Based on experience I would expect that a combination of physical damage from cyclones, moderate bleaching-related mortality and low recovery due to highly turbid conditions may all have occurred.

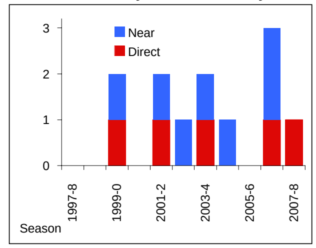
3.2.2 Cyclones

Cyclone activity is very high around Madagascar (figure below), with cyclones forming both in the open ocean and in the Mozambique channel, approaching the island from both sides, and some passing directly over the island without dissipating. The northern tip, focusing on the NW region around Nosy Hara, experiences multiple direct hits from cyclones, with direct hits in 5 of the last 11 years (including the last two seasons) and one or more cyclones passing overhead or nearby in 7 of the last 11 years.

The degree of coral breakage on the reefs is consistent with frequent physical disturbance from cyclones, and reefs in the area will have evolved with this as a consistent evolutionary pressure. However addition of bleaching events, even if minor, and heavy fishing, may reduce the ability of the reefs to recover from the frequent physical disturbance, and may lead to long term decline.



Composite figure of cyclone tracks around Madagascar, from 1998-2008. Cyclone intensity increases from blue-green-yellow-red. Source: http://australiasevere weather.com/cyclones/history.htm



3.2.3 Predators

Pest infestations, such as crown of thorns or *Drupella* are possible, as the high-nutrient conditions favour the survival of their larvae. However there are no reports of past infestations from the area. Crown of thorns were very infrequent, but the snail Drupella was frequently observed in branching corals, particularly Acropora, and was one of the main factors associated with recent mortality on corals.

3.2.4 Fishing

The impacts of fishing were clearly recorded by the surveys:

- Near-complete absence of all large fish, include piscivores (sharks, groupers, snappers, emperors), invertebrate eaters (napoleon/humphead wrasse) and herbivores (buffalo parrotfish and other parrotfish).
- Dominance by planktivores and small resident herbivores, particularly of damselfish, which are low in the food chains.
- The poorest fish communities being found close to land and villages, and best at the the most remote and difficult to access locations.

Fishing in the area is done to supply the markets in Diego (Antsiranana) about 2 hours drive away, when the roads are passable. Little fish is available in the local markets. Fishermen use a range of vessels from dugout canoes powered by sails, to larger wooden boats with sails and/or engines. They frequently spend several days out fishing, sometimes camping on islands. Line- and net-fishing are the most common methods. No statistics on fishing were available to document current catch levels, however the fish stocks are clearly depleted.

Fish populations can recover rapidly when protected from extraction, if conditions are right. The imposition of some fishing reserves in the area, allowing adult populations to increase in number and grow to larger sizes is essential to start the process of improving the health of the reefs, and catch levels in the fishery. Controls on gear type, seasons and areas for fishing and numbers of fishermen should also be considered for fished areas, to rehabilitate fish stocks to better levels.

3.2.5 Causes and effects of Lyngbya *and* Enteromorpha *dominance*

Enteromorpha is an ephemeral, stringy macroalga that grows in mats on the substrate. *Lyngbya* is a filamentous cyanobacterium that grows in long strands up to 5 cm and more, that mat together and can carpet large areas of substrate. Photos. Both are detrimental to coral recolonization and regrowth as they monopolize the substrate competing directly with corals, and their likely chemical effects that suppress corals. *Lyngbya* can cause severe oxygen depletion as well as releasing toxic chemicals (ref), both of which can cause coral mortality and severely suppress survival and growth of young corals. Macroalgae such as

Enteromorpha may leach large amounts of carbon into the water, that promotes growth in the microbial community which in turn suppresses coral growth (Smith et al. 2006).

The site Iavolova, at the NE tip of Nosy Hara, was the only site with a small lagoon/reef crest, and this likely channeled freshwater from rainfall onto the reef surface. This was previously dominated by branching/columnar corals, including *Acropora* and *Galaxea astreata*. But following death of these corals, and overgrowth by algae – the dominance by *Enteromorpha* may be preventing recovery of young corals and a phase shift back to a coral-dominated reef. Similarly, thick beds of *Lyngbya* from about 3 m and deeper at Rameza, which is close to the shoreline, may be suppressing growth and/or recovery of the depauperate coral fauna there, compared to that at Bejabora which is structurally similar, but without such a heavy infestation of *Lyngbya*.

3.3 Other important factors

3.3.1 Terrestrial/freshwater influence

Sedimentation and freshwater influence in Nosy Hara is exceedingly high, and in my experience among the highest on any sites I have visited globally. As with the influence of cyclones, this has been a consistent influence over a long time, and the reefs have evolved under these conditions. Visibility levels at sites on the platform was very low, with more than half of the sites between 7-12 m. Sites with > 15 m visibility were on the outer edge of the platform (N. Vaha, Passe N. Hara), and Bejabora and Rameza recorded on the same day, which are close the southern edge of the platform. The high terrestrial influence was also clear from very high levels of fine silt in the sediments, following a similar pattern.

Distinguishing an additional human component to terrestrial influence was in general not possible during the surveys, due to the high levels of influence throughout. Only at the fringing reef in front of Ampisandava village was it possible to infer increased anthropogenic influence, but this still apparently low compared to background levels. It may be that land clearing and deforestation has greatly increased terrestrial influence to the area, but to determine this more accurately will need some historical studies using coral coring and any past data on rivers, groundwater and vegetation cover.

3.3.2 Connectivity and large scale patterns

The connectivity indicators used in this study are preliminary ones and did not vary greatly among reefs. In general terms however, the well developed reefs in Nosy Hara are on the order of 100s of meter to 1-2 km in extent, around the fringes of islands or on the tops of banks on the main platform. Only the reefs fringing the platform are continuous, likely extending around the whole perimeter of the platform. As such they are rated as being 'moderately' connected to one another, as currents on the platform likely cause high levels of mixing, and it is clear that the steeper slopes around the karst islands allow for greater coral recruitment and growth by supplying a larger larval source pool.

At a larger scale, given the importance of island slopes for good coral growth, reef development appears to be concentrated around the groups of islands along the NW coast (Nosy Hara, N. Mitsio, N. Be, heading southwards), and this has provided the focus for surveys in the past (McKenna et al. xxx). On the east coast, the steep continental slope and fringing reefs from the Mer Emeraude, southward past Ambodivahibe to xxx and Masoala are exposed to much clearer water conditions and thus deeper reef communities. Connectivity among these nodes for reef development will be an important factor in coral recruitment and recovery from major impacts. However it is currently not known what the dominant current flows are in this area, the degree of connectivity by longshore currents along the NW coast, nor of currents from the NE coast supplying larvae to the Nosy Hara area.

3.4 Reef resilience in Nosy Hara

Reefs in the Nosy Hara area show clear effects from threats, which definitely includes terrestrial influence, cyclones and fishing, and may include mass coral bleaching and pest outbreaks. The first two in the list – terrestrial influence and cyclones are present at high levels naturally and over a long historical time. The others – fishing, bleaching and pests – likely show a strong human influence, increasing in the last few decades as population pressure has increased locally (and globally for bleaching).

Coral reefs in the area show a broad spread of resilience to all these threats:

- At the high end, reefs show high resilience with high abundance of corals, high recruitment rates and numbers of medium-sized corals, and high diversity, as well as good popoulations of other benthic invertebrates, moderate fish populations and low levels of macroalgae and microbial growth (*Lyngbya*). These reefs are on the outer platform or on steeper and deeper reef slopes, exposed to currents and water motion.
- In the middle, reefs show a reasonably high resilience – their current status is not as good as the high-end reefs, but over time (assuming no major impact occurs such as a mass bleaching event, major cyclone or increased fishing or pollution), they may recover to similar levels as the high end reefs.
- At the low end, some reefs may be in the process of switching to an alga/microbial dominated state, with the corals unable to recolonize and regrow.

In terms of the factors that are influencing the resilience of reefs in Nosy Hara, the most positive factors are the good current condition of reefs, absence of negative associates (i.e. pests and other taxa indicative of poor condition of corals), good connectivity among the reefs within N. Hara and screening by the turbid waters (protection from bleaching)

Condition	Sites	Comments	Recommendations
Good	Nosy Vaha, Passe Nosy Hao, Lakandava, Andavakalovo	Good condition, with strong currents/ waves and steeper slopes, outer edges of study area. Generally inaccessible for fishing, so have some natural protection.	Full protection, to maintain biodiversity and as source reefs for fishing and other sites
Medium	Agnahibe, Nosy Mbamaho, Nosy Hara Est, Ankarabo, Nosy Hao, Rejabora, Antsikoa	Reasonable condition with quite variable characteristics, generally accessible for fishing.	Moderate protection, minimizing damage and including fishery regulations.
Low	Iavoloha, Andrivan'i Paul, Rameza, Ampasindava, Sandoz	Poor condition for variety of reasons.	Moderate protection combined with rehabilitation provisions where possible.

4 Detailed Methodology

4.1 Site selection

Survey sites were dispersed across the study area, though there was insufficient time to be able to access the far western edges of the reef system (fig. 2.1). Within the area surveyed, sites were selected to cover the full range of island, bank/platform and fringing reefs, and type of island. Surveys were conducted at each site at the main zone of reef growth to record maximum levels of coral development.

4.2 Survey methods

4.2.1 Benthic cover

Benthic cover was recorded in Point Intercept Transects, using the same 25 m lines as the coral size class surveys, and recording the benthic category at each 25 cm point, for a total of 100 points per line. Categories used were the following, with coral and algae further identified to the genus level.

Table 4.2.1 Benthic categories for identification.

Invertebrates	Algae	Other	Substrate
Coral	Algae-Fle	Microbial	Rock
Recent Dead Coral	Algal Assemblage	Seagrass	Rubble
Scoral	Coralline Algae	Unidentified	Sand
Inverts	Halimeda		
Sponge			

4.2.2 Coral community structure

Proportional abundance of all genera at a site was estimated on a five-point scale (Table 2.3), towards the end of the dive.

Table 4.2.2. Dominance classes for coral abundance

Code	Class	Explanation	Numerical (approximate)
5	Dominant	Dominate the coral community and/ or structure of the site	>30% of coral cover
4	Abundant	Visually abundant and seen in large numbers. Co-dominate the site	10-30% coral population by number or area and/or large number of colonies (>100) seen/inferred in the immediate area of the site (2500 m^2)
3	Common	Easily found/seen on site, but not dominant in any way	>1% of coral population by number or area and/or >20 colonies seen/inferred in the immediate area of the site (2500 m^2)
2	Uncommon /Occasional	Not easily found, but several individuals seen or can be found by dedicated searching.	<10 colonies seen/inferred in the immediate area of the site (2500 m^2)
1	Rare	Found by chance occurrence or only 1 or 2 found by dedicated searching.	<2 colonies seen/inferred in the immediate area of the site (2500 m^2)

4.2.3 Coral population structure

Coral population structure was quantified using fixed size classes of corals, from the smallest recruits to the largest adults at a site. A belt transect 25 m long and 1 m wide was used to record the number of colonies larger than 10 cm. For corals smaller than 10 cm, subsampling was done using six 1 m^2 quadrats at the 0, 5, 10, 15, 20, and 25 marks. Only colonies whose center lies within the sampled units were counted – large colonies with their center outside the transect were ignored. A 1 m stick was used to help guide estimation of transect width, marke the 1 m^2 quadrats and marked at relevant points helped guide size estimation of coral heads (Table 2.4). Genera that covered a range of bleaching susceptibility from high to low (Table 2.4), and that are generally common on East African reefs were selected.

