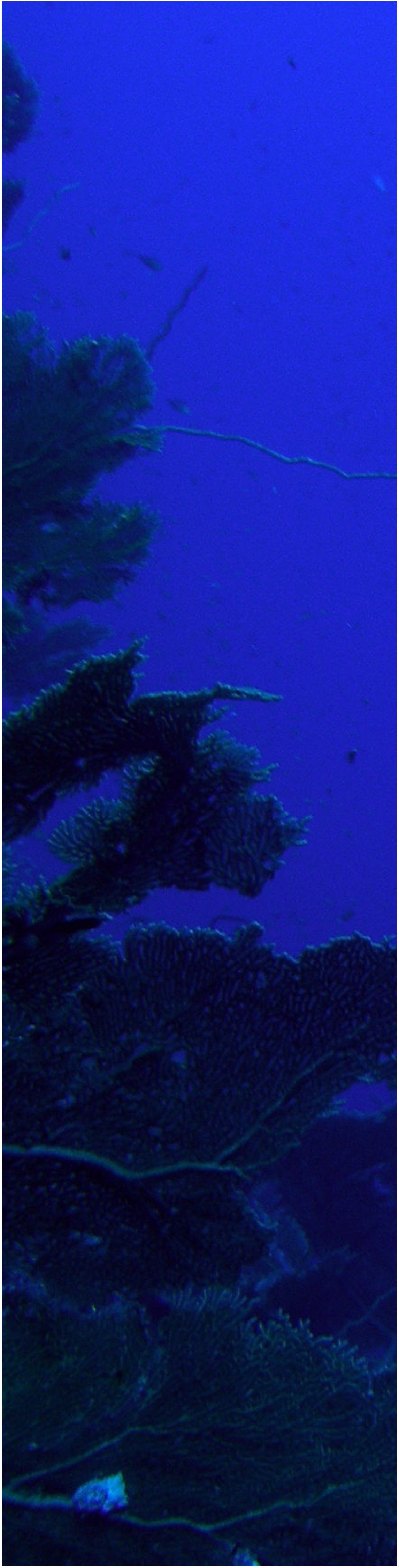

Gough, C., Harris, A., Humber, F. and Roy, R.

«Etude de la diversité biologique et de la santé des récifs coralliens des sites pilotes du projet Gestion des Ressources Naturelles Marines du Sud de Toliara» (Projet MG0910.01)

Biodiversity and health of coral reefs at pilot sites south of Toliara

WWF Southern Toliara Marine Natural Resource Management project MG 0910.01

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Acknowledgements: The authors would like to thank the WWF teams in Toliara and Antananarivo and the Blue Ventures London staff for logistical support. Thanks to Vola Ramahery and Gaetan Tovondrainy from WWF Toliara for their support in the field and Mathieu Sebastien Raharilala and Soalahatse for their technical assistance. Thanks also go to the Blue Ventures dive team for their hard work and scientific expertise. Many thanks also to each of the village communities for their kind help and hospitality. Our sincere thanks also to Geo-Eye for their kind donation of the high-resolution satellite imagery.

Recommended citation: Gough, C., Harris, A., Humber, F. and Roy, R. (2009). Biodiversity and health of coral reefs at pilot sites south of Toliara WWF Marine resource management project MG 0910.01

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List of Abbreviations

ANOSIM	Analysis of Similarity
ASEAN	Association of South East Asian Nations
COPEFRITO	Compagnie de Pêche Frigorifique de Tuléar
GIS	Geographical Information Systems
IHSM	Institut Halieutique et des Sciences Marines
LIT	Line Intercept Transect
MHW	Mean High Water
MLW	Mean Low Water
MPA	Marine Protected Area
MDS	Multi-Dimensional Scaling
NCRI	National Coral Reef Institute
NGO	Non Governmental Organisation
SDI	Simpson's Diversity Index
SE	Standard Error
SRPRH	Service Régional de la Pêche et des Ressources Halieutiques
SGP	Small Grants Programme
UVC	Underwater Visual Census
WIO	Western Indian Ocean
WWF	World Wildlife Fund
MWIOPO	Madagascar and Western Indian Ocean Program Office

Executive Summary

This report presents the results of coral reef ecosystem assessments conducted as part of a research partnership between Blue Ventures Conservation and WWF MWIOPO (Madagascar and Western Indian Ocean Program Office) in southwest Madagascar in December 2008. Results are presented to advise co-management strategies being developed by WWF Madagascar and local Vezo fishing communities.

- The results of this study suggest that the coral reefs of Itampolo, Beheloke, Maromena and Befasy show serious signs of degradation likely to be a result of unsustainable exploitation of marine resources.
- Hard coral cover overall is poor, although two reefs, Ambolafoty and Nosimbato exhibited exceptionally high levels of coral cover.
- Fish diversity and biomass appear to be relatively high but data suggest instability of trophic structure as a result of the removal of top level carnivores, and the presence of increasing numbers of herbivores. This is likely to be a result of unsustainable biomass removal.
- Low biomass of carnivorous fish in all survey zones indicates that these populations are in a state of serious depletion.
- High urchin populations reflect densities and biomass levels from degraded reefs in other areas of the western Indian Ocean. This may be linked to low abundance of their main predators caused by chronic overfishing.
- Ambohibola’s reefs were in the best health of those surveyed. The benthic composition shows greater similarity to less intensively fished or protected areas in Madagascar and the western Indian Ocean region.

  However, despite encouraging health of coral communities at these reefs, reef fish biomass and community structure on these sites are similar to levels seen on more degraded reefs in the region indicating that marine resources are suffering from similar levels of exploitation.
- If present levels of fishing intensity continue, these reefs will have little capacity to resist or recover from future acute disturbances such as mass bleaching or severe storm damage because of their low coral cover, poor benthic structural complexity, high macro-algal cover, and abnormally low density of herbivorous fish.
- Effective management of these reefs is likely to be critical to restoring key functional groups and maintaining ecosystem resilience and recovery potential.
- Fisheries management through gear and catch restrictions have proven successful in restoring fish biomass and sustainability of fisheries. These should be considered a potentially useful management tool to act as an alternative or in conjunction with marine reserves and protected areas.
- Reefs that already exhibit signs of resilience in their benthic community structure, such as the patch reefs in Ambohibola and Itampolo, should be taken into account when developing management strategies. These areas may show the most significant recovery responses if fisheries restrictions are imposed effectively.
- Co-management of proposed marine protected areas in Itampolo, Beheloke, Maromena and Befasy by WWF and local village councils will help ensure that management plans meet with high levels of compliance by local communities.
- Community educational programmes should be adopted in order to ensure greater understanding of reef recovery and resilience and the dynamics of coral ecosystems.
- Community management goals should be realistic, measurable and verifiable.
- Quantifiable achievements in conservation and fisheries management will support the long-term credibility of and adherence to management strategies, whilst the perception of short-term failures may have negative repercussions for future management policies.

Data from this research are available from WWF Madagascar for use by relevant parties. Please contact the authors for more information.

Introduction

Threats to Madagascar's coral reefs

Madagascar's coastline spans 14° of latitude, harbouring over 3500km of coral reefs in widely differing oceanographic settings. The most extensive reefs are found in the northeast, northwest, and southwest of the country, and together support the highest species richness of corals in the central and western Indian Ocean (Veron and Turak 2005).

Almost all of the country's accessible reefs are exploited by traditional artisanal fisheries. Fishing effort on reefs has increased considerably over the past decade as a result of rapidly expanding market demand from fisheries collection enterprises.

The growth of fishing effort has coincided with diversification of the range of species targeted by fishers and collectors. Rapid development and increasing production of small-scale artisanal and traditional fisheries has arisen in response to growing demand for export and through the introduction of improved fishing materials and techniques (Iida 2005).

In addition to the negative impacts of unsustainable and largely unmonitored biomass removal, reef degradation is attributable to the chronic anthropogenic impacts of hyper-sedimentation from fluvial discharge, as well as organic enrichment and pollution of coastal waters.

Cyclonic activity in Madagascar is high, with severe localised damage to coral reefs attributable to cyclones and tropical storms occurring on an approximately annual basis.

No quantitative data exist to document the responses of coral reefs in the immediate aftermath of the bleaching events that caused devastating mortality to Madagascar's reefs in 1998, 2001 and 2002. However it is likely that fast growing corals, in particular *Acropora*, the most diverse and often the most common genus on Indo-Pacific reefs, were particularly heavily impacted by these bleaching events, as was observed at numerous monitoring sites elsewhere in the Indo-Pacific (Wilkinson 2000; Sheppard *et al*. 2002; McClanahan *et al*. 2004).

With the exception of a moderate bleaching episode affecting northeastern reefs in 2005, no subsequent widespread bleaching-related coral mortality events have been recorded in Madagascar over the past 6 years.

Status of Madagascar's reefs

Northern reefs

Several rapid assessments of coral reefs have been undertaken over recent years in the north of the country, where coral reefs are generally considered to be in better condition than in the south (Cooke *et al*. 2000; Ahamada *et al*. 2002; McKenna & Allen 2003; Harding & Randriamanantsoa 2008). In addition, annual quantitative reef monitoring programmes are ongoing within several of Madagascar's established Marine Protected Areas managed by the National Parks Service, *Madagascar National Parks*. These include the protected areas of Nosy Hara, Masoala and Mananara Nord, all of which are situated in the north and northeast of Madagascar (Harding & Randriamanantsoa 2008).

Reef surveys in the northwest of Madagascar in 2003 suggested that most sites in this area exhibited above 20% hard coral cover with an average of 30% over all sites surveyed (McKenna & Allen 2003). However, a 2006 study in the northeast and northwest of Madagascar recorded sites as being far more degraded, exhibiting a range of between 2 and 23% hard coral cover (Harding & Randriamanantsoa 2008).

This latter study, which provides the most recent published information on coral reefs within the marine reserves of northern Madagascar, shows mean *Acropora* cover to be less than 1.7% at all marine parks, with the exception of Cap Masoala (4.5%). The main *Acropora* life forms recorded in this study were submassive and encrusting colonies, despite evidence at several sites of large, intact *Acropora* skeletons assumed to be relics of an earlier mortality episode, probably occurring in 1998. Similarly, the vast majority of non-*Acropora* corals comprised encrusting or massive forms. The same study found reef fish biomass to range from 100 to 900 kg ha^{-1}, similar to studies from southwestern reefs (Harding 2006; Harding & Randriamanantsoa 2008).

Southwestern reefs

Reefs in the southwest of the country, which extend from Androka in the south to the Mangoky delta in the north (a total distance of approximately 410 km), have historically been the most studied in Madagascar. The Grand Récif barrier reef in Toliara was the focus of intensive research efforts by Toliara's Marine Station from 1961-1972, a period during which approximately 400 scientific reports were published on the status region's marine environment. These studies, although focused primarily on taxonomic research of the reef, provide a valuable insight into the condition of the region's coral reefs prior to current elevated levels of direct anthropogenic disturbance (Pichon 1971).

There is limited published research documenting the status of the region's coral reefs over the intervening decades (McVean *et al.*; Walker & Roberts; Rey 1982; Laroche & Ramananarivo 1995; Laroche *et al.* 1997; Gabrie *et al.* 2000; Frontier 2003; Walker & Fanning 2003; Webster *et al.* 2003; Woods-Ballard *et al.* 2003; McVean *et al.* 2005; WWF 2006a; WWF 2006b; Ory 2008). Levels of exploitation of marine resources in areas of the southwest are considered to be similar to those observed in other areas in the western Indian Ocean (WIO), such as Mauritius, that are believed to be over-fished (Laroche & Ramananarivo 1995).

However, there has been considerable expansion of coral reef research in the region since 2003, in large part as a result of research undertaken by independent marine conservation NGOs working in partnership with Toliara's *Institut Halieutique et des Sciences Marines* (IHSM) in Ranobe bay (approximately 30 km north of Toliara) and the region of Andavadoaka (approximately 200 km north of Toliara) (Figure 1). A number of ecological and biodiversity assessment studies having been undertaken in recent years to support ongoing marine and coastal conservation efforts in the region (Nadon *et al.* 2005; Harding *et al.* 2006; Gillibrand *et al.* 2007; Weis *et al.* 2008).

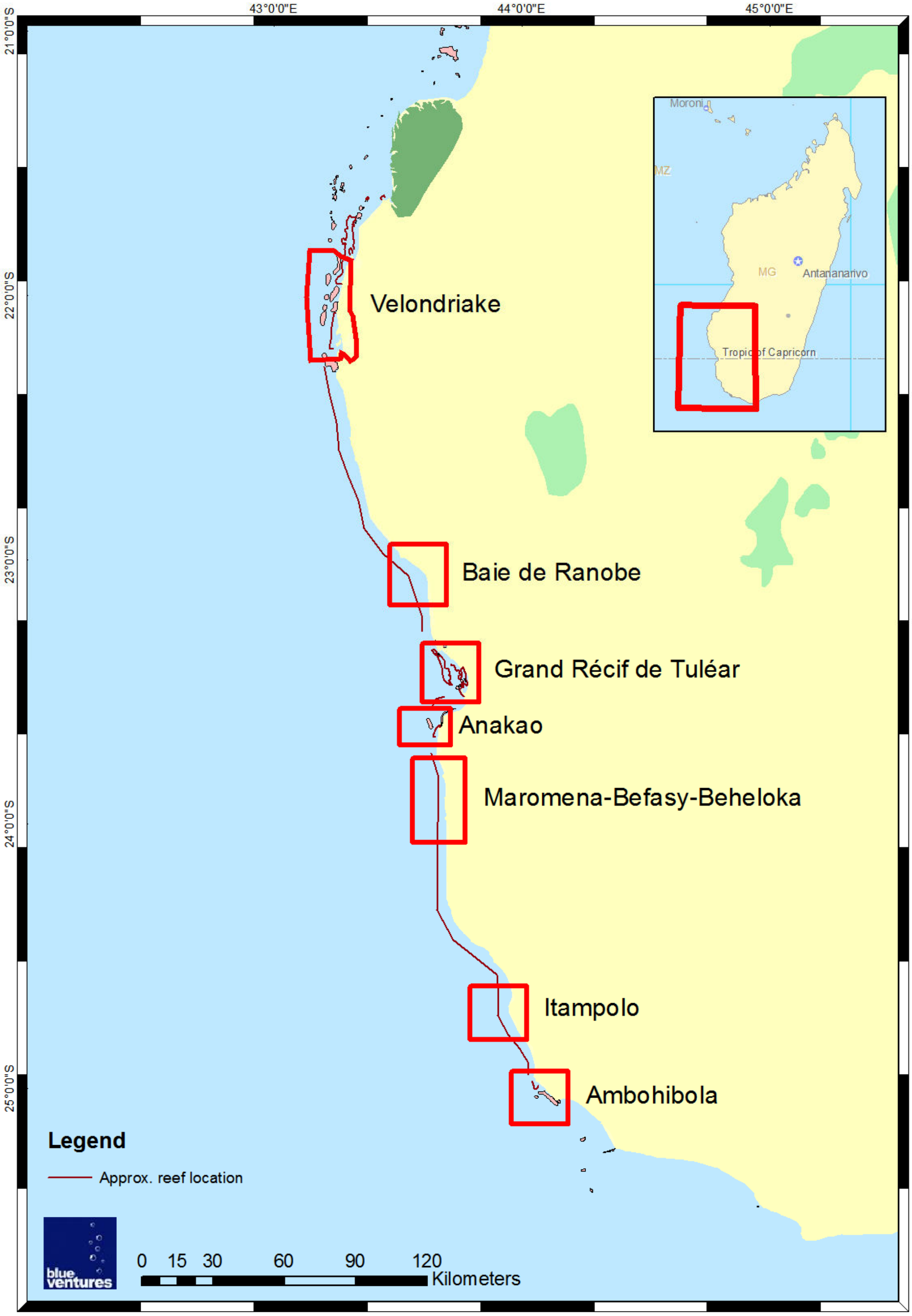

Figure 1 Map of southwest Madagascar highlighting areas of previous research and the extent of the reef system.

(i) Andavadoaka

Surveys of Andavadoaka's coral reefs have identified a total of 385 species of fish, belonging to 182 genera and 57 families; 235 mollusc species in 112 genera and 71 families; and 164 hard coral species in 55 genera and 17 families (including 19 species not recorded elsewhere in Madagascar and at least 4 species that can only been identified to genus level, and may be species new to science (Harding 2006). An extrapolation of these fish diversity data to facilitate comparative analysis of species richness data with other reference sites in the Indo-Pacific region provides a theoretical value of species richness of at least 529 species (Allen & Werner 2002; Harding *et al.* 2006; Gillibrand *et al.* 2007).

Existing long-term monitoring sites in the Andavadoaka region encompass fringing, barrier and patch reef sites experiencing a range of fishing pressures. Most seaward fringing and barrier reefs in this and the broader southwest region have undergone a phase shift from coral to algal-dominated communities. Typical seaward reefs in the region exhibit coral cover < 20%, with high or dominant levels (35-80%) of turf and macro-algae, particularly *Lobophora* sp., *Dictyota* sp., and *Turbinaria* sp..

Faviids, poritiids, agaricids, and mussids are generally the dominant corals in reef communities at all depths and in all geomorphological classes of reef in the region, although much of the eroded coral framework in these areas suggests that most sites were previously dominated by branching Acroporids. On exposed seaward sites the collapsed reef structure has generally been smoothed into planar surfaces by wave action and hardened by encrusting turf and calcareous algae. Conversely, the substrate of many sheltered fringing reefs and lagoonal patches remains loose unconsolidated coral rubble. Like high cover of seaweeds, such a highly mobile substrate may play a role in limiting reef recovery in the region by preventing effective hard coral recruitment.

Coral cover at a number of heavily-fished nearshore sites has remained stable at 5-10% over five years of monitoring since 2004, showing no trend of recovery. Conversely, total seaweed and algal turf cover has remained high, at 60-80%, showing no evidence of decline.

Studies of fish biomass in Andavadoaka show similar patterns to those described at exploited reef sites in the northeast of Madagascar (Harding & Randriamanantsoa 2008) with the more easily accessible fringing and barrier reefs exhibiting lower levels of biomass than the less intensely fished patch reef sites (Harris *et al.* 2009).

Notwithstanding the general poor status of Andavadoaka's reefs, recovery at a number of less-exploited sites has been considerable, with certain sites showing substantial improvement to coral-dominated communities. For example, several deep lagoonal patch reef sites in the region of Andavadoaka, all experiencing low fishing effort, have shown a progressive annual increase in coral cover from ~30% to ~70% between 2004 and 2008. This upward trend in coral cover has been accompanied by a concurrent reduction in algal coverage, which has shown a progressive decrease from ~50% to ~20% over the same five-year period.

The observed stark differences in recovery trajectories of heavily-exploited and less exploited reef sites over the past five years suggest that it is likely the resilience and recovery potential of many coral reefs in this region may be inhibited by present high levels of fishing. Such observations of reef recovery dynamics provide valuable insight into the potential effectiveness of reef management interventions in the region. Strategies to reduce the widespread algal dominance on the region's coral reefs should focus on increasing herbivory by reducing fishing, and decreasing terrigenous nutrient runoff. This may serve to enhance coral settlement and recruitment, and improve reef resilience from future disturbance events.

(ii) Salary and Ranobe

Like Andavadoaka, recent surveys of the coral reefs of Salary bay (located approximately equidistant between Ranobe bay and Andavadoaka) (Figure 1) show characteristic variability in coral cover between reef areas, with coral cover generally increasing with depth (WWF 2006b). Sites below 20 m generally exhibited greater than 30% cover of hard coral, while sites shallower than 10 m were generally considerably more degraded. The authors hypothesise that the higher coral cover at deeper sites may be a result of greater thermal protection of deeper water from bleaching, whilst shallower sites may have been more severely affected by past bleaching episodes, as well as being more vulnerable to anthropogenic factors (WWF 2006b).

Recent studies conducted in the Ranobe bay suggest that coral cover at lagoonal and barrier reef sites are similar to that of the patch reefs sampled in Andavadoaka (Ory 2008).

(iii) South of Toliara

With the exception of studies undertaken in the vicinity of Anakao in 2003 (Frontier 2003; Walker & Fanning 2003; Webster *et al.* 2003) limited coral reef research has been undertaken on the reefs south of Toliara. A WWF marine diagnostic report suggests increasing species richness and reef health with increasing distance south from Toliara, attributed to reduced anthropogenic influences from tourism and fishing, and reduced impacts of sedimentation, compared to those experienced by reefs closer to Toliara due to the proximity of the Onilahy river (WWF 2006a).

Long-term trends

Assuming the condition of Andavadoaka's reefs may be considered to be approximately representative of the status of the broader southwestern reef system, these data serve to illustrate the extent of degradation of coral reefs in southwest Madagascar over the past 30-40 years since the studies of Toliara's reefs in the 1960s and 1970s.

Pichon (1978) describes the coral community composition on the outer reefs in Ranobe bay as being extremely lush, with outer slopes characterised by well-developed spur-and-groove systems with wide grooves and vertical or overhanging side walls. Accounts of the barrier reef flats at this time describe the fore-reef flats as being dominated by crustose coralline algae (*Porolithon onkodes* and *Lithophyllum* sp.), seaward of a middle zone approximately 250 m in width composed almost exclusively of homogeneous branching *Acropora* spp. (reported as *A. pharaonis* and *A. arbuscula*) covering 100% of the substrate. At a reef site south of the village of Ifaty this zone was reported to stretch uninterrupted for an area of 1 km by 200-250 m. These zones were succeeded by an inner reef flat characterised by extremely high coral diversity, albeit comparatively smaller and more isolated colonies, primarily of massive growth forms, with substrate cover averaging "only" 50%. Seagrass beds were the typical habitat on the back reef flat. Pichon (1972) describes similar prolific coral growth and reef on sites surveyed at the southern limit of the southwestern reef system, in the region of Androka.

Observations of thriving reef condition and composition such as this are almost unimaginable in southwestern Madagascar's reefs today. A rapid assessment survey of benthic community composition at 10 m depth on the outer reef slope of Toliara's Grand Récif carried out by the authors in 2008 provides some degree of quantification of the long term degradation to Toliara's reefs since the studies of the 1960s and 1970s (Figure 2).

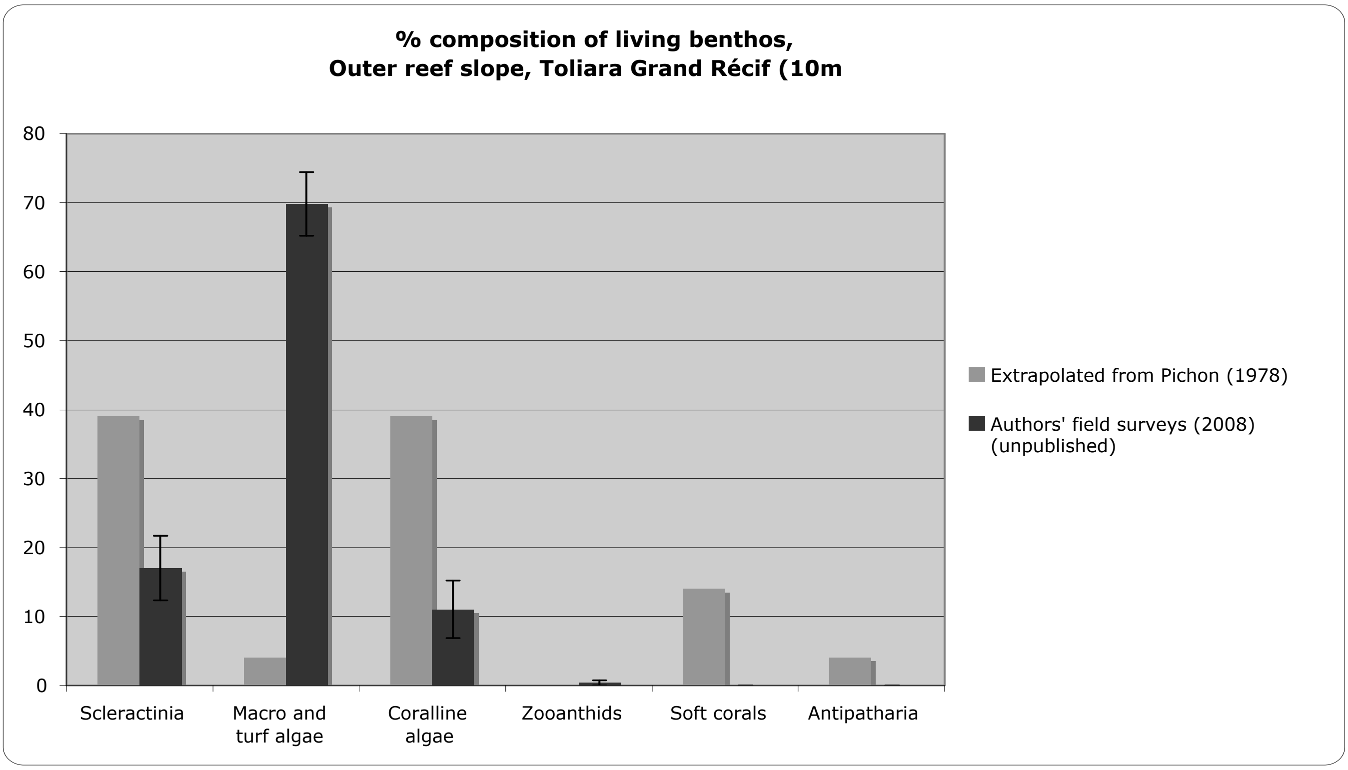

Figure 2 Change in Benthic Composition of the Grand Recif Toliara between 1978 and 2008

Importance of expansion of reef research in southwest Madagascar

Whilst ongoing annual reef assessments at sites such as Andavadoaka and Ranobe provide an insight into reef condition and recovery responses in this region, the current paucity of past studies or long-term quantitative reef assessments from elsewhere in the broader southwest region – in particular the 180 km of coral reefs south of Toliara - means that the health and status of much of Madagascar's vast southwestern coral reef system remain scientifically unknown.

Given Madagascar's current drive for considerable expansion of marine and coastal protected area coverage as part of the Durban Vision, it is considered critical that the scope of existing reef monitoring efforts is expanded to provide relevant information on ecosystem status, recovery and resilience to protected area managers and decision makers.

Managing for resilience

Global climate change forecasts and publications predict ever-worsening impacts of climate change on coral reefs and related marine environments. Effective zoning of marine protected areas (MPAs) requires not only a knowledge of the range of direct anthropogenic threats affecting a given marine ecosystem, but also an understanding of the ecosystem's likely ability to cope with climate change.

The near-ubiquitous degradation of Madagascar's southwestern coral reefs over recent decades is attributed in part to the bleaching-related mass mortality events of 1998-2002, as monitored and quantified on coral reefs throughout the central and western Indian Ocean region over recent years (Goldberg & Wilkinson 2004).

Importantly for MPA managers, global climate change models predict increasing frequency and severity of climate-related perturbations to coral reef systems over coming decades (Hoegh-Guldberg 1999; Hughes *et al.* 2003; Hoegh-Guldberg *et al.* 2007)

A number of recent studies have shone light on the ability of coral reefs to withstand or recover from climate-induced disturbance (Sheppard *et al.* 2008). Observed patterns of recovery and resilience in reef systems are complex, commonly showing patchiness and heterogeneity between and within sites, but on the whole favouring reefs on which direct sources of anthropogenic disturbance have been minimised or removed.

Observations from surveys carried out in southwest Madagascar exemplify this variability in resistance and resilience, with some sites appearing to have been less affected than others by the 1998 bleaching events (WWF 2006a), whilst others have shown signs of considerable recovery since 1998 (Harris *et al.* 2009). Still the vast majority of sites at a regional scale remain in a serious condition of degradation, showing no indication of likely recovery if present levels of exploitation remain unchanged

Given the increasingly gloomy prognoses regarding the likely future impacts of climate change on Madagascar's already highly stressed coral reefs over the coming decades, an understanding of current patterns of reef health across broad ecosystems - such as Madagascar's southwestern reef system - provides an all-important means of identifying those areas which are showing high levels of resilience and recovery potential. In order to establish effective reserves local managers must have a means of identifying resilient and resistant reefs for protection. Such information is fundamental to the development of resilient MPA networks, since enduring reefs are likely to play a pivotal role in reseeding reefs in the aftermath of future mortality episodes.

