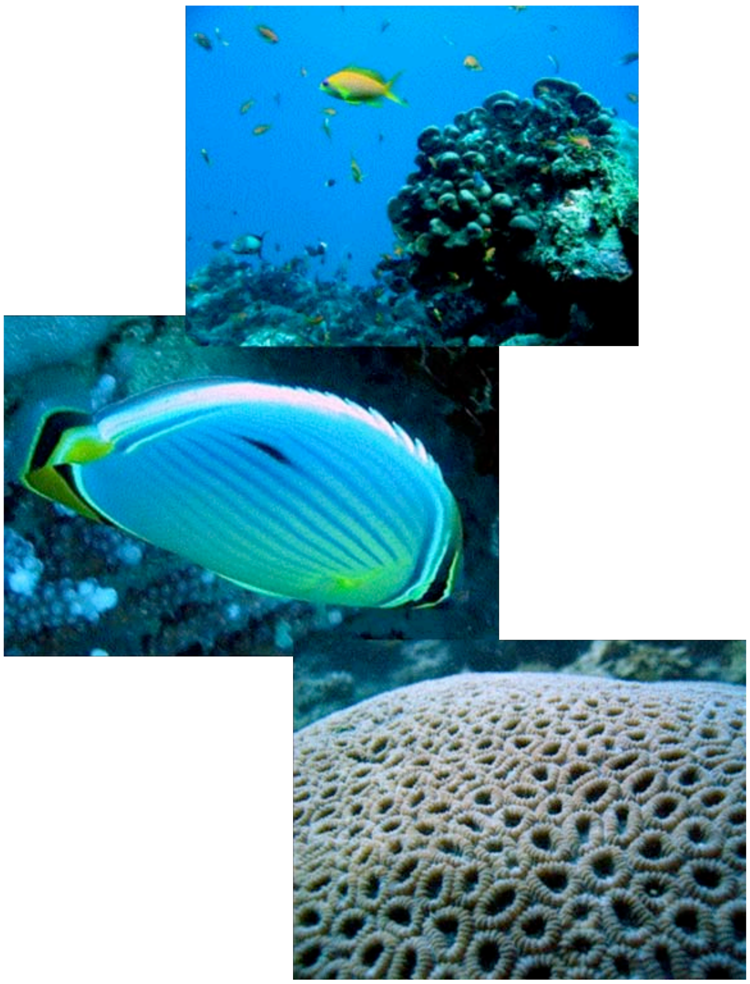
The coral reefs of Andavadoaka, southwest Madagascar



Nadon, M.-O., Griffiths, D. and Doherty, E.

Blue Ventures 2005

The coral reefs of Andavadoaka, southwest Madagascar

Recommended citation:

Nadon, M.-O., Griffiths, D. and Doherty, E. (2005) The coral reefs of Andavadaoaka, southwest Madagascar. Blue Ventures, 52 Avenue Road, London, UK.

Table of contents

Acknowledgements

For their help in the field with sampling design, the establishment of monitoring stations, volunteer training and data collection thank you to Etienne Bemanaja, Melanie Gomes, Matt Sommerville, Will Proto, Dan Logan, Henk van Rein, Katie Yewdall, Victor Bonito, Kit Gillibrand, Bic Manahira, Daniel Raberinery and Josephine Langley. In the UK office thank you to Alasdair Harris, Tom Savage, Anju Nihilani and Hugo Selbie for their hard work in enabling the field research to continue. Thank you to Dr. Man Wai Rabenevanana and Dr. Mara Edouard Remanevy at the Institut Halieutique et des Sciences Marines for all technical assistance and their invaluable continued support in country. Thank you to Simon Harding at the Wildlife Conservation Society for guidance with reef monitoring methodologies. Special thanks to Richard Nimmo, not only for all his help with data collection and training but for ensuring all logistical requirements, which are considerable in Andavadoaka's remote location, were always taken care of. Finally, many thanks to all volunteers who have worked with Blue Ventures in Andavadoaka, without whom none of the information recorded in this unique region could have been collected. This work was funded by Blue Ventures, and forms part of ongoing research and monitoring being undertaken in Andavadoaka to promote conservation of the region's marine resources.

Cover photos: M.-O. Nadon

Summary

This report presents the findings of the first in depth survey of the coral reefs of the Andavadoaka region, southwest Madagascar. Three reef systems (fringing, barrier and patch reefs) were surveyed between September 2004 and June 2005 for substrate composition, key invertebrate densities (e.g. sea urchins) and fish assemblages. The coral reefs in the region are in generally pristine shape, ranging from moderate to excellent. Patch reefs had the highest coral cover and highest density of coral recruits (~45% and 35 recruits per 20 m^2), followed by barrier reefs (~12% and 25 per 20 m^2) and fringing reefs (~8% and 15 per 20 m^2). Sea urchin assemblages varied greatly between reef systems, with fringing reefs being dominated by *Echinothrix* sp., barrier reefs by the rock-boring sea urchin *Echinostrephus molaris* and patch reefs by *Diadema* sp. On all reef types, algae grazing sea urchin densities were similar to levels encountered on protected reefs elsewhere in the western Indian Ocean and six times lower then on over fished reefs. The density of certain rare or commercial invertebrates (giant clams, triton shells and sea cucumbers) did not differ significantly between the relatively unexploited patch reefs versus barrier and fringing reefs, which suggests that these are not yet over fished in the region. Coral reef fish assemblages were significantly different on each reef system, with patch and barrier reefs being dominated by planktivores (e.g. fusiliers and sweepers) and fringing reefs being dominated by herbivores (e.g. damselfish). Reef fish densities were high on both patch and barrier reefs (~170 per 100 m^2) compared to fringing reefs (~90 per 100 m^2). This compares favourably with the lower densities found on both protected and unprotected reefs in Kenya and Tanzania (~80 per 100 m^2). Patch and barrier reefs also had a higher reef fish diversity. The coral reefs of the Andavadoaka region are not directly threatened by terrigenous sedimentation, as elsewhere in the country, due to the absence of major rivers. However, they are at risk from over fishing from a still small but rapidly increasing population of Vezo fishermen. Conservation efforts are currently underway to maintain the present status of these coral reefs, including the establishment of a marine protected area network encompassing parts of the barrier and patch reef systems.

Introduction

The terrestrial environment of Madagascar has for many years been the focus of national and international conservation efforts owing to the vulnerability of its abundant endemic flora and fauna. As a consequence, its extensive marine ecosystems - encompassing coral reefs, mangroves and seagrass beds - have been relatively ignored (Cooke et al. 2000). Despite this bias, an increasing amount of attention has been given to the marine and coastal environment as a principal focus of the third phase of Madagascar's environmental plan, following the country's commitment to create 6 million hectares of protected areas. This recent spur of interest in marine ecosystems has shed light on the poor and fragmented state of our scientific knowledge of them (Gabrié et al. 2000). Past research on marine and coastal ecosystems in Madagascar has focused on a few well studied regions, such as around Toliara in the southwest (Pichon 1971), Nosy Be in the northwest (McKenna & Allen 2003) and around the Masoala Peninsula in the northeast (McClanahan & Obura 1998). Much of the coastline remains scientifically unknown to researchers and government officials. To help compensate for this lack of knowledge, Blue Ventures, a non-governmental organization (NGO) based in the United Kingdom, established itself in October 2003 near the remote fishing community of Andavadoaka, southwest Madagascar, to begin work on the conservation of one of the most pristine marine environment in Madagascar.