Table 4.2.3. Left - size classes of corals for size class measurements. Right - selected genera in classes of bleaching susceptible, intermediate and resistant.

Size classes (cm)	Sampling method
(1) 0-5 (2) 6-10	Recorded in six 1m^2 quadrats per transect
(3) 11-20 (4) 21-40 (5) 41-80 (6) 81-160 (7) 161-320 (8) > 320	Recorded in 25*1 m belt transects

Susceptible	Intermediate	Resistant
Acropora *Montipora* *Pocillopora* *Seriatopora* *Stylophora*	*Porites* (branching) *Galaxea* *Echinopora* *Platygyra* *Favia* *Favites* *Lobophyllia* *Fungia* *Hydnophora*	*Porites* (non-branching) *Pavona*

Replication of transects depended on logistics at a site and the complexity of the coral community, varying between 2 and 4.

4.2.4 Fish community structure

Fish surveys focused on herbivore functional groups following Green et al (2009) and see IUCN-CCCR (2008), with abundance classes estimated for other fish. This is because herbivory has been found to be a key process influencing the recovery of corals following mass mortality and other major disturbances, and is a major factor affecting the resilience of a reef community. Herbivory is important as it limits competition and obstruction by algae. Six functional groups of herbivorous fishes were used: large excavators, small excavators, scrapers, grazers, browsers and grazers/detritivores (Table 2.5), each playing a unique ecological role in coral reef resilience. Fish families that make up these functional groups include: Acanthuridae (surgeonfish), Ephippidae (batfish), Kyphosidae (chubs), Pomacanthidae (angelfish), Scaridae (parrotfish) and Siganidae (rabbitfish).

Table 4.2.4 functional groups of herbivorous fishes recorded in this survey. For full details on the fish included/excluded, consult the authors.

Functional group	Taxonomic groups	Function and notes
Large excavators Humpheaded parrotfish – large individuals (>35	*Bolbometopon*, *Chlorurus microrhinos*, *C. frontalis* and *Cetoscarus bicolour*. All	Bioerosion. They take fewer, larger, deeper bites, remove more of the substratum with each bite, and play a key role in bioerosion.

cm)	humpheads > 35 cm	
Small excavators Humpheaded parrotfish – small individuals (<35 cm)	As above and other *Chlorurus* species (*C. bleekeri* and *C. sordidus*; All humpheads <35 cm)	Bioerosion. Take more, smaller, shallower bites, and remove less of the substratum with each bite.
Scrapers Other parrotfish	*Scarus* and *Hipposcarus*	Bioerosion, colonization surfaces. Remove algae, sediment and other material by closely cropping or scraping the substrate.
Grazers Small rabbits, many surgeons	Small rabbitfish (<20cm), all *Centropyge*, all *Zebrasoma,* most *Acanthurus* (excl. planktivores/ringtails).	Algal control. Remove epilithic algal turf from the reef substratum, but do not scrape the surface, prevent coral overgrowth and shading by macroalgae.
Browsers Unicorns, chub, batfish, large rabbits, Calotomus	Chub, batfish, large siganids (> 20cm), and parrotfish of genus *Calotomus, Leptoscarus*. Unicornfish - all sizes of *N. brachycentron, N. elegans, N. lituratus, N. tonganus* and *N. unicornis*, Unicornfish - <20cm of *N. annulatus, N. brevirostris, N. maculatus, N. mcdadei*, and *N. vlamingii*	Algal control. Feed on macroalgal fronds, reduce coral overgrowth and shading by macroalgae.
Grazers/detritivores Ringtail surgeons	Ringtail surgeonfish - *Acanthurus blochii, dussumieri , leucocheilus, maculiceps, nigricauda, olivaceus, pyroferus, A tristis* and *A xanthopterus*.	Algal/sediment control. feed on a combination of algal turf, sediment and some animal material similar role to grazers, remove macroalgae before it can become established.

Sampling was done using three belt transects of 50*5 m belt transects. The transects were separated by at least 5 to 10m from the end of the previous transect. All fish in the above categories were counted

The abundance of non-herbivore fish families normally recorded in UVC surveys were estimated in the transects, in abundance classes (Talbe 2.6). Table 5.2 shows an example that was decided for Mafia Island marine Park, Tanzania, but this can be altered to suit local conditions and datasets to which it will be compared.

Table 4.2.5 Other fish families and broad abundance classes to be included in survey.

Abundance classes	Fish families
1: 1-2	
2: 2-5	Balistidae, Caesionidae,
3: 6-10	Carangidae, Haemulidae,
4: 11-25	Lethrinidae, Lutjanidae,
5: 26-50	Mullidae, Serranidae,
6: 50-100	Sharks
7: 100+	

4.2.5 Resilience indicators

Resilience indicators were measured or estimated during each sampling dive, generally towards the second half of the dive to allow time for familiarization with the site. The indicators, and their overall grouping, is shown in Table 2.7.

Table 4.2.5 Indicators recorded.

Group	**Factor**	**Variable**	**Group**	**Factor**	**Variable**
1-Cover	Coral	Coral cover	3-Coral community	Size/age	Largest corals (3)
	Algae	Fleshy Algae		Condition	Coral bleaching
		CCA			Mortality-new
	Substrate	Rubble			Mortality-old
2-Physical	Substrate	Topogr. Complex. - micro			Recovery-old
		Topogr. Compl. - macro			Coral disease
		Sediment texture	4-Coral associates		Obligate feeders
		Sediment layer			Branching residents

Cooling & flushing	water movement			Competitors
	deep water (30-50m)			Bioeroders (urchins, nonfish)
	depth of reef base			Bioeroders (internal, spo)
	wave energy/ exposure			Corallivores (negative)
Temperature	Temperature (^{o}C)	5-Anthropo-genic	Water	Nutrient input
Shading & screening	depth (m)			Pollution (chemical)
	aspect		Substrate	Pollution (solid)
	slope (degrees)			Turbidity/Sedimentation
	phys. shading			Physical damage
	canopy corals		Fishing	Destructive fishing
	Visibility (m)/ turbidity			Fishing pressure
Acclimatization	Exposed low tide			
	Ponding/pooling			

A semi-quantiative 5-point scale was used for estimation of most of the indicators, except for those (such as temperature, visibility) that could easily be measured or estimated quantitatively. Classification of the 5-point scale was done using local and regional knowledge (Annex xxx). In the 5-point scale general principles were to assign them as follows: minimum (1), maximum (5) and moderate (3) level for each indicator for the region of application, and intermediate levels of low (2) and high (4).

For analysis, two operations had to be applied to the raw data collected in situ:

- for variables measured quantitatively, transformations were applied to assign them to a 5 point scale for consistency in multivariate analysis of the data. In general terms, the distribution of values could be even across sites (resulting in even numbers of sites assigned to levels 1 to 5), humped around the middle (large number of sites at moderate level 3), or strongly skewed to one side (most sits high or low for a variable).
- In situ estimation of 5-point scales were done based on the parameter itself, ie. from low to high. For consistent multivariate analysis, some indicators had to be reversed so that all values 'good' for corals scored 5, and all values bad for corals scored 1. For example, algal levels in the field might have been scored '5' for high levels, but in analysis, this was recoded as '1', being bad for corals.

Variables like temperature and visibility were estimated during the dive, however are best quantified using continuous data recorders. Care was therefore taken during analysis to consider the measured differences against background patterns, and at some sites, temperature loggers were put out to provide more comprehensive data for future consideration.

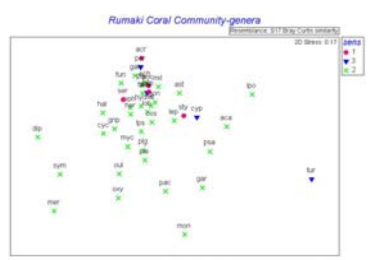
4.3 Analysis

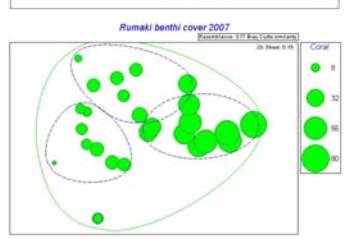
Analysis proceeded through the following broad steps, for each dataset collected:

1) Calculation and plotting of basic distributions for each variable, across all study sites. These are done first to illustrate the basic patterns shown by individual variables and indicators

2) Multi-dimensional Scaling (MDS) analysis helps to reveal patterns in datasets that include multiple variables, and particularly usefulness where parametric tests (e.g. ANOVA) are not appropriate.

   By projecting all variables onto x and y axes, an MDS plot helps illustrate which points are close to one another and which are distant. Thus the physical distance of points on the plot (upper right) illustrates their relative distance in the dataset. By superimposing a variable in the dataset on the points, where the size of a circle represents the magnitude of the variable, 'bubbleplots' (below right) can help to illustrate which variables are most important in determining the relatedness among points on the plot. The circles around clusters of points illustrate significant groupings of sites, and help interpretation of the results

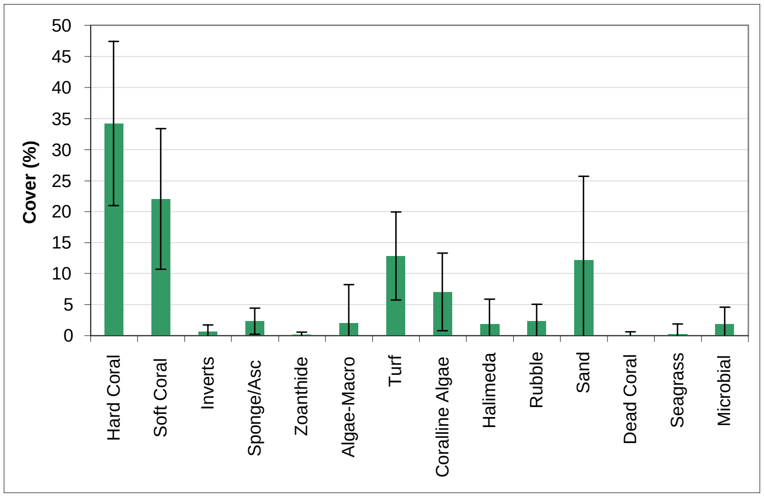




5 Detailed Results

Due to the complex datasets in this study, results and discussion will be presented together in numbered sections for each dataset, with more synthetic discussion and findings presented in section 3.