Clearly local management measures, such as reserves and networks of reserves, are not only an effective fisheries management tool; they also provide a practical means of mitigating the effects of climate change on coral reef ecosystems. Thus management of direct, local stressors affecting resilient reefs can be prioritised as a means of reinforcing an ecosystem's ability to deal with the threats of future climatic disturbance. Failure to take account of reef resilience in marine conservation planning risks compromising the effectiveness and management objectives of marine and coastal protected areas.

Purpose of this study

Context

At the Worlds Park Congress in Durban, South Africa in 2003, President Marc Ravalomanana declared his Government's 'Durban Vision'; that Madagascar would more than triple its protected area coverage from 1.7 to 6 million hectares, including five new marine protected areas.

Faced with the combined effects of climate change and direct anthropogenic factors such as over-fishing and rapid population growth on coral reefs throughout the WIO, an increasing number of management strategies are being developed throughout the region in order to protect and conserve these vital marine resources (Obura 2008).

As well as its importance in safeguarding marine biodiversity and coral reef ecosystem resilience, effective marine conservation in southwest Madagascar is critical to the livelihoods and cultures of the local and migrant indigenous

Vezo fishing communities, as well as to the long-term financial sustainability of fisheries collection and export enterprises that account for a significant proportion of income in coastal communities in southern and western Madagascar.

With unmanaged fisheries constituting a key driver of reef degradation throughout the WIO region, governments, NGOs and local fishing communities are increasingly collaborating and sharing management responsibilities to ensure the viability and sustainability of conservation plans (Obura 2008). Traditional and community-managed fishing zones have been shown to have as effective an outcome on fish size and biomass as other types of managed area (McClanahan *et al.* 2006a).

To address problems of deteriorating marine resources in southwest Madagascar through climate change and increasing exploitation, WWF-Madagascar is working alongside local Vezo communities to develop and implement marine resource conservation management strategies. The WWF Marine Programme is establishing, at pilot sites, the sustainable management of the living marine and coastal resources of southern Toliara. This work, in collaboration with local fishermen, the Malagasy Fisheries administration, collectors, retailers and the local populations will primarily benefit the local communities along the coast that are reliant on traditional fishing, including men, women and children. One of the main aims of the WWF project is to build capacity among the users of fish resources (permanent and intermittent fishers) through the development of socio-organizational and marine resource management structures, in order to establish and implement management plans for the sustainable use of marine fisheries resources. This work is being carried out in collaboration with the Fisheries Services (*Service Régional de la Pêche et des Ressources Halieutiques* or SRPRH), which contributes technical expertise, as well as other stakeholders involved in fish production, such as COPEFITO, Murex International and the IHSM. The objectives of this WWF project will be reached through the establishment of alternative livelihood strategies, development and implementation of feedback systems, and the essential collaboration and communication between fisheries management authorities, local fishermen and other stakeholders and partners in the region. This will provide the local fisheries authorities with a model and tools to ensure continued cooperation at the end of the WWF project. This will also provide the necessary incentive and justification for fisheries management authorities to implement similar initiatives for management, communication and collaboration in other coastal regions in Madagascar. The establishment of the "*dina*" (social convention) legalises the natural resources management rules allowing proper judicial enforcement. The establishment of the *dina* is of vital importance for the technical sustainability, since its design allows local communities to implement a transparent management strategy and enforce regulations in an autonomous way.

Marine resource management strategies are currently being planned by WWF-Madagascar in collaboration with local communities within four zones south of Toliara.

- Zone A - Maromena/Befasy (commune of Anakao)
- Zone B – Beheloke (commune of Beheloke)
- Zone C – Itampolo (commune of Itampolo)
- Zone D – Ambohibola (commune of Androka)

Within each of these zones local communities are working to establish fisheries management strategies regulating fishing methods and resource use throughout their local fishing grounds. Local councils and management committees have been established within each village for planning, decision making and problem solving within the communities.

WWF will chiefly play an advisory role with their recommendations for management strategies to be agreed and subsequently implemented by the community, while the council's main responsibility will be to communicate management decisions to the communities and enforce regulations once they are in place.

As conservation plans develop, these management units will be used for decision-making on local fishing regulations as well as to enforce the management plans within the villages' fishing grounds.

Many of the surveys and reef health assessments undertaken in different areas of Madagascar and the western Indian Ocean have been carried out to assess the status of the region's coral reefs prior to the implementation of management plans (Harding *et al.* 2006; WWF 2006a; Harding & Randriamanantsoa 2008; Ory 2008).

Understanding certain aspects of the ecological and socioeconomic context of communities and ecosystems - including local knowledge, resource use, ecosystem health, biodiversity and fish biomass - is fundamental to enable stakeholders, research organisations and resource managers to design appropriate zoning plans and management strategies.

Moreover this information is essential to understanding temporal changes in these parameters; a prerequisite to monitoring the effectiveness of conservation interventions and fisheries management efforts, and to adapting management strategies to best protect reef resources.

Objective

The objective of this study was to survey the health of coral reefs within each of the four designated management zones, in order to gain an overview of relative reef status within each of the four areas (Figure 3).

This technical report summarises the baseline ecological surveying carried out on coral reefs within each of the four management zones in December 2008. In addition to its quantitative outputs, the study interprets the findings in a regional context, viewed alongside concurrent coral reef research being undertaken in southwest Madagascar.

Based on the findings of this study, preliminary recommendations for management are made, along with recommendations for future ecological research relative to the zoning and management of the proposed fisheries management areas.

Overall, this study aims to:

- Map the main characteristics of the surveyed marine areas
- Undertake a biological assessment of the above mentioned coral reef areas, which would become marine managed areas, providing and indication of the health status of the coral reefs and associated living organisms
- Structure the collected raw data in an easy format allowing insertion of future data
- Analyse the collected data in order to allow comparison with previous findings in the area and other regions of Madagascar and the Western Indian Ocean.
- Provide key information allowing WWF to develop an appropriate monitoring and evaluation strategy for each of the pilot sites.

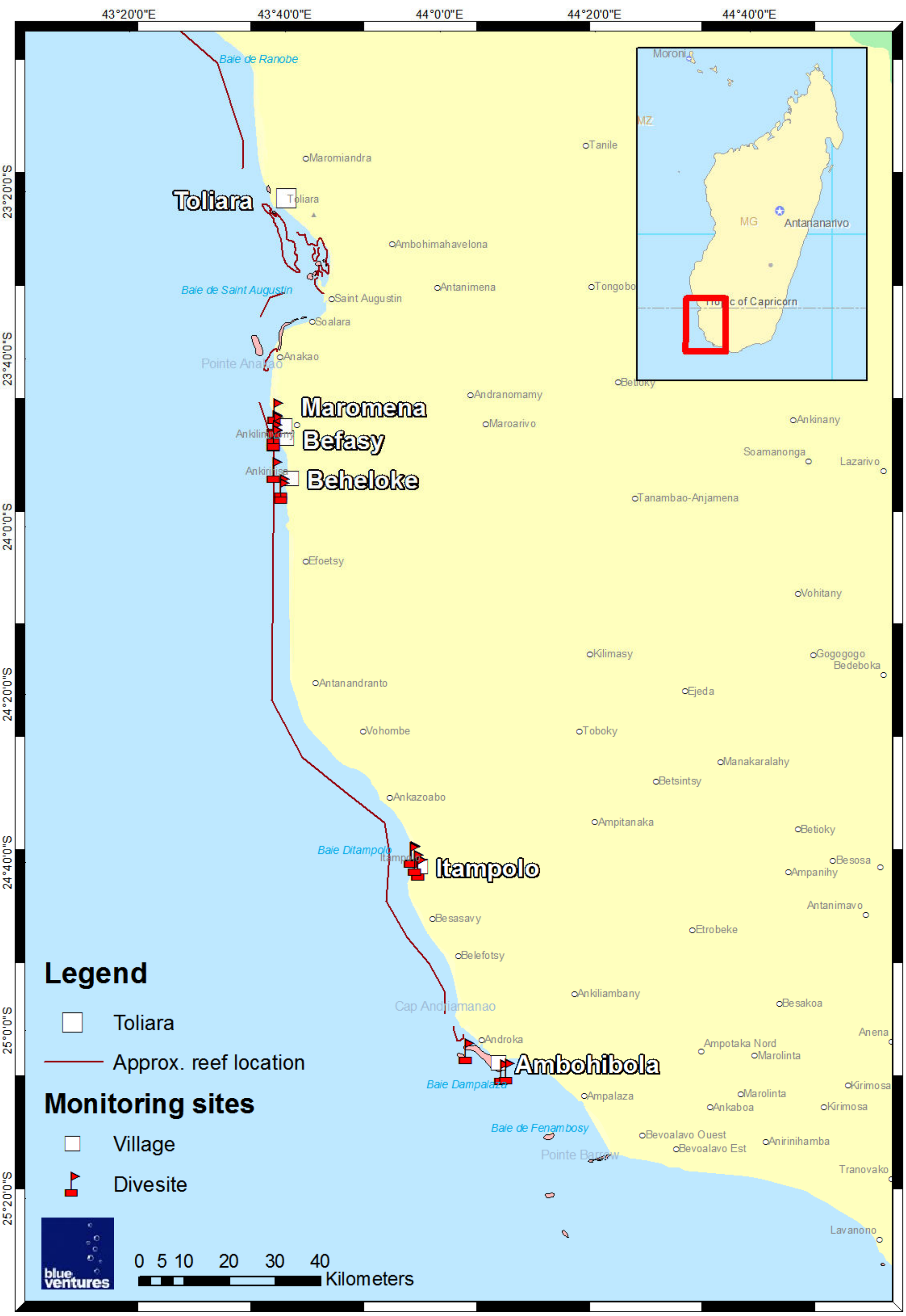

Figure 3 Map of South West Madagascar indicating the location of villages and survey zones

Methods

The methodologies employed during this study were adapted from Manual and Field Guide for Monitoring Coral Reef Ecosystems, Fisheries, and Stakeholders - Wildlife Conservation Society (McClanahan 2008). The main adaptations to these standard reef survey methodologies were to allow for logistical and time constraints within the study period.

Different geomorphological reef types have been shown to display significantly dissimilar assemblages of reef fish and benthic communities in southwest Madagascar. These differences have been seen to be particularly pronounced between nearshore fringing reefs, offshore barrier reefs and lagoonal patch reefs, probably as a result of varying fishing pressure based on differing accessibility of these reef types to fishers (Pichon 1972; Nadon *et al.* 2005; Gillibrand *et al.* 2007). Therefore, this study aimed to survey one representative sample of each of the above reef types within each management zone.

Benthic Community Structure

Corals are particularly sensitive to relatively small changes in environmental conditions such as water temperature, pH levels, and sedimentation. Stress often results in bleaching and associated mortality is commonly a major factor influencing changes to the benthic community structure of reefs (Brown *et al.* 2000; McClanahan 2000a; Ostrander *et al.* 2000; Obura 2001a; Goldberg & Wilkinson 2004). Studies have shown that coral species vary in their susceptibility to bleaching, due to the dynamic relationship between the coral and its symbiotic algae, as well as the ability of corals to exhibit acclimatisation and genetic adaptation to high levels of temperature or irradiance (Brown *et al.* 2000; Fitt *et al.* 2001; Obura 2001b).

Examination of the benthic community structure of a coral reef can provide insight into the ecological processes and pressures within the ecosystem. Healthy reef communities are often dominated by hard corals while declining reef health is commonly characterised by an ecological 'phase-shift' with increasing dominance of macro algae. A number of studies have shown that anthropogenic factors such as fishing pressure and pollution greatly affect the ability of a reef to recover from natural disturbances and may even help to push a mid-equilibrium reef into decline (Levitan 1992; Roberts 1995; McClanahan *et al.* 1999; Grimsditch & Salm 2005; Mumby *et al.* 2007)

Benthic community surveys are therefore paramount to reef health assessments as they not only inform us of the diversity and structure of the reefs themselves but also act as a key indicator to the health of the reef ecosystem in general.

Line Intercept transects

The Line Intercept Transect (LIT) is a widely used method that allows researchers to retrieve accurate, quantitative percentage cover data for all benthic categories (English *et al.* 1997; Hill & Wilkinson 2004; McClanahan *et al.* 1999).

General procedure

- One observer is responsible for reading the measurements for the entire transect and recording the data on a pre-prepared slate.

- At the survey depth, a 10 m measuring tape is secured at one end, under or around a rock or other suitable anchor, and then rolled out, loosely following the depth contour, leaving the second end free.
- The benthic or substrate groups lying directly under the transect line are recorded by noting the point along the tape at which the benthos or substrate changes.
- Readings start at one end, at the first marking.
- No measurements under 3 cm are taken and all measurements are taken to the nearest centimetre, along the contour, as close to the substratum as possible, even if the transect line does not directly follow the contour.
- Each coral colony is recorded separately but other categories can be summed as convenient.
- Once the observer reaches the end of the transect, marked by the last 'meter mark', they go back along it, leaving the anchored end secured pressing the transect line down close to the substratum, following the contour. When the surveyor reaches the end again, the point on the substratum where the end of the transect line reached is marked and the line is pulled taut. The difference in the lengths between the marked point and the extended taught lines is then recorded. Subtracting this value from 1000 (cm) gives the value for the contour, as a comparable value for rugosity.
- The transect is now complete and the observer rolls in the line to repeat the transect at another area.
- The transect is repeated six times for each survey site at haphazardly-chosen non-overlapping points. Care must be taken to avoid bias between transects by avoiding carrying transects out in one area or laying survey lines through large areas of non-reef habitat, for example seagrass beds or lagoonal floor.
- Results are recorded in centimetres under the following categories;
    - Coral (genus level)
    - Algae (genus level)
    - Soft coral
    - Sponge
    - Sand
    - Algal turf
    - Contour

Fish Underwater Visual Census (UVC)

In addition to being the major coral reef resource used by local communities, coral reef fish play an important ecological role in coral reef ecosystems. The role of herbivores is particularly well documented in being a key factor influencing the health of coral reefs (Hixon & Brostoff 1996; Carreiro-Silva & McClanahan 2001; Mumby *et al.* 2007). Reef fish communities are vulnerable to natural disturbances and anthropogenic activities, particularly those that impact on the physical structure of the reef (Graham *et al.* 2007).

Coral reef fish are commercially important, particularly in resource-poor coastal regions with low agricultural productivity, such as southwest Madagascar, where local artisanal fisheries are the primary income-generating activity (Watson & Ormond 1994; Laroche & Ramananarivo 1995; Walters & Samways 2001; Woods-Ballard *et al.* 2003).

With changes in fish community structure acting as indicators of reef health it is vitally important to assess fish diversity and abundance as well as determining stock biomass of commercially important species, so that appropriate conservation and management strategies can be implemented and their effects monitored over time.

Underwater Visual Census (UVC) is a widely used surveying technique for the assessment of reef fish communities. This study employs two UVC methods:

Discrete Group Sampling

General procedure:

- A 50 m line is laid out along the coral reef benthos at the appropriate depth 5 minutes prior to sampling.
- One observer then swims along this line, at a constant distance of 2.5 m from it carrying a slate with length markings, at a steady pace, counting and recording fish seen 2.5 m either side of the line, covering an area of 250 m^2
- The transect is passed 4 times, with fish identified to species level with 1-3 fish families sampled with each pass of the line transect.
- The observer adjusts the swimming rate slightly (10-30 min $transect^{-1}$), to account for the varying fish densities in different sites; sites with high fish densities are sampled slower than those with low densities.
- Other observers ensure they remain well out of the way to avoid scaring fish.
- The fish counts are preferably conducted during neap high tides as the lower movement of the water means it is less likely for the fish to hide. Although due to time constraints during this study this was not always possible
- While reef fish diversity is adequately assessed using this method, it does not provide a full biodiversity assessment of the reef, as the observations are limited to those fish that are observed during the transects.

Abundance and Biomass Assessment

General procedure:

- A 50 m line is laid out along the coral reef benthos at the appropriate depth 5 minutes prior to sampling.
- One observer then swims along at a steady pace, perpendicular to and at a constant distance of 2.5 m from this line, carrying a slate with length markings, counting and recording fish seen 2.5 m either side of the transect line covering an area of 250 m^2.
- Fish are placed in size categories: 3-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80 and >80 cm, and into their families. Fish smaller than 3 cm are omitted to standardize density comparisons.
- The observer adjusts the swimming rate slightly (10-30 min $transect^{-1}$), to account for the varying fish densities in different sites; sites with high fish densities are sampled slower than those with low densities.
- Other observers ensure they remain well out of the way to avoid scaring the fish.
- The fish counts are preferably conducted during neap high tides as the lower movement of the water means it is less likely for the fish to hide. Although due to time constraints during this study this was not always possible
- Observers conduct daily underwater length estimation tests, (Hill & Wilkinson 2004) to maintain a high level of accuracy throughout the biomass surveys.

Echinoderm Assessment

Sea urchins are recognised as 'keystone' species within coral reef habitats, and as such their biological and ecological interactions within reef communities have been widely studied (Carpenter 1988; Levitan 1992; Watson & Ormond 1994; McClanahan 1998; McClanahan 1999). Urchins are grazers and the most significant invertebrate bioeroders within reef ecosystems (Carreiro-Silva & McClanahan 2001) removing high proportions of dead coral substrate alongside algae. Urchin abundance and their ecological influences have also been shown to be controlled by predator levels, such as triggerfish, which are often reduced by increasing fishing pressure (McClanahan & Muthiga 1989; McClanahan 1998; McClanahan 1999; McClanahan 2000b). Urchin surveys are therefore of great importance in assessing the rate of herbivory and bioerosion that is occurring on reefs, as well as indicating the level of fishing intensity.

Sea Urchin Quadrats

Quadrats are a simple and effective method to quantify urchin abundance, diversity and biomass over a reef habitat. This survey uses a rectangular quadrat 10m^2, performed at the same time as the LIT.

General procedure:

- Each quadrat is studied by one observer who also records the count on the pre-prepared slate.
- The tape measure is laid for 10 m and the observer swims recording the number of each species 0.5 m either side of the tape measure. The observer checks under rocks and in holes for hidden individuals until returning to the starting point.
- The quadrat is repeated until all sea urchins are counted and identified to species level.
- Transects are repeated six times by haphazardly placing the quadrat following a random swim.
- Care must be taken to avoid bias between transects by avoiding over-sampling one area of reef, or laying survey lines through large areas of non-reef habitat, for example seagrass beds or across the lagoonal floor.

Holothurian Surveys

The collection or gleaning of invertebrates from shallow reefs and tidal areas is common practice throughout the Western Indian Ocean. Most of the animals collected are consumed locally, however some, such as sea cucumbers (bêche-de-mer) are traded for the international market (McVean *et al.* 2005),

While little research has been undertaken on the effects of over-fishing of holothurians on marine ecosystems, it is understood that these detritivores play an important role in the biotubation of sediments and that removal of these animals could lead to major changes in ecosystem productivity (Lovatelli & Conand 2004).

With high-value international markets driving exploitation stocks are starting to diminish throughout the WIO. It is important both ecologically and commercially to assess holothurian populations and the effects of management strategies on their abundance and diversity.

Holothurian belt transects

The use of the belt transect UVC method for fish communities allowed observers to conduct holothurian surveys along the same belt transects as laid out for fish surveys, maximising the efficiency of time underwater. Belt transects provide a simple method for the assessment of the diversity, biomass and abundance of holothurians within the reef habitat.

General Procedure:

- A 50 m line is laid out on the substrate at the appropriate survey depth parallel to the shore.
- An observer swims parallel to the line at a distance of 2 m, all the while searching the substrate for holothuria, under large boulders or rubble, within crevices and other hiding places.
- A total search area of 100 m^2 (50 m line) will be covered.
- All sea cucumbers encountered are counted, identified and measured (wherever possible).
- A total of 4 (50 m) replicate belts is surveyed at each site,

Physical Environmental Parameters

The physical properties of a reef; temperature, turbidity, aspect, may affect its ability to resist stress or readily recover from it. It is therefore important to observe the different physical attributes of each survey site as these factors may offer further information on the causes of degradation. Physical environmental measurements were collected in addition to biological assessments.

General procedure:

- Site maps were drawn up during the preliminary dive on each site prior to the biological surveys
- During each dive information was recorded on the
  - Water temperature – determine using a dive computer (Apeks, Quantum)
  - Depth (m) – determined using a dive computer (Apeks, Quantum)
  - Horizontal visibility (m) – determined by the distance a single observer could swim with a tape measure before they were out of visible sight.

Survey Sampling Strategy

The sampling strategy was determined solely by the information provided by WWF regarding reef locations, with scope constrained by the limited time scale of the surveys.

The surveys were directed by the location of the fishing sites indicated by the WWF Project Co-ordinator and the local fishermen (the project co-ordinator explained to the fishermen that we wanted to survey reef fishing sites). Each fishing site and the surrounding area that was identified, was snorkelled, in order to assess its suitability for biological survey. All of the sites that were identified to be suitable and representative of each reef type in the area were those at depths between 6 and 12m. Potentially there could have been sites that were at 25m, but all the sites that the fishermen identified were relatively shallow and those that went deeper were not representative of the general health of the reefs in that area at these depths.

- Sites were initially indicated by local community members and the WWF project manager who accompanied the dive team.

- Between 5 and 10 fishing site areas (between 200 and 500 m^2) indicated by the fishermen were snorkelled in order to ascertain the size, morphological structure and general make-up and condition of each fishing site, and the broader reef condition.
- Sample sites were subsequently chosen based on the general perceived health of the snorkelled area and thus their ability to serve as representative indicators of habitat health in addition to being suitable for showing future change in response to stressors or management regimes.
- Surveys were generally carried out at depths between 6 and 12 m, as these depths were seen to be the most representative.

Data Analysis

Mean percentage cover of broad benthic categories was calculated as standard, with between sample variability measured as a standard error (SE) value. The percentage contribution of each coral and algae genera were also calculated in order to allow increased knowledge of community composition and floral and faunal diversity.

Diversity for all categories (fish, benthos and macro-invertebrates) was calculated using Simpson's Diversity Index (SDI).

$$\text{Simpson's Diversity Index } (1-\lambda) = 1-(\Sigma pi2)$$

Where pi = the proportion of the total count arising from the *i* th species (Magurran 1988).

This index down weights the relative importance of abundant categories, expressing diversity not only as a measure of species richness but also how evenly individuals are distributed among the different species.

Simpson's index is often referred to as an equitability index such that an increasing SDI value corresponds with increasing diversity, while unequitability through dominance of a few or a single species lowers the SDI value.

Therefore, you would normally expect a coral reef to house a high diversity of fish species and have a SDI of around 0.8 or 0.9. The higher the 1- λ value also indicates that the samples are not only highly diverse but they are also not dominated by a few/single species as this lowers the SDI value. Sites with >0.9 SDI show good/normal reef fish diversity whilst sites with SDI values <0.8 show reduced diversity either due to dominance by few species or reduced species richness.

Species richness was calculated as the total number of species observed on each site.

Reef fish biomass ($Kgha^{-1}$) was calculated using representative length-weight conversions, used by McClanahan and Kaunda-Arara (1996) to convert size-frequency data into biomass data, using the mid point of each size class to calculate biomass. The mean biomass for each site was calculated with the standard error representative of the variability between samples.

Biomass data were analysed at the family level to assess contributions ($Kgha^{-1}$) by each family group. Fish families were also assigned into 8 trophic categories; herbivores, omnivores, corallivores (Chaetodontidae), diurnal carnivores, nocturnal carnivores, piscivores, diurnal planktivores and nocturnal planktivores (Harmelin-Vivien 1979; Gillibrand & Harris 2007), groups were subsequently reassigned with all groups other than herbivores, omnivores and corallivores, being regrouped as carnivores (Chabanet & Durville 2005), and the mean wet weight calculated for each trophic guild.

Urchin wet weight (Kgha-1) was calculated for each species through multiplying the population densities by an average wet weight determined by McClanahan *et al.* (1999).

Holothurian biomass was determined through length:weight ratios taken from Conand *et al.* (2007) for commercial species. Mean wet weight for each macro invertebrate category was then calculated with variation between samples expressed as the standard error value.

Multivariate analysis

Analyses of benthic community composition data were carried out using non-metric Multi-Dimensional Scaling (MDS) ordinations based on Bray-Curtis dissimilarities of root transformed multivariate sample data. Transformation was used as a means of down-weighting the importance of highly abundant benthos and substrate types (such as scleractinia), so that community similarities depended not only on their values but also those of less common ('mid-range') categories (such as alcyonidae). ANOSIM was used to identify significant differences between groups of replicate samples defined by factors a priori, including site, depth, management area and geomorphological class of reef.

Site Descriptions

Zone A - Maromena/Befasy (commune Anakao)

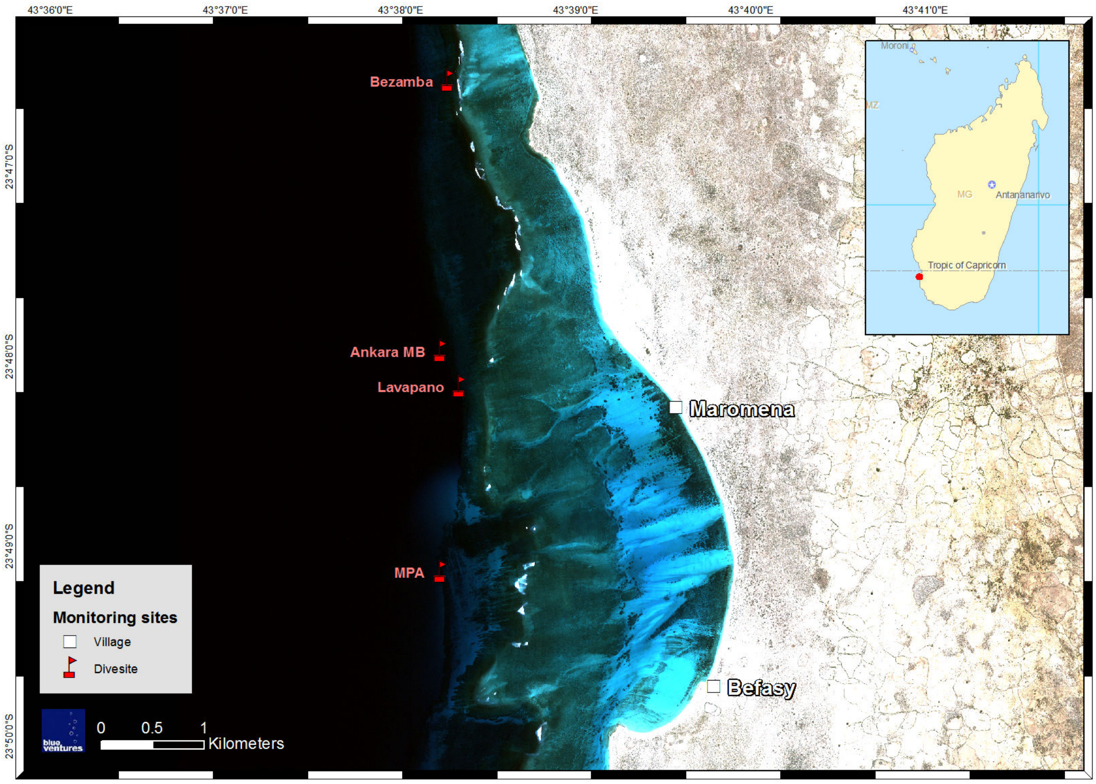

Figure 4 Satellite imagery of survey areas in Maromena and Befasy

GPS coordinates :

GPS Maromena - Latitude -23.805083° Longitude 43.659251°

GPS Befasy - Latitude -23.829502° Longitude 43.662619°

Patch Reef (Ankara MB)

GPS : Latitude -23.799858° Longitude 43.636856°

Size : 80 m x 50 m

Depth : 13-18 m

Description : The reef top, which is approximately oval in shape, starts at around 13 m Mean High Water (MHW), dropping away steeply at the edges to around 18m at a gradient of approximately 1:2. The edges of the reef have higher hard coral cover and greater numbers of fish than the reef top which is dominated by turf and encrusting algae, with small colonies of hard corals and large patches of macro algae, predominantly *Turbinaria* spp. The fish community is dominated by herbivorous species, with the main families being Acanthuridae, Labridae and Scaridae. The edge of the reef houses a number of larger fish such as Serranidae and Haemulidae where the reef drops away to deeper water. There are some notable arches and caves within the reef structure at approximately 15 m. The top of the reef is largely degraded and dominated by algae while the seaward slope has greater coral cover and appears to house a greater diversity of fish species.