Of the main marine ecosystems present in southwest Madagascar, coral reefs are by far the richest and most diverse habitat with an estimated 6000 reef-associated species, including 752 fish species and 340 coral species (McKenna & Allen 2003). Unfortunately, they are also the most fragile and most at risk from anthropogenic impacts (McClanahan 2000). The three main threats currently affecting the country's coral reefs are global warming, excessive sedimentation and over fishing (Cooke et al. 2000). Abnormally warm surface waters, related to a strong ENSO event, affected the region particularly strongly in 1998 and caused widespread coral bleaching in the north of Madagascar (McClanahan & Obura 1998). Smaller bleaching episodes were reported by dive operators in the Baie de Ranobe (some 200km south of Andavadoaka) in February 2002, and in Antongil Bay and the Masoala Peninsula in the northeast in March 2005 (S. Harding, pers. comm.). Other bleaching events that may have occurred between 1998 and 2003 are likely to have gone unreported, due to the low levels of research, monitoring and recreational diving being carried out in the region. Terrigenous sedimentation, due to poor agricultural practices such as large-scale deforestation, has caused considerable damage to coral reefs located near large river mouths, such as the Onilahy, Fiherenana and Manombo rivers in southwest Madagascar (Gabrié et al. 2000). Finally, the number of traditional Malagasy fishermen and boats has increased by a factor of five in the last two decades leading to the overexploitation of marine resources, especially near urban centres such as Toliara (Gabrié et al. 2000). In addition, the recent arrival of trawlers has raised concerns of direct reef damage and extreme biomass removal through by-catches. These impacts on coral reefs are particularly worrisome for the impoverished fishing communities that rely almost exclusively on coral reef products as a source of proteins and revenue, such as the Vezo communities of southwest Madagascar.

Fortunately, a significant proportion of the coastline remains scarcely populated and remote from river mouths, such as the region around Andavadoaka in the southwest. Most of the reefs in this region are believed to be in pristine conditions and have attracted the attention of NGOs (e.g. Blue Ventures, Wildlife Conservation Society) and the Malagasy government as one of the most sites for developing marine conservation initiatives in the country. Blue Ventures commenced monitoring of these coral reefs in earnest in 2004. The aim of this first report is to give a detailed description of the current, baseline, status of the coral reefs of Andavadoaka.

Methods

Study site

The research site is located in southwest Madagascar near the remote fishing community of Andavadoaka which lies 150 km north of the regional capital of Toliara and 50 km south of Morombe (43°13`30 E, 22°04`22 S). The area is characterized by two distinct fringing and barrier reef systems separated by a 5 km wide lagoon and a series of patch reefs inside the lagoon (Fig. 1). The barrier reef is composed of a series of discontinuous sand cay islands and submerged platforms, and extends for approximately 20 km in the vicinity of Andavadoaka. The fringing reef system is separated from land by a shallow lagoon a few hundred meters wide and is mostly continuous over 15 km of coastline in the region. Only a few patch reefs have yet been discovered in the study area and it is doubtful that they cover more than a few square kilometres (Fig. 1).

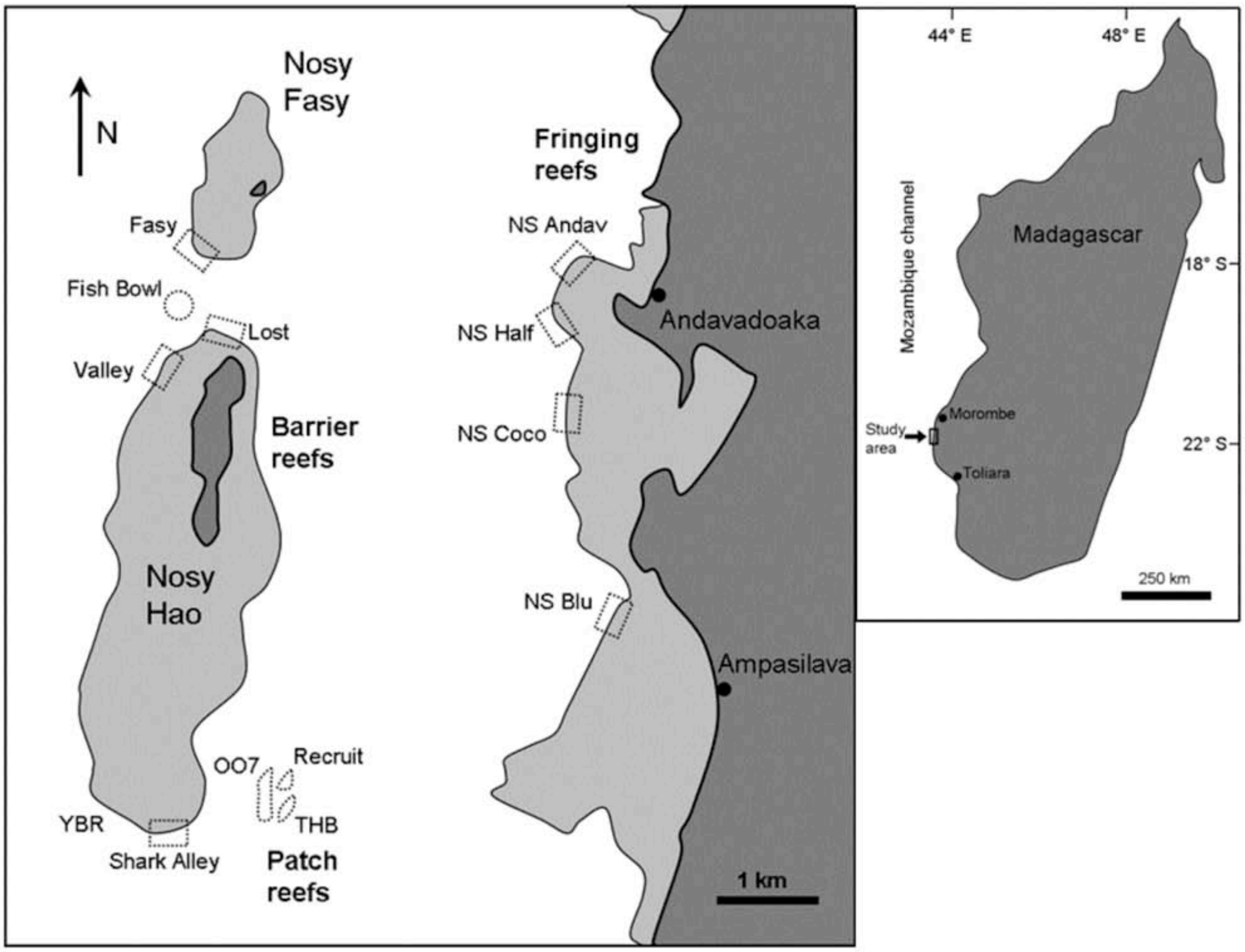


Fig 1 – The three reef systems of the Andavadoaka region with sampling sites (fringing, barrier and patch reefs).