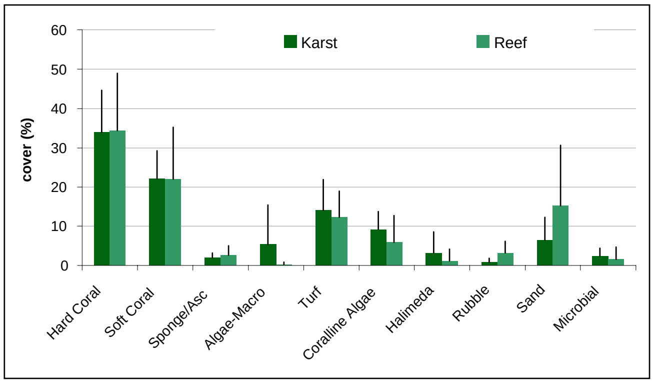
5.1 Benthic cover



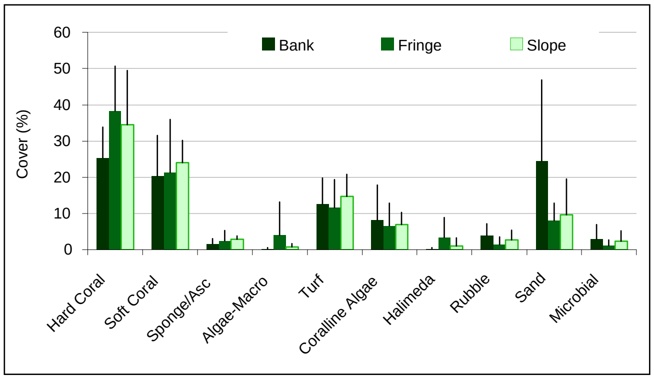
5.1.1 – Benthic cover
Benthic cover, all sites in 2008 (mean and standard deviation).

Hard corals were the most abundant cover on Nosy Hara coral reefs at 34%, followed by soft corals (22%), algal turf (12%) and sand (12%). Macro (fleshy) algae were a very small component of the overall community, at 2%.

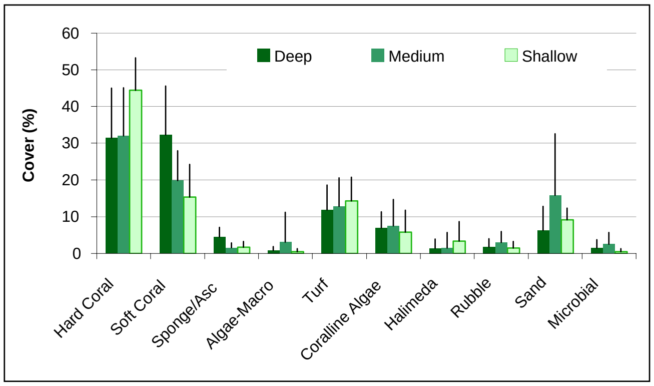
The next section describes the small differences in reef community structure by substrate, reef type, depth and exposure. Apart from exposure, none of the differences were statistically significant.



5.1.2 – Rock substrate
Benthic cover was very similar between sites on karst slopes (the main islands/tsingy) and reef/carbonate platforms (the low islands and extensive banks). The only difference was in a higher cover of sand on the reef/carbonate substrate reefs.

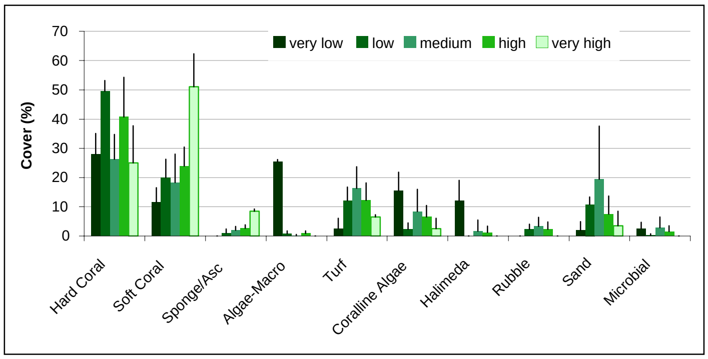


5.1.3 – Reef type
Sites were classified into reef slopes, fringing reefs and bank reefs. Fringing and slope reefs had similar high hard coral cover while banks had higher sand cover, due to being flat and they tend to be closer to the shoreline and sediment inputs from land. Other cover types, such as soft corals were the same, but the composition shifted from leathery soft corals on fringing/slope reefs (e.g. *Sinularia*) to smaller colony forms (e.g. *Xenia*) on banks – also showing the influence of sediment from land.



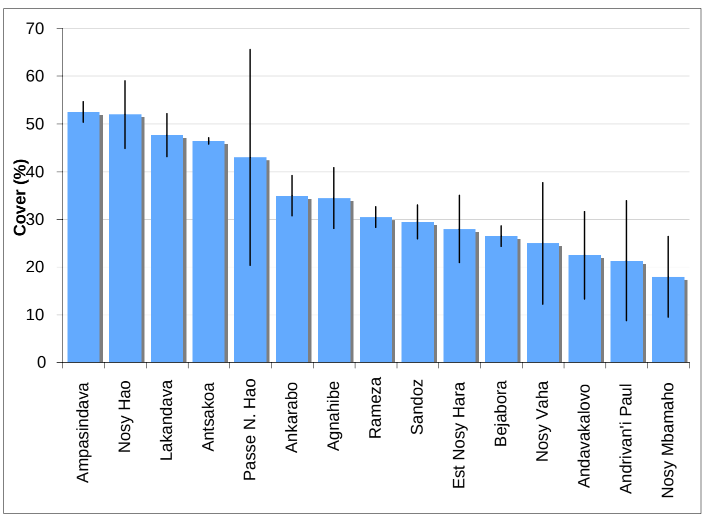
5.1.4 – Reef depth

Sites were sampled at 1-2 m (shallow), 4-6 m (medium) and 8-10 m (deep). Hard coral had the highest cover on the shallow reefs, and soft coral showed the opposite. Sand had slightly higher cover at medium depths.



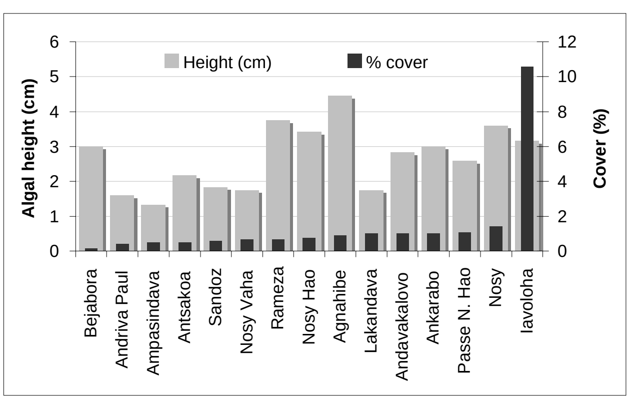
5.1.5 – Reef exposure

Sites were classified from very low exposure (fully sheltered, e.g. east side of Nosy Hara) to very high (e.g. outer platform edge at Nosy Vaha). Hard corals showed no pattern of variation, but soft coral and sponge/ascidian cover increased with exposure. Turf algae and sand were highest at intermediate exposure. Macro algal cover was high at the lowest wave exposure. ANOSIM 1.5 % – significant.



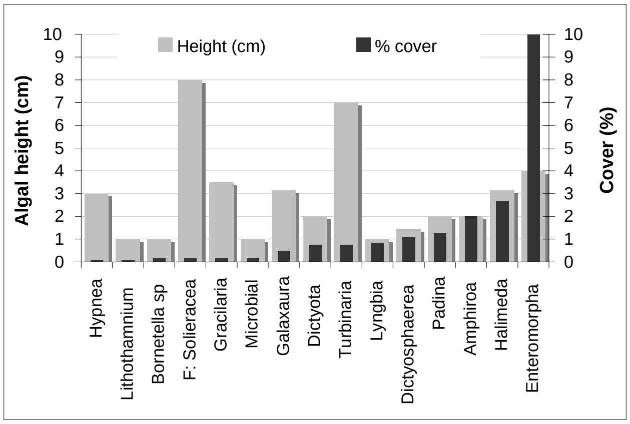
5.1.6 – Hard coral cover

Coral cover varied from a maximum of 52.5% to 18%, with high variation across all the four grouping variables above. Within sites, coral cover was also variable.



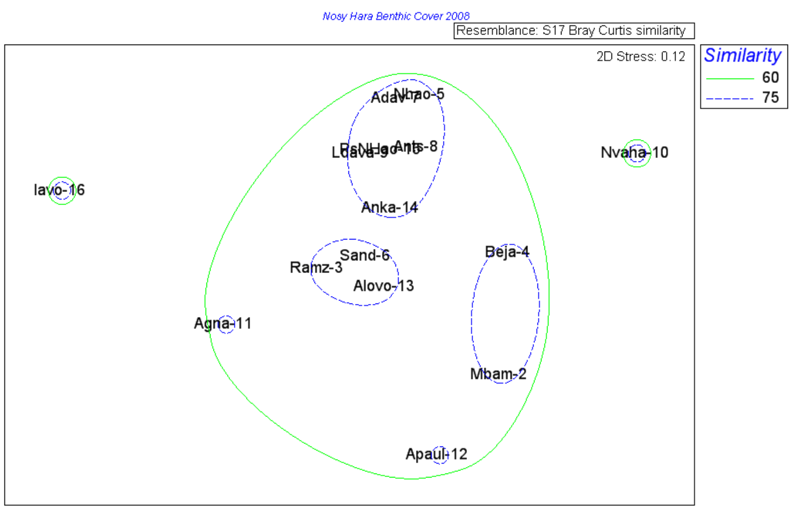
5.1.7 – Fleshy algae

Fleshy algal cover varied from <1 to 10% across sites. Algal fronds were small, between 1-4 cm in height, indicating high levels of herbivory and control of the algal population. The dominant fleshy alga was the filamentous green alga *Enteromorpha* – this would form extensive mats and tables of filaments attached between dead coral branches, on flat surfaces and on rubble. The bacterium *Lyngbya* was undersampled during these surveys, as it is not a fleshy alga, but would form similar mats of filaments as *Enteromorpha*. Together, these two genera were the most distinctive fleshy algae/bacteria complex and ubiquitous across sites. Typical fleshy algae indicative of low herbivory, such as *Padina, Turbinaria, Sargassum* and others were



at low abundances.