Fringing Reef (Bezamba)

GPS : Latitude -23.776160° Longitude 43.637823°

Size : 50 m x 40 m

Depth : 3 to 8 m

Description : Shallow fringing reef site, located in the surge zone of the reef. Hard corals dominated by *Acropora* spp. and reef characterised at edges by large beds of *Sargassum* spp. and *Turbinaria* spp. phaeophytes. Coral cover appears to be low, with mostly small sized corals providing little complexity to the benthic structure.

Fish predominantly herbivorous with Acanthuridae, Labridae, and Pomacentridae families dominant with species characteristic of the surge zone environment.

Barrier Reef (Lavapano)

GPS : Latitude -23.802972° Longitude 43.638630°

Size : 100 m x 50 m

Depth : 12 to 18 m

Description : Long steep-sided reef edge with deep spur and groove formations. The reef top at 12 m MHW is dominated by turf algae with small colonising hard corals, and numerous soft corals. Higher abundance and coverage of hard corals as the reef drops away to sand at 18 m. Here coral colonies appear larger and the benthic substrate more complex. Fish are abundant and diverse, although dominant families are herbivorous; predominantly Acanthuridae, Labridae and Scaridae. As the reef drops away other families are apparent, such as schools of Lutjanidae and large Serranidae

Zone B – Beheloke (commune Beheloke)

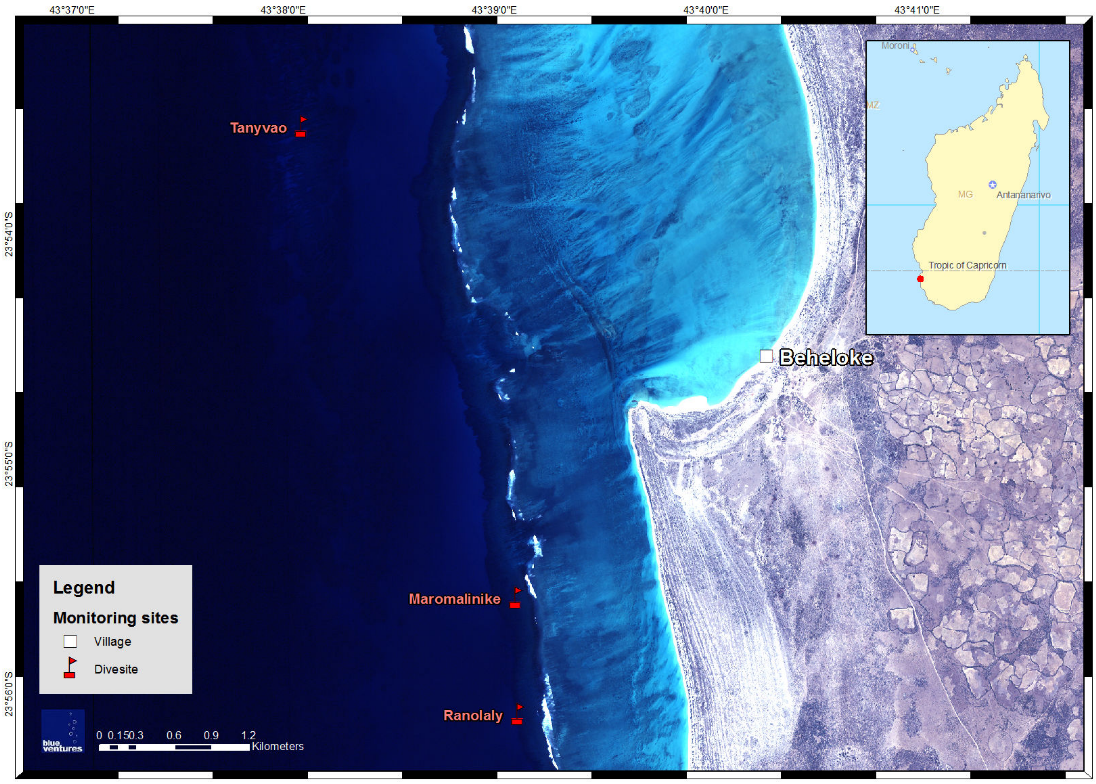

Figure 5 Imagery depicting survey sites in Beheloke

GPS Beheloke: Latitude -23.909315° Longitude 43.671238°

Patch Reef (Tany-Vao)

GPS : Latitude -23.892318° Longitude 43.634762°

Size : 60 m x 50 m

Depth : 10 to 14 m

Description : Patch reef situated off the seaward side of the barrier with deep spur and grooves, parallel with those of the barrier reef. The reef starts at around 10 m MHW, with the benthos comprised mainly of calcareous algae and juvenile hard coral colonies. Towards the edge of the reef hard coral cover becomes higher with more moderately sized coral colonies, and turf and coralline algae is replaced by *Lobophora* spp. suggesting that this area may be afforded some protection due to its increasing depth. Fish are abundant and diverse but dominant families again appear to be herbivorous, generally being Acanthuridae, Labridae and Scaridae.

Fringing Reef (Maromalinike)

GPS : Latitude -23.926659° Longitude 43.651302°

Size : 100 x 120 m

Depth : 5 to 12 m

Description : Reef top is flat with small gullies and channels. The edge of the reef gradually drops away to sand at 10 to 12 m. The reef appears to be relatively degraded with the benthic community dominated by macro-algae, predominantly *Turbinaria* spp. and *Padina* spp. phaeophytes, with low abundance of juvenile soft and hard coral colonies. The fish community is dominated by Acanthuridae with other herbivorous fish such as Labridae also numerous.

Barrier Reef (Ranolaly)

GPS : Latitude -23.935096° Longitude 43.651406°

Size : 100 m x 100 m

Depth : 8 m to 25 m

Description : Deep spur and groove topography with the top of the spurs at around 8 m dropping sharply at the edges to 18 to 20 m leading to sand at around 23 m. The top of the reef is dominated by small colonies of hard coral and encrusting algae, while the edges of the reef appear to house greater diversity and greater cover. Fish are diverse and dominated by Acanthurids and Labrids with greater diversity as the reef drops away into deeper water, including large Serranids.

Zone C – Itampolo (commune Itampolo)

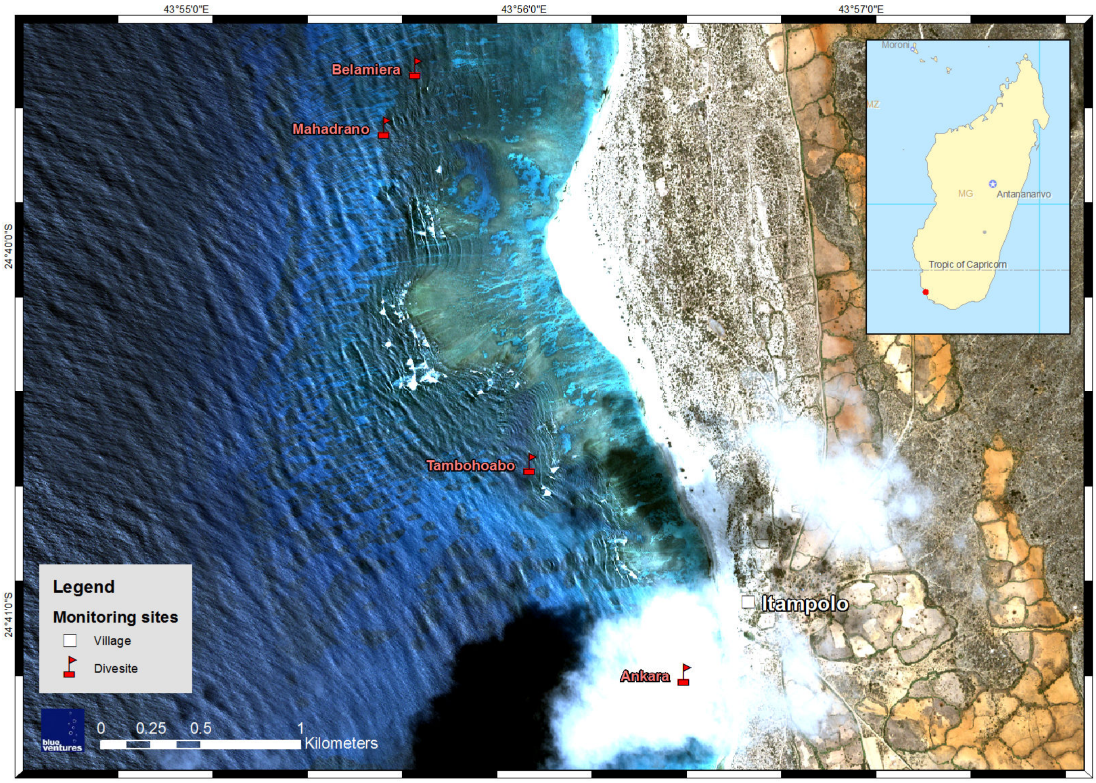

Figure 6 Image of the survey sites for Itampolo

GPS Itampolo: Latitude -24.682996° Longitude 43.944253°

Patch reef (Ankara)

GPS : Latitude -24.686240° Longitude 43.941064°

Size : 50 m x 30 m

Depth : 1 to 7 m

Description : Shallow reef inside the lagoon, and close to the shore. High hard coral cover estimated to be approximately 60% with *Montipora* and *Acropora* spp. dominating the benthic community. Fish community diverse, and at the southern edge of the reef are two large *Porites* spp. colonies with large schools of Pempheridae and Lutjanidae. The northern and eastern parts of the reef raise up onto a reef flat which is dominated by *Turbinaria* spp. and turf encrusted rubble.

Fringing Reef (Tambohoabo)

GPS : Latitude -24.676699° Longitude 43.933534°

Size : 100 m x 60 m

Depth : 4 to 10 m

Description : Relatively flat reef top at around 4.5 m Mean Low Water (MLW), dropping gently seaward to sand at around 10m. This site appears to be substantially degraded with high algal cover, with few small hard coral colonies. Fish are relatively abundant but little diversity, with mainly herbivorous fish such as Acanthuridae and Scaridae dominating the community.

Barrier Reef (Belamiera)

GPS : Latitude -24.658740° Longitude 43.928016°

Size : 50 m x 50 m

Depth : 4 to 8 m

Description : Small site with shallow spur and groove formation, projecting east to west. Whilst coral cover is estimated at approximately 30 to 40% but the majority of these are small juvenile colonies of *Acropora*, *Pocillopora* and *Stylopora* spp. Large numbers of herbivorous fish are apparent, mainly comprised of families such as Scaridae, Labridae and Acanthuridae.

Barrier Reef (Mahadrano)

GPS : Latitude -24.661410° Longitude 43.926450°

Size : 100 m x 80 m

Depth : 6 to 8 m

Description : Shallow spur and groove formation projecting east to west. Dominant benthos is coralline and turf algae. Hard coral cover is approximately 30-40% but this is mostly small colonies, with *Acropora*, *Pocillopora* and *Stylophora* dominant. The upper surface of the seaward ends of the spurs at around 7 m have around 80% macro algal cover with the dominant phaeophyte *Padina* spp. Fish are abundant, mainly comprised of herbivores, such as Scaridae, Labridae and Acanthuridae.

Note : Mahadrano and Belamiera are adjacent sites. Both were surveyed as one will be chosen for protection through the Small Grants Programme (SGP) funding as a community-managed fishing site.

Zone D – Ambohibola (commune Androka)

Figure 7 Survey sites for the village of Ambohibola

GPS Ambohibola: Latitude -25.074806° Longitude 44.112772°

Patch reef (Nosimbato)

GPS : Latitude -25.092438° Longitude 44.129195°

Size : 50 m x 40 m

Depth : 6 to 8 m

Description : This patch reef is dominated by high hard coral cover estimated at around 70-80%. Hard corals dominated by foliose and encrusting *Montipora* spp., and branching *Acropora* spp. Large massives of *Porites* spp. at the edges of the reef. Fish however have a seemingly low diversity with dominant families of Pomacentridae and small Labridae, and few representatives from other families.

Fringing Reef (Ambolafoty)

GPS : Latitude -25.093683° Longitude 44.119237°

Size : 100 m x 50 m

Depth : 6 to 8 m

Description : Very high coral cover estimated at approximately 80-90%. The north end of the reef has two large monospecific areas of *Pavona clavus*. The majority of the reef is comprised of foliose *Montipora* spp.

with large branching *Acropora* and *Pocillopora* spp. At the edges of the reef are large massives of *Porites* spp. and *Lobophyllia* spp., and the back of the reef drops down onto a seagrass bed that is comprised mostly of *Thallassodendron cilliatum*. The fish community is relatively diverse with large numbers of Acanthuridae and some larger species from Serranidae and Haemulidae families.

Barrier Reef (Ankara Ambohoe)

GPS : Latitude -25.051677° Longitude 44.042760°

Size : 100 m x 100 m

Depth : 8 to 12 m

Description : Shallow spur and groove formation deepening to the west. Reef is flat on the top of the spurs dropping to sand in the narrow valleys. The reef top is dominated by macro algae, namely the phaeophyte *Sargassum* spp. and rodophyte *Euchema* spp. which are interspersed with small colonies of soft and hard coral, although coral cover is estimated to be relatively low at around 20%. Fish are relatively abundant, and dominated by Labridae and Acanthuridae families.

Results

Benthic Composition

Hard coral cover was variable at all survey sites (Figure 8) with the highest levels found in Ambohibola (57.44% ± 4.84 SE) where both Ambolafoty and Nosimbato reefs exhibited exceptionally high levels of coral cover (73.63% ± 4.20 SE and 67.02% ± 7.64 SE respectively). The smallest percentage coral cover, 15.93% (± 3.47 SE), was recorded at Maromalinike in Beheloke.

Hard coral diversity (Figure 9) did not differ greatly between sites, however it was notable that sites which presented a higher percentage of hard coral cover such as Nosimbato, Ambolafoty and Ankara (Itampolo) generally exhibited lower diversity (SDI 0.6 to 0.7) values, as their community structure was dominated by a single or few coral genera (Figure 10, Figure 11), while sites such as Belamiera and Tambohoabo, with only 20% hard coral cover exhibited higher diversity values (SDI 0.9).

Bleaching was not observed to any significant level at any of the reef survey sites during the course of the study in December, and it was documented that the water temperatures were consistently between 23 and 26 °C (Figure 12).

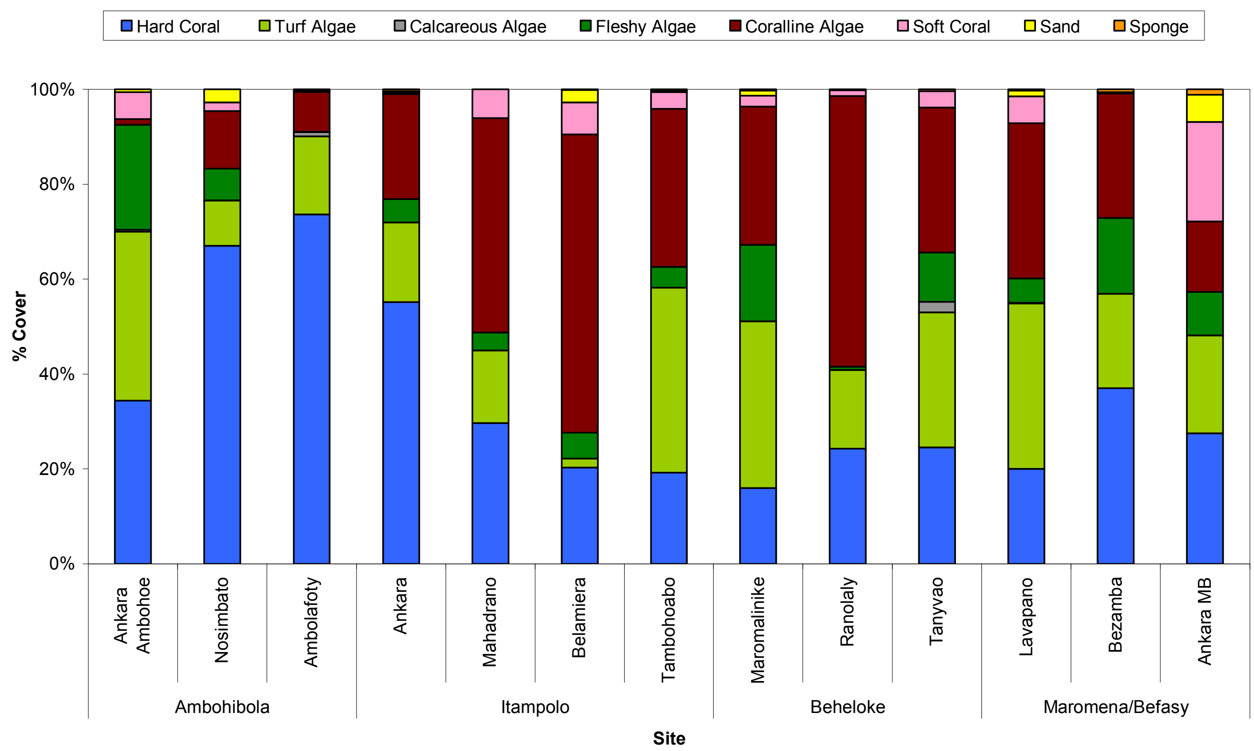

Figure 8 Benthic Composition, depicting percentage contributions for each substrate type

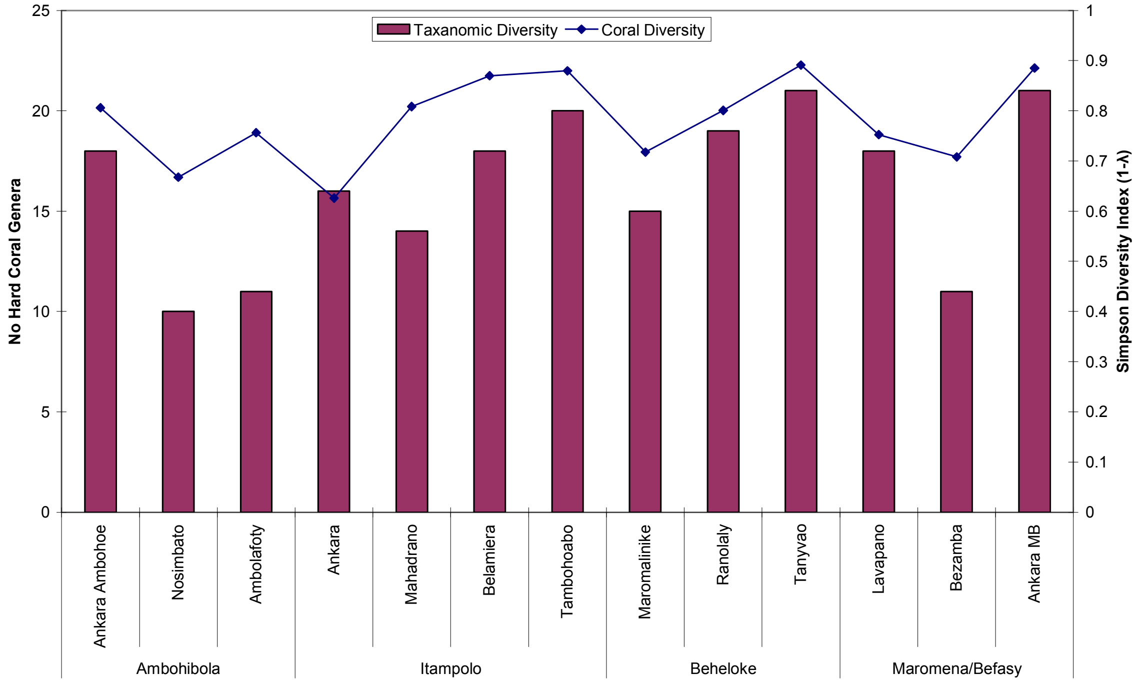

Figure 9 Graphical representation of hard coral taxonomic diversity and Simpsons Diversity Index (SDI)

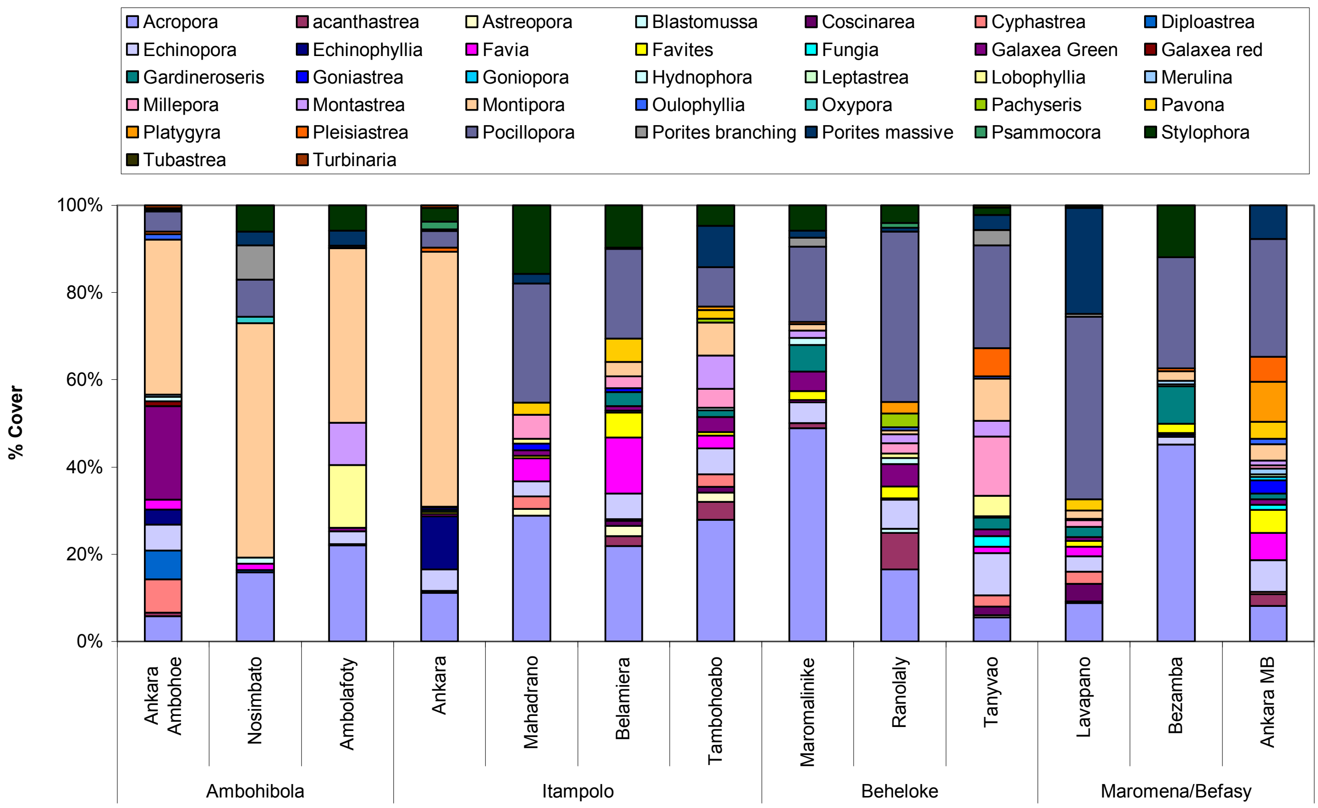

Figure 10 Percentage contribution of each scleractinian genus to total hard coral cover

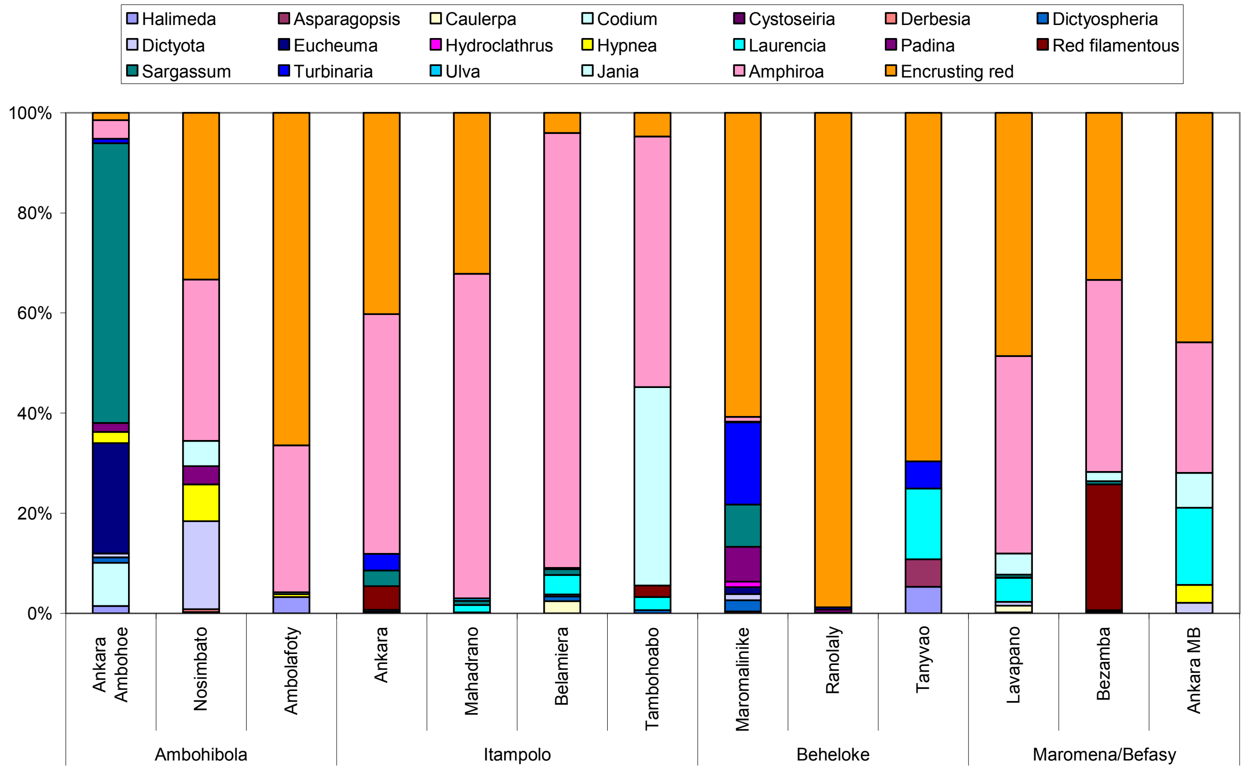

Figure 11 Contribution of each algal genus to total substrate cover

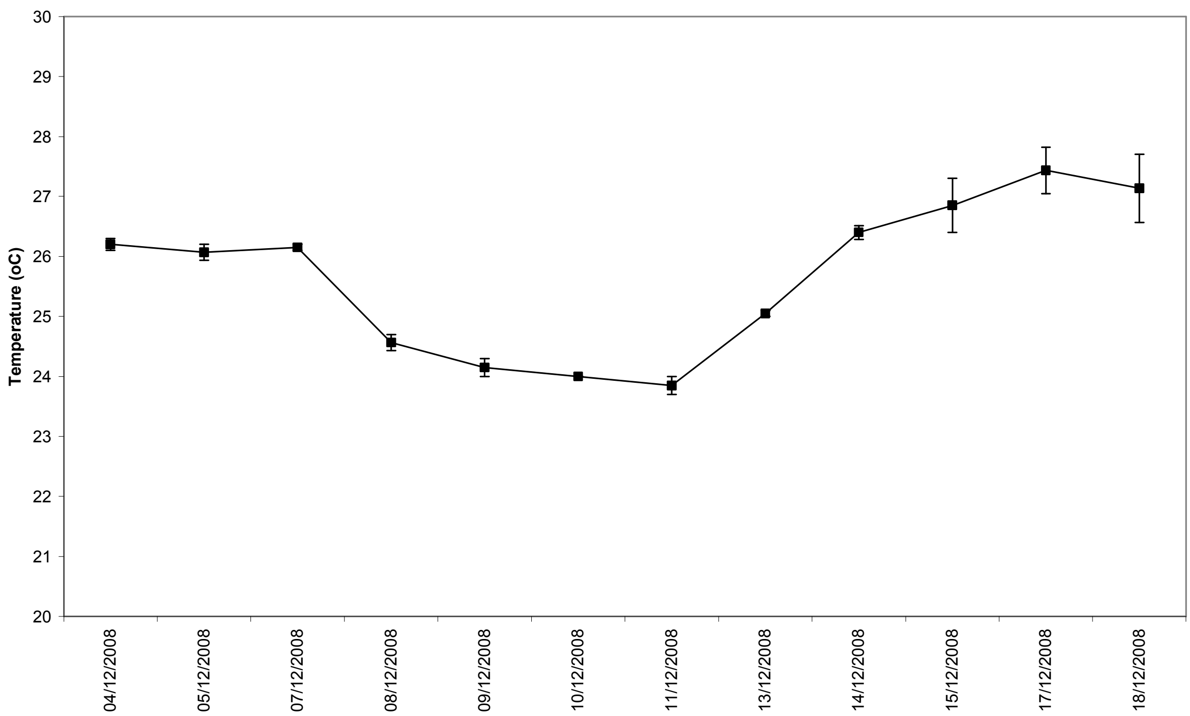

Figure 12 Average daily water temperatures throughout surveying period

Reef Fish Diversity

Species richness was variable between survey sites, with Bezamba only recording 26 species whilst Ankara MB housed 75 different fish species (Figure 13).