The only fishing communities present in the region are Andavadoaka (pop. 1200), Ampasilava (pop. 600) and a small settlement on the island of Nosy Hao (pop. 50). These communities are almost entirely composed of Vezo fishermen who rely heavily on coral reef resources for both subsistence and income. Fishing is carried out using pirogues (small sailing canoes) or walking, limiting most fishing effort to the nearby reef systems, with fishing at deeper, offshore sites only possible in favourable conditions. The main exploited organisms are fin fish (e.g. Lethrinidae, Serranidae, Scombridae, Lutjanidae), the octopus *Octopus cyanea*, squids and lobsters. The main fishing grounds are around the barrier reefs (~60% of fin fish catches), followed by the fringing reefs (~40% of fin fish catches; unpublished data). Patch reefs, being deeper and harder to locate, are mostly unexploited. Although fishing methods are still traditional, the recent introduction of commercial buyers for fresh fish, as opposed to the traditional dried and salted fish market, has led to an increase in the exploitation of certain species (e.g. *Octopus cyanea*) and the proliferation of a cash economy.

Climate and sea conditions

The climate is tropical with distinct winter and summer seasons. Mean air temperatures for the region range from 22 °C in July-August to 25 °C in January-February. Rainfall is largely restricted to short episodes during summer months with a very low regional average of only 35 cm of rain per year. Andavadoaka is occasionally affected by cyclones, though not as severely as the coast further north (Cooke et al. 2000). The wind is predominantly from the southwest all year and is relatively mild with wind speeds of 14 km h^{-1} on average (unpublished data) and about 340 days a year with wind speeds lower than 10 km/h (Cooke et al. 2000). Swell direction is predominantly from the turbulent southern ocean and encountering 3 to 4 m high swells outside the lagoon is not uncommon. Surface water temperatures within the lagoon range from 24 to 31 °C throughout the year (Fig 2). There are no large river outlets within 100 km of Andavadoaka and preliminary studies suggest terrigenous sediment levels, particularly after storm events, are much lower than for reef systems near the Onilahy and Manombo rivers (DG, pers. obs). Tidal range is high compared to the east coast as oceanic waters are funnelled through the Mozambique Channel. The large tidal regime, coupled with a usually strong afternoon wind, makes underwater visibility highly variable within the Andavadoaka lagoon.

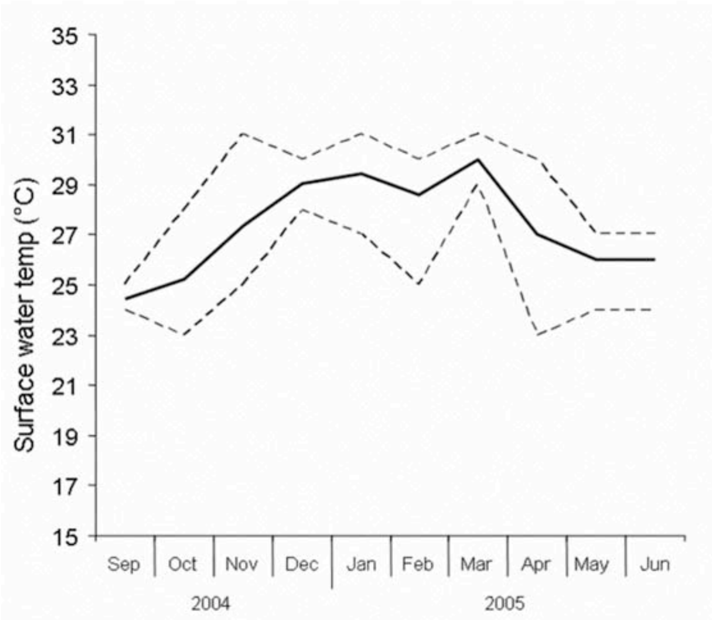


Fig 2 – Surface water temperature recorded during dives at sites around Andavadoaka (average with minimum and maximum).

Survey methods

Coral reef monitoring was carried out by SCUBA diving from September 2004 to June 2005 at 11 survey sites (4 fringing reef sites, 4 barrier reef sites and 3 patch reef sites; Fig. 1) using a combination of marine biologists and trained, non specialist, volunteers. Certain zones of the extensive reef flat surrounding the island of Nosy Hao were also surveyed during this period.

Benthic composition

Point intercept transects (PIT) were deployed at each survey site along permanent transects delineated by fixed iron stakes to record the composition of the substrate (see appendix for locations and depths). Each transect was 10 m in length and the upper most substrate type observed below every 20 cm marker within the transect was recorded, giving 50 sub-sample points per transect. Substrate types were classified in the following categories: hard coral, turf algae (thin algal filaments < 1 cm long), macroalgae, soft coral, crustose coralline algae, cyanobacteria, sand, bleached coral and other invertebrates (e.g. zoanthids, tunicates, sponges, etc.). A minimum of 6 permanent transects were put in place at each survey site (up to 10 transects where there was sufficient reef area). Survey sites are revisited every 4 months. Surveys of the Nosy Hao reef flat were carried out by foot during periods of low tide using a slightly different method than for reef surveys (20 m long non-permanent transects, with 100 sub-samples).

The density of ecologically and commercially important invertebrates was recorded over a 2 m wide belt along each 10 m long permanent transect by a second observer using the same tape measure as for PITs. The invertebrates recorded were: four groups of sea urchins (*Diadema* sp., *Echinothrix* sp., *Echinometra mathaei*, *Echinostrephus molaris*); triton shell gastropods; giant clams; and sea cucumbers. The number of coral recruits (diameter < 5cm) was also recorded during these surveys.

Fish assemblages

The density and taxonomic composition of coral reef fishes were surveyed along belt transects at each site. Belt transects were carried out by deploying a 20 m long transect line following the contour of a reef at two different depths (side and top of a reef) and waiting for 5 minutes to compensate for the disturbance caused by the divers. Two observers then swam along the transect at a speed of approximately 4 m per minute recording fish numbers in an area extending 2.5 m on both sides of the line and 5 m above the line (5 m x 5 m x 20 m). All fish encountered within a transect (excluding cryptic species) were recorded to family level and, if observers were sufficiently trained, to species level. The list of the 30 families and 150 species of reef fish most commonly encountered in the region is shown in the appendix. All observers were required to accurately identify the families and species from that list to undertake sampling.