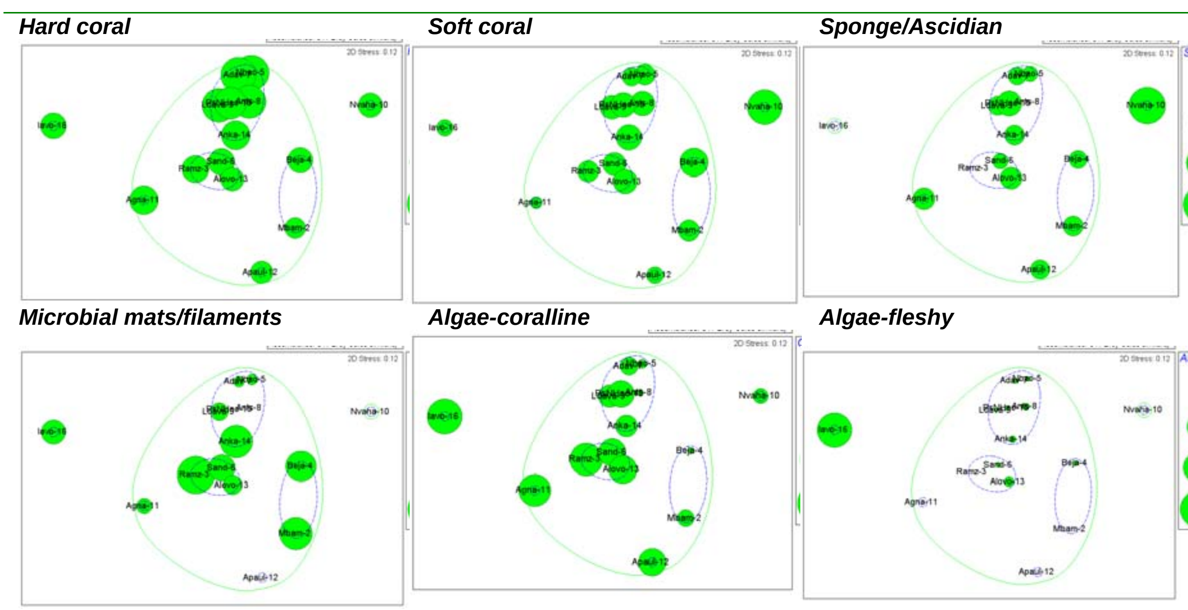
Seasonal variation in algal populations must be considered – these surveys were done at the beginning of the warm season when algal abundance is minimal, thus in March much higher algal abundance is expected. However since it decreases seasonally, this is indicative of low algal influence on the reefs.



5.1.8

MDS plot of benthic cover results. At 60% similarity three clusters on main group of sites is shown with two outliers: Iavolo at the NW tip of Nosy Hara (due to high microbial/fleshy algae cover) and Nosy Vaha, the outer platform edge site due to high combined soft coral and sponge/ascidian cover.

Within the main group, 3 subgroups and two outliers are shown, due to variation in hard corals, coralline algae, turf algae and microbial mats (below)



5.1.10 Other observations include the following:

- Coral cover is well distributed throughout the area, with no single reef type being consistently higher than others.

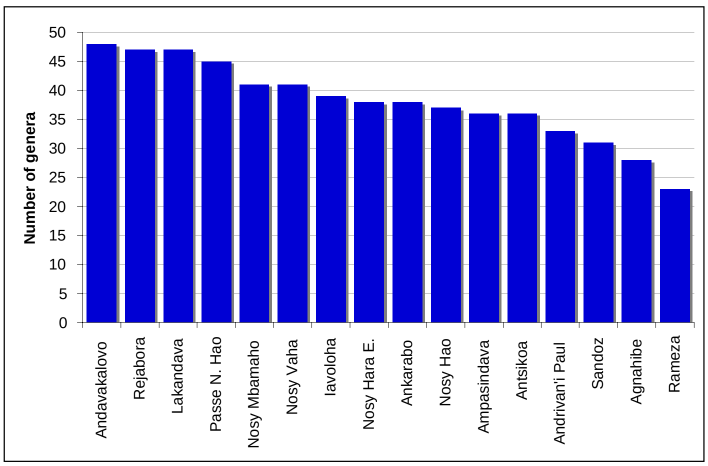
- The influence of terrestrial freshwater and nutrients is clear in the abundance of macroalgae and microbial mats, particularly in the inner parts of the marine park. Nevertheless, many of these sites have high coral cover, indicating this is a natural condition for the sites and doesn't necessarily indicate high degradation. However some sites (Rameza, Nosy Hara Est) had high cover of *Lyngbya*, a toxic filamentous bacterium, and had visibly poorer coral communities. It may be that under the most severe conditions, microbial activity may undermine coral growth and health.

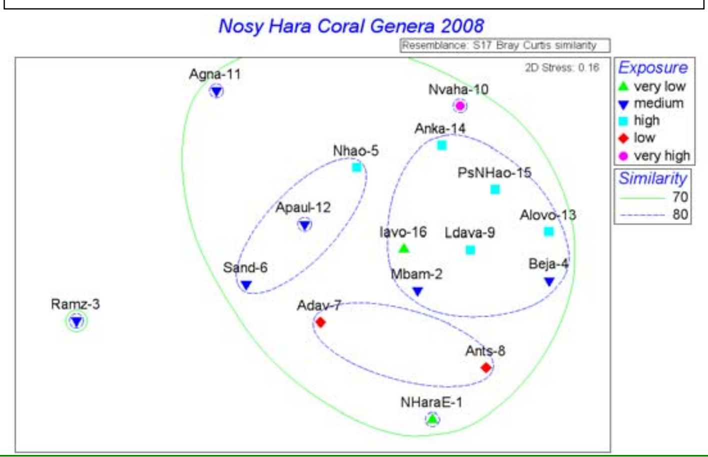
- The outer exposed site at Nosy Vaha, and the sites at Nosy Hao had the cleanest water conditions, and N. Vaha had the highest cover of ascidians and soft corals characteristic of clear-water outer reefs.

- The deeper slope sites on the small islands at Nosy Hara, Lakandava and Andavakalovo had the most complex benthic/coral communities, with evidence of high flushing due to the steep slopes and currents that flow across the broad banks to the north. Though coral cover was not significantly higher at these sites, diversity and complexity were higher.

- Dead corals were apparent at all sites, likely due to mortality some 4-10 years previously. It was not possible to determine if these might have been from bleaching (the major event in 1998, or smaller events since then), or to cyclones (see Section 3).

5.2 Coral community structure





5.2.1 – coral community, sites

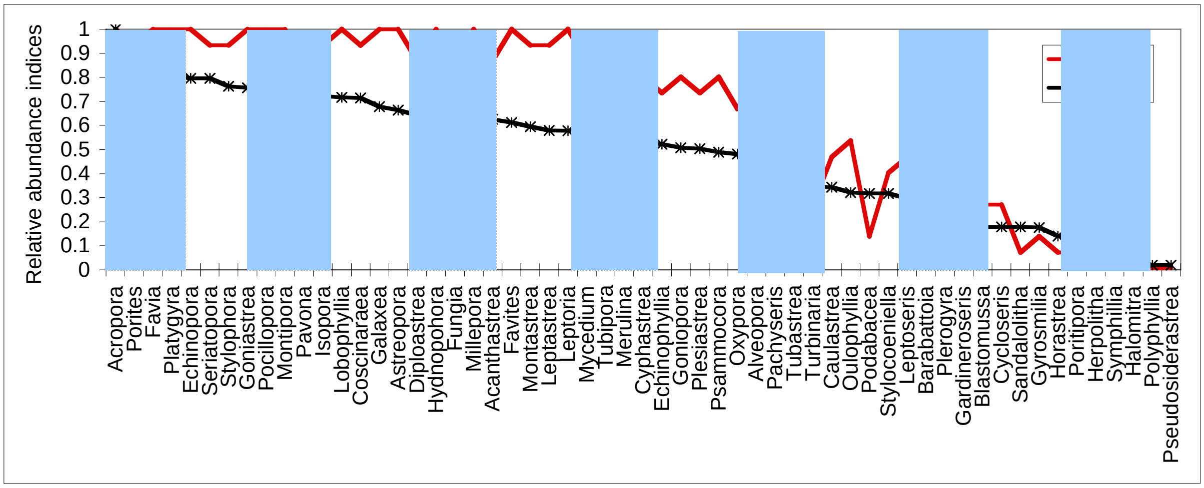
The total number of coral genera was 57, with maxima of 45-44 at Andavakalovo, Rejabora and Lakandava, and minimum of 23 at Rameza.

Coral genera did not distribute regularly by any of the reef classifications, though the three sites with highest coral abundance at high exposure to waves and currents, suggesting water movement is an important factor promoting coral diversity and reef health in the area. The most highly exposed site, Nosy Vaha had moderately high coral cover, but there was evidence of damage by waves, and potentially of past mortality as there were extensive areas of bare rock and high cover of soft corals.

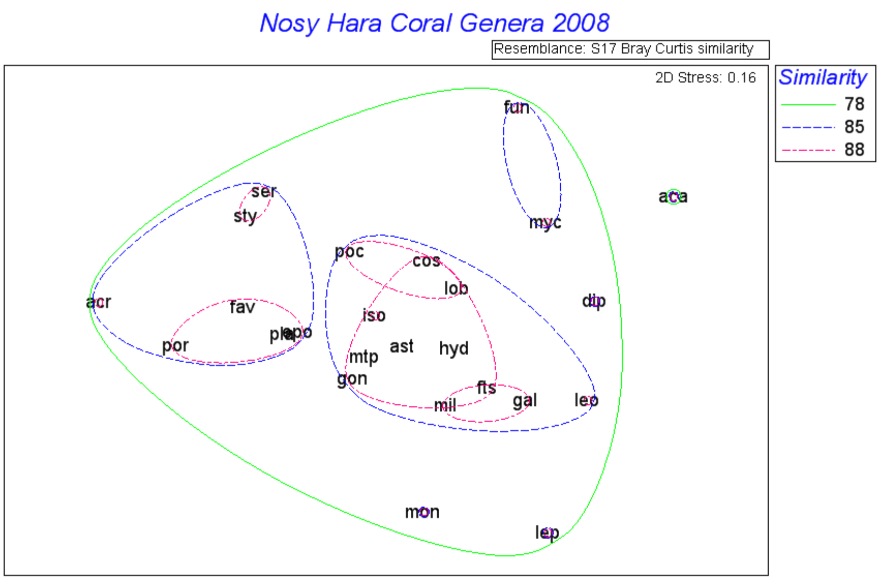
Rameza stood out as a depauperate site, dominated by extensive *Lyngbya* on the sand slightly deeper than the fringing coral community, and *Enteromorpha*.

Agnahibe was a fringe of coral at 1-2m depth around the banks north of Nosy Hara, with high dominance and cover by *Acropora* but low diversity.

5.2.1 – coral community, genera



Coral genera by rank abundance. Two different abundance statistics are shown, scaled from 1 (highest) to zero (lowest). The number of sites shows genera present at all sites (p=1) to those present in only one site (p>0), in red/no symbols. The black line with crosses combines information on relative abundance of each genus at each site. 57 genera were recorded, with *Acropora* being clearly dominant, followed by *Porites*. The evenly descending RA curve indicates a very homogeneous coral community across sites, and over half of all genera were present at > 70% of sites. Three genera were identified at only one site each – *Halomitra, Polyphyllia* (both fungiids, or mushroom corals) and *Pseudosiderastrea*.