Simpsons diversity index indicates that there is little variation in fish diversity between the majority of sites, with 1-λ varying between 0.8 and 0.9 at 11 of 13 sites. It is notable however that both Nosimbato and Bezamba, those sites that exhibit the lowest species richness also appear to have lower diversity due to dominance by fewer species (SDI 0.6 and 0.7 respectively) (Figure 14).

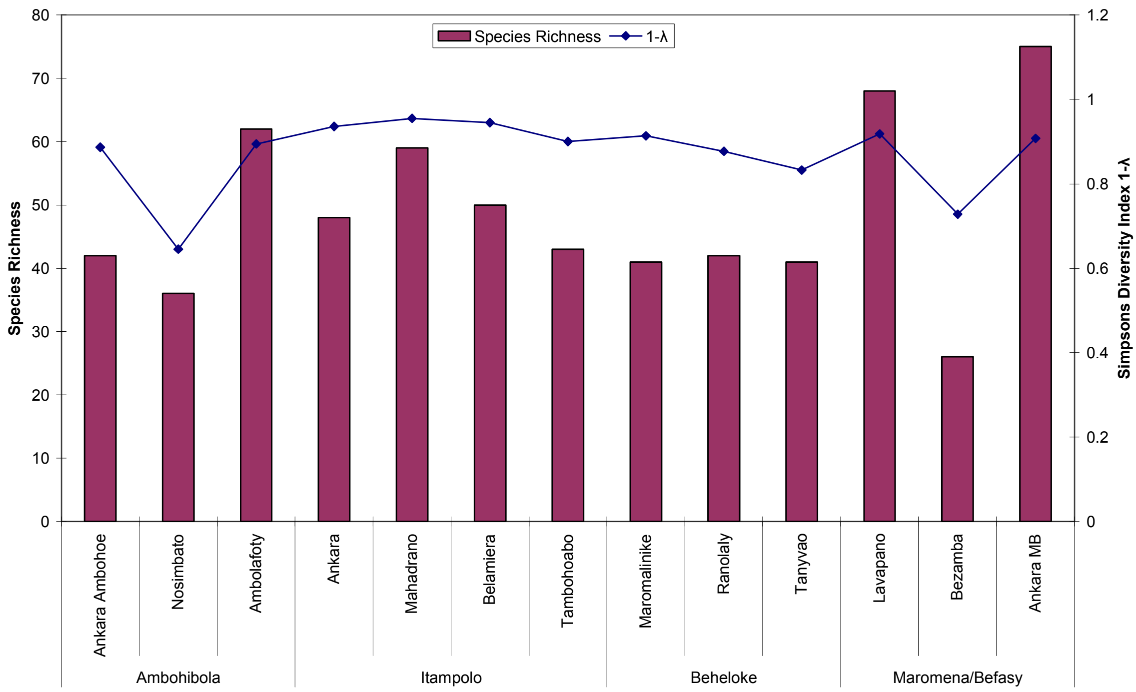

Figure 13 Reef fish species richness and diversity (SDI)

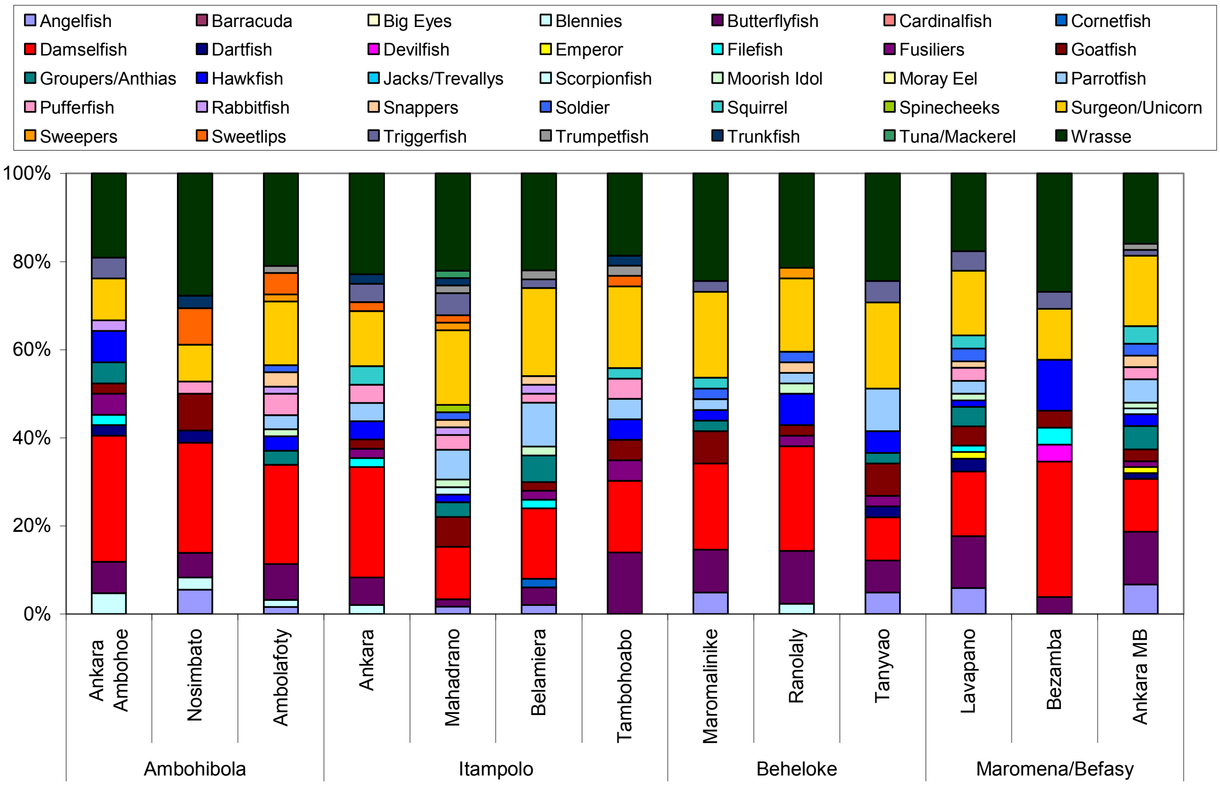

Figure 14 Family contributions to fish species diversity

Reef Fish Biomass

Reef fish biomass was highly variable between survey sites from 157.11 Kg ha-1 (± 24.11 SE) at Bezamba to 2295.05 Kg ha-1 (±1136.52 SE) at Belamiera (Figure 15).

The highest biomass was recorded for Acanthuridae, which contributed between 50 Kg ha-1 and 1190 Kg ha-1 and constituted 30-80% of biomass at 10 out of the 13 reefs surveyed and 20-30% at the other reefs (Figure 16).

The second largest contribution to biomass was from the Labridae family generally comprising 10-20% of biomass, closely followed by Pomacentridae 10-15%

The remaining biomass is predominantly comprised of Scarids, Chaetodontids and Serranids each contributing between 2 and 5% of biomass.

Trophic guild analysis shows that herbivores make by far the greatest contribution to fish biomass (100 Kg ha-1 to 1760 Kg ha-1) on 12 of the 13 sites surveyed (with the exception of Nosimbato) accounting for 40-90% of total biomass. Nosimbato is the only site where carnivore biomass (226.373 Kg ha-1 ± 64.100 SE) exceeds herbivore biomass (173.162 Kg ha-1 ± 36.261 SE).

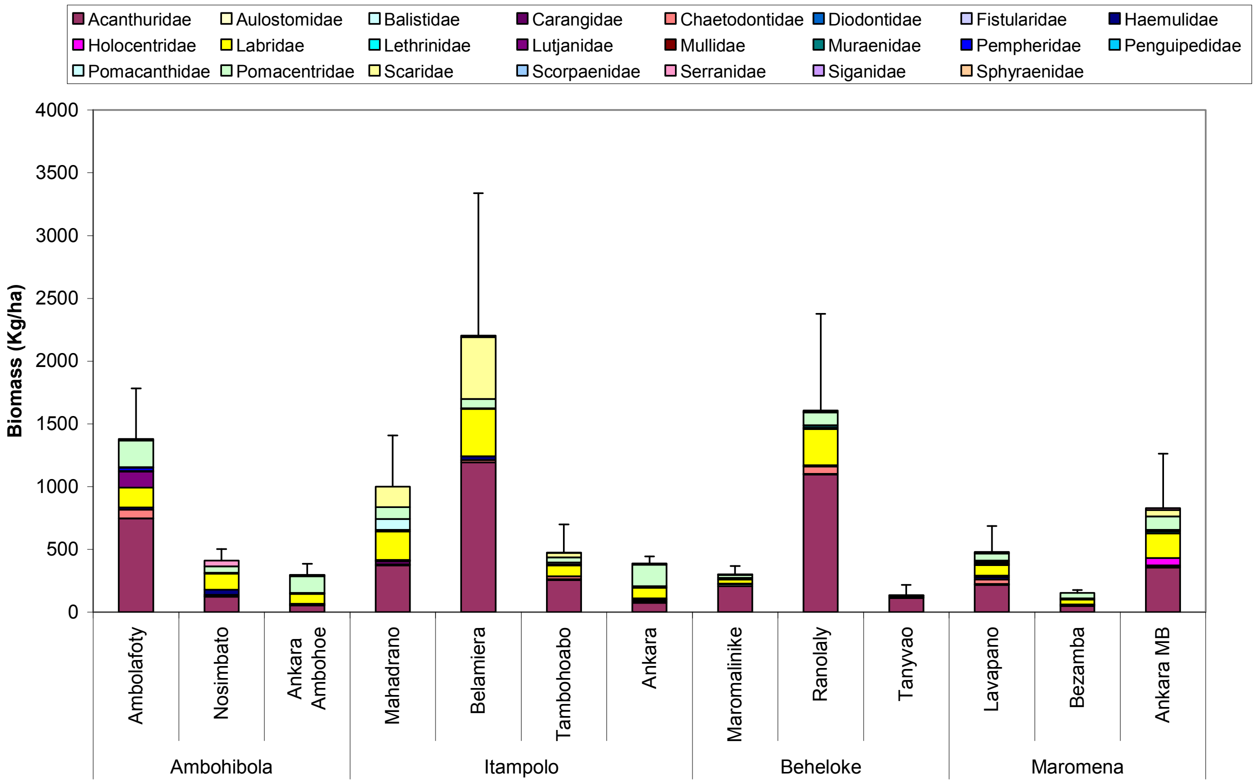

Figure 15 Biomass of Reef fish (Kg ha^{-1}) and contribution of fish families to biomass. (Error bars = ± Standard Error)

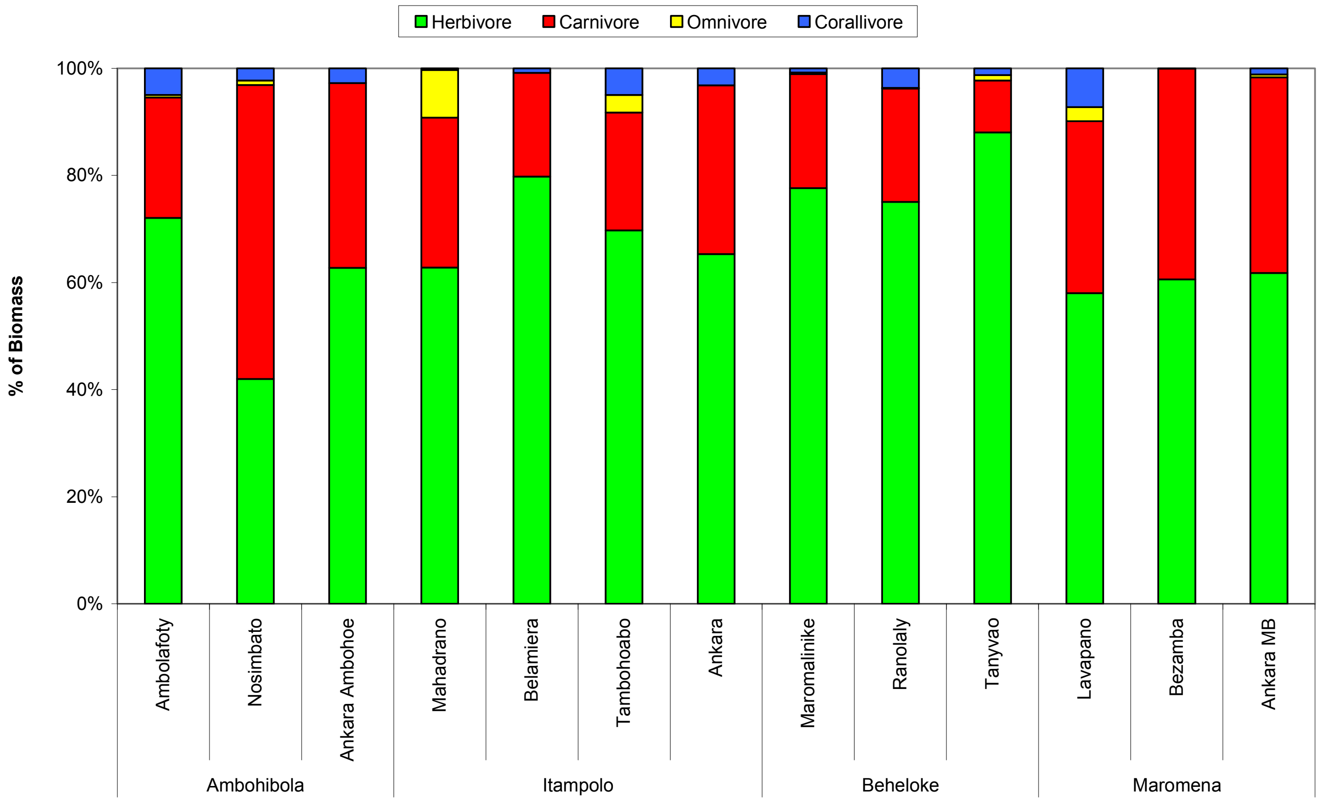

Figure 16 Percentage contribution of each trophic guild to total reef fish biomass

Urchin Diversity and Biomass

Urchin diversity and biomass was highly variable across all survey sites. With a maximum of 5 species of urchin observed at any one site, diversity remains relatively low at all sites with the highest diversity (SDI 0.5) found at Belamiera, in Itampolo (Figure 17).

Biomass of urchins was also highly variable, with the highest biomass found at Mahadrano (6022.92 Kg ha^{-1} ± 653.86 SE) and the lowest at Ambolafoty (0 Kg ha^{-1}± 0 SE) where urchins were absent.

Echinothrix diadema makes the greatest contribution to biomass at the majority of sites. At some sites however the greatest contribution comes from *Echinometra matheii*.

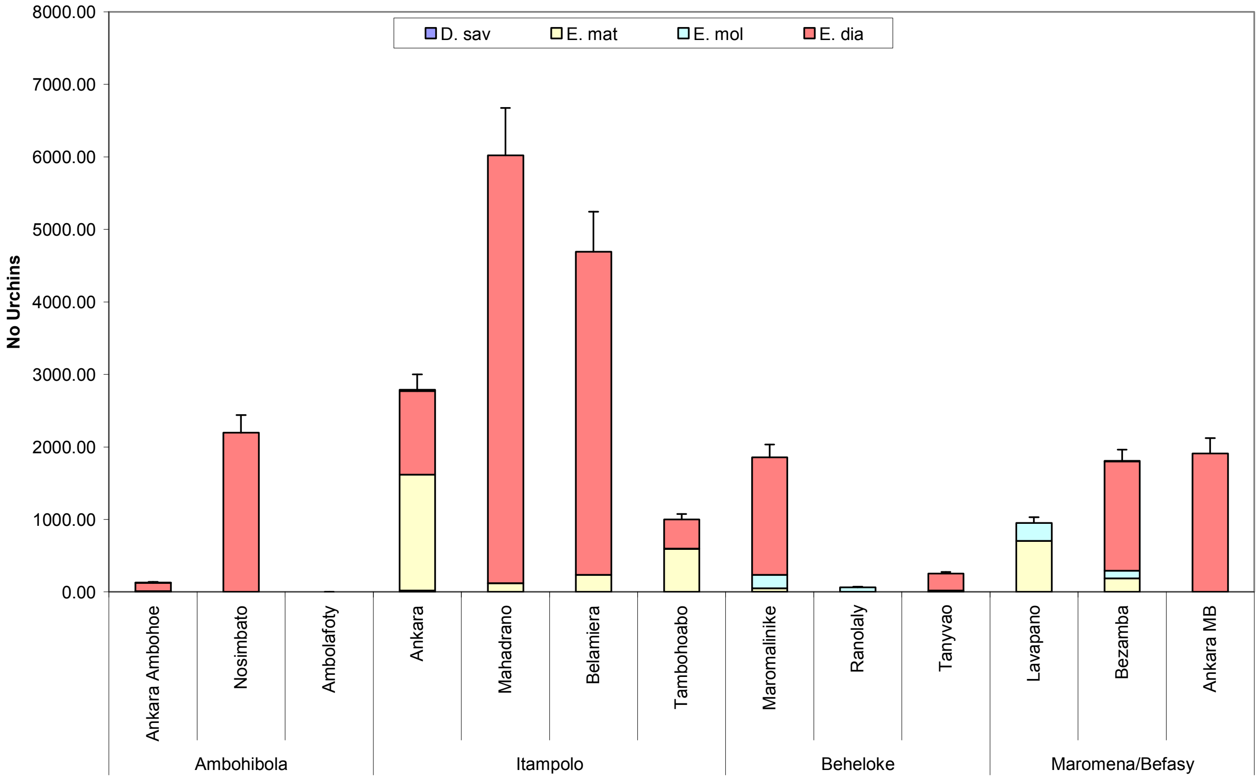

Figure 17 Contribution of sea urchin species to total urchin biomass (Kg ha^{-1}) (Error Bars = ± Standard Error)

Holothurian Diversity and Biomass

Sea Cucumbers were notably absent at many sites, and if present were relatively few in number (Figure 18). Sea cucumber diversity was low with only 3 species identified throughout the study period, *Actinopyga mauritiana*, *Holothuria edulis* and *Pearsonothuria graefii*.

The highest holothurian biomass was exhibited in the Maromena and Befasy management region. Lavapano displayed the highest biomass 0.47 Kg ha-1 ± 0.10 SE.

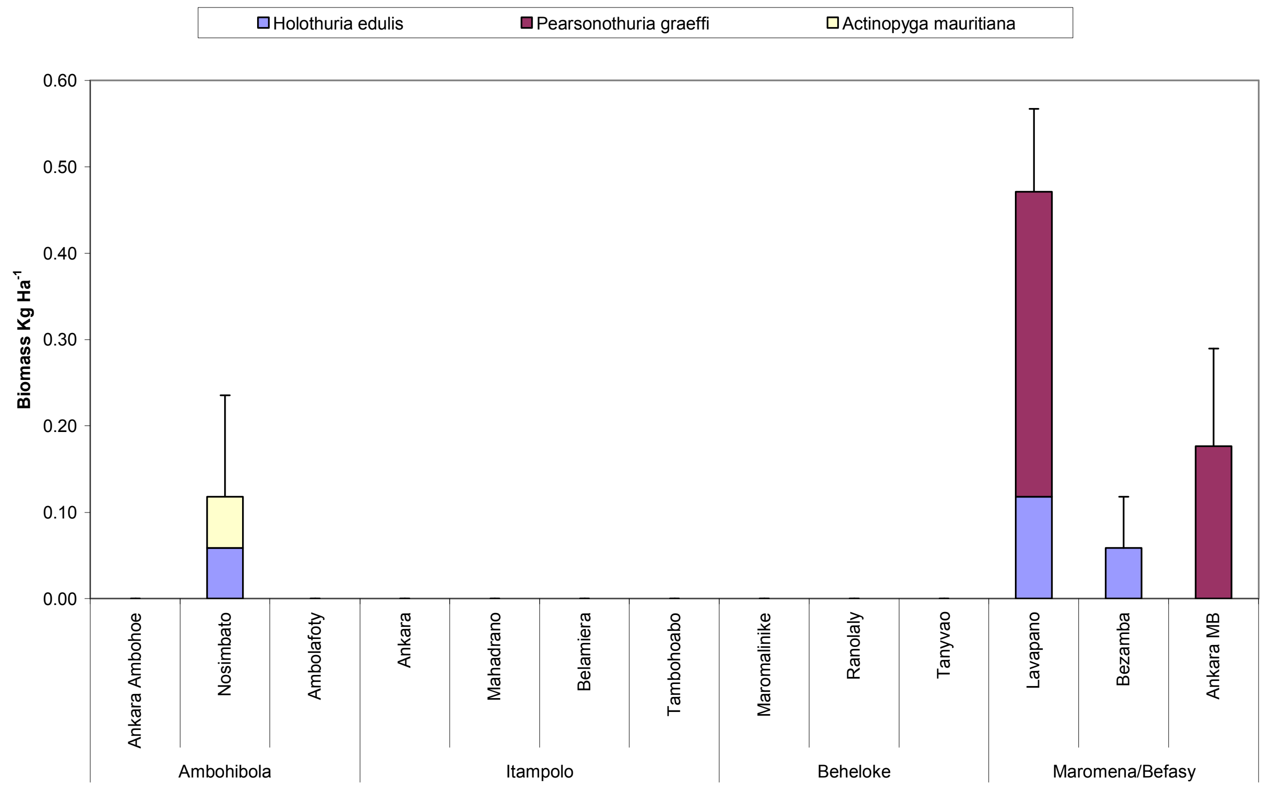

Figure 18 Species contribution to Holothurian biomass (Kg ha-[1]) (Error bars = ±Standard Error)

Maromena and Befasy

Benthic Composition

Bezamba exhibits the highest coral cover of the Maromena/Befasy reefs (36.87% ± 2.94 SE). However it also presents with the lowest richness (11 genera) and diversity with an SDI value of 0.7 due to a dominance of *Acropora* (45%) and *Pocillopora* (26%) species, which is consistent with a high energy, surge dominated environment.

After hard coral, coralline algae is the next most abundant benthic substrate (26.07% ± 3.76 SE) followed by turf and fleshy algae each contributing 19.85% (± 2.88 SE) and 16.00% (± 4.54 SE) respectively.

In contrast to Bezamba, turf algae is the dominant benthic substrate at Lavapano 34.55% (± 8.77 SE) with coralline algae (32.45% ± 5.70 SE) also making a substantial contribution to benthic substrate. Lavapano, despite exhibiting the lowest hard coral cover (19.83% ± 4.43 SE), displays a similar diversity to Bezamba, with 18 coral genera and an SDI of 0.75. Again SDI is low due to the samples being dominated by *Pocillopora* (42%) and *Porites* (24%) species.

Reef Fish Diversity

At Maromena and Befasy there is a marked difference in species richness, with the Patch (Ankara MB) and Barrier (Lavapano) reefs housing between 68 and 75 fish species, while the Fringing reef (Bezamba) had only 26 species.

This is also reflected in Simpsons Diversity Index which shows that Bezamba exhibits greater dominance by fewer species with an SDI 0.7, while Lavapano and Ankara MB have index values of 0.9, indicating a greater level of evenness.

Reef Fish Biomass

Maromena and Befasy also exhibit low biomass, with the fringing reef site Bezamba exhibiting the lowest biomass of 157.11 Kg ha-1 (± 24.11 SE), while Lavapano (555.93 Kg ha-1 ± 205.55 SE) and Ankara MB (963.11 Kg ha-1 ± 432.84 SE) house slightly higher but still relatively low levels of biomass.

The Herbivore:Carnivore ratio at these reefs remains about 3:2 with herbivores consisting predominantly of Acanthurids, Pomacentrids and Scarids, whilst carnivores comprise mainly of Labrid species.

Urchin Diversity and Biomass

In Maromena and Befasy the highest species richness is found at Bezamba, with five species of urchin observed, while the other two sites house only two species. Both Bezamba and Lavapano have diversity index values of 0.3, while Ankara MB has an index value < 0.1 demonstrating a dominance of the urchin community by the species *Echinothrix diadema*. Due to the large body size of these urchins Ankara MB also displays the highest biomass values of the three sites 1908.92 Kg ha^{-1} ± 212.05 SE with Bezamba also exhibiting a relatively high urchin biomass 1810.92 Kg ha^{-1} ± 164.30 SE.

Holothurian Diversity and Biomass

Two species of sea cucumber were identified on the reefs of Maromena and Befasy, *Holothuria edulis* and *Pearsonothuria graefii*. As previously noted, Lavapano exhibited the highest biomass of all sites, with both species present and a density of 27 individuals/ha ± 11.37 SE. Ankara MB displayed the second highest biomass 0.18 Kg ha-1 ± 0.11 SE while Bezamba had a biomass of only 0.06 Kg ha-1 ± 0.06 SE. High error margins are due to sea cucumbers being observed on few transects.

Beheloke

Benthic Composition

Survey sites in Beheloke exhibited evidence of a clear benthic shift towards erect macroalgal dominance, with turf algae dominating the benthos at Maromalinike (35.08% ± 8.17 SE), and coralline algae the principal benthic category observed at Tanyvao (29.97% ± 6.68 SE) and Ranolaly (56.23% ± 7.64 SE).

But while Tanyvao also shows elevated levels of turf and fleshy algal coverage (28.00% ± 6.37 SE and 10.23% ± 4.53 SE) Ranolaly displayed considerable abundance of turf algae (16.35% ± 4.80 SE) but little coverage by fleshy algal species (0.65% ± 0.0.42 SE).

Hard coral cover is highest at Tanyvao (24.10% ± 3.71 SE) but lowest at Maromalinike (15.93% ± 3.47 SE). Fleshy algae at Maromalinike show a similar contribution (16.07% ± 4.16 SE) as hard coral genera which indicate increasing competition for space between algae and corals.

Maromalinike not only shows the lowest coral cover but also exhibits the lowest coral diversity, with only 15 coral genera surveyed and an SDI value of 0.7. Ranolaly and Tanyvao, despite having the highest percentage coral cover exhibited greater dominance by *Pocillopora* and *Acropora* spp. resulting in a higher SDI value (0.8 and 0.9 respectively).

Reef Fish Diversity

Survey sites at Beheloke all exhibit similar diversity, with a richness of 41 species at Maromalinike and Tanyvao, and 42 species at Ranolaly. Simpsons index again indicates relatively low dominance by any single species with SDI values of 0.8 and 0.9 at all sites.

Reef Fish Biomass

Despite a similarity in diversity, Beheloke reefs display variable biomass, with Ranolaly exhibiting higher biomass (1620.02 Kg ha-1 ± 772.46 SE) than Maromalinike and Tanyvao, which displayed relatively low levels of biomass, 315.12 Kg ha-1 (± 65.04 SE) and 216.74 Kg ha-1 (± 83.40 SE) respectively.

Trophic guild analysis showed dominance of herbivorous fish (> 75%) with Acanthuridae providing greater than 65% of biomass at all sites.