Data analysis

The aim of this report being to describe the reef ecosystem around Andavadoaka at a regional level, most figures and data analysis were made at the scale of the three reef systems (fringing, barrier and patch reefs). Individual site data can be found in the appendix. Data were analysed using ANOVA statistical tests (following verification of basic assumptions) and Fisher's Least Significant Difference (LSD) pairwise multiple comparison test when necessary. The Systat statistical software was used for all analysis.

Results

Composition of the benthos

Substrate types

Up to 200 species of hard corals (order Scleractinia) have up to now been identified on the reefs surrounding Andavadoaka by Blue Ventures scientists and specimens from 90 species are stored on site.

250 linear intercept transects were carried out on the reefs in the region. Coral cover varied significantly between the three types of reef studied (fringing, barrier and patch reefs; ANOVA, df=2, 247, F=109, $p<0.0001$). Patch reefs had significantly higher hard coral cover (42 % ± 2 SE) than barrier reefs (14 % ± 1 SE; LSD pairwise, $p<0.0001$) and fringing reefs (8 % ± 1 SE; LSD pairwise, $p<0.0001$). Coral cover was significantly higher on barrier reefs than on fringing reefs (LSD pairwise, p=0.04). The OO7 and Recruitment patch reefs were the sites with the highest coral cover in the region with around 50 % of the substrate covered by live coral (Fig. 3). Similarly to coral cover, the density of coral recruits differed markedly between reef types (ANOVA, df=2, 129, F=7.53, p=0.001). Recruits were in greater abundance on patch reefs (~ 35 recruits per 20 m^2; Fig. 4), compared to barrier reef (~ 25 recruits per 20 m^2; LSD pairwise, p=0.03) and fringing reefs (~ 15 recruits per 20 m^2; LSD pairwise, $p<0.0001$). The density of recruits between fringing and barrier reefs was not statistically different (LSD pairwise, p=0.07). Filamentous turf algae and macroalgae covered about 60% of the available substrate on fringing and barrier reefs, but only 30 % of the substrate on patch reefs. On all reef types, the remaining substrate cover consisted of crustose coralline algae (~10%), soft coral (~5%) and small patches of cyanobacteria (~2%). No significant occurrence of coral bleaching has been observed since monitoring began in 2003.

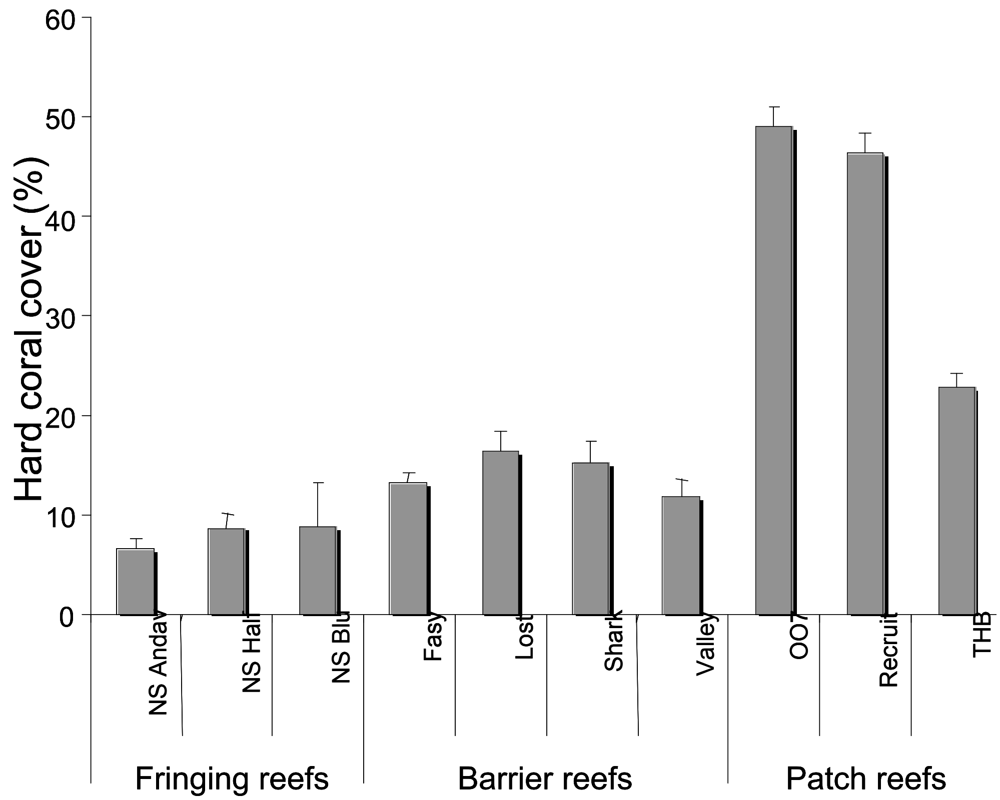


Fig 3 – Percent hard coral cover at various sites around Andavadoaka (mean ± SE).

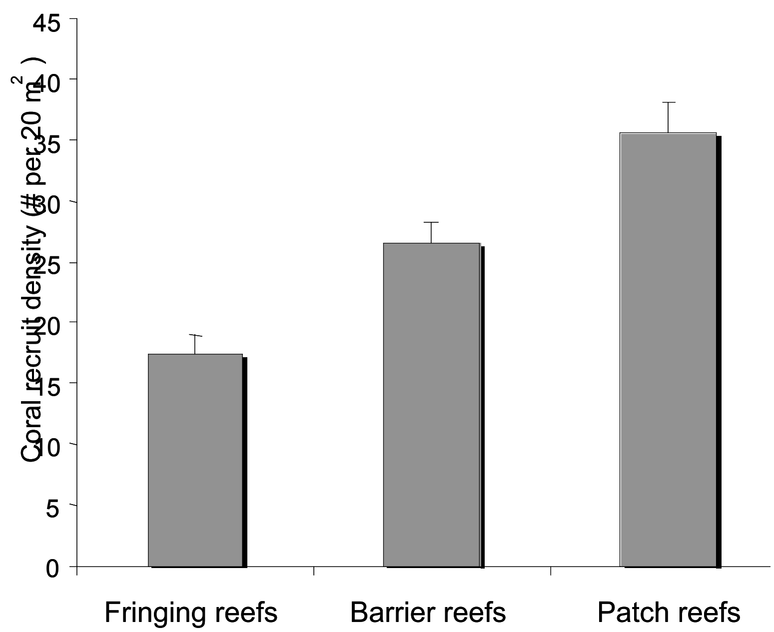


Fig 4 – Density of coral recruits (< 5 cm diameter) on the three reef systems (mean ± SE).