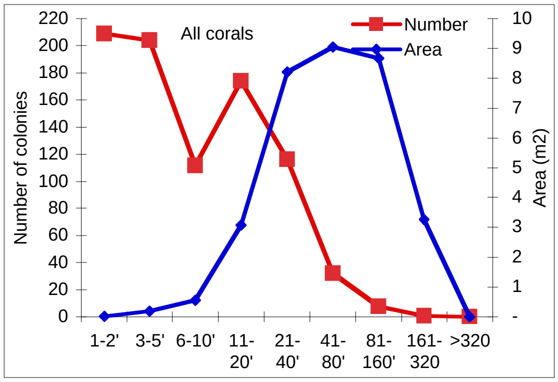


5.2.3

The consistency in the coral population is also shown in this MDS plot of the most common genera. *Acropora* stands out as the most abundant, the genera *Porites, Favia, Platygyra* and *Echinopora* clustered closely, and *Seriatopora* and *Stylophora* were very similar in distribution and abundance (both are branching, susceptible to bleaching/disturbance and weedy),.

5.3 Coral population structure

Size class data was collected for a restricted set of coral genera, based on them being generally abundant, and fall on a range from low to high susceptibility to bleaching. The genera sampled are:
High susceptibility: *Acropora, Montipora, Pocillopora, Seriatopora* and *Stylophora*
Intermediate: *Acanthastrea, Coscinaraea, Echinopora, Favia, Favites, Fungia, Galaxea, Goniopora, Hydnophora, Lobophyllia, Platygyra, Porites* (branching),
Low susceptibility: *Pavona, Porites* (massive),.

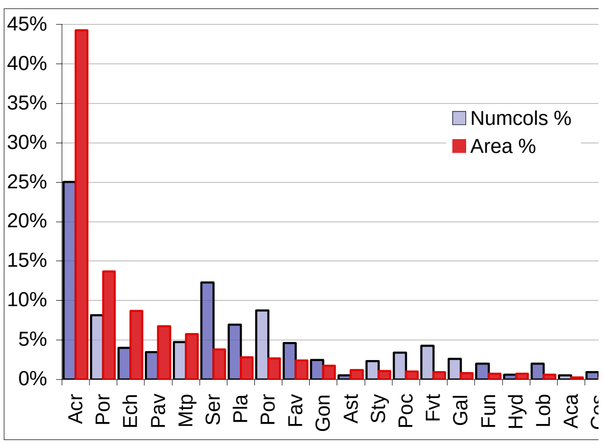


5.3.1 Overall sizes

The distribution of size classes is shown by number of colonies, and by area of colonies for all size classes. On average, there were 855.3 colonies in an area of 100m^2, corresponding to 33.1 m^2 of coral colony surface.

The dominant size classes by area, were 21-40, 41-80 and 81-160 cm, all mid-sized colonies. The low contribution of large colonies > 1.6 m indicates past mortality, which may be from regular disturbance, such as cyclones, or possibly bleaching events in the last decade.

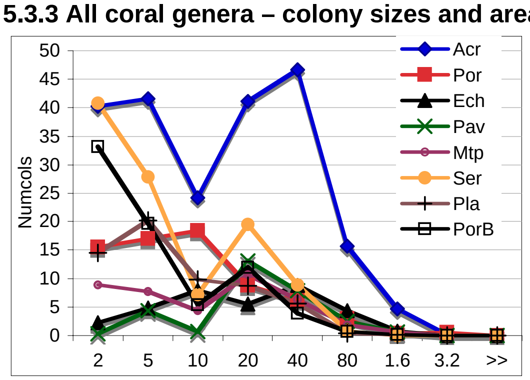
The drop in the number of colonies for 6-10 cm corals is perhaps indicative of low coral reproduction and recruitment for this cohort, which may represent corals of 3-10 years age, depending on their growth rates (i.e. one or more major stress or mortality events between 1998 and 2005).

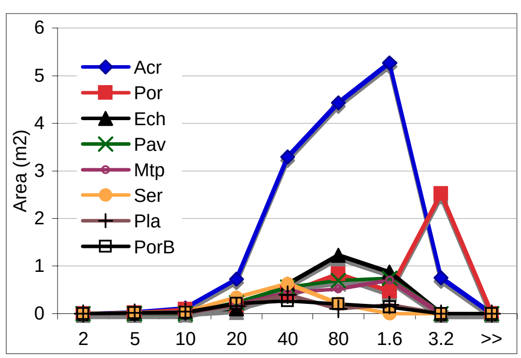


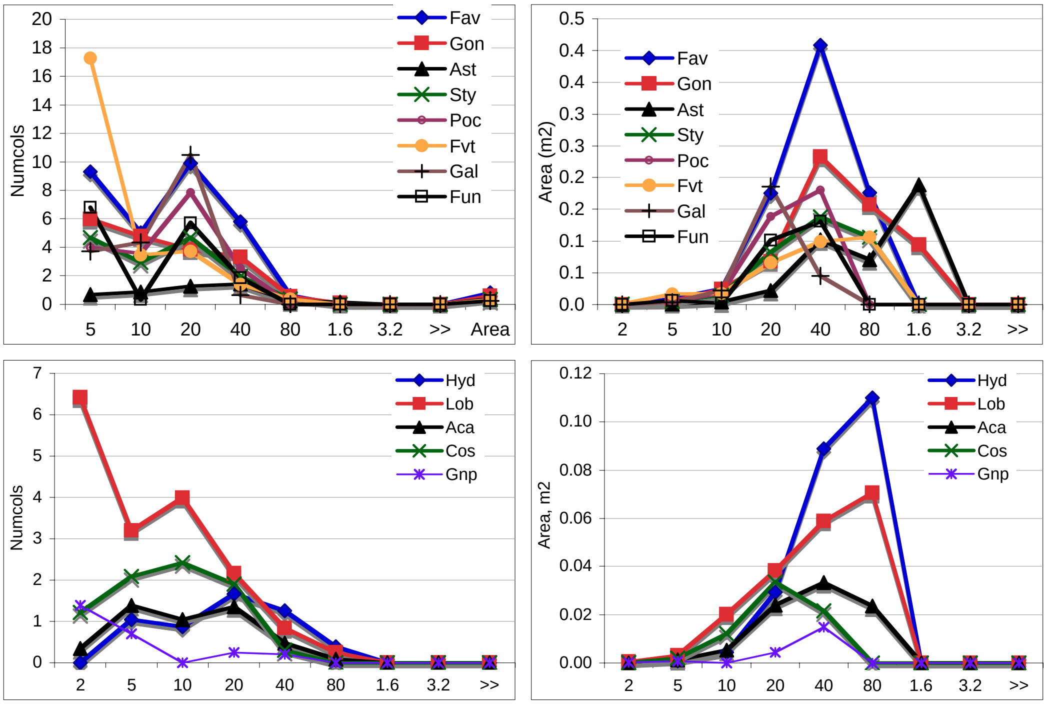
5.3.2

Acropora strongly dominated the coral community, accounting for 44% of coral area, and 25% of all colonies. Other important genera by area were *Porites* (14%), *Echinopora* (9%) and *Pavona* (7%). *Seriatopora* (12%) and branching *Porites* (9%) were important by number of colonies.

5.3.3 All coral genera – colony sizes and area distributions

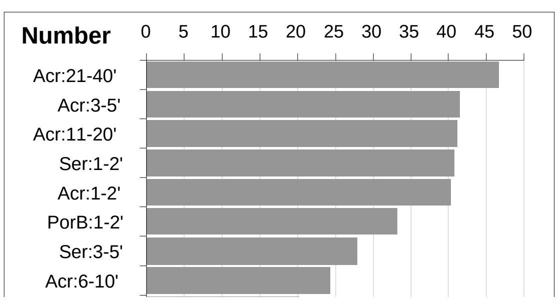


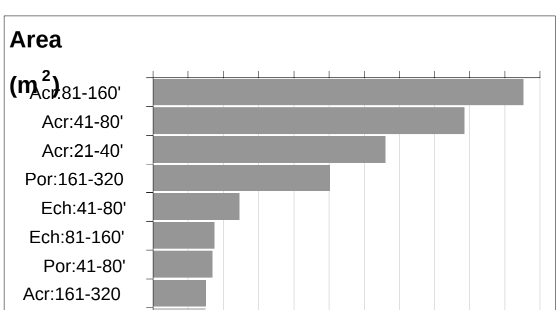




The pattern of overall coral size class distribution (5.3.1) is clearly determined by the *Acropora* size class distribution, for both number and area. No colonies > 3.2 m were recorded in transects and only Acropora and Porites were recorded with colonies in the 1.6-3.2 m size class. Within almost all genera, colonies in the 21-40 and 41-80 cm size classes were the largest contributors to coral cover.

The number of colonies in a size class distribution normally has a decreasing slope from small to large colonies, reflecting mortality over time. The low number of *Acropora* colonies < 10 cm, and in particular the dip in the 5-10 cm size class is unusual. This dip is also shown in *Seriatopora*, branching *Porites*, *Montipora* and *Pavona*, which are all genera that can be weedy and recruit in large numbers. This may indicate a major disturbance in the last 3-5 years, perhaps from minor bleaching events, or cyclones.

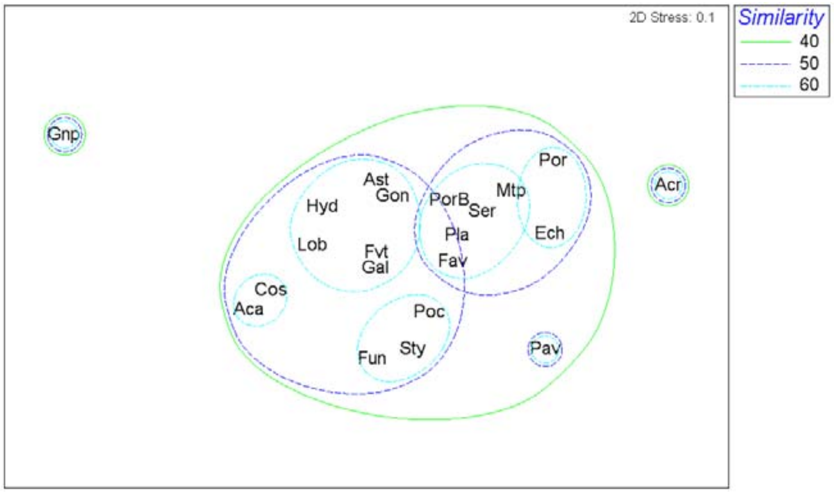




5.3.4 – *Acropora* dominance

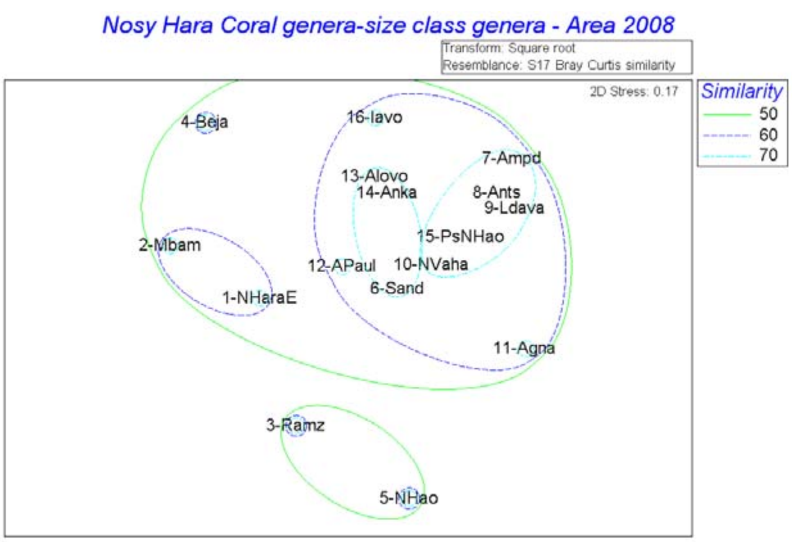
The dominance of *Acropora* in Nosy Hara is shown by the numerical dominance of 21-40 cm colonies, and cover dominance of 81-160 cm colonies. For both numbers and area, Acropora contributed 5 and4, respectively, of the top 8 genus/size classes. The opportunitic genera *Seriatopora* and branching *Porites* were next in importance numerically, whereas for area coverage, the sediment-tolerant genera *Porites* (non-branchig forms) and *Echinopora* were next in importance.