Urchin Diversity and Biomass

In Beheloke, all sites exhibit low urchin diversity and biomass. Ranolaly has only one species present, the rock boring urchin *Echinostrephus molaris*, and so has the lowest diversity index (0) and also the lowest biomass (63.33 Kg ha^{-1} ± 7.04 SE). Maromalinike is also dominated by *Echinostrephus molaris* and so too has a relatively low diversity index value (0.1), but the highest biomass of the three sites (1856.75 Kg ha^{-1} 177.83 SE).

Tanyvao has 4 species of urchin present, each in relatively low numbers, although *Echinostrephus molaris* remains the dominant species, and the diversity index value is therefore higher at this site (0.3). However the biomass here remains relatively low at 250.58 Kg ha^{-1} ± 25.48 SE.

Holothurian Diversity and Biomass

Sea cucumbers were absent on all reefs in Beheloke**.**

Itampolo

Benthic Composition

Itampolo displayed remarkable variability in hard coral cover between survey sites. Belamiera and Tambohoabo displayed the lowest proportion of hard coral composition (19.35% ± 3.20 SE and 18.77% ± 2.85 SE), yet the highest SDI (0.9). While Mahadrano located in close proximity to Belamiera presented a higher percentage cover (29.48% ± 4.35 SE), but a lower SDI (0.8). Ankara in comparison exhibited the highest hard coral cover (53.17% ± 8.04 SE), yet, as previously stated, the lowest diversity (SDI 0.6), with *Montipora* spp dominating (58%) the hard coral fauna.

At sites where coral cover is low it is notable that coralline algae accounts for a large proportion of the remaining substrate. At Mahadrano 44.92% of benthic fauna (± 4.84 SE) and 59.98% at Belamiera (± 3.46 SE) are coralline algae, while at Tambohoabo the substrate is governed more by algal turf (38.10% ± 4.04 SE).

Reef Fish Diversity

Reef fish species richness was comparable between all four survey sites in Itampolo with the number of fish species identified varying between 43 (Tambohoabo) and 50 (Belamiera).

Simpsons Index also indicates relatively high diversity with low levels of single species dominance with SDI values of 0.9 at all sites.

Reef Fish Biomass

In Itampolo the mean biomass of reef fish was highest on the two barrier reef sites, Mahadrano 1022.24 Kg ha^{-1} (± 409.43 SE) and Belamiera 2295.05 Kg ha^{-1} (± 1136.52 SE), whilst the nearshore fringing and patch reef sites, Tambohoabo and Ankara had the lowest mean biomass 485.97 Kg ha^{-1} (± 225.25SE) and 389.02 Kg ha^{-1} (± 57.72 SE).

All sites in Itampolo were dominated by herbivorous fish with Acanthuridae, Pomacentridae and Scaridae species accounting for more than 60% of biomass on all sites.

Urchin Diversity and Biomass

Itampolo demonstrated relatively high levels of urchin diversity and biomass. Mahadrano exhibited the highest biomass 6022.92 Kg ha^{-1} ± 653.86 SE whilst Tambohoabo had the lowest 1000.08 Kg ha^{-1}.± 75.06 SE

Despite all sites showing similar species richness (between 4 and 6 species observed at each site) Ankara and Tambohoabo demonstrated lower SDI values (0.2) in comparison to Mahadrano and Belamiera indicating a dominance of the biomass by a single species, *Echinometra mathaeii*.

Holothurian Diversity and Biomass

Holothurians were absent on Itampolo reefs.

Ambohibola

Benthic Composition

Hard coral cover in Ambohibola was lower at the barrier reef site Ankara Ambohoe (34.22% ± 3.38 SE) than at both the patch, (Nosimbato) and fringing (Ambolafoty) reef sites which exhibited high levels of coral cover (67.02% ± 7.64 SE and 73.63% ± 4.20 SE respectively).

The hard coral community was characterised at all three sites by a dominance of *Montipora* spp., Ankara Ambohoe (36%), Nosimbato (53%), and Ambolafoty (40%). *Acropora* spp. formed a large proportion of the hard coral community at Nosimbato (16%) and Ambolafoty (22%) while Ankara Ambohoe exhibited lower values (6%) of *Acropora* spp., but a greater coverage from *Galaxea* spp. (21%).

A diversity index was calculated for corals, urchins and fish using the following form of the Simpson's Index, $1- \lambda = 1- (\Sigma p i^2)$, such that diversity increases with increasing SDI. Where $p_{i\,=}$ the proportion of the total count arising from the *i*th species (Magurran 1988).

Simpsons diversity index adjusts for the dominance of a single species, thus Nosimbato and Ambolafoty whose hard coral communities are characterised by dominance of *Montipora* and *Acroporas* have a lower coral diversity (0.7) value than Ankara Ambohoe (0.8), which exhibits lower levels of dominance.

Algal cover mirrored the hard coral cover with lower levels of turf (16.50 % ± 3.78 SE, 9.43% ± 3.63 SE) and fleshy (<1 % ± 0.13 SE, 6.63% ± 3.13 SE) algae at Ambolafoty and Nosimbato, whilst a higher level of algal cover was exhibited at Ankara Ambohoe (Turf algae 35.47% ± 5.89 SE), and fleshy algae 22.08% (± 5.09 SE). The fleshy algae at Ankara Ambohoe comprised mainly of phaeophytes *Sargassum* spp. and rodophyte *Eucheuma* spp.

Reef Fish Diversity

Reef fish species richness was highly variable at the 3 survey sites in Ambohibola. Ambolafoty exhibited the highest relative species richness of the sites with 62 species identified. This site is not only more diverse than the other sites but also shows a greater degree of evenness (SDI = 0.89).

Nosimbato and Ankara Ambohoe have similarly low levels of species richness, with 36 and 42 species identified at each site respectively.

However despite this similarity in species richness, Ankara Ambohoe appears to have greater diversity (SDI 0.9) than Nosimbato (SDI 0.6), possibly due to a large number of individuals from a single species.

Reef Fish Biomass

Fish biomass was highly variable on the reefs of Ambohibola with the fringing reef Ambolafoty having the highest biomass 1469.90 Kg ha^{-1} (± 242.03 SE), whilst the patch (Nosimbato) and barrier reef (Ankara Ambohoe) sites harboured lower biomass 412.46 Kg ha^{-1} (± 88.36 SE) and 346.69 Kg ha^{-1} (±87.98 SE) respectively.

Similarly to other sites in the survey Ambolafoty and Ankara Ambohoe both display trophic dominance by herbivorous fish (72 and 63% respectively) whilst Nosimbato appears to be more dominated by carnivorous fauna (55%). This may start to be explained by the large biomass contribution of the carnivorous family groups Labridae 127.856 Kg ha^{-1} (± 42.251 SE) and Serranidae 47.254 Kg ha^{-1} (± 23.255 SE) at this site.

Urchin Diversity and Biomass

Sea urchin diversity and biomass differed greatly at the three sites in Ambohibola, with Ambolafoty being notable by the absence of urchins. Nosimbato has the highest urchin biomass (2197.67Kg ha^{-1} ± 244.19 SE) of the three sites but the lowest diversity, with the population dominated solely by *Echinothrix diadema* species. Meanwhile Ankara Ambohoe has a relatively low biomass (124.42 Kg ha^{-1} ± 12.77 SE) with 2 species of urchin present.

Holothurian Diversity and Biomass

The only site to house sea cucumbers in the Ambohibola region was the patch reef, Nosimbato. This reef displays a density of 7 individuals ha^{-1} ± 0.11 SE with just two species identified as *Actinopyga mauritiana* and *Holothuria edulis*. The site exhibited a biomass of 0.12 Kg ha^{-1} ± 0.12 SE. The high margin of error is due to all sea cucumbers occurring in a single transect whilst there were none in all other transects.

Multivariate Analysis

MDS ordination plots representing survey samples as points in 2-dimensional space provide a useful means of identifying patterns of similarity in reef benthic composition. Clustering of samples can be identified between sites and other factors identified *a priori*, such as management areas and depths. In this case the relative distances between points represent the rank order of Bray-Curtis dissimilarities of samples.

Results indicate that replicate samples show varying degrees of similarity based on different factors, as shown for 5 m surveys in Figure 19. Samples from different survey sites generally cluster together (Figure 19), and there is notable grouping of sites from the Ambohibola management area, indicating dissimilarity from other management areas.

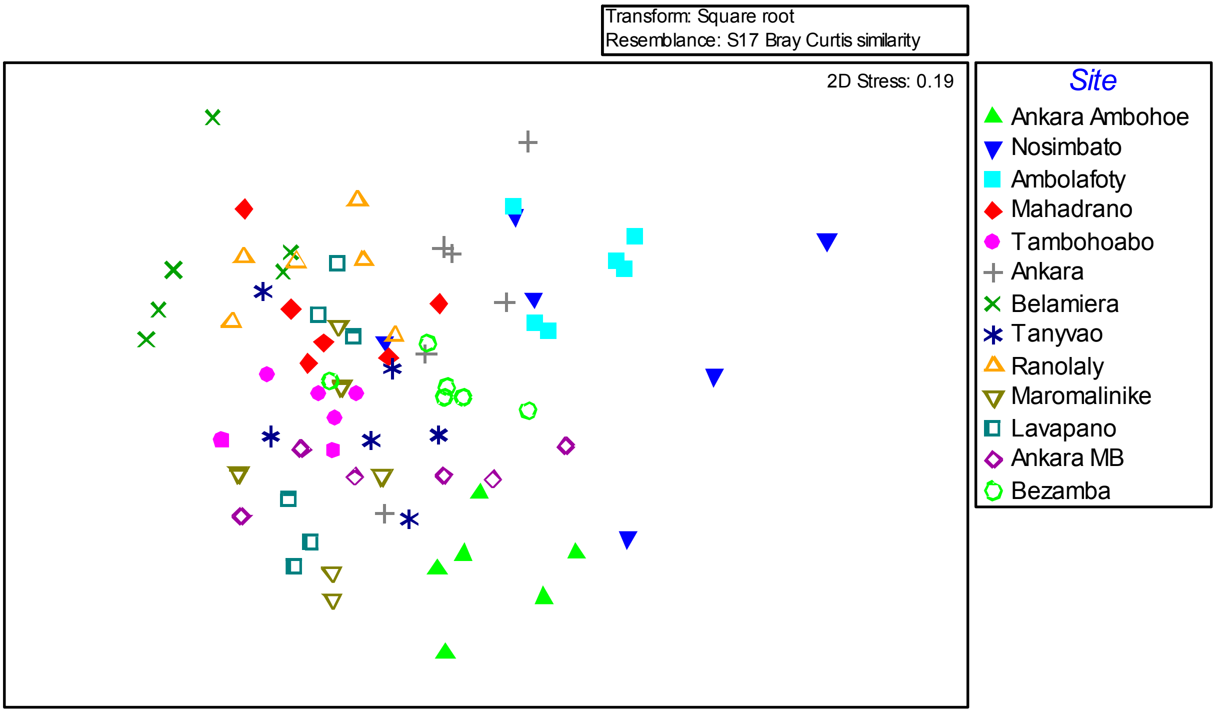

Figure 19 non-metric MDS ordination of samples (all replicates, all sites) based on intercept transect benthic community data.

Overlaying Bray-Curtis similarity clusters on these ordination plots emphasises similarities between samples, with Ambohibola sites generally grouping apart from other sites at a level of 65% Bray-Curtis similarity (Figure 20). This observation does not imply that different groups have no characteristics in common, but that different characteristic patterns of benthic composition are found consistently within the different groups. The effect of reef geomorphology is less clear, with little evidence of clustering of samples between barrier, fringing and patch reefs (Figure 21).

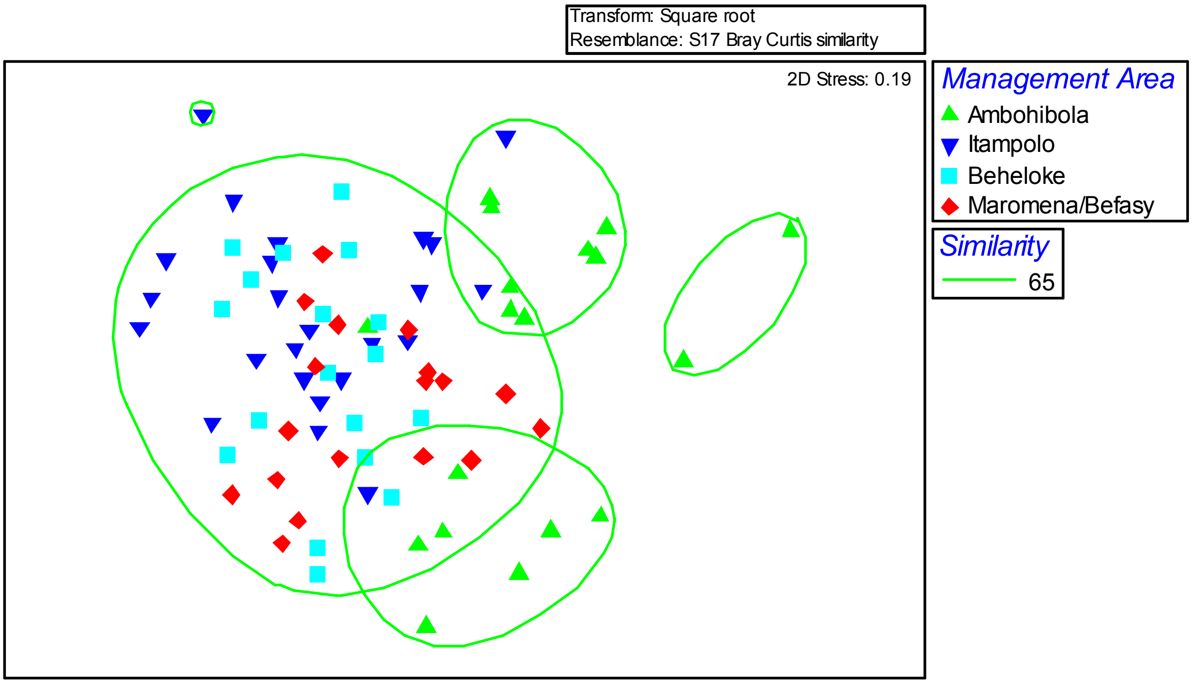

Figure 20 MDS ordination from Figure 19 labelling sites based on management area. Samples grouped based within Bray Curtis similarity boundaries at 65% similarity

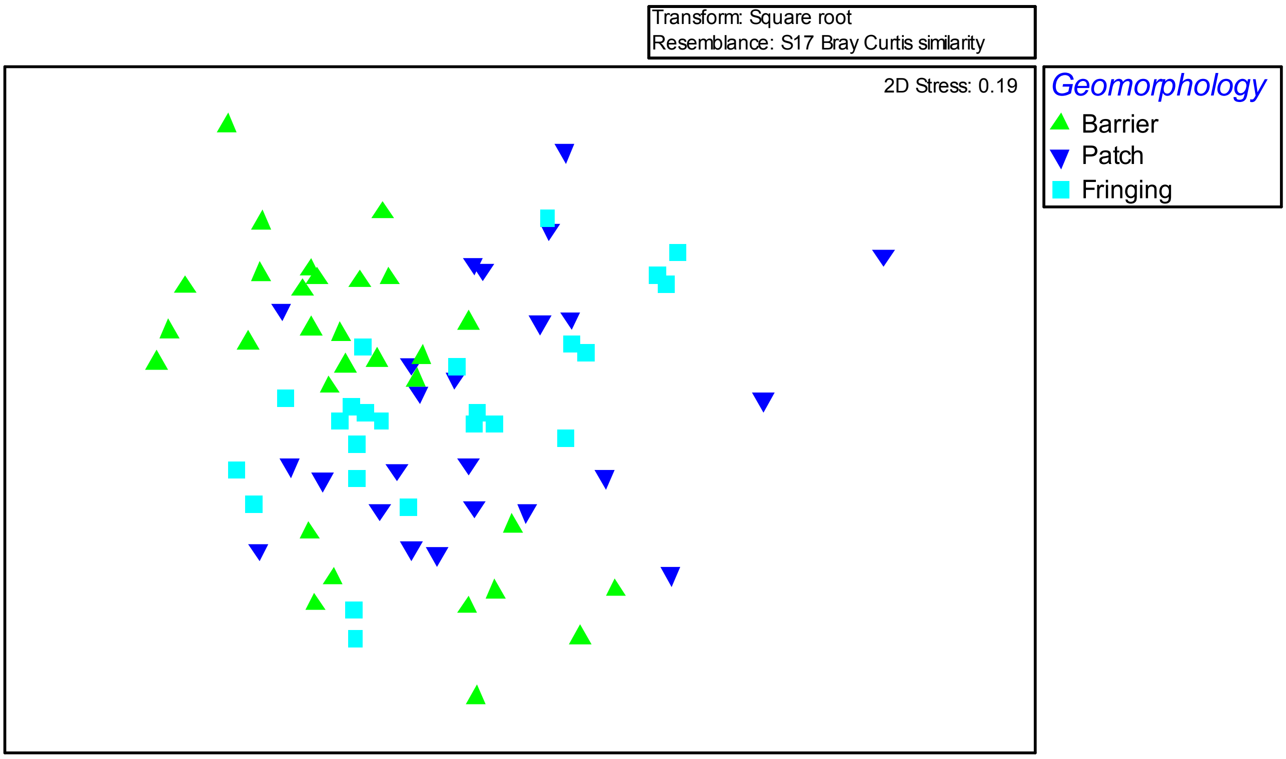

Figure 21 MDS ordination from Figure 19 labelling sites based on geomorphological class of reef.

Superimposing univariate hard coral cover values on the MDS plot shown in figure 19 clearly illustrates changes in this variable between sites, giving an indication of the importance of this variable in structuring the patterns of dissimilarity seen across the pool of samples (Figure 22).

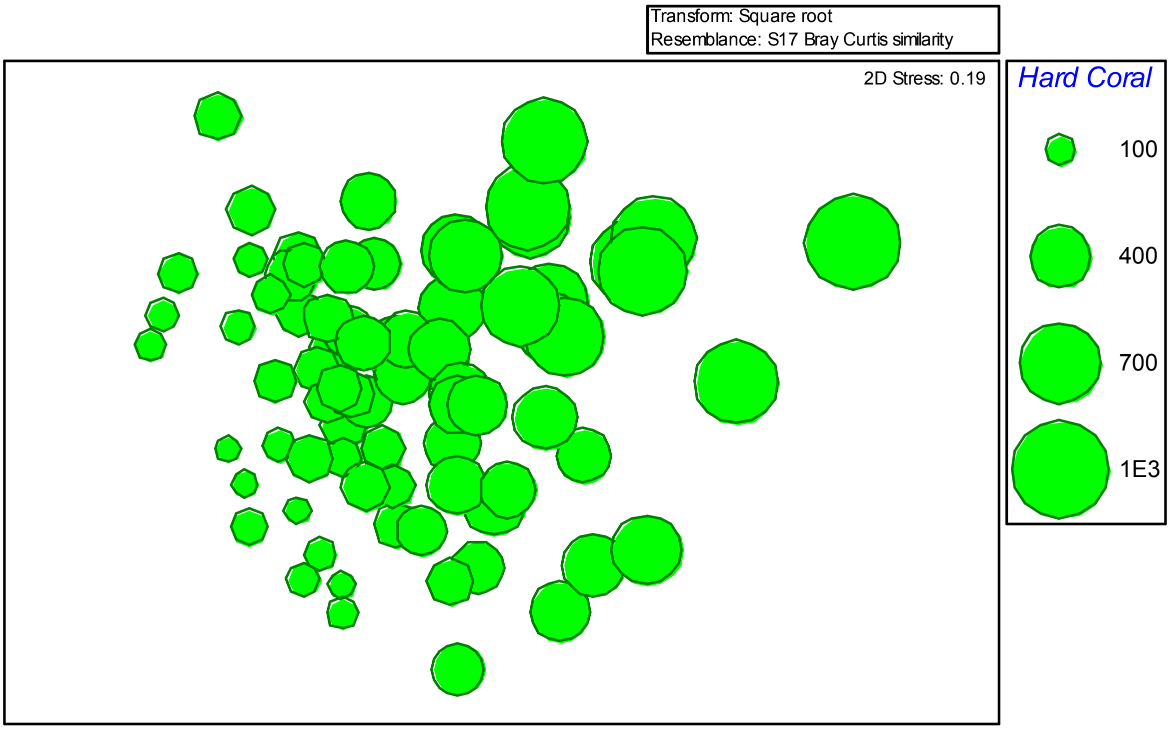

Figure 22 Bubble plot showing relative variation in hard coral cover between samples based on MDS ordination of Figure 19

Two-way crossed ANOSIM testing for benthic community differences between samples confirms the significance of the observed dissimilarities between different management areas (global $R = 0.50$, $p < 0.1\%$) and different reef geomorphologies (global $R = 0.43$, $p < 0.1\%$). This result suggests that different characteristic patterns of benthic composition are found consistently within the different groups.

Discussion

Here the main findings of this study are discussed. The relative health of the reefs in the four different survey areas are compared, and interpreted alongside the data from other studies that have been conducted both in Madagascar and the broader western Indian Ocean region. To conclude, the management implications of our findings are evaluated, focusing on how information gained during this study may be of benefit to coral reef conservation programmes being developed in the region.

Benthic Composition

Throughout this study the general observation was one of relatively poor reef health with low levels of scleractinian coral cover. Typical coral cover on all reef types was below 35%, with high coverage of erect fleshy algae, generally above 5% and algal turfs covering approximately 20%. The three sites exhibiting high coral cover (Ambolafoty, Nosimbato, and Ankara) were the exception rather than the rule.

The ASEAN (Association of South East Asian Nations) system for describing the health of coral reefs states that coral reefs with hard coral cover less than 25% are described as being in 'poor' health, whilst those of cover in excess of 25% are described as 'fair' (Wilkinson 1984).

Using the ASEAN classification, 6 of the sites surveyed out of 13 would therefore be described as being of poor health, while only 4 of the sites exhibit sufficiently high coral cover to be described as being in good/excellent health.

Table 1 Health value of survey reef sites south of Toliara, southwest Madagascar

Village	Site Name (M - Managed)	% Hard Coral Cover	Coral Health Value
Ambohibola	Ankara Ambohoe	34.22	Fair
	Nosimbato	67.02	Excellent
	Ambolafoty	73.63	Excellent
Itampolo	Ankara	53.17	Good
	Mahadrano	29.48	Fair
	Belamiera	19.35	Poor
	Tambohoabo	18.77	Poor
Beheloke	Maromalinike	15.93	Poor
	Ranolaly	23.92	Poor
	Tanyvao	24.10	Poor
Maromena/Befasy	Lavapano	19.83	Poor
	Bezamba	36.87	Good
	Ankara MB	27.25	Fair

The reefs of Ambohibola appear to be in the best health of the reefs that we surveyed, with the nearshore, patch and fringing reefs, Nosimbato and Ambolafoty, two of only three sites in the survey to exhibit greater than 50% hard coral cover.

The values seen at Nosimbato, Ambolafoty and Ankara are similar to values of hard coral cover observed on offshore patch reefs in Andavadoaka, where fishing levels are lower than on other reefs in the area (Harding *et al.* 2006).

Variability in hard coral cover, from 16% to 74% with standard errors from 2 to 8% indicates that there is considerable heterogeneity between, as well as within survey sites, similar to that observed in other areas of southwest Madagascar (Harding *et al.* 2006; Ory 2008; Harris 2009) as well as that recorded in Kenya, the Seychelles, Comoros and Mauritius (Engelhardt 2004; Ledlie *et al.* 2007; Graham *et al.* 2007; Ahamada *et al.* 2008; Hagan *et al.* 2008; McClanahan *et al.* 2006b) in recent years (Table 2).

Sites that exhibited high percentage coral cover generally displayed lower generic scleractinian diversity, with corals being dominated by a single or few genera. For example Ambolafoty, Nosimbato and Ankara exhibited dominance of *Montipora* spp., which, consistent with other species from the Acroporidae family show a preference for clear waters in high energy environments (Veron 2000).

The most notable of the three exceptional reefs surveyed is Ankara in Itampolo, which despite being particularly shallow (< 6m) as well as in close proximity to the beach and fishing access, displays extensive coral cover (53.17 ± 8.04 SE).

Most reefs in Itampolo, Beheloke and Maromena/Befasy show relatively low levels of coral cover, indicative of poor reef health. However they exhibit relatively high coral diversity (average SDI 0.8 ± 0.03 SE) which may indicate competition between recruiting corals and algae for space within the reef community. Future disturbances to these reef communities, for example by high levels of exploitation, nutrient enrichment, or bleaching related mortality may allow this disequilibrium to shift into an algal-dominated phase (Knowlton 1992; Knowlton 2004) from which it is increasingly difficult for corals to recover (Mumby *et al.* 2007).

The reefs that exhibit lower levels of hard coral cover frequently display high levels of coralline red algae. Encrusting red algae plays a key role in stabilising broken and mobile rubble within the benthic community, as well as providing a favoured substrate for recruitment of juvenile corals.

These reefs also exhibit variable coverage by algal turf. This matt-forming algae has been shown to be the only form of reef benthos that persists despite intense grazing by high densities of sea urchins (Muthiga & McClanahan 1987). High levels of turf algae may mean that juvenile corals are unable to settle and the systems' equilibrium is shifted. Without the consolidation and complexity that hard coral structures provide, systems are more susceptible to physical stress such as currents and wave action (Obura & Abdulla 2008), and reduced reef complexity has been reported to directly influence reef fish diversity (Graham *et al.* 2006; Wilson *et al.* 2006). High densities of sea urchins also competitively exclude other herbivores, particularly fish species, therefore undermining the natural trophic structure of the reef system(Carreiro-Silva & McClanahan 2001).

Fleshy algae cover does not yet surpass that of hard coral. The benthic substrate at all of the reefs surveyed exhibit an abundance between 5 and 20%. This may be an indication that levels of herbivory, from both urchins and fish, are still relatively high and fleshy algae populations are being maintained. However it should be noted that these levels, are extremely high compared to historical values from southwest Madagascar (Figure 2) (Pichon 1979).

Table 2 Table comparing data from other studies conducted throughout Madagascar and the Western Indian Ocean (Walker & Fanning 2003; Engelhardt 2004; Graham *et al*. 2006; Harding 2006; McClanahan *et al.* 2006b; WWF 2006; Ledlie *et al.* 2007; WWF 2007; Graham *et al*. 2007 ; Ahamada *et al.* 2008; Hagan *et al.* 2008; Harding & Randriamanantsoa 2008; Ory 2008). Ma = Madagascar, Mau = Mauritius, Sey = Seychelles.