The surveyed area of the Nosy Hao reef flat was divided into 4 mostly homogeneous zones: the northwest (NW), west (W), southwest (SW) and south (S) zones (Fig. 5). In all zones, sand covered about a third of the substrate and live coral cover was less then 1%. Large stems of macroalgae, mostly *Sargassum* genus, covered about a third of the substrate in all zones except the SW, where macroalgae was replaced by extensive patches of seagrass. Seagrass patches were also present in the other zones, but in smaller areas (Fig. 5). The southernmost zone of the reef flat has not yet been surveyed due to difficulty of accessing it.

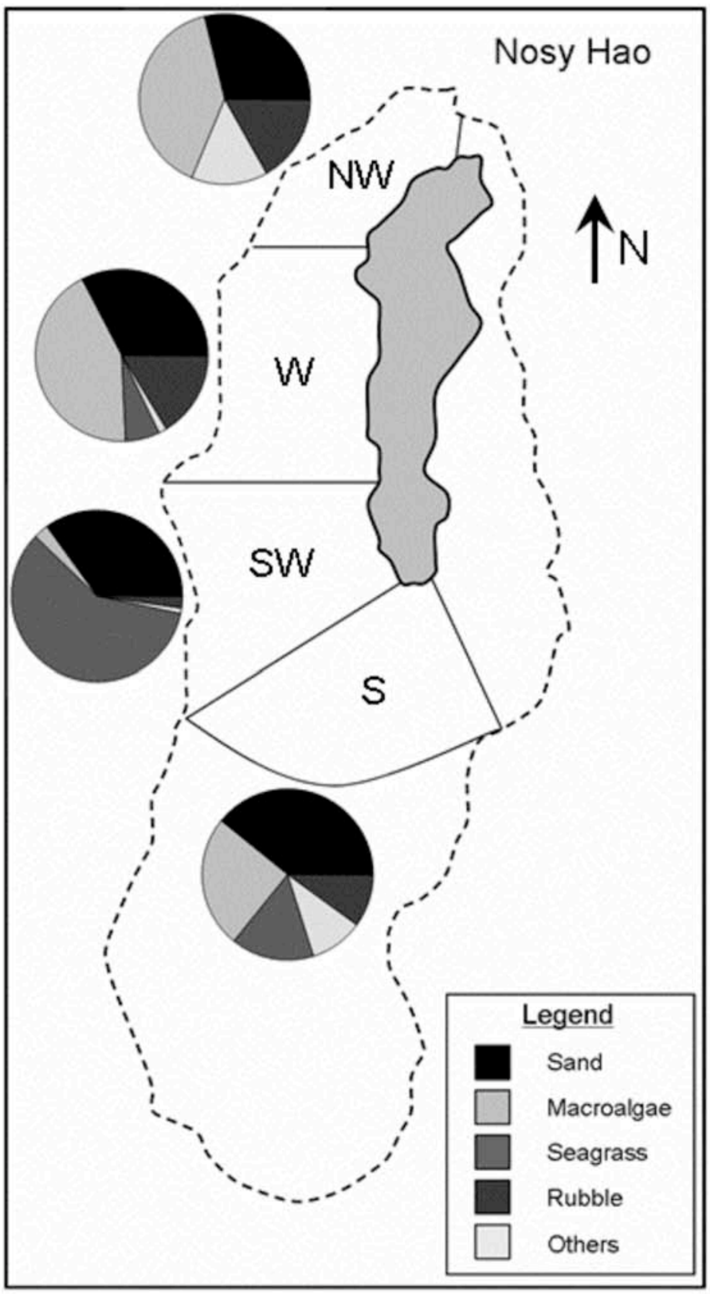


Fig 5 – Benthic composition of the Nosy Hao reef flat.

Key invertebrates

In total, 278 invertebrate belt transects were carried out. The sea urchin populations varied markedly between the three types of reef. The rock-boring sea urchin *Echinostrephus molaris* was significantly more abundant on barrier reefs (mean of 1000 individuals per hectare) than on the two other types of reef (ANOVA, df=2, 275, F=10.2, p<0.0001; Fig. 6). *Echinothrix* individuals were more common on fringing reefs than on either patch or barrier reefs (ANOVA, df=2, 275, F=11.3, p<0.001). Finally, patch reefs had a significant presence of *Diadema* (ANOVA, df=2, 275, F=6.1, p=0.003; Fig. 6) compared to the other types of reef. In general, fringing and patch reefs had the greatest number of algae grazing sea urchins (*Diadema*, *Echinometra* and *Echinothrix*) with around 600 individuals per hectare, versus only 120 individuals per hectare on barrier reefs.

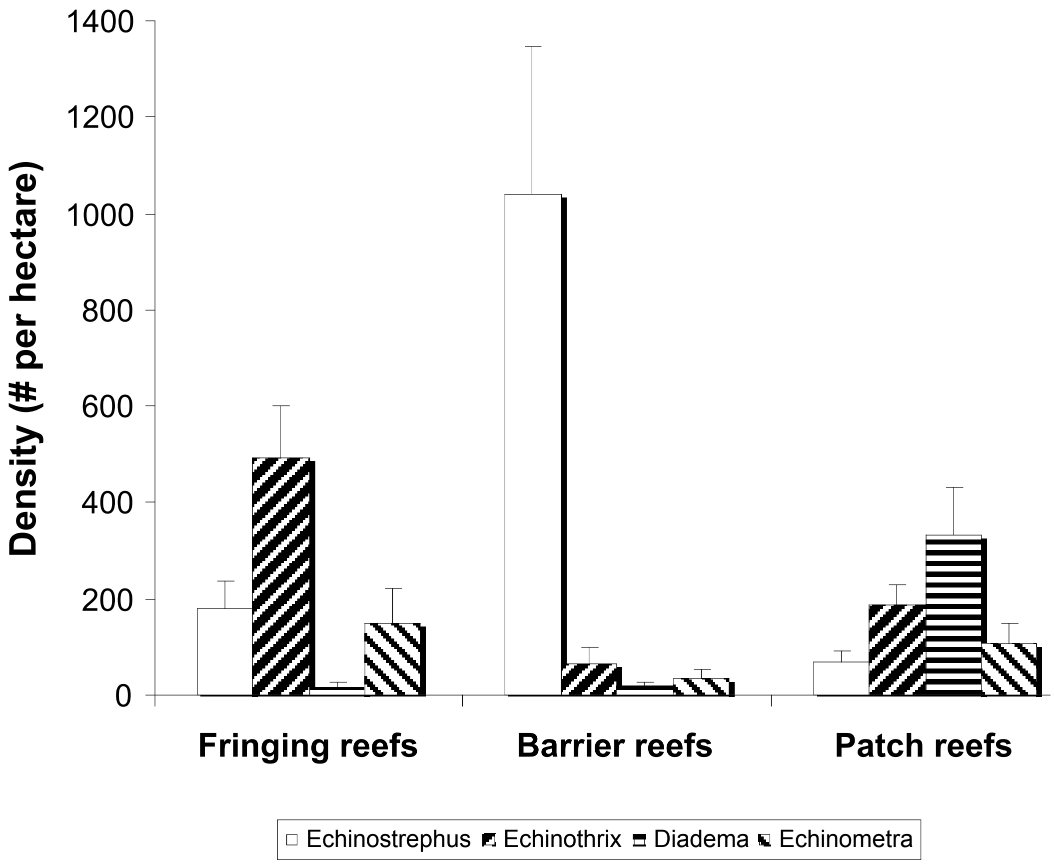


Fig 6 – Sea urchin densities on the three reef systems (mean ± SE).