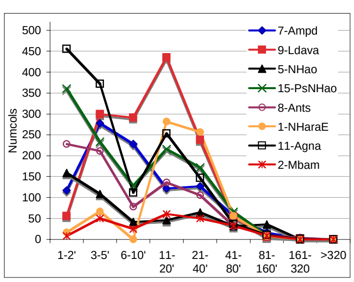
Since *Acropora* is one of the most susceptible corals to bleaching, its suggests past impacts are more likely due to physical disturbance, which provide a means of asexual reproduction and rapid growth from fragments, rather than bleaching, which causes greater physiological stress and mortality, and greater dependence on sexual reproduction and recruitment. Whatever the disturbance, it has not shifted the coral community away from *Acropora* dominance, which is likely its normal state over recent decades.

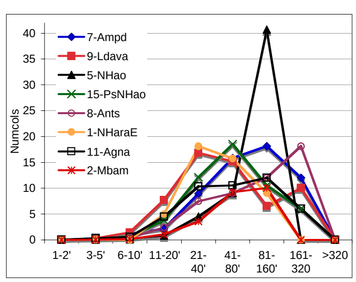


5.3.5

Three genera were atypical in their size class distributions – *Acropora*, being very dominant and abundant across many size classes, *Goniopora*, with only 2.5 colonies per 100 m^2, and *Pavona, Porites, Echinopora* and *Montipora* had moderate numbers of small colonies but with a small number of large colonies in 81-160 or 161-320 cm classes. Genera farther to the left in the plot were at lower abundances and with only small colonies represented. The even spread of coral genera suggests consistent conditions at the site, with no strong pressures that distinguish among genera.







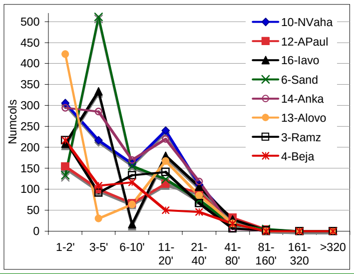
5.3.6

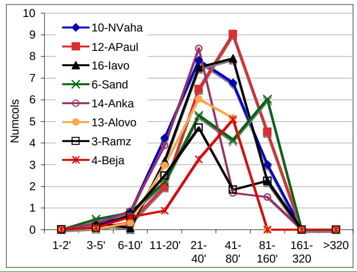
The size class distributions of corals identified the following groups of sites:

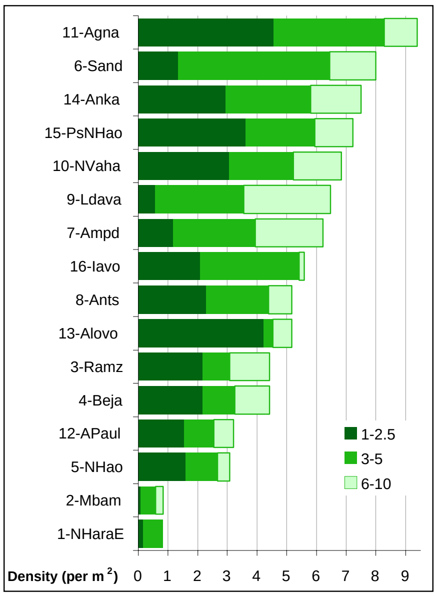
a) One outlier, (Rameza and Nosy Hao)
b) A second outlier (N. Mbamaho and N. Hara E)
c) A third outlier comprising only Bejabora
d) Within the main cluster of sites several inner divisions are apparent.

Differences between the clusters are subtle, with:

a) Single dominant size class by area (N. Hao 81-160 cm, Rameza 21-40 cm).
b) Very low numbers of small corals < 10 cm and peak in 11-20 cm size class.
c) Lowest coral cover.
d) Among the remaining sites, those in the upper right had high cover of corals, declining to the left and downwards.



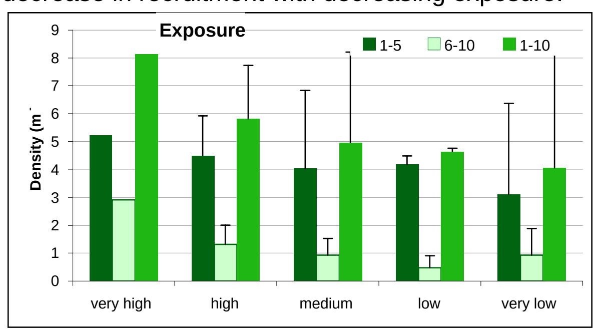


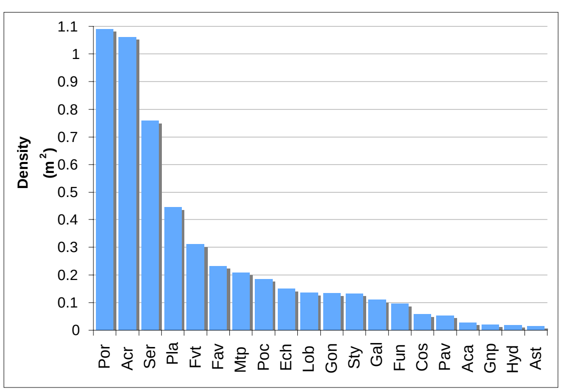


5.3.7 Coral recruitment

The density of colonies < 10 cm. equivalent to 'recruitment' measurements from annual monitoring is shown. The maximum was 8.3 m^{-2} for colonies < 5 cm, or 9.4 for colonies < 10 cm, both at Agnahibe, a narrow fringe of coral around the banks in the central part of the protected area. Lowest densities of small corals were recorded in the first two sites that were sampled, which suggests these are a result of inexperience, rather than real low levels.

There was no strong patterns of recruitment by depth, substrate type or reef type. However there was a decrease in recruitment with decreasing exposure.

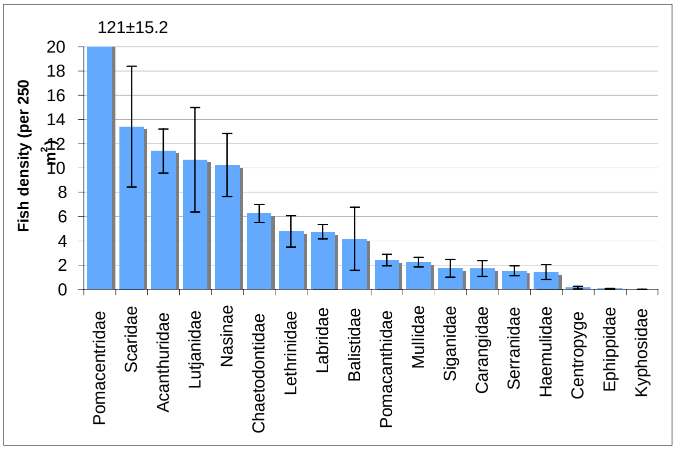


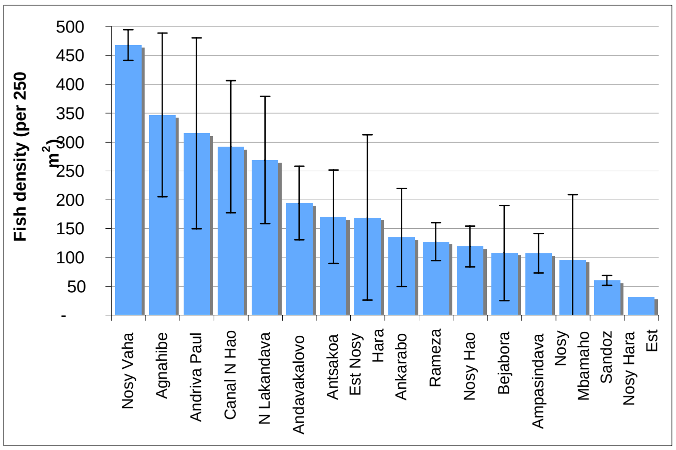


5.3.8

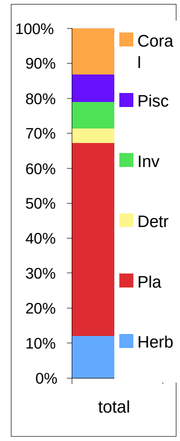
Recruit populations were more evenly balanced than adult populations. *Porites* was the most abundant, at 1.09 m^{-2} (approx. even densities of branching and massive growth forms), followed by *Acropora* (1.06 m^{-2}), and *Seriatopora* (0.76 m^{-2}).

5.4 Fish community structure



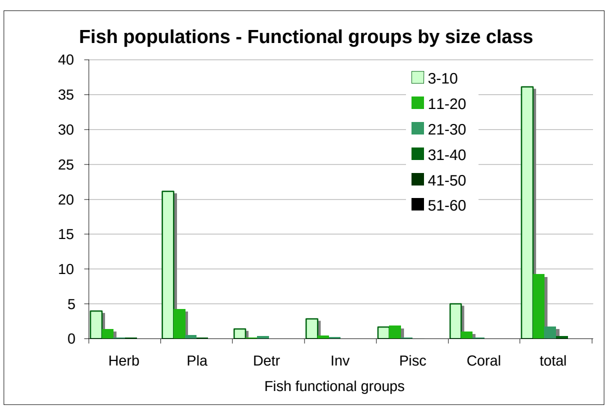


5.4.1



By number, damselfish (Pomacentrids) were the most abundant fish, at over 120 per 250m^2, compared to other fish families which were all below 14 per 250m^2. The abundance of schooling planktivorous damselfish was very high. Among the other families, parrotfish (scarids), surgeonfish (acanthurids), snappers (lutjanids) and unicornfish (nasinae) were at similar abundance, at 10-12 per 250m^2. Thus herbivores and corallivores were at similar abundances, with lower numbers of piscivores, invertivores and detritivores

Nosy Vaha was the site with the highest fish density, and was the outermost and most exposed site in the surveys. Next in abundance were sites towards the north and west of the study area – Agnahibe, Andriva Paul, and Canal Nosy Hao – and the site with highest coral diversity, Nosy Lakandava. Lower fish densities were found at sites closer to villages in the south of the study area, likely due to fishing pressure.