Location			Reference		Benthic		Fish			Urchins	Holothurians
Country	Village	Site Name (M - Managed)		Year	Hard Coral % Cover	SEM	Species Richness	Mean Biomass Kg/ha	SEM	Biomass (Kg/ha)	Average Density/ha
Madagascar	Ambohibola	Ankara Ambohoe	Present Study	2008	34.22	3.38	42	296.92	21.99	124.42	0.00
		Nosimbato	Present Study	2008	67.02	7.64	36	412.38	22.09	2197.67	6.67
		Ambolafoty	Present Study	2008	73.63	4.20	62	1378.37	100.82	0.00	0.00
	Itampolo	Ankara	Present Study	2008	53.17	8.04	48	386.52	14.43	2790.67	0.00
		Mahadrano	Present Study	2008	29.48	4.35	49	998.49	102.36	6022.92	0.00
		Belamiera	Present Study	2008	19.35	3.20	50	2202.12	284.13	4690.08	0.00
		Tambohoabo	Present Study	2008	18.77	2.85	43	474.07	56.31	1000.08	0.00
	Beheloke	Maromalinike	Present Study	2008	15.93	3.47	41	301.64	16.26	1856.75	0.00
		Ranolaly	Present Study	2008	23.92	4.10	42	1604.31	193.11	63.33	0.00
		Tanyvao	Present Study	2008	24.10	3.71	41	135.02	20.85	250.58	0.00
	Maromena and Befasy	Lavapano	Present Study	2008	19.83	4.43	68	479.10	51.39	951.92	26.67
		Bezamba	Present Study	2008	36.87	2.94	26	153.39	6.03	1810.25	3.33
		Ankara MB	Present Study	2008	27.25	3.32	75	829.18	108.21	1908.92	10.00
Madagascar	NW Madagascar	Sahamalaza (M)	Harding and Randriamanantso	2008	16.40	2.50	X	252.00	16.40	0.00	105.00
		Tanjona (M)	Harding and Randriamanantso	2008	12.10	1.10	X	110.50	12.10	13.53	0.00
		Cap Masoala (M)	Harding and Randriamanantso	2008	13.00	1.60	X	95.70	13.00	27.64	10.00
		Tampolo (M)	Harding and Randriamanantso	2008	24.30	3.50	X	163.40	24.30	50.67	30.00
		Mananara (M)	Harding and Randriamanantso	2008	13.40	1.70	X	102.40	13.40	29.07	5.00
Madagascar	Andavadoaka	SA	Harding et al.	2006	22.50	X	71.00	403.42	104.91	0.00	80.00
		NF	Harding et al.	2006	17.25	X	74.50	302.95	64.89	0.00	26.67
		Valley	Harding et al.	2006	13.75	X	81.50	425.68	76.05	41.59	26.67
		THB	Harding et al.	2006	40.25	X	68.50	660.27	446.17	30.47	66.67
		OO7	Harding et al.	2006	49.67	X	60.00	513.83	70.95	234.70	80.00
		Recruitment	Harding et al.	2006	46.00	X	54.50	351.50	144.47	0.00	80.00
		Coco beach	Harding et al.	2006	32.25	X	80.00	463.77	288.78	0.00	53.33
		Andava Rock	Harding et al.	2006	8.75	X	62.50	396.06	242.16	223.40	26.67
		HalfMoon	Harding et al.	2006	4.00	X	64.50	52.53	3.14	700.20	0.00

Table 2 – continued

Location			Reference		Benthic		Fish			Urchins	Holothurians
Country	Village	Site Name (M - Managed)		Year	Hard Coral % Cover	SEM	Species Richness	Mean Biomass Kg/ha	SEM	Biomass (Kg/ha)	Average Density/ha
Madagascar	Ranobe	Ankaran-djelita	Nicolas Ory	2008	57.00	4.20	37.2	X	X	X	X
		Cathédrale	Nicolas Ory	2008	18.60	0.50	34.3	X	X	X	X
		Vato Be	Nicolas Ory	2008	12.00	5.70	36.4	X	X	X	X
		Coral Garden	Nicolas Ory	2008	35.30	10.00	42.8	X	X	X	X
		Massif des roses (M)	Nicolas Ory	2008	44.10	10.60	36.4	X	X	X	X
		Beantsitsy	Nicolas Ory	2008	59.40	8.40	25.5	X	X	X	X
Ma	Anakao	Soalara/Anakao	Walker and Fanning, Frontier	2002	X	X	26.71	1460.00	X	308.9	X
Ma	Salary	Salary North	WWF MG0885	2006	33.10	3.92	48.50	X	X	X	X
Ma	Tulear South	Beheloke to Itampolo	WWF MG0885	2006	32.07	X	40.80	1364.9	615.40	X	X
East Africa	Tanzania	Managed (M)	McClanahan et al 2006	2004	27.8	4.3	41.10	457.40	7.90	1800	X
	Kenya	Protected (M)	McClanahan et al 2006	2004	32.7	5.8	47.40	1354.20	89.10	960	X
	Kenya	Fished Control	McClanahan et al 2006	2004	19.70	2.50	X	81.9	9	3687.4	X
	Kenya	Unfished Control	McClanahan et al 2006	2004	22.20	3.50	X	1204.70	34.70	384.5	X
Seychelles		Marie-Louise	Hagan et al 2008	2005	16	X	X	X	X	X	X
		Boudeuse	Hagan et al 2008	2005	7	X	X	X	X	X	X
		Poivre	Hagan et al 2008	2005	9	X	X	X	X	X	X
		Alphonse	Hagan et al 2008	2005	22	X	X	X	X	X	X
Sey		Seychelles (78 different sites)	Engelhardt 2004	2004	10.2	X	86	X	X	X	X
Sey		Cousin Island	Ledlie 2007	2005	<1	X	X	X	X	X	X
Sey			Graham et al 2006	2005	X	X	X	157.40	X	X	X
Mau	Port-Louis	Pointe aux Piments	Graham et al 2007	2005	43	10	101	X	X	X	X

Table 2 – continued

Location			Reference		Benthic		Fish			Urchins	Holothurians
Country	Village	Site Name (M - Managed)		Year	Hard Coral % Cover	SEM	Species Richness	Mean Biomass Kg/ha	SEM	Biomass (Kg/ha)	Average Density/ha
West Indian Ocean	Comoros	Bimbini	Ahamada et al 2008	2007	24.00	X	X	X	X	X	X
		Moheli (M)	Ahamada et al 2008	2007	72.00	X	X	X	X	X	X
		Fomboni	Ahamada et al 2008	2007	30.00	X	X	X	X	X	X
		Comoros (mean)	Ahamada et al 2008	2007	65.70	5.00	X	X	X	X	X
	Mayotte		Ahamada et al 2008	2007	70.00	X	X	X	X	X	X
	Mauritius		Ahamada et al 2008	2007	16.00	5.00	X	X	X	X	X
	Rodrigues		Ahamada et al 2008	2007	34.80	4.00	X	X	X	X	X
	Reunion	Trois Chameux	Ahamada et al 2008	2007	29.80	X	X	X	X	X	X
		Planch'Alizes	Ahamada et al 2008	2007	26.30	X	X	X	X	X	X
		Etang Sale	Ahamada et al 2008	2007	37.30	X	X	X	X	X	X
		St Pierre	Ahamada et al 2008	2007	74.00	X	X	X	X	X	X
		Reunion (mean)	Ahamada et al 2008	2007	42.30	X	X	X	X	X	X
	Seychelles	Curieuse (MP)	Ahamada et al 2008	2007	24.60	X	X	X	X	X	X
		Amirantes Islands	Ahamada et al 2008	2007	7.00	X	X	X	X	X	X
		Seychelles (mean)	Ahamada et al 2008	2007	24.60	2.00	X	X	X	X	X
Chagos		Egmont	Sheppard and Harris 2008	2008	6.00	X	X	X	X	X	X
		Diego Garcia	Sheppard and Harris 2008	2008	87.00	X	X	X	X	X	X

This suggests that disturbance to reef health has occurred at these sites, presumably through a combination of direct anthropogenic disturbances and bleaching-related coral mortality episodes.

This may not be the case for all reefs in the area, however based on observations gathered by the research team whilst surveying and carrying out reconnaissance of the sites, it can be assumed that this may the case, as other reefs in the region generally appeared to be in lower condition to those that were surveyed. This observation is perhaps unsurprising, given that survey site locations were selected based on local knowledge and understanding of the locations of healthy coral reef areas as well as the ability of surveys sites to indicate change over time. The results of this survey are therefore likely to reflect the upper limits of coral cover and reef health within each management area, whilst other reefs within these areas may be in poorer condition.

Fish

Fish Diversity was similar throughout the study with all sites displaying a Simpson's Diversity Index (SDI) of between 0.6 and 0.9. This comparable figure of species diversity not only accounts for the number of species in a sample but also their relative dominance. The SDI value thus increases with increasing diversity and evenness (Magurran 1988). Fish species richness and community composition were also similar between survey sites with observations of between 40 and 50 species per site.

It is not possible to extrapolate total estimated species richness from the data contained in this study, as has been carried out using timed biodiversity surveys in other areas in Madagascar (McKenna & Allen 2003; Harding *et al.* 2006). However extrapolation from the WWF 2006 Marine diagnosis estimated total reef fish diversity for this survey area at 393 species.

Species richness and diversity in the reefs south of Toliara are similar to that observed in other areas of western Madagascar (Harding et al. 2006; Harding and Randriamanantsoa 2008; Ory 2008) and that recorded in managed areas in Kenya (McClanahan et al. 2006b), while lower than that observed in Mauritius and the Seychelles (Engelhardt 2004; Graham *et al.* 2007)

Further examination of the species composition shows that herbivorous fish families such as Acanthuridae, Pomacentridae and Labridae account for a large proportion of this diversity. This is similar to observations from fringing and barrier reef sites in the vicinity of Andavadoaka (Harding 2006), which are described as being subjected to moderate levels of fishing pressure. These patterns of fish species community composition are also similar to that observed on fished reefs in Kenya (McClanahan *et al.* 2006b), Rodrigues, Reunion, Mauritius and the Seychelles (Graham *et al.* 2007; Ahamada *et al.* 2008). While reefs such as the offshore patch sites of Andavadoaka, protected areas in Kenya and other unexploited or protected reefs of the Indian Ocean (McClanahan *et al.* 2006a; McClanahan *et al.* 2006b; Ahamada *et al.* 2008; Campbell *et al.* 2008) exhibit greater family diversity, in particular Serranidae, Lethrinidae and Lutjanidae. It has been demonstrated that on reefs, such as Kingman reef in the Line Islands, south of Hawaii, not been subjected to fishing pressures, predatory fish species dominate the ecosystem accounting for around 85% of fish biomass (Pala 2007), a vastly different picture to that observed during this survey or indeed elsewhere in Madagascar or the wider Western Indian Ocean. The lower abundance and biomass of these species recorded during this study may be attributable to the inherent variability of underwater visual census technique; families such as Lutjanidae, Serranidae and Lethrinidae are commonly under-represented by UVC surveys (McClanahan *et al.* 2007). To account for potential methodological bias, it may be useful to carry out comparative analysis of the abundance and diversity seen on UVC surveys with catch and effort surveys conducted in each of the villages (Connell *et al.* 1998), however fisheries landings monitoring was beyond the remit of this study.

These fish families commonly show high vulnerability to fishing pressure, mainly due to long population doubling times (Cinner *et a*l. 2005b). Consequently the relative scarcity of Lutjanidae, Serranidae and Lethrinidae in this study may be an indication of unsustainable exploitation.

Fish biomass at the survey sites (753.89 kg ha^{-1} ±173.13 SE) was generally higher than observed on reefs north of Toliara in Andavadoaka (335 kg ha^{-1} ±126.9 SE) (Harding *et al.* 2006) but lower than reefs surveyed at Sahamalaza MPA in the northwest of Madagascar (929 kg ha^{-1}) (Harding and Randriamanantsoa 2008).

Reef fish biomass levels throughout the study show similarity to those recorded in other surveys on reefs in the same region of southwest Madagascar (640 kg ha^{-1}± 170 kg ha^{-1}SE) (Woods-Ballard *et al.* 2003) and also similar to Kenyan reefs (McClanahan *et al.* 2006b).

Fish biomass on 'pristine' reefs in Kenya has been estimated at 1200 kg ha^{-1} (McClanahan 2006a). While some of the reefs in the present study exhibit much higher levels than this they exhibit a number of other characteristics that suggest their condition is far from pristine. These conflicting indicators suggest that the reefs of southwest Madagascar may be able to accommodate a higher total fish biomass than Kenyan coastal reefs.

Fish biomass is higher on the offshore reefs of Belamiera, Ranolaly, Lavapano and AnkaraMB. This may be indicative of higher fishing pressures on the more accessible nearshore sites, a conclusion which has been drawn from other studies conducted in the region (Nadon *et al.* 2005; Harding *et al.* 2006).

Nosimbato, a lagoonal patch reef in Ambohibola is noteworthy as the only site where the biomass of carnivorous fish, particularly Labrid species, exceeds that of herbivorous species. This elevated biomass may be the result of the presence of abundant small-bodied species which have been shown to benefit from increased fishing pressure through the removal of either predatory or competitive species (Russ 1989; McClanahan *et al.* 1999).

Despite some still encouraging levels of fish biomass these reefs exhibit signs of exploitation, possibly induced by 'fishing down marine food webs' (Pauly *et al.* 1998). The trophic structure of reef fish on almost all reefs surveyed in this study shows dominance of herbivorous fish species (Figure 16, Figure 23). However, previous studies from the reefs of Toliara and elsewhere in the western Indian Ocean region (Harmelin-Vivien 1979; Chabanet 1994; Chabanet 2002; Durville *et al.* 2003; Chabanet and Durville 2005), show that reef fish assemblages were formerly dominated by higher trophic guilds (Table 3).

The explanation for this comes from the primary extraction of larger, more commercially-valuable piscivorous fish species such as Serranids and Lutjanids causing 'trophic cascades' (Coleman & Williams 2002). These larger carnivorous fish have a tendency to show greater longevity and lower fecundity than smaller fastgrowing species, making their populations more susceptible to overfishing (Pauly *et al.* 1998).

While it has recently been shown that omnivorous fish populations, like other reef dwelling species, are positively correlated to live coral cover (Patterson *et al.* 2008) there is limited understanding of the effects of fishing on omnivores or planktivores. However it can be assumed that these species may exhibit similar responses to fishing down marine food webs as herbivorous species (Pauly *et al.* 1998; Coleman & Williams 2002), thriving in the absence of predation and reduced competition from the more commercially valuable carnivorous fish species.

Overfishing is a major factor driving reef degradation. High fishing pressure can alter reef community structure, reduce species diversity and cause the removal of keystone species, as well as potentially removing entire functional groups from the ecosystem and thereby destroying integral ecosystem processes, functions and resilience (Roberts 1995).

Table 3 Table of reef fish trophic biomass updated from Gillibrand *et al*. 2007

Location	Observer	Year	Carnivore (%)	Herbivore (%)	Other (%)
South Madagascar	Harmelin-Vivien 1979	1979	74	14	12
Réunion	Chabanet 1994	1994	51	25	24
Mayotte	Chabanet 2002	2002	69	18	12
Geyser & Zélée	Chabanet *et al*. 2002	2002	69	15	16
Glorieuses	Durville *et al*. 2003	2003	73	15	12
Juan de Nova	Chabanet & Durville 2005	2005	73	11	16
Andavadoaka (Madagascar)	Gillibrand & Harris	2004	76	13	11
SW Madagascar -Andavadoaka	Harding *et al*. 2006	2006	34	62	4
SW Madagascar - Ranobe	Ory 2008	2008	32	47	21
SW Madagascar - S Tulear	Gough (Present Study 2008)	2008	29	67	4

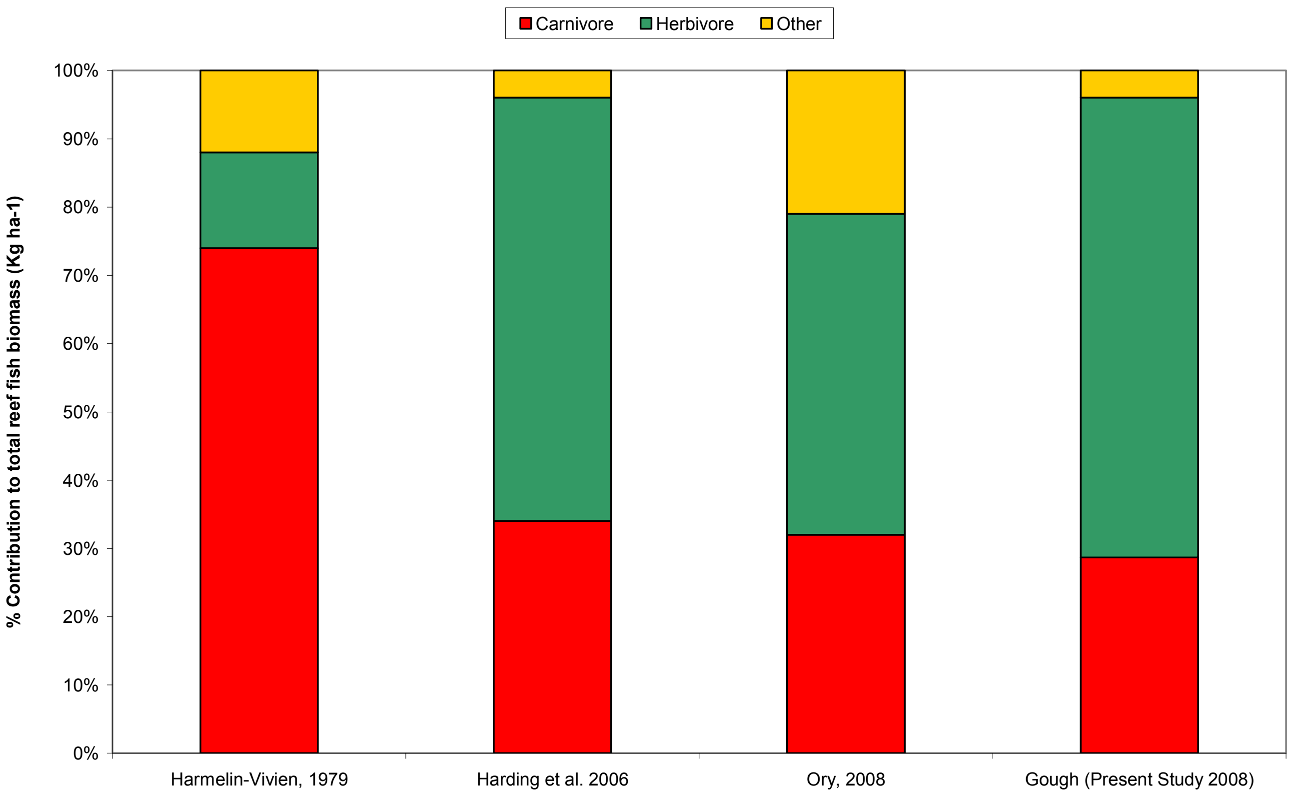

Figure 23 Graph depicting change in trophic guild dominance on reefs of southwest Madagascar between 1979 and the present

A brief socio-economic survey of coastal communities within the study area found that more than 90% of economic activities are marine-based (WWF 2007). The survey indicated that the 5 main species of target fish are: Siganidae (Keliholy), Lethrinidae (Angelike), Scaridae (Bodoloha), Acanthuridae (Fiantsifa and Angy). It is likely that exploitation has resulted in the reduction in populations of larger more economically valuable species, such as Serranidae (Lovo) and Lutjanidae (Amporama) which would have been preferentially targeted by fishers in the past (Langley 2006). Consequently fishers today are targeting species that are still abundant on the reefs, which are predominantly herbivorous species, a consequence of the 'shifting baseline' phenomena (Bellwood *et al.* 2004; Bunce *et al.* 2007) where fishers wrongly perceive ecosystems and resources at their current levels to be the norm, and fail to recognise changes caused by over-exploitation.

If fishers continue to exploit remaining fish populations at unsustainable levels of extraction this may result in a collapse of herbivorous fish populations. A loss of herbivory would pose a major threat to reef stability and resilience, since herbivorous fish play a crucial role in regulating algal biomass through grazing. In doing so healthy herbivorous fish populations are fundamental to maintaining reef community structure and in preventing benthic phase shifts from coral to algal dominance (Wilder 2003).

Urchins

Levels of urchin biomass also indicate that the reefs surveyed are experiencing unsustainable levels of fishing, with many of the survey sites exhibiting urchin biomass levels similar to unprotected and overfished reefs in Kenya (McClanahan *et al.* 2006b).

The reefs surveyed also exhibit higher levels of urchin biomass than other areas of Madagascar (Harding *et al.* 2006; Harding & Randriamanantsoa 2008).

Sea urchin abundance and diversity is a key indicator of the inhibition of hard coral growth and recovery (Obura & Grimsditch 2008).

The Triggerfish, *Balistapus undulatus* is recognised as a keystone species on East African reefs , being responsible for almost 80% of observed urchin predation (McClanahan 2000b; McClanahan & Muthiga 2006). Other competitive predators include *Balistapus viridescens*, *Cheilinus trilobatus* and *Cheilinus undulatus*. It is notable that *Balistapus undulatus* was observed only once throughout the surveys at Tanyvao, while *B. viridescens* and *C. undulatus* were absent from all samples. *C. trilobatus* was observed at a number of sites although not in any considerable abundance. *C trilobatus* is one of the main competitors of *B. undulatus* and despite being the subordinate when in direct competition *C. trilobatus* may display characteristics that make it more resilient to overfishing, providing a potential explanation for its presence in these surveys (McClanahan 2000b).

Removal of predatory fish such as Balistidae, commonly results in proliferation of urchin populations. Urchins play an important role in regulating reef benthic community structure by grazing algae so that areas are available for colonisation by recruiting corals. However, if urchin numbers increase due to removal of their predators, this grazing may have a detrimental effect on corals due to increased bioerosion (Carreiro-Silva & McClanahan 2001), as well as further exacerbating the reduction of herbivorous fish populations, through competitive exclusion of various species (McClanahan & Kaunda-Arara 1996).

Elevated levels of urchin grazing have also been shown to result in turf algae dominating the benthos, as other benthic groups are unable to tolerate the intense disturbance encountered in these conditions (Muthiga & McClanahan 1987).

Rapid reductions in urchin populations, which can occur as a result of disease, or low recruitment, or a reduction in grazing intensity through the expansion of grazable unit areas following natural disturbances such as cyclones or bleaching-induced mortality can have devastating consequences, coupled with reduced herbivorous fish abundance (either as a result of competitive exclusion or direct overfishing), lead to sites becoming increasingly dominated by algae, as they outcompete hard corals for space (McClanahan 1999). Caribbean reefs experienced just such a ecological catastrophe, in the early 1980s when disease induced mortality removed more than 95% of the *Diadema antillarum* population from the reefs, from which it is only recently beginning to show recovery(Knowlton 2004).

Holothurians

Densities and diversity of holothurians on the reefs south of Tulear are similar to that exhibited on the reefs of Andavadoaka (Blue Ventures, unpublished data), and the northeast of Madagascar. However both density and diversity are much lower than on reefs within the Sahamalaza national park in the northwest of Madagascar.

Sea cucumbers have been exported from Madagascar since the early 20th century (Conand & Mara 2000), primarily for markets in Singapore and Hong Kong (Rey 1982). Current low levels of holothurians on reefs may be a result of persistent overfishing, as many collectors of sea cucumbers work out of the commercial centre of Toliara.

Signs of overfishing of sea cucumber species in Madagascar have been seen since the early nineties, with declining size and weight, increasing prices and more recently increasing use of illegal harvesting equipment (Conand & Muthiga 2007).

The pronounced impact of market demand on sea cucumber populations is supported by the relatively high abundance observed during this study of the single species *Pearsonothuria graefii*. This species is not noted as being a preferred target species of collectors (Langley 2006; Conand & Muthiga 2007).

Holothuria are detritivores feeding on organic matter created by diverse biological and ecological processes within the reef ecosystem. Reduction of sea cucumber populations through over-exploitation may result in hyper-nutrification of marine sediments. Nutrient enrichment (although not specifically linked to reduction of holothuria populations) has a number of detrimental effects on coral reef health, notably exacerbating pathological infections and enhancing the growth rates of competitive algal species. Algal overgrowth reduces the ability of hard corals to recruit and grow.

Management Implications

The variable condition of coral reef habitats, coupled with diverse resource use practices, high resource dependence and extreme poverty of Vezo fishers in southwest Madagascar present considerable challenges for marine resource management.

Protected Areas

Local threats and stresses to coral reefs, such as unsustainable biomass removal, reduction of water quality – for example increasing levels of sedimentation, pollution, toxins and disease - may compound the impacts of natural disturbances such as climate change, weakening reefs' ability to adapt to the broad-scale physical and chemical impacts of global climatic change.

The interaction of chronic long-term anthropogenic disturbances can exacerbate stresses to reefs, bringing about more pronounced changes to reef community structure than acute short term natural disturbances such as bleaching (McClanahan *et al.* 2002).

Coral loss through 'natural' disturbances, such as mass mortality as a result of bleaching, has been shown to take a number of years to result in losses of reef structural complexity. The physical structure of coral reefs has been identified as being of vital importance to reef fish community diversity, and has been shown to be of particular importance for the presence of coral feeding or dwelling species such as Monacanthidae, Chaetodontidae and Pomacanthidae on a reef (Graham *et al.* 2006). Fish populations have also been revealed to exhibit a lag effect of between 3 and 5 years after a significant bleaching or mortality event, as the loss of benthic three dimensional complexity reduces the available habitat for juvenile fish, which are subsequently unable to replace adult fish removed from the population through natural death or fishing *(Graham et al.* 2007). If hard corals can recover between intervals of rare climatic disturbances then habitat complexity may remain sufficient to maintain fish diversity (McClanahan 2006b).

Reef resilience - defined as the ability of corals and reef ecosystems to recover from disturbance whilst sustaining habitat complexity, fish communities, and complex ecosystem functions - is vitally important to the long term survival of reefs and the sustainability of reef fisheries (Grimsditch & Salm 2005; Obura 2005; Grimsditch *et al.* 2008; Obura & Grimsditch 2008).

Reef resilience is weakened by anthropogenic stresses such as hypersedimentation, nutrient enrichment and particularly unsustainable or destructive fishing practices. Moreover, the threats of climate change are greatest where reef resilience is already weakened by anthropogenic stress factors (Hoegh-Guldberg *et al.* 2007). Therefore management of direct anthropogenic stresses to reefs is a fundamental precondition to the effective management of marine resources (Obura & Grimsditch 2008).

Whilst short-term temporary closures and gear management techniques can be suited to some forms of fisheries management, permanent closures are far more effective in restoring or preserving coral reef populations and ecosystem function (McClanahan 2000b).

One potential reef management strategy for improving and protecting reef resilience, health and biodiversity within this proposed management area would be to implement varying management regimes reflecting the varying conditions of reef habitats and resource use needs of local communities. For example, areas that currently exhibit high levels of reef health and complexity could be protected by permanent restriction of fishing, while gear restrictions or temporary closures could be implemented in other areas in order to reduce the use of destructive and unselective gear types and to allow more degraded reef areas to start to recover.

The local marine environmental management plan selected by communities in these areas is to develop and enforce fisheries zone management through various regulations of catch, gear types and zoning.

Fisheries Management

While the effects of marine reserves and permanent area closures have been widely studied (McClanahan & Kaunda-Arara 1996; Russ & Alcala 1996; McClanahan *et al.* 1999; Done 2001; Gell & Roberts 2002; Halpern & Warner 2002; Russ 2002; McClanahan *et al.* 2007) the results of restricted use areas, gear prohibition and traditional community management zones are less known (Denny & Babcock 2004; Cinner *et al.* 2005a; McClanahan *et al.* 2006a; McClanahan *et al.* 2006b).

Partial closures, gear restrictions, and community management have been demonstrated to work effectively in some areas, such as Tanzania, Phillipines, Papua New Guinea and Northern Sumatra (McClanahan *et al.* 2006a; McClanahan *et al.* 2006b; Campbell *et al.* 2008) while failing in others, for example Mimiwhangata in northeast New Zealand (Denny and Babcock 2004). However, locally managed fisheries are gaining increasing acceptance as one of the most effective ways of managing marine resources in tropical coastal countries (Russ 2002).

The effectiveness of reduced fishing pressure is suitably illustrated by the offshore lagoonal patch reefs of Andavadoaka. Despite not having protected status, their small size and remote location, means that they have in effect experienced reduced fishing pressure, similar to that of a fisheries management strategy. These reefs, have shown a progressive annual increase in coral cover from 30% to 70% between 2004 and 2008, and subsequently exhibit much greater fish biomass levels than other reefs in the area, attributed to the fact that they are unexposed to the chronic disturbances caused by comparatively heavy fishing pressure experienced by other reefs (Harris *et al.* 2009).

Different fishing gears work with varying degrees of selectivity thus their use can affect the efficiency of fish capture, and in turn the sustainability of a fishery. It is an understanding of the social and economic factors that determine gear choice, particularly that of destructive or unselective gear types, that are fundamental to implementing social and ecological change (McClanahan & Mangi 2004).

Gear restrictions can often be introduced more easily than management of fishery landings, for example by restricting species, size, or trophic level of catches) (McClanahan & Mangi 2004). This is particularly true in remote areas where capacity for enforcement of legislation is limited.

It has also been demonstrated that while fisheries no take zones can displace fishing pressure, allowing continuous, gear-restricted fishing, such as the prohibition of nets, as an alternative strategy can reduce fishing effort sufficiently to improve biomass within managed zones (Cinner *et al.* 2005a).

Prohibition of fishing gears has however been perceived as a constraint by some communities, with concerns over reduced catches as a result of the restrictions (McClanahan & Mangi 2004), and other area users not adhering to management regulations. Where enforcement is difficult it is recognised that management regimes that are designed more to meet community goals achieve greater compliance, and are subsequently more successful, than those designed primarily for biodiversity conservation (McClanahan *et al.* 2006a).