The three groups of commercial invertebrates surveyed in this study did not differ significantly between the three reef types (ANOVA, df=2, 191, p>0.10 for sea cucumbers, triton shells and giant clams). Although these differences were not statistically significant, giant clams and triton shells were encountered more commonly on barrier reefs (Fig. 7). On all types of reef, sea cucumber density was on average 72 individuals per hectare; giant clam density 57 individuals per hectare and, finally, triton shells density was of 21 individuals per hectare.

The crown-of-thorns starfish (*Acanthaster planci*), although rarely encountered, was in greater abundance on fringing reefs (50 individuals per hectare) than on either patch reefs (5 individuals per hectare) or barrier reefs (never encountered; ANOVA, df=2, 191, p=0.005). There was no difference in *Acanthaster* abundance between barrier and patch reefs (LSD pairwise, p=0.89).

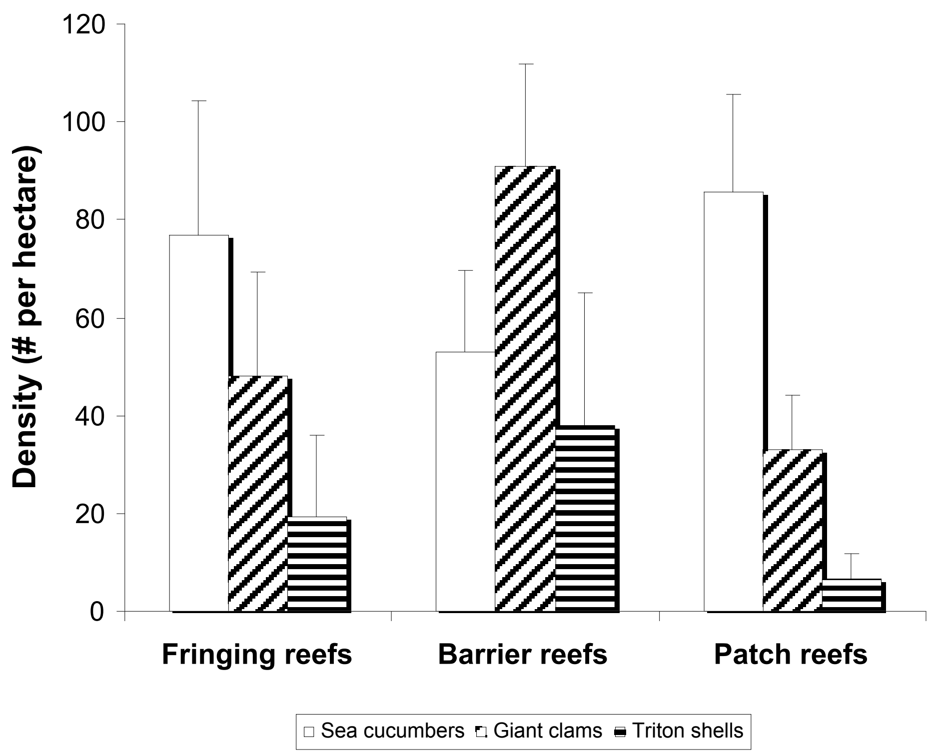


Fig 7 – Density of rare and commercially important invertebrates (mean ± SE).

Coral reef fish

We conducted 187 fish belts on the reefs around Andavadoaka. Of these, 92 were at the species level and the rest at the family level. Coral reef fishes formed three distinct species assemblages on fringing, barrier and patch reefs when analyzed in a multi-dimensional scaling (MDS) plot (Fig. 8; ANOSIM, R=0.31, p=0.03). Patch reefs had a greater diversity of fish assemblages, followed by barrier reefs and fringing reefs (Fig. 8).

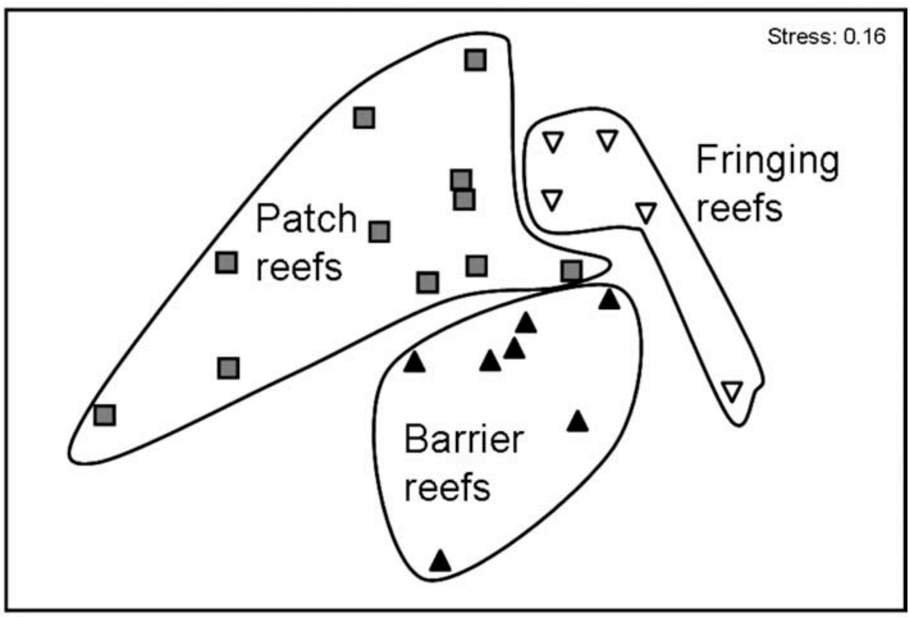


Fig 8 – MDS plot of fish assemblage composition from various sites, sampled at different occasion. Points close to one another have similar reef fish populations.

Diversity

Currently, 350 species of fish from about 60 families have been identified in the area with 240 of them photographed. The family richness (average number of fish families encountered per transect) differed significantly between reef types (ANOVA, df=2, 184, F=14.8, P<0.0001; Fig. 9). Patch and barrier reef family richness were not statistically different with on average 10 fish families encountered per transect (LSD pairwise, p=0.45). Family richness was significantly less on fringing reefs compared to the two other types of reef with only 7 families per transect on average (Fig. 9; LSD pairwise, p<0.0001 for both barrier and patch reefs compared to fringing reefs). There were no statistically relevant differences between the three types of reef in species richness per transect (average of 12 species per transect; Fig. 9). Although this number is highly affected by the heterogeneity of our sampling effort between sites, the absolute species richness was higher on barrier and patch reefs (63 and 61 species encountered on transects, respectively) than on fringing reefs (42 species encountered). It is also worth noting that this number only included the most common species in the region, present in our sampling list: the true number of fish species on each type of reef is still higher. There was no significant difference in Shannon diversity indexes (H`) between reef types at either the family or species level (Fig. 10; ANOVA, p=0.11 for family H` and p=0.19 for species H`).