5.4.2

The fish popoulation was overwhelmingly dominated by small fish of < 10 cm, for all functional groups, particularly of the planktivorous damselfish. The two largest fish recorded in surveys, parrotfish, were in the 41-50 cm size class.

Family	*Total*
Pomacentridae	1200
Scaridae	576
Acanthuridae	374
Siganidae	75
Centropyge	6
Ephippidae	2
Kyphosidae	0

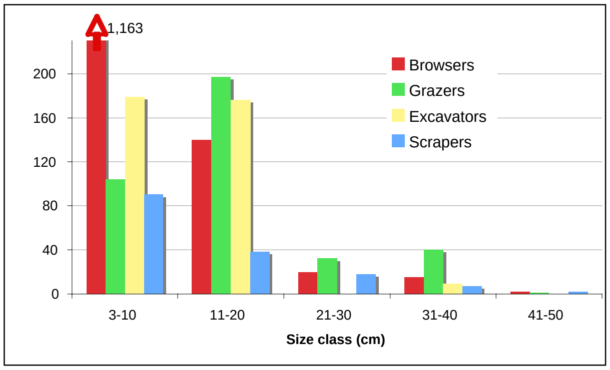
Group	*Total*
Browsers	1340
Grazers	374
Excavators	364
Scrapers	155

5.4.4

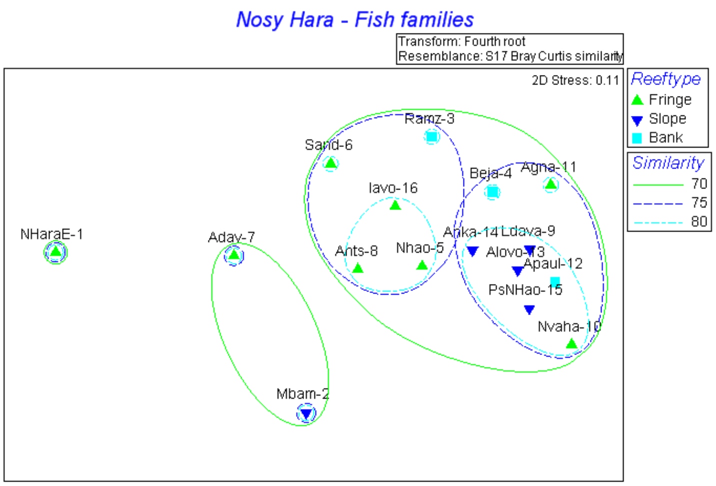
Among the herbivore functional groups, browsers were very dominant, overwhelmingly made of up damselfish (54%). Damselfish are small browsers that eat algal turfs and crop macroalgae, and were mostly < 10 cm in size.

Parrotfish (26%) and rabbitfish (17%) were next. Only 2 batfish (ephippidae) and no chub (kyphosidae) were counted.

Large excavators were almost absent, with only 8



recorded at only one site, Bejabora, in the 31-40 cm size class.



5.4.4

MDS of fish densities shows how N. Hara East stands out due to low counts of fish. Ampisandava and N. Mbamaho were also separated to the left due to low fish densities. All the other sites were closely grouped to the right with no major patterns of difference among them, suggesting that density, rather than community structure of fish is the primary distinguishing feature among sites.

These results suggest that the main feature distinguishing the fishing communities among the sites is density of fish, and that density is highest in the outer sites farthest from land and also with some proximity to deep water. Thus fishing pressure is the dominant factor controlling the fish populations, and apparently depletes a wide variety of fish, rather than only depleting a small number of target species.

5.5 Resilience indicators

For each indicator, levels 1 to 5 were assigned according to local minimum/maximum levels and the distribution of values in between. A total of 55 variables were scored, that were grouped into the following factors:

Group	Explanation	Factor	Explanation
Cover	Benthic cover	Benthic	Benthic cover – combined estimates of hard and soft corals, and algae
Coral	Condition of coral community	Current	Current status shown by bleaching, disease, sexual recruitment and fragmentation of corals.
		Historic	Past impacts to coral community as shown by evidence of past mortality, evidence of recover potential and size class distributions
Ecological	Broader ecological factors that affect corals	Negative	Negative associates of corals – such as predators and epiphytes on coral surfaces
		Positive	Positive associates of corals, such as obligate feeders (butterflyfish) and invertebrates and fish in branching corals.
		Herbs	Herbivorous fish populations
Physical	Environmetnal and habitat	Acclimatization	Past and present temperature dynamics that may protect corals by acclimatization/adaptive responses

	features that affect corals	Cool &flush	Degree of cooling/flushing of deeper and/or oceanic waters
		Shade &scrn	Degree of shading or screening of corals by turbid water, reef slope, canopy corals, etc.
		Substrate	Substrate quality, such as sediment type and thickness, amount of rubble.
Connectivity	Connectivity and larval supply	Larvae	Estimate of larval supply from contiguousreefs, separated reefs and distant reef systems
		Transport	Currents providing transport of larvae and effect of barriers to dispersal.
Anthropogenic	Human pressures on reef sites	Fishing	Degree of fishing, shown by fish populations and/or other data
		Substrate	Anthropogenic alterations to substrate – from sediment, damage, etc.
		Water	Anthropogenic alterations to water quality – from runoff, pollution, etc.

Each factor was scaled from 1 (poor conditions for corals) to 5 (good conditions for corals), and the sites ranked from highest overall resilience to the lowest.

Figure – ranking of overall resilience by site (left) and by factor (right).

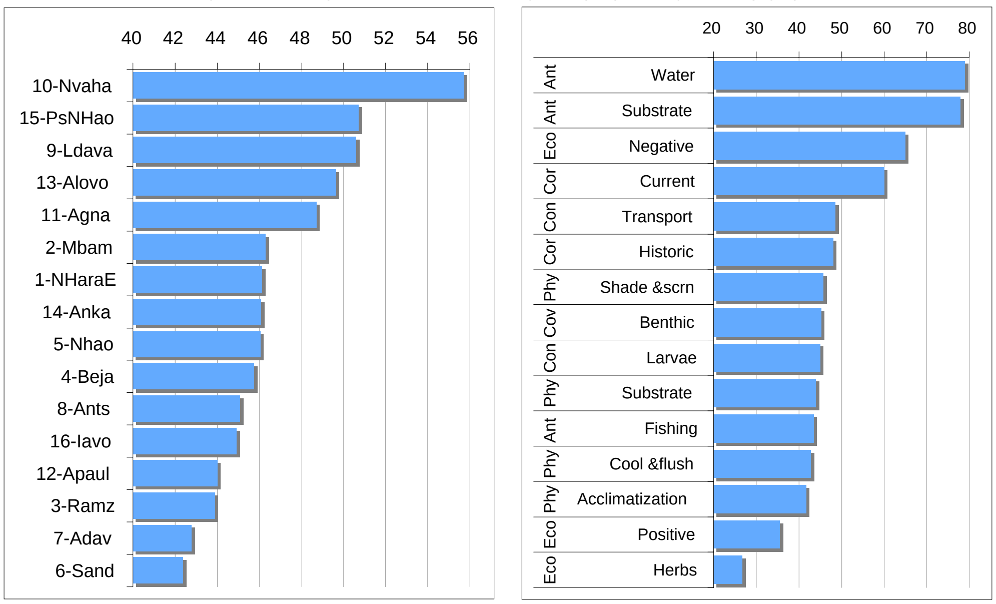


Table – cross-tabulation of sites and resilience factors from the graphs above, colour coded from dark green (5, good for corals) to red (1, poor for corals).

	Group	Cover	Coral		Ecological			Physical				Connectivity		Anthropogenic				
	Factor	Benthic	Current	Historic	Negativ	Positive	Herbs	Acclimat	Cool	Shade	Substra	Larvae	Transp	Fishing	Substra	Water	sum	avera
Nosy Vaha	H10	4	4	4	4	4	3	2	4	3	3	3	4	5	5	5	56	3.7
Passe Nosy hao	H15	3	4	3	4	2	3	2	4	2	3	3	4	4	5	5	51	3.4
Lakandava	H09	4	5	3	4	2	2	2	4	3	4	3	4	3	5	5	51	3.4
Andavakalovo	H13	3	4	3	4	3	2	2	4	3	3	3	4	4	5	5	50	3.3
Agnahibe	H11	3	5	4	5	3	2	4	2	3	3	3	3	2	5	5	49	3.2
Nosy Mbamaho	H02	2	3	3	4	3	1	3	3	3	3	3	3	3	5	5	46	3.1
Nosy Hara Est	H01	3	4	4	4	3	1	3	2	4	4	3	3	2	5	5	46	3.1
Ankarabo	H14	3	4	3	4	2	2	2	3	3	3	3	3	3	5	5	46	3.1
Nosy Hao	H05	3	3	2	4	3	2	3	3	2	3	3	4	3	5	5	46	3.1
Rejabora	H04	3	4	3	4	2	1	3	2	3	3	3	3	2	5	5	46	3.1
Antsikoa	H08	3	4	3	4	2	1	3	2	3	3	3	3	2	5	5	45	3.0
Iavoloha	H16	2	4	3	4	2	1	2	3	3	3	3	3	4	5	5	45	3.0
Andrivan'i Paul	H12	2	3	2	4	3	2	3	3	2	2	3	3	3	5	5	44	2.9
Rameza	H03	3	4	2	4	2	2	3	2	3	2	3	3	2	5	5	44	2.9
Ampasindava	H07	3	4	4	3	2	1	4	2	3	3	3	3	2	4	4	43	2.9
Sandoz	H06	2	3	2	4	2	1	2	2	3	3	3	3	3	5	5	42	2.8
	Sum	45	60	48	65	36	27	42	43	46	44	45	49	44	78	79		50
	Mean	3	4	3	4	2	2	3	3	3	3	3	3	3	5	5		3

5.5.1 – overall site resilience rankings

Nosy Vaha ranked highest among the sites, standing clear of the next group, which included Passe Nosy Hao, Lakandava, Andavakalovo and Agnahibe. The high resilience scoring of these sites was due to overall high coral/ecological conditions at N. Vaha and the lowest fishing pressure there, and good coral growth at the other sites (scores of 4 and 5) combined with deep channels and high current flows (which both contribute to cooling/shading and good larval transport).