Fish populations show diverse responses to marine management. These responses are influenced by a number of factors including reef size and structure, proximity to other reef areas and the level of compliance with management regulations (Campbell *et al.* 2008). Populations may take many years or even decades to recover to previous levels (McClanahan *et al.* 2007). If compliance is solely based around anticipation of positive fisheries results then motivations may fall if results are not quickly achieved or perceived (Cinner *et al.* 2005a). It is therefore important that, alongside fisheries management efforts, communities are supported to understand, through environmental education activities, the dynamics of marine systems and their recovery from disturbance.

Recommendations for future research

Despite the broad scope of this and related studies, there remains a critical need for accurate data on coral reef habitat status and biodiversity in southwest Madagascar on which to base systematic MPA planning methods. Research must focus on the identification of factors conferring ecological resilience in coral reef ecosystems, and how they vary within habitat types and across large spatial scales. Such data will be essential for the adoption of a holistic, ecosystem-scale approach to conservation planning in the region and a fundamental prerequisite to the development of a resilient network of marine and coastal protected areas across Madagascar's southwestern reef system.

However, the acquisition of reliable data documenting the location, distribution and status of marine habitats using conventional ecological monitoring techniques is logistically difficult, limited in geographical scope, and can become prohibitively expensive when working on a broad scale.

Working with the United States National Coral Reef Institute (NCRI) and local communities in the Velondriake protected area network, a detailed map of local marine and coastal ecosystems has been created, based on 2.4 metre resolution QuickBird imagery. This is comprised of a high-resolution spectral bathymetry and coastal habitat map covering 800 sq km, over which additional data layers, derived from ongoing MPA development programmes, have been incorporated. The accuracy of the outputs is estimated to be higher than 70%, at a cost of approximately $2/hectare. The data are combined in a geographical information system (GIS) allowing for further analysis, vulnerability mapping and a range of cartographic outputs which provide the basis for encouraging and fostering community dialogue about local resource use.

The results from the Velondriake mapping project have been presented to the community management committee responsible for resource zoning, and have formed the basis for delineating protected area boundaries.

This novel approach has enabled the production of the highest resolution habitat and bathymetric maps available for the region. These outputs have proven to be instrumental in developing a coherent protected area zoning plan and set of measureable management objectives for Velondriake, and this technique serves as a cost effective solution for surveying large swathes of shallow marine and coastal habitat.

A future project using this technology could be applied to benefit the conservation sites in this study, providing a high resolution, regional footprint of the marine and coastal resources south of Toliara. The resulting cartographic outputs would serve to assist stakeholders in rapidly assessing coverage of natural resources, and in evaluating the state of these resources across gradients of environmental and anthropogenic stressors. This knowledge can be used to define management and conservation objectives; to identify potential conservation areas and vulnerable ecosystems; and to define marine and coastal sites for monitoring and protection in collaboration with local communities.

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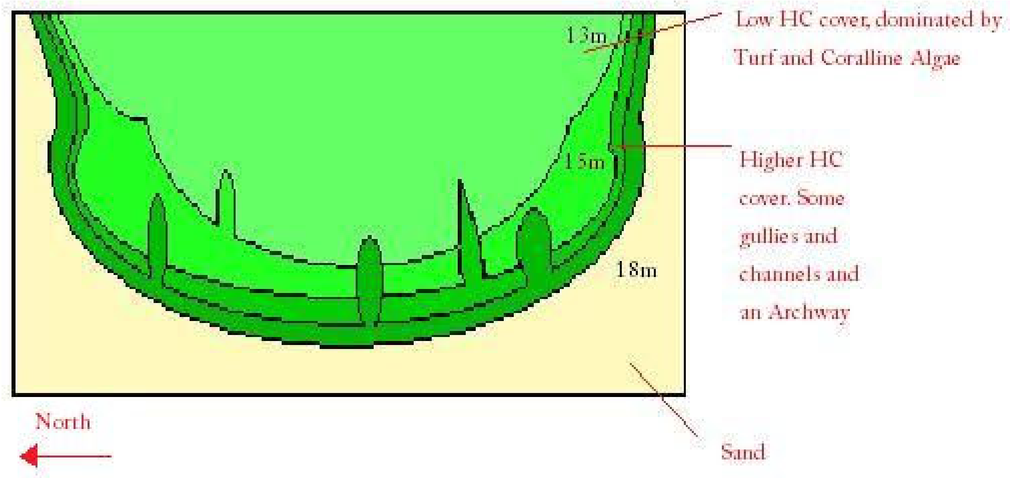
Appendices

Areas of reefs surveyed

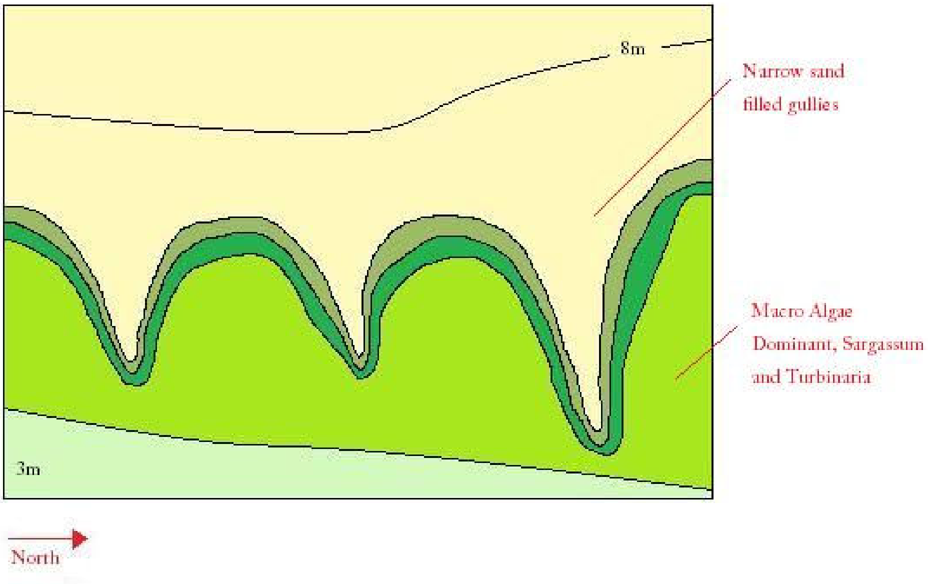
Village	Site	Size
Maromena/Befasy	AnkaraMB	80m x 50m
	Bezamba	50m x 40m
	Lavapano	100m x 50m
Beheloke	Tanyvao	60m x 50m
	Maromalinike	100 x 120m
	Ranolaly	100m x 100m
Itampolo	Ankara	50m x 30m
	Tambohoabo	100m x 60m
	Belamiera	50m x 50m
	Mahadrano	100m x 80m
Ambohibola	Nosimbato	50m x 40m
	Ambolafoty	100m x 50m
	Ankara Ambohoe	100m x 100m

Maps of reefs surveyed

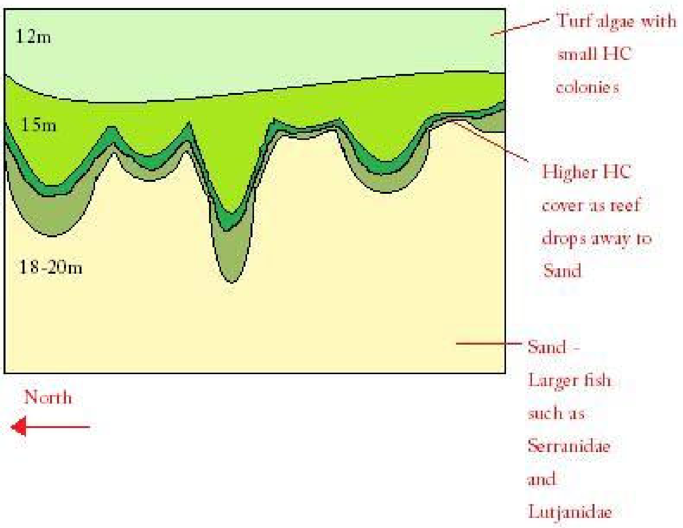
Appendix 1 Maromena and Befasy, Patch Reef - Ankara MB



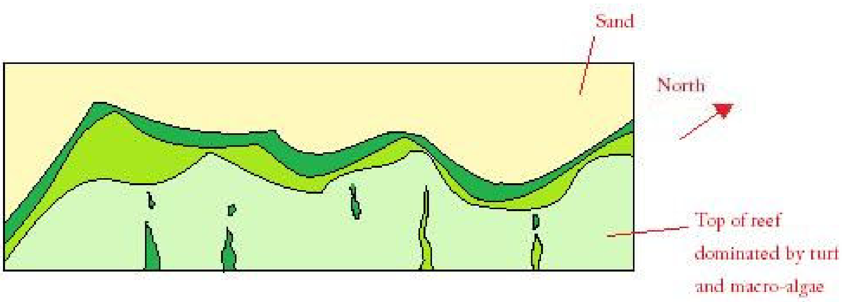
Appendix 2 Maromena and Befasy, Fringing Reef - Bezamba



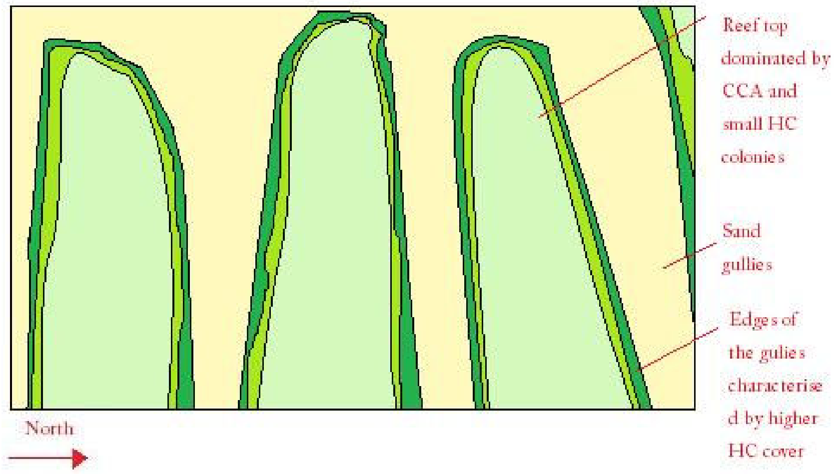
Appendix 3 Maromena and Befasy, Barrier Reef – Lavapano



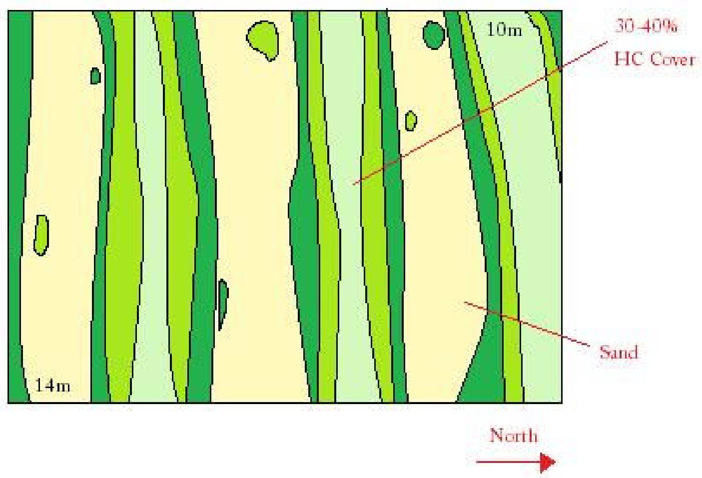
Appendix 4 Beheloke, Fringing Reef - Maromalinike



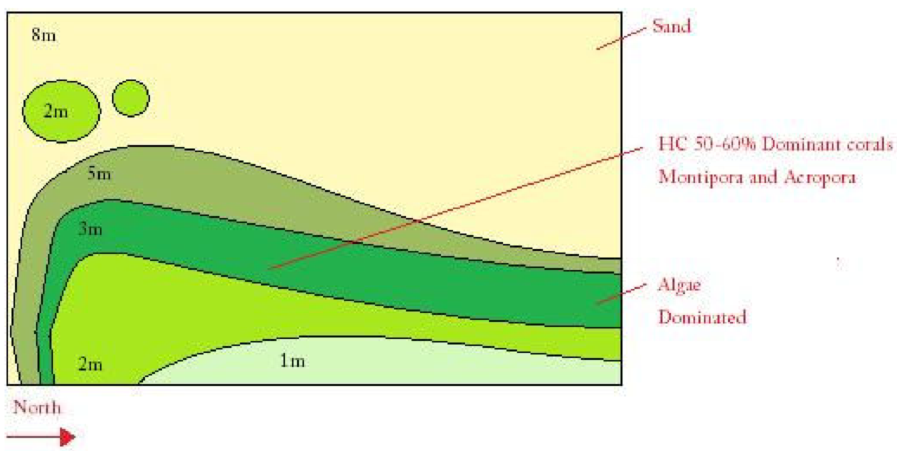
Appendix 5 Beheloke, Barrier Reef – Ranolaly



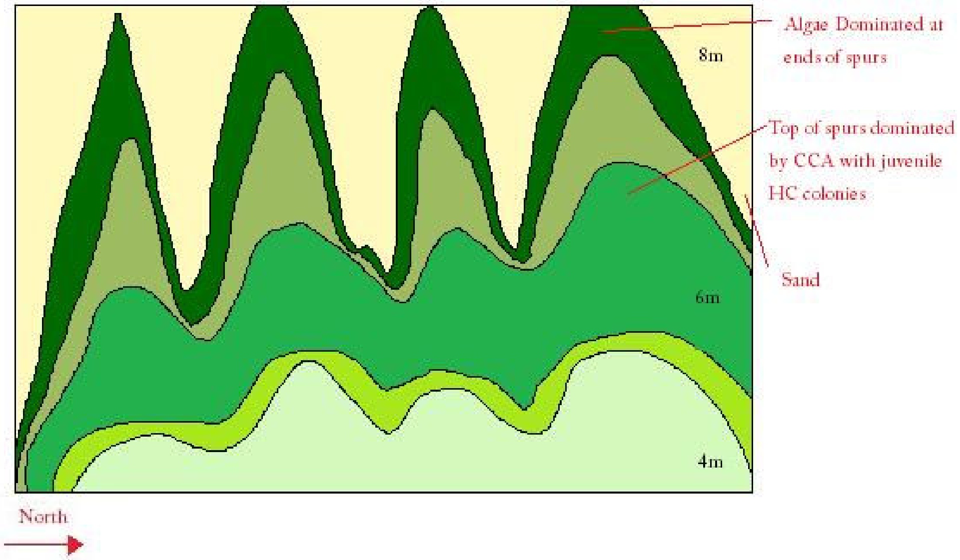
Appendix 6 Beheloke, Patch Reef - Tanyvao



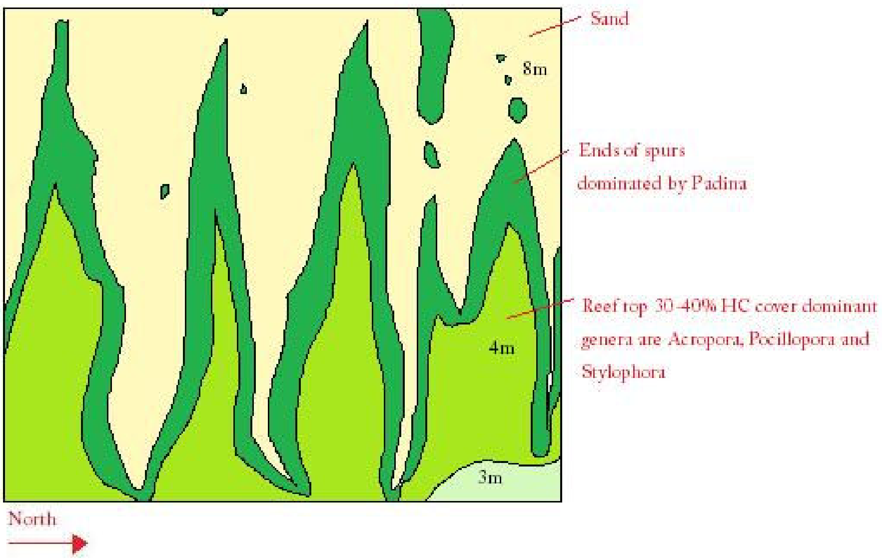
Appendix 7 Itampolo, Patch Reef – Ankara



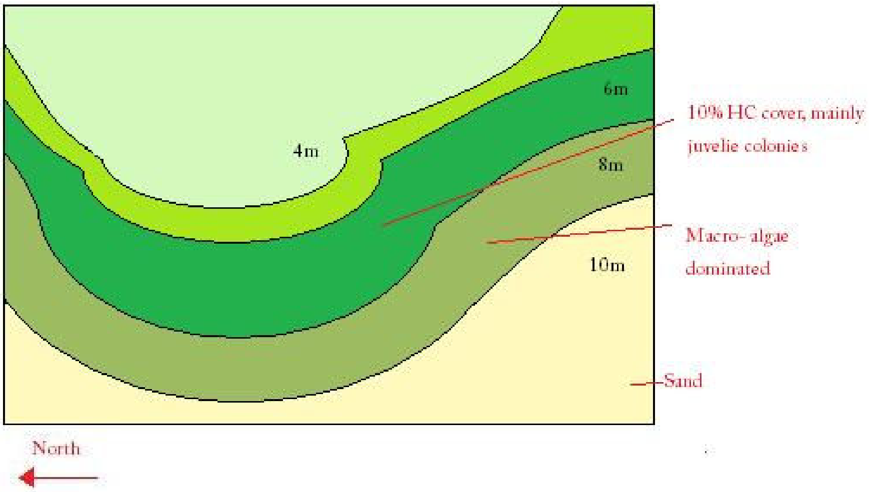
Appendix 8 Itampolo, Barrier Reef - Belamiera



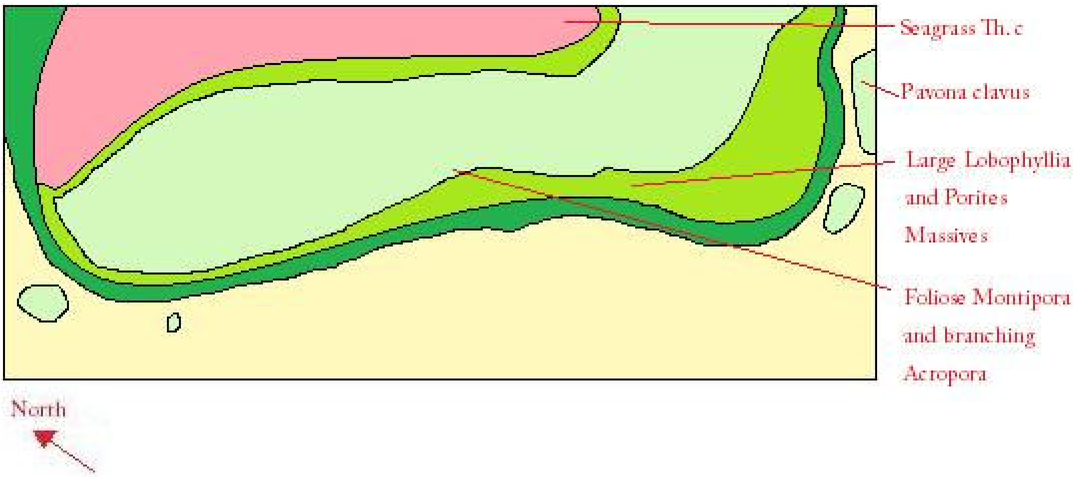
Appendix 9 Itampolo, Barrier Reef – Mahadrano



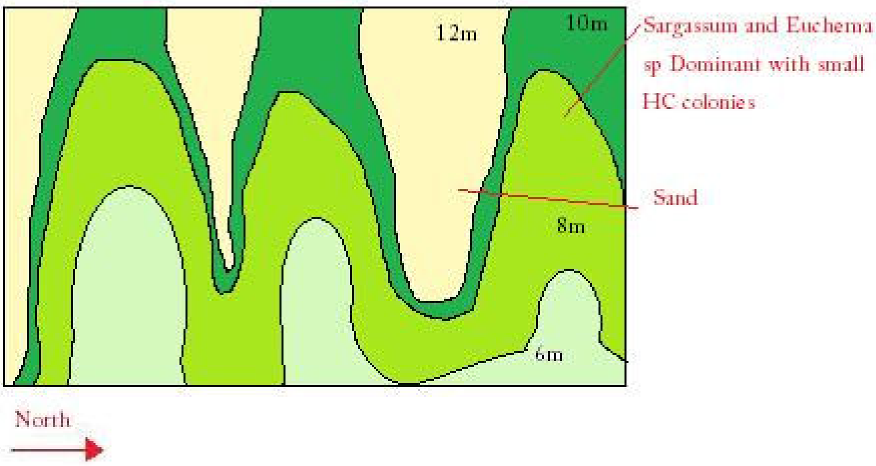
Appendix 10 Itampolo, Fringing Reef - Tambohoabo



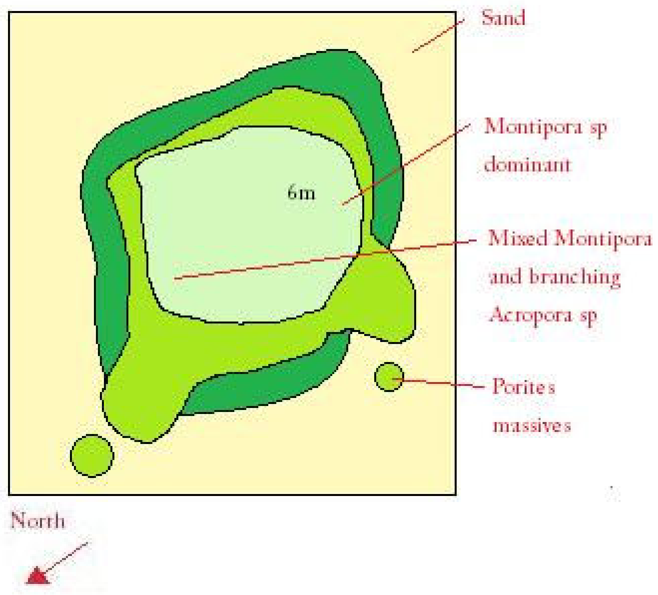
Appendix 11 Ambohibola, Fringing Reef - Ambolafoty



Appendix 12 Ambohibola, Barrier Reef - Ankara Ambohoe



Appendix 13 Ambohibola, Patch Reef - Nosimbato



Data Tables

Appendix 14: Percentage Cover and Standard Error for all Benthic Categories at each survey site

Village	Ambohibola			Itampolo				Beheloke			Maromena and Befasy		
Site Name	Ankara Ambohoe	Nosimbato	Ambolafoty	Ankara	Mahadrano	Belamiera	Tambohoabo	Maromalinike	Ranolaly	Tanyvao	Lavapano	Bezamba	Ankara MB
Hard Coral	34.22	67.02	73.63	53.17	29.48	19.35	18.77	15.93	23.92	24.10	19.83	36.87	27.25
Standard Error	3.38	7.64	4.20	8.04	4.35	3.20	2.85	3.47	4.10	3.71	4.43	2.94	3.32
Turf Algae	35.47	9.43	16.50	16.22	15.25	1.80	38.10	35.08	16.35	28.00	34.55	19.85	20.32
Standard Error	5.89	3.63	3.78	5.61	4.12	0.53	4.04	8.17	4.80	6.37	8.77	2.88	3.61
Calcareous Algae	0.33	0.07	0.80	0.00	0.00	0.00	0.00	0.00	0.00	2.17	0.13	0.00	0.00
Standard Error	0.33	0.07	0.80	0.00	0.00	0.00	0.00	0.00	0.00	2.17	0.13	0.00	0.00
Fleshy Algae	22.08	6.63	0.13	4.80	3.77	5.22	4.30	16.07	0.65	10.23	5.07	16.00	9.10
Standard Error	5.09	3.13	0.13	3.08	1.89	1.74	1.57	4.16	0.42	4.53	3.45	4.54	3.79
Coralline Algae	1.17	12.25	8.45	21.35	44.92	59.98	32.50	29.08	56.23	29.97	32.45	26.07	14.67
Standard Error	0.54	5.18	2.37	3.37	4.84	3.46	1.32	5.77	7.64	6.68	5.70	3.76	2.44
Soft Coral	5.60	1.77	0.35	0.23	6.05	6.45	3.43	2.28	1.22	3.52	5.52	0.23	20.80
Standard Error	1.47	1.37	0.26	0.23	2.42	1.79	1.15	0.92	0.45	1.26	2.08	0.23	4.61
Sand	0.63	2.75	0.00	0.42	0.00	2.50	0.37	1.08	0.00	0.00	1.22	0.00	5.68
Standard Error	0.63	2.44	0.00	0.33	0.00	2.50	0.37	0.53	0.00	0.00	0.50	0.00	5.05
Sponge	0.00	0.00	0.13	0.30	0.00	0.08	0.25	0.25	0.15	0.32	0.30	0.65	1.12
Standard Error	0.00	0.00	0.13	0.19	0.00	0.08	0.25	0.17	0.15	0.32	0.30	0.31	0.76

Appendix 15: Percentage contribution of hard coral genera to total hard coral cover at each survey

Village	Ambohibola			Itampolo				Beheloke			Maromena and Befasy		
Site Name	Ankara Ambohoe	Nosimbato	Ambolafoty	Ankara	Mahadrano	Belamiera	Tambohoabo	Maromalinike	Ranolaly	Tanyvao	Lavapano	Bezamba	Ankara MB
Acropora	2.00	10.65	16.20	46.40	8.50	5.25	5.95	1.32	3.95	7.80	0.02	0.02	0.17
Acanthastrea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Astreopora	0.28	0.00	0.00	5.00	0.00	0.75	0.00	0.00	2.00	0.17	0.00	0.01	0.00
Coscinarea	0.00	0.00	0.00	2.40	0.47	0.42	0.00	0.13	0.00	0.00	0.00	0.00	0.00
Cyphastrea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
Diploastrea	0.00	0.00	0.00	2.80	0.00	0.23	0.22	0.50	0.00	0.00	0.01	0.00	0.00
Echinpora	2.62	0.00	0.22	4.60	0.83	0.55	0.00	0.60	0.00	0.00	0.01	0.00	0.00
Echinophyllia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Favia	2.27	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Favites	2.00	0.00	2.20	6.20	1.03	1.10	2.60	2.35	1.58	0.77	0.01	0.02	0.01
Fungia	1.18	0.00	0.00	0.00	0.00	0.00	6.53	0.00	0.00	0.00	0.00	0.00	0.00
Galaxea Green	0.77	0.95	0.00	27.40	1.55	0.55	0.23	0.33	0.07	0.08	0.00	0.02	0.00
Galaxea red	0.00	0.00	0.00	12.60	0.18	0.17	0.27	0.00	0.67	0.33	0.00	0.01	0.01
Gardineroseris	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.60	0.00	0.00	0.00	0.00	0.00
Goniastrea	7.33	0.00	0.60	2.20	0.37	0.65	0.00	0.35	1.22	0.72	0.00	0.00	0.00
Goniopora	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Herpolitha	0.00	0.00	0.00	2.40	0.00	0.28	0.00	0.67	0.00	0.97	0.00	0.00	0.03
Hydnophora	0.00	0.00	0.00	2.00	0.43	0.00	0.27	0.00	0.00	0.00	0.00	0.01	0.00
Leptastrea	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00
Lobophyllia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Merulina	0.33	0.97	0.00	0.00	0.00	0.12	0.00	0.00	0.33	0.27	0.00	0.00	0.00
Millepora	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Montastrea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Montipora	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oulophyllia	0.00	0.00	10.62	0.00	0.35	0.00	0.00	1.12	0.25	0.00	0.00	0.00	0.00
Oxypora	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pachyseris	0.00	0.00	0.00	2.20	1.60	0.80	0.00	3.28	0.55	0.00	0.00	0.00	0.00
Pavona	0.00	0.00	7.08	0.00	0.00	1.43	0.00	0.85	0.50	0.25	0.00	0.00	0.00
Physogyra	12.17	35.98	29.43	5.60	0.00	1.42	31.05	2.33	0.22	0.25	0.00	0.01	0.01
Platygyra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plerogyra	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.17	0.00	0.00	0.00	0.00
Pleisiastrea	0.00	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pocillopora	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.75	0.00	0.00	0.00	0.00
Porites branching	0.00	0.00	0.17	3.20	0.83	0.37	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Porites massive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psammocora	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.63	0.00	0.00	0.03	0.00
Stylophora	0.20	0.00	0.00	0.00	0.00	0.00	0.52	1.57	0.00	0.08	0.00	0.02	0.00
Tubastrea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turbinaria	1.57	5.78	0.28	34.60	8.03	1.72	2.05	5.67	9.33	2.73	0.08	0.07	0.09