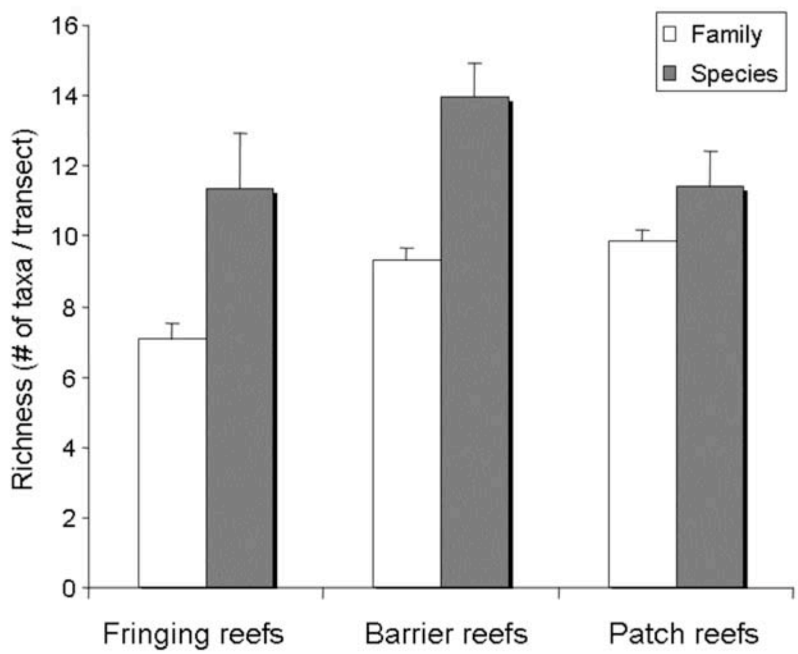


Fig 9 – Species and family richness standardized to sampling effort (mean per transect ± SE).

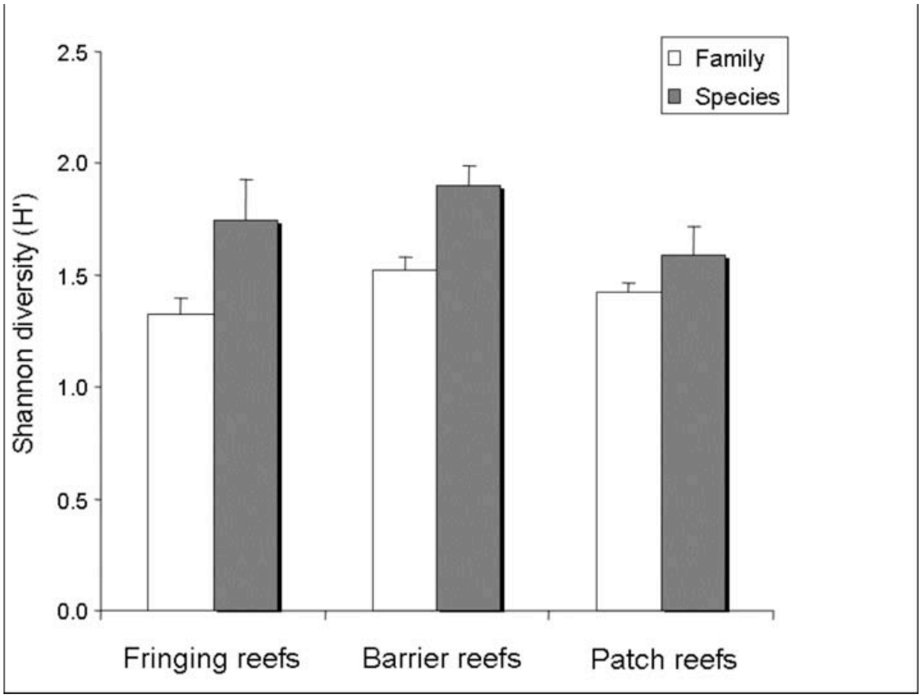


Fig 10 – Species and family diversity measured by the Shannon index (H` ± SE).

Abundance

Reef fish abundance (number of fish per transect) was significantly different between reef types (ANOVA, df=2, 184, F=4.1, p=0.02). There were twice as many fish on barrier reefs (155 fish per transect) and patch reefs (180 fish per transect) than on fringing reefs (80 fish per transect; Fig. 11). LSD pairwise comparisons were significant between patch and fringing reefs (p=0.005) and between barrier and fringing reefs (p=0.05). There was no significant difference in fish abundance between patch and barrier reefs (LSD pairwise, p=0.46). These differences are due to a greater number of both planktivores (e.g. fusiliers and sweepers) and omnivores (e.g. triggerfish and pufferfish) on these types of reef (Fig. 11). There were also significantly more coralivores (e.g. butterflyfish) on reefs with higher coral cover (linear regression, df=1, 8, F=58.6, R^2=0.88, p<0.0001; Fig. 12).