Resilience was least at the fringing reef sites Ampasindava and Sandoz, and the bank reefs Andr'ivapaul and Rameza, which scored low on many factors, in particular fishing effect, low herbivores, negative coral associates (sea urchins), poor coral community, high algal cover and higher anthropogenic influence than other sites.

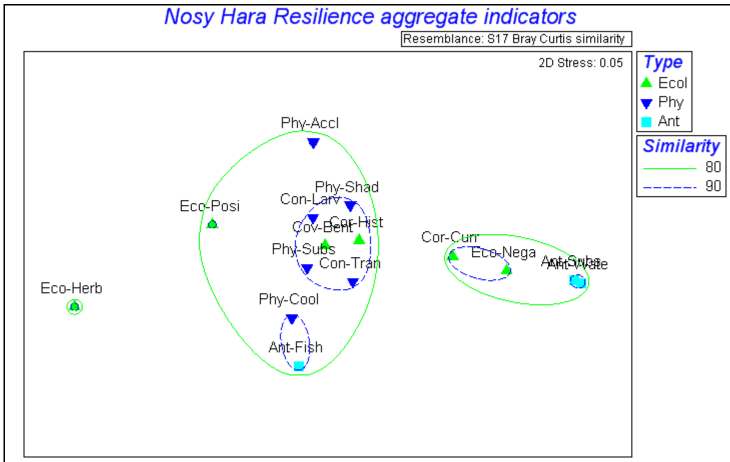
5.5.2 – Influence of resilience factors

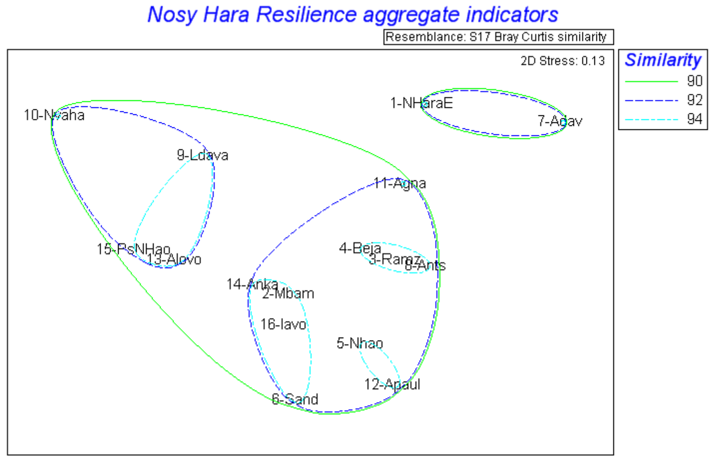
The influence of different factors was also ranked. Anthropogenic alteration to water and substrate quality was ranked to be minimal, most likely because the overall background water/sediment influence is very high, and it was not possible to distinguish a clear additional effect by people. Because these variables were uniform across all sites, they have little influence on analysis between sites.

The current growth of corals was ranked high, as well as the absence of negative associates of corals (crown of thorns and other predators, disease, etc). Historic growth was ranked above average, indicating relatively low past mortality of corals and/or good recovery since then. Currents and water transport ranked highly, but were also very uniform across sites, so had little influence on analysis.

Of the physical factors that affect coral bleaching, shading/screening was ranked most highly, due to the high turbidity of the area, but the actual score was not much higher than those for cooling/flushing and acclimatization.

At the bottom end of the ranking, fish herbivore communities ranked lowest, and fishing pressure was also close to the bottom indicating a strong negative effect on coral health.



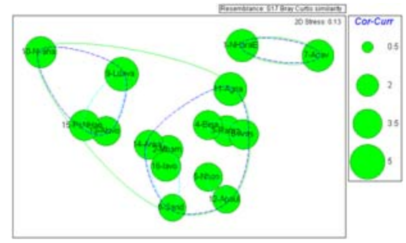


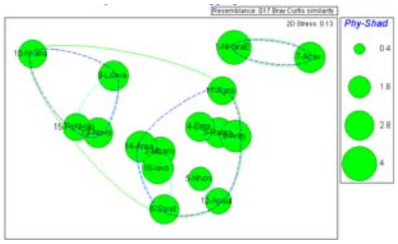
The relationships among sites and resilience factors is shown in the MDS plots at left.

The x axis shows the influence of each factor, lowest at the left (herbivory) and highest at the right (coral condition, negative ecological associates, anthropogenic water/substrate quality effects). The other other factors are more or less grouped in the middle.

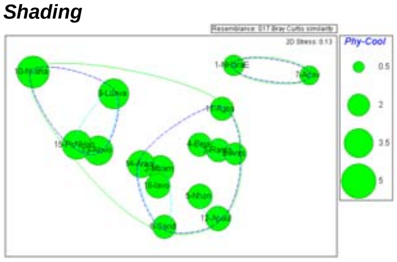
The sites clearly separate into three clusters, with those in poorest overall state in the upper right, best state in the upper left, and the others in a large central cluster.

The bubble plot below shows current coral cover/health, with good coral growth in the upper clusters at left and right, and poor coral growth in the central cluster towards the bottom.



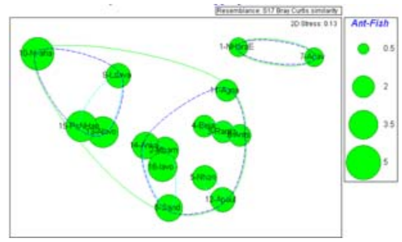


Shading

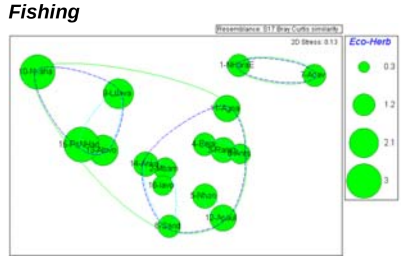


Cooling

Left
Shading factors showed highest influence in the upper right (inner sites) and less at the upper left (outer sites), while cooling followed the opposite pattern – both having a role in reducing bleaching, but in opposite influence across the study area.



Fishing



Herbivory

Left
Fishing influence was highest inshore, intermediate at central sites and lowest at offshore, reflected in the influence of herbivory, which followed the same pattern.

In total, no single factor appears to dominate the coral communities in the study area, with the following appearing to have some contribution:

- Shading and screening factors were strongest inshore and weakest offshore, and reefs showed least impact of historical mortality on inshore reefs.
- Cooling due to proximity to deep water and exposure to currents and waves followed the opposite pattern.
- Fishing was strongest inshore and weakest offshore.

5.6 Comparisons with past surveys

5.6.1 WWF baseline surveys, 2006 and 2007

Past surveys from November 2006 and July 2007, conducted using snorkeling so restricted to sites < 5 m, showed broadly similar reef conditions. Single transects were reported from each location, and two sites from each island. Here these have been averaged to provide an overview of conditions.

Coral cover varied between near-zero to 27.5% at the five sites. Of these locations, 4 were also surveyed during this study (highlighted in green), however it is only at Lakandava and Nosy Hara that it is likely that the same reef patches were surveyed due to recognizable small scale features for selecting survey sites. Both Nosy Valiha (Nosy Vaha in this study) and Rameza are extensive flat reef systems, so it is unlikely that the same locations were surveyed. Because of this, values are not plotted together to compare between the surveys.

Interestingly, very high dead coral was recorded at Nosy Valiha and Rameza in 2006 and 2007, in the latter, this may be related to the low cover recorded here, and in the influence of *Lyngbya* monopolizing dead coral substrates.

Coral reef survey results from 2006 and 2007 (Source, WWF untitled document).

	Hard Coral		**Dead coral**		**Soft Coral**		**Rock**		**Rubble**	
Site	**2006**	**2007**	**2006**	**2007**	**2006**	**2007**	**2006**	**2007**	**2006**	**2007**
Andranjara	0.9	0.3			12.3	6.7	30.6	50.6	39.6	42.4
Lakandava	1.5	27.0			5.0	18.0		43.5	74.5	1.5
Nosy Hara	22.4	25.0			10.0	18.2	44.4	44.7	20.8	3.4
Nosy Valiha	-	1.9	20.4	17.1	29.0	1.7	13.7	74.9	46.8	2.6
Rameza	27.5	27.0	47.0		10.0	5.0		2.5	11.0	57.5

5.6.2 Conservation International – Rapid Assessment, 2005

This survey covered three regions along the northwest coast, of which Nosy Hara was the northern most, and the others being the Nosy Mitsio area (middle) and Nosy Be (south) (McKenna and Allen 2006). They found that highest overall diversity of corals was found in the Nosy Mitsio area, with Nosy Hara area (northern section) in second place. They noted that overall reef development in the region is relatively low, as noted here likely due to terrestrial influence (sediments) and frequent cyclone disturbance, but nevertheless had high diversity and abundance of species.

Two results of relevance to this study were:

- Nosy Hao was listed as having three of the most exceptional sites across the whole NW region, considering multiple groups (corals, mollusks, fish) and reef health. They particularly mentioned the pass, that was sampled in this study.
- Among the sites within the Nosy Hara area, Nosy Hao, Andavakalovo and Lakandava had the highest coral diversity.

In this study the survey site labeled Nosy Hao was on the flat platform extending NW from Nosy Hao island, and was not of particularly high diversity, though it had extensive regrowing thickets of staghorn Acropora. The pass site was exceptionally high in coral development, and it is likely that the outer reef edge would be similar to that sampled at Nosy Vaha, which scored highest in this study. The observations on the reef slopes and their condition at Andavakalovo and Lakandava are consistent.

6 References

7 Annexes

7.1 Survey participants

LISTE DES PARTICIPANTS
AU « RESILIENCE SURVEY » –Nosy Hara
(16 au 27 novembre 2008)

Intervenant/formateur/encadreur : David Obura – CORDIO East Africa

Noms	Responsabilités/fonctions	Participation		
		Formation	Plongée	Logistique
ANGAP (MNP)				
Razanakoto Ignace	Chef de volet technique ANGAP Nosy Hara	X	X	
Razafindratondra Samoel Firmin	Chef secteur ANGAP Nosy Hara	X	X	
Radison Jean Claude	Chef secteur ANGAP Nosy Hara	X	X	
Jaomanana	Directeur de Parc marin ANGAP Nosy Hara	X		
Randimbison Landisoa	Chef de volet appui scientifique ANGAP Diégo	X		
Zavatra Jean Baptiste	ANGAP Masoala	X	X	
Raspaul	Skipper ANGAP Nosy Hara			X
Ralison Serge	Chauffeur ANGAP Nosy Hara			X
8 WCS				
Randriamanantsoa Bemahafaly	Marine Programme Officer	X	X	
Maro José	Technicien (accompagnateur des équipements)			X
C.I				
Tombolahy Lucie Monica	CI Diégo	X	X	
Rakotomandimby Dera	CI Diégo	X		
9 WWF				
Volanirina Ramahery	Marine Programme Coordinator	X	X	
Holihasinoro Andriamandimbisoa	Marine Programme Coordinator	X		X
Rabemananjara James	Responsable Parc Roulant			X
Rasolofoson Brigitte	Secrétaire Comptable			X