Appendix 16: Percentage contribution to benthic substrate by each algae genera

Village	Ambohibola			Itampolo				Beheloke			Maromena and Befasy		
Site Name	Ankara Ambohoe	Nosimbato	Ambolafoty	Ankara	Mahadrano	Belamiera	Tambohoabo	Maromalinike	Ranolaly	Tanyvao	Lavapano	Bezamba	Ankara MB
Calcareous													
Halimeda	1.50	0.25	3.27	0.00	0.00	0.00	0.00	0.00	0.00	5.30	0.20	0.00	0.00
Fleshy													
Asparagopsis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.51	0.00	0.00	0.00
Caulerpa	0.00	0.00	0.00	0.33	0.00	2.42	0.00	0.00	0.00	0.00	1.34	0.00	0.00
Codium	8.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cystoseiria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Derbesia	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00
Dictyospheria	1.12	0.00	0.00	0.37	0.00	0.98	0.65	2.22	0.12	0.00	0.00	0.28	0.00
Dictyota	0.75	17.53	0.00	0.00	0.19	0.37	0.00	1.19	0.00	0.00	0.77	0.00	2.12
Eucheuma	22.06	0.00	0.00	0.00	0.00	0.00	0.00	1.39	0.00	0.00	0.00	0.00	0.00
Hydroclathrus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.00
Hypnea	2.24	7.35	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.55
Laurencia	0.00	0.00	0.00	0.00	1.46	3.91	2.62	0.00	0.00	14.12	4.77	0.37	15.39
Padina	1.72	3.64	0.00	0.00	0.00	0.00	0.00	6.99	0.62	0.00	0.00	0.00	0.00
Red filamentous	0.00	0.00	0.00	4.75	0.00	0.00	2.30	0.00	0.00	0.00	0.10	25.11	0.00
Sargassum	55.87	0.00	0.00	3.10	0.85	1.10	0.00	8.42	0.00	0.00	0.55	0.62	0.00
Turbinaria	0.90	0.00	0.00	3.35	0.00	0.31	0.00	16.40	0.47	5.43	0.00	0.00	0.00
Ulva	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00
Coralline													
Jania	0.00	5.06	0.41	0.00	0.00	0.00	39.62	0.00	0.00	0.00	4.18	1.86	6.98
Amphiroa	3.74	32.22	29.32	47.89	64.87	86.89	50.03	0.95	0.00	0.00	39.52	38.32	26.08
Encrusting red	1.50	33.33	66.46	40.21	32.16	4.02	4.78	60.76	98.79	69.65	48.57	33.44	45.87

Appendix 17: Species richness of each reef fish taxonomic family

Village	Ambohibola			Itampolo				Beheloke			Maromena/Befasy		
Site Name	Ankara Ambohoe	Nosimbato	Ambolafoty	Ankara	Mahadrano	Belamiera	Tambohoabo	Maromalinike	Ranolaly	Tanyvao	Lavapano	Bezamba	Ankara MB
Family													
Acanthuridae	4	3	9	6	10	10	8	8	7	8	10	3	12
Apogonidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulostomidae	0	0	1	0	1	1	1	0	0	0	0	0	1
Balistidae	2	0	0	2	3	1	0	1	0	2	3	1	1
Blennidaae	2	1	1	1	0	0	0	0	1	0	0	0	0
Caesionidae	2	0	0	1	0	1	2	0	1	1	0	0	1
Carangidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetodontidae	3	2	5	3	1	2	6	4	5	3	8	1	9
Cirrhitidae	3	0	2	2	1	0	2	1	3	2	1	3	2
Fistularidae	0	0	0	0	0	1	0	0	0	0	0	0	0
Haemulidae	0	3	3	1	1	0	1	0	0	0	0	0	0
Holocentridae	0	0	1	0	1	0	0	1	1	0	2	0	2
Holocentridae	0	0	0	2	0	0	1	1	0	0	2	0	3
Labridae	8	10	13	11	13	11	8	10	9	10	12	7	12
Lethrinidae	0	0	0	0	0	0	0	0	0	0	1	0	1
Lutjanidae	0	0	2	0	1	1	0	0	1	0	1	0	2
Monacanthidae	1	0	0	1	0	1	0	0	0	0	1	1	0
Mullidae	1	3	0	1	4	1	2	3	1	3	3	1	2
Muraenidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemipteridae	0	0	0	0	1	0	0	0	0	0	0	0	0
Ostraciidae	0	1	0	1	1	0	1	0	0	0	0	0	0
Pempheridae	0	0	1	0	1	0	0	0	1	0	0	0	0
Plesiopidae	0	0	0	0	0	0	0	0	0	0	0	1	0
Pomacentridae	0	2	1	0	1	1	0	2	0	2	4	0	5
Pomacentridae	12	9	14	12	7	8	7	8	10	4	10	8	9
Priacanthidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptereleotridae	1	1	0	0	0	0	0	0	0	1	2	0	1
Scaridae	0	0	2	2	4	5	2	1	1	4	2	0	4
Scombridae	0	0	0	0	1	0	0	0	0	0	0	0	0
Scorpionidae	0	0	0	0	1	0	0	0	0	0	0	0	1
Serranidae	2	0	2	0	2	3	0	1	0	1	3	0	4
Siganidae	1	0	1	0	1	1	0	0	0	0	0	0	0
Sphyraenidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontidae	0	1	3	2	2	1	2	0	0	0	2	0	2
Zanclidae	0	0	1	0	1	1	0	0	1	0	1	0	1
Total No species	42	36	62	48	59	50	43	41	42	41	68	26	75

Appendix 18: Biomass contribution (Kgha^{-1}) from each reef fish family group and Trophic guild

Trophic Category	Village / Site	Ambohibola: Ankara Ambohoe	Ambohibola: Nosimbato	Ambohibola: Ambolafoty	Itampolo: Ankara	Itampolo: Mahadrano	Itampolo: Belamiera	Itampolo: Tambohoabo	Beheloke: Maromalinike	Beheloke: Ranolaly	Beheloke: Tanyvao	Maromena: Lavapano	Maromena: Bezamba	Maromena: Ankara MB
Carnivore	Aulostomidae	0.00	0.00	1.94	0.00	8.62	0.00	6.25	0.00	0.00	0.00	1.94	0.00	4.31
	Balistidae	4.77	4.04	0.00	10.46	0.09	0.00	0.00	16.38	4.13	1.35	4.44	7.62	3.49
	Carangidae	0.00	0.00	0.00	0.00	26.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Diodontidae	0.00	0.00	0.00	3.06	2.86	0.20	2.64	0.00	6.17	0.00	0.20	0.00	0.40
	Fistularidae	0.00	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Haemulidae	0.00	42.85	17.27	0.00	0.00	31.00	0.00	0.00	0.00	0.00	17.27	0.00	0.00
	Holocentridae	0.00	0.00	0.00	8.33	4.17	0.00	0.15	0.00	3.40	0.00	15.32	4.17	57.34
	Labridae	78.71	127.86	157.60	84.54	227.51	377.34	85.93	34.39	287.66	9.51	83.17	38.77	198.18
	Lethrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.68	0.00	14.88
	Lutjanidae	2.84	0.00	128.06	2.84	0.00	0.00	0.66	0.05	6.90	0.00	0.61	0.00	5.73
	Mullidae	6.03	3.03	5.20	8.90	10.39	5.20	4.88	12.95	2.83	0.47	10.99	9.81	3.86
	Muraenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.02	0.00	12.47	0.00	0.00
	Pempheridae	0.00	0.00	24.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Penguipedidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Scorpaenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Serranidae	10.21	47.25	0.00	3.68	0.00	13.69	3.68	0.47	9.01	1.07	6.49	0.00	14.43
	Sphyraenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corallivore	Chaetodontidae	8.13	9.44	68.20	12.28	2.97	18.16	23.46	2.43	59.05	1.75	34.74	0.08	9.40
Herbivore	Acanthuridae	53.89	121.59	746.38	74.75	371.37	1192.43	254.97	207.16	1097.53	113.15	218.15	48.78	354.72
	Pomacentridae	130.48	51.57	211.61	171.95	91.82	72.89	40.71	23.53	101.48	2.87	53.73	44.05	105.17
	Scaridae	0.00	0.00	10.56	5.73	163.82	491.22	35.05	3.50	5.45	2.81	6.14	0.10	52.14
	Siganidae	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.42
Omnivore	Pomacanthidae	0.00	3.40	6.80	0.00	88.75	0.00	15.67	0.79	1.66	1.31	12.64	0.00	4.71
	Others	49.77	0.08	91.53	2.50	23.75	92.93	11.91	13.48	15.71	81.71	76.84	3.72	133.94
Mean Biomass		346.69	412.46	1469.90	389.02	1022.24	2295.05	485.97	315.12	1620.02	216.74	555.93	157.11	963.11
Standard Error		87.98	88.36	242.03	57.72	409.43	1136.52	225.25	65.04	772.46	83.41	205.55	24.11	432.84

Appendix 19: Estimates of Urchin species Biomass (Kgha^{-1}) on each survey site

Village / Site Name	Ambohibola: Ankara Ambohoe	Ambohibola: Nosimbato	Ambohibola: Ambolafoty	Itampolo: Ankara	Itampolo: Mahadrano	Itampolo: Belamiera	Itampolo: Tambohoabo	Beheloke: Maromalinike	Beheloke: Ranolaly	Beheloke: Tanyvao	Maromena/Befasy: Lavapano	Maromena/Befasy: Bezamba	Maromena/Befasy: Ankara MB
Diadema savignyi	0.00	0.00	0.00	20.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Echinometra mathaei	0.00	0.00	0.00	1595.00	121.00	236.50	594.00	49.50	0.00	5.50	704.00	187.00	0.00
Echinostrephus molaris	8.75	0.00	0.00	0.00	2.92	0.42	1.25	187.92	63.33	13.75	247.92	107.08	0.42
Echinthrix diadema	115.67	2197.67	0.00	1156.67	5899.00	4453.17	404.83	1619.33	0.00	231.33	0.00	1503.67	1908.50
Tripneustes gratilla	0.00	0.00	0.00	18.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stomopneustes variolaris	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.50	0.00
Biomass (Kgha^{-1})	124.42	2197.67	0.00	2790.67	6022.92	4690.08	1000.08	1856.75	63.33	250.58	951.92	1810.25	1908.92
Standard Error	12.77	244.19	0.00	228.47	653.86	553.19	75.06	177.83	7.04	25.48	79.62	164.30	212.05

Appendix 20: Estimated Biomass (Kgha^{-1}) of Holothuria species at each survey site

Village / Site Name	Ambohibola: Ankara Ambohoe	Ambohibola: Nosimbato	Ambohibola: Ambolafoty	Itampolo: Ankara	Itampolo: Mahadrano	Itampolo: Belamiera	Itampolo: Tambohoabo	Beheloke: Maromalinike	Beheloke: Ranolaly	Beheloke: Tanyvao	Maromena/Befasy: Lavapano	Maromena/Befasy: Bezamba	Maromena/Befasy: Ankara MB
Actinopyga mauritiana	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Holothuria edulis	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.06	0.00
Pearsonothuria graeffi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.18
Biomass	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.06	0.18
Standard Error	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.06	0.11

Appendix 21: Inventory of fish species observed in each survey area

Family	Species	Ambohibola	Itampolo	Beheloke	Maromena and Befasy
Acanthuridae	Acanthurus auranticavus	X	X		X
Acanthuridae	Acanthurus dussumieri	X			
Acanthuridae	Acanthurus leucosternon	X		X	X
Acanthuridae	Acanthurus lineatus	X	X	X	X
Acanthuridae	Acanthurus mata	X	X		
Acanthuridae	Acanthurus nigricauda	X	X	X	X
Acanthuridae	Acanthurus nigrofuscus	X	X	X	X
Acanthuridae	Acanthurus tennenti	X			X
Acanthuridae	Acanthurus Thompsonii	X	X	X	X
Acanthuridae	Acanthurus triostegus	X	X	X	X
Acanthuridae	Acanthurus xanthopterus	X	X		
Acanthuridae	Ctenochaetus binotatus	X	X	X	X
Acanthuridae	Ctenochaetus striatus	X	X	X	X
Acanthuridae	Ctenochaetus strigosus	X	X	X	X
Acanthuridae	Naso brachycentron	X			X
Acanthuridae	Naso brevirostris	X			X
Acanthuridae	Naso hexacanthus	X	X		
Acanthuridae	Naso liturarus	X	X		X
Acanthuridae	Naso unicornis	X			X
Acanthuridae	Zabrasoma veliferum	X			X
Acanthuridae	Zebrasoma desjardinii				
Acanthuridae	Zebrasoma gemmatum	X			X
Acanthuridae	Zebrasoma scopas	X	X	X	X
Apogonidae	Apogon aureus				
Apogonidae	Archamia fucata				
Apogonidae	Cheilodipterus quinquelineatus				
Aulostomidae	Aulostomus chinensis	X	X		X
Balistidae	Balistapus undulatus	X		X	
Balistidae	Balistoides conspiculum	X	X		X
Balistidae	Balistoides viridescens	X	X		
Balistidae	Rhinecanthus acualetes	X	X		
Balistidae	Rhinecanthus rectangulus	X			X
Balistidae	Sufflamen bursa	X			X
Balistidae	Sufflamen chrysoptherus	X	X	X	X
Blennidae	Plagiotremus rhinorhynchos	X			
Blennidae	Plagiotremus tapeinosoma	X	X	X	
Blennidae	Plagiotremus tapeinosoma	X			
Caesionidae	Caesio caerulaurea	X	X	X	
Caesionidae	Caesio lunaris	X		X	
Caesionidae	Caesio xanthonota	X	X		
Caesionidae	Pterocaesio capricornis	X			
Caesionidae	Pterocaesio chrysozona	X	X		X
Carangidae	Carangoides ferdau				
Carangidae	Gnathanodon speciosus				
Chaetodontidae	Chaetodon auriga	X	X	X	X
Chaetodontidae	Chaetodon blackburnii	X		X	
Chaetodontidae	Chaetodon falcula	X	X		
Chaetodontidae	Chaetodon guttatissimus	X	X	X	X
Chaetodontidae	Chaetodon kleinii	X			X
Chaetodontidae	Chaetodon lineatus	X			X
Chaetodontidae	Chaetodon lunula	X	X	X	
Chaetodontidae	Chaetodon madagascariensis	X	X	X	X
Chaetodontidae	Chaetodon melannotus	X	X		X
Chaetodontidae	Chaetodon meyeri	X		X	X

Family	Species	Ambohibola	Itampolo	Beheloke	Maromena and Befasy
Chaetodontidae	Chaetodon trifascialis	X			
Chaetodontidae	Chaetodon trifasciatus	X	X	X	X
Chaetodontidae	Chaetodon vagabondus	X	X	X	X
Chaetodontidae	Chaetodon xanthocephelus	X			
Chaetodontidae	Cheatodon interruptus	X			X
Chaetodontidae	Forcipiger longirostris	X			X
Chaetodontidae	Hemitaurichthys zoster	X			X
Chaetodontidae	Heniochus acuminatus	X			X
Chaetodontidae	Heniochus monoceros				
Cirrhitidae	Cirrhites pinnulatus	X			X
Cirrhitidae	Cirrhitichthys aprinus	X		X	X
Cirrhitidae	Paracirrhites arcatus	X	X	X	X
Cirrhitidae	Paracirrhites forsteri	X	X	X	X
Cirrhitidae	Paracirrhites hemistictus	X		X	
Fistularidae	Fistularia commersonii	X	X		
Haemulidae	Plectorhinchus chubbi	X	X		
Haemulidae	Plectorhinchus flavomaculatus	X			
Haemulidae	Plectorhinchus gatterinus	X	X		
Haemulidae	Plectorhinchus playfairi	X			
Holocentridae	Mypristis kuntee	X		X	X
Holocentridae	Myripristis adusta	X	X		
Holocentridae	Myripristis murdjan	X		X	X
Holocentridae	Neoniphon sammara	X	X		X
Holocentridae	Sargocentron caudimaculatum	X		X	X
Holocentridae	Sargocentron diadema	X	X		X
Labridae	Anampses caeruleopunctatus	X	X	X	
Labridae	Anampses melegrides	X	X	X	X
Labridae	Anampses twistii	X	X		X
Labridae	Bodianus anthioides	X	X		X
Labridae	Bodianus axillarius	X	X	X	X
Labridae	Bodianus bilunulatus	X	X		
Labridae	Bodianus diana	X			X
Labridae	Cheilio inermis	X	X		
Labridae	Chelinius trilobatus	X	X	X	X
Labridae	Chelinus undulatus				
Labridae	Epibulus insidiator	X	X		
Labridae	Gomphosus caeruleus	X	X	X	X
Labridae	Halichoeres cosmetus	X		X	
Labridae	Halichoeres hortulanus	X	X	X	X
Labridae	Halichoeres nebulosus	X		X	X
Labridae	Halichoeres scapularis				
Labridae	Hemigymnus fasciatus	X	X	X	X
Labridae	Hologymnosus annulatus	X	X	X	
Labridae	Labrichthys unilineatus	X	X		
Labridae	Labroides bicolor	X	X		X
Labridae	Labroides dimidiatus	X	X	X	X
Labridae	Novaculichthys taeniourus	X			
Labridae	Oxycheilinus rhodochrous	X		X	
Labridae	Pseudocheilinus hexataenia	X		X	X
Labridae	Pseudocheilinus octotaenia	X		X	
Labridae	Thalassoma amblycephalum	X			X
Labridae	Thalassoma hardwickle	X	X		
Labridae	Thalassoma hebriacum	X	X	X	X
Labridae	Thalassoma lunare	X	X	X	X
Labridae	Thalassoma purpureum	X			X

Family	Species	Ambohibola	Itampolo	Beheloke	Maromena and Befasy
Lethrinidae	Gnathodentex aureolineatus	X			X
Lethrinidae	Lethrinus borbonicus				
Lethrinidae	Lethrinus harak				
Lethrinidae	Lethrinus lentjan				
Lethrinidae	Lethrinus obsoletus				
Lethrinidae	Lethrinus olivacea				
Lethrinidae	Monotaxis grandaculis	X			X
Lutjanidae	Lutjanus bohar	X			
Lutjanidae	Lutjanus fulviflamma	X		X	
Lutjanidae	Lutjanus gibbus	X	X		X
Lutjanidae	Lutjanus kasmira	X			X
Lutjanidae	Lutjanus lutjanus	X	X		
Lutjanidae	Lutjanus monostigma				
Lutjanidae	Lutjanus notatus				
Lutjanidae	Macolor niger	X			X
Monacanthidae	Amanses scopus				
Monacanthidae	Cantherhines dumerilii				
Monacanthidae	Cantherines pardalis	X	X		X
Mullidae	Mulloidichthys vanicolensis	X		X	X
Mullidae	Parapeneus cyclostomus	X	X	X	
Mullidae	Parapeneus macronemua	X	X	X	X
Mullidae	Parupeneus barberinus	X	X	X	
Mullidae	Parupeneus bifasciatus	X	X	X	X
Mullidae	Parupeneus indicus	X			X
Muraenidae	Gymnothorax javanicus				
Nemipteridae	Scolopsis bimaculatus				
Nemipteridae	Scolopsis ghanam	X	X		
Ostraciidae	Ostracion cubicus	X	X		
Ostraciidae	Ostracion meleagris	X	X		
Pempheridae	Pempheris oualensis	X	X		
Pempheridae	Pempheris schwenkii				
Pempheridae	Pempheris vanicolensis	X		X	
Plesiopidae	Calloplesiops altivelis	X			X
Pomacanthidae	Apolemichthys trimaculatus	X		X	X
Pomacanthidae	Centropyge multispinus	X	X	X	X
Pomacanthidae	Pomacanthus chrysurus	X			X
Pomacanthidae	Pomacanthus imperator	X		X	
Pomacanthidae	Pomacanthus semicirculatus	X			X
Pomacanthidae	Pygoplites diacanthus	X			X
Pomacentridae	Abudefduf natalensis				
Pomacentridae	Abudefduf sexfasciatus	X	X		
Pomacentridae	Abudefduf sparoides	X	X		X
Pomacentridae	Abudefduf vaigiensis				
Pomacentridae	Amloyglyphidodon indicus				
Pomacentridae	Amphiprion akallopiosis	X	X		
Pomacentridae	Amphiprion latifasciatus	X		X	
Pomacentridae	Chromis agilis				
Pomacentridae	Chromis chrysura	X			X
Pomacentridae	Chromis dimidiata	X	X	X	X
Pomacentridae	Chromis lepidolepis	X		X	X
Pomacentridae	Chromis ternatensis	X	X	X	
Pomacentridae	Chromis viridis	X			
Pomacentridae	Chromis weberi	X		X	X
Pomacentridae	Chrysiptera leucopoma/brownriggii	X	X	X	X
Pomacentridae	Chrysiptera unimaculata	X	X	X	
Pomacentridae	Dascyllus carneus				

Family	Species	Ambohibola	Itampolo	Beheloke	Maromena and Befasy
Pomacentridae	Dascyllus trimaculatus	X	X		X
Pomacentridae	Neopomacentrus azysron	X	X	X	X
Pomacentridae	Plectroglyphidodon dickii	X	X	X	X
Pomacentridae	Plectroglyphidodon imparipennis	X			X
Pomacentridae	Plectroglyphidodon johnstonianus	X			
Pomacentridae	Plectroglyphidodon lacymatus	X	X	X	X
Pomacentridae	Plectroglyphidodon leucozonus	X			X
Pomacentridae	Plectroglyphidodon phoenixensis	X			X
Pomacentridae	Pomacentrus baenschi	X	X		X
Pomacentridae	Pomacentrus burroughi	X			
Pomacentridae	Pomacentrus caeruleus	X			X
Pomacentridae	Pomacentrus sulfureus	X	X		
Pomacentridae	Pomacentrus trilineatus	X			
Pomacentridae	Pomachromis richardsoni	X		X	X
Pomacentridae	Stegastes fasciolatus	X	X	X	X
Priacanthidae	Priacanthus hamrur				
Ptereleotridae	Nemateleotris magnifica	X		X	X
Ptereleotridae	Ptereleotris evides	X			X
Scaridae	Cetoscarus bicolor				
Scaridae	Chlorurus capistratoides	X			X
Scaridae	Chlorurus cyanescens	X	X		X
Scaridae	Chlorurus sordidus	X	X	X	X
Scaridae	Hipposcarus harid	X	X		
Scaridae	Scarus ghobban				
Scaridae	Scarus niger	X	X	X	
Scaridae	Scarus rubroviolaceus	X	X	X	X
Scaridae	Scarus scaber	X	X	X	
Scombridae	Scombridae	X	X		
Scorpionidae	Pterois volitans	X	X		X
Serranidae	Aethaloperca rogaa	X			X
Serranidae	Cephalopholis argus	X	X		X
Serranidae	Cephalopholis boenak	X		X	
Serranidae	Cephalopholis miniata	X			X
Serranidae	Epinephelus caeruleopunctatus				
Serranidae	Epinephelus fasciatus	X			X
Serranidae	Epinephelus macrospilos	X			
Serranidae	Epinephelus melanostigma	X	X		
Serranidae	Epinephelus merra	X	X		
Serranidae	Epinephelus spilotoceps	X	X		
Serranidae	Epinephelus tauvina	X	X		
Serranidae	Epinephelus tukula				
Serranidae	Plectropomus punctatus	X			
Serranidae	Pseudanthias	X		X	X
Serranidae	Variola louti				
Siganidae	Siganus argentes				
Siganidae	Siganus luridus	X	X		
Siganidae	Siganus sutor	X	X		
Sphyraenidae	Sphyraena barracuda				
Sphyraenidae	Sphyraena flavicauda				
Sphyraenidae	Sphyraena jello				
Tetraodontidae	Arothron hispidus	X			X
Tetraodontidae	Arothron nigropunctatus	X			
Tetraodontidae	Canthiagaster bennetti	X	X		
Tetraodontidae	Canthigaster amboiensis	X	X		
Tetraodontidae	Canthigaster solandri	X	X		X
Tetraodontidae	Canthigaster valentini	X	X		X
Zanclidae	Zanclus cornutus	X	X	X	X

Appendix 22: Malagasy Vezo names for common fish families

Latin	Vezo
Acanthuridae	Angy or Fiantsifa
Apogonidae	Tsaborandanda
Aulostomidae	Fia sody
Balistidae	Tsontso
Blennidae	Tabilolo
Caesionidae	Fitse
Plesiopidae	N/A
Carangidae	Lagnora
Chaetodontidae	Fianakoho
Cirrhitidae	Tabonagna
Fistularidae	Antserakantsiva
Haemulidae	Fiandraty or Angarera
Holocentridae	Masikime
Labridae	Lemy
Lethrinidae	Angelike
Lutjanidae	Amporoma or Fiam-poty
Monacanthidae	Tsontso
Mullidae	Fiantsomoke
Muraenidae	Lamiera
Nemipteridae	Tsabeabato
Ostraciidae	Takalo
Pempheridae	Boleake
Pomacanthidae	Lafindaka
Pomacentridae	Fiankara
Priacanthidae	Fia bemaso
Ptereotoidae	Valala
Scaridae	Bodoloha
Scombridae	Lamatra
Scorpionidae	Lafo
Serranidae	Lovo
Siganidae	Keliholy
Sphyraenidae	AloAlo
Tetradontidae	Botana
Zanclidae	Jalaraike

Appendix 23: Inventory of Hard Coral and Algae genera observed in each survey area

	Genus	Ambohibola	Itampolo	Beheloke	Maromena and Befasy
Scleractinia (Hard Coral Genera)	Acropora	X	X	X	X
	Alveopora				
	Acanthastrea	X	X	X	X
	Astreopora		X	X	X
	Blastomussa			X	
	Coscinarea		X	X	X
	Cyphastrea	X	X	X	X
	Cycloseris				
	Diploastrea	X			
	Echinopora	X	X	X	X
	Echinophyllia	X	X		X
	Favia	X	X	X	X
	Favites		X	X	X
	Fungia		X	X	X
	Galaxea green	X	X	X	X
	Galaxea red	X			
	Gardineroseris		X	X	X
	Goniastrea		X		X
	Goniopora		X		X
	Herpolitha				
	Hydnophora	X	X	X	X
	Leptastrea			X	X
	Leptoria				
	Leptoseris				
	Lobophyllia	X	X	X	
	Merulina	X			X
	Millepora		X	X	X
	Montastrea	X	X	X	X
	Montipora	X	X	X	X
	Mycedium				
	Oulophyllia	X		X	X
	Oxypora	X			
	Pachyseris		X	X	
	Pavona	X	X		X
	Physogyra		X		
	Platygyra		X	X	X
	Pleisiastrea	X	X	X	X
	Plerogyra				
	Pocillopora	X	X	X	X
	Porites branching	X		X	X
	Porites massive	X	X	X	X
	Psammocora		X	X	X
	Synarea				
	Seriatopora				
	Stylophora	X	X	X	X
	Tubastrea			X	
	Tubipora				
	Turbinaria	X	X		

	Genus	Ambohibola	Itampolo	Beheloke	Maromena and Befasy
Algae Genera	Halimeda	X		X	X
	Asparagopsis	X			
	Caulerpa	X	X		
	Codium	X			
	Cystoseiria				
	Derbesia	X		X	
	Dictyospheria	X	X	X	X
	Dictyota	X	X	X	X
	Eucheuma	X	X	X	X
	Hydroclathrus			X	
	Hypnea	X			
	Laurencia	X			X
	Padina	X	X	X	X
	Red filamentous	X		X	
	Sargassum	X	X	X	X
	Turbinaria	X	X	X	X
	Ulva		X	X	X
	Jania				
	Amphiroa	X		X	X