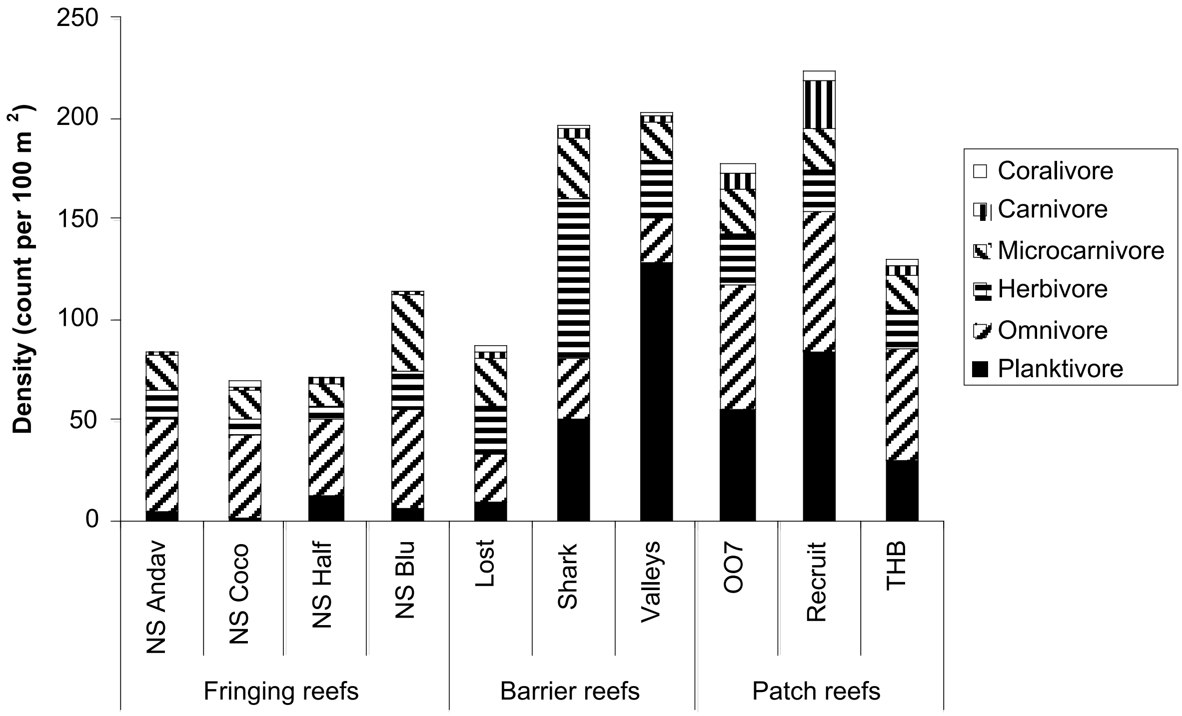


Fig 11 – Average coral reef fish abundance at all survey sites classified by trophic guild.

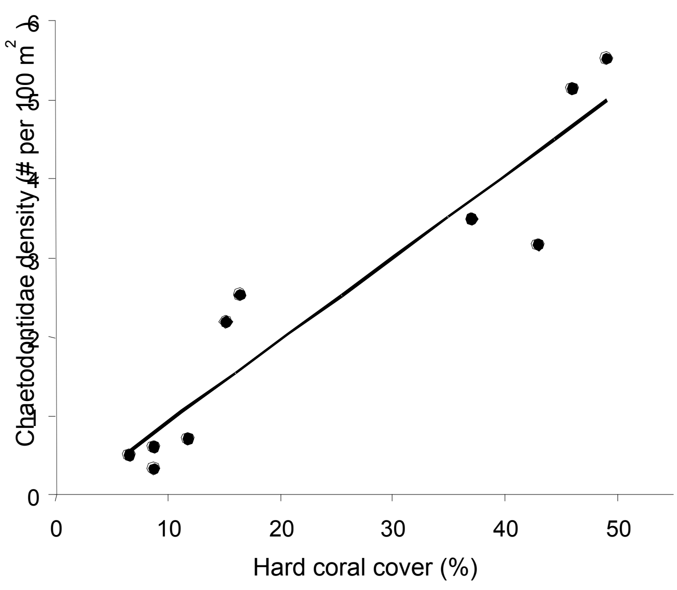


Fig 12 – Linear regression of the abundance of coralivorous chaetodontids (butterflyfish) with coral cover at 10 sites around Andavadoaka.

Focal species sightings

Besides common invertebrates and coral reef fish, the following rare, protected or endangered species have also been sighted on reefs in the region: the napoleon wrasse (*Cheilinus undulatus*), the giant grouper (*Epinephelus lanceolatus*), the white-tip reef shark (*Triaenodon obesus*), the black-tip reef shark (*Carcharhinus melanopterus*), the grey reef shark (*Carcharhinus amblyrhynchos*), the zebra/leopard shark (*Stegostoma fasciatum*), the scalloped hammerhead shark (*Sphyrna lewini*), the whitespot giant guitarfish (*Rhynchobatus djiddensis*), the spotted eagle ray (*Aetobatus narinari*), the manta ray (*Manta birostris*), the hawksbill sea turtle (*Eretmochlelys imbricata*), the green sea turtle (*Chelonia mydas*) and, finally, the loggerhead sea turtle (*Caretta caretta*). All of these sightings occurred on barrier and patch reefs.

Discussion

Current status of coral reefs

The reefs around Andavadoaka are in variable conditions ranging from moderate to excellent. On almost all aspects, patch reefs are in the healthiest condition, followed by barrier reefs and, finally, by fringing reefs (Table 1).

	Fringing reefs	Barrier reefs	Patch reefs
Invertebrates			
Live coral cover	3	2	1
Coral recruit density	3	2	1
Absence of bleaching event?	Yes	Yes	Yes
Grazing urchin density (lowest)	2	1	2
Rare invertebrate density*	3	2	1
Acanthaster density (lowest)	3	1	1
Coral reef fish			
Reef fish abundance	3	2	1
Chaetodontidae density	3	2	1
Family richness	3	1	1
Species richness*	3	1	2
H’ (family level)*	3	1	2
H’ (species level)*	2	1	3
Other considerations			
Total area in the region	2	1	3
Fishing pressure (lowest)	2	3	1
Focal species sightings?	No	Yes	Yes

Table 1 – Ranking of the three reef types according to certain reef health indicators. All differences are significant at the 0.05 level except those with an *.

Hard coral cover

The patch reefs found near the southern edge of the Nosy Hao reef flat are by far the best reefs in the region with about 45% live coral cover, with some exceptional sites approaching 70% live coral cover (e.g. OO7 south). These reefs compare with the best ones found in other parts of Madagascar such as in the northwest (~70% coral cover; McKenna & Allen 2003) and around Nosy Be (~50% coral cover; Webster & McMahon 2002). They also compare favourably with the best reefs found in Ifaty (~40%) and Belo-sur-Mer (~55% coral cover; Ahamada et al. 2002). Unfortunately, this group of patch reefs covers only a few hectares and although monitoring has begun on a recently discovered patch reef located between the island of Nosy Hao and Nosy Fasy (see *Fish bowl* on map) it is doubtful that many more such reefs will be discovered at this depth in the region. Barrier and fringing reefs, on the other hand, occupy a much larger area than patch reefs, but have far less live coral cover (~12 % and ~8%, respectively). Similarly, the densities of coral recruits are also lower on both barrier and fringing reefs compared with patch reefs, which suggests that these two reef areas will probably not achieve coral covers similar to patch reefs in the near future. The higher coral covers found on patch reefs and to a lesser extent, barrier reefs, are probably partly due to their greater depth, which reduces their susceptibility to coral bleaching from abnormally warm surface waters.

Key invertebrates

The over harvesting of certain species of fish can drastically increase the density of key invertebrates, typically sea urchins, by removing their predators (Roberts 1995, McClanahan 1998). Sea urchins are important reef eroders and their number can strongly affect coral reef structure (Carreiro-Silva & McClanahan 2001). Algae grazing sea urchins (i.e. all genera studied except *Echinostrephus*) can also benefit coral reefs by removing significant amounts of algae which can potentially compete against coral for space and lead to algae dominated states (Hughes 1994, Hughes et al. 1999). In the region presently studied, sea urchin assemblages vary greatly between the three types of reef, with fringing reefs being dominated by large individuals from the *Echinothrix* genus, barrier reefs being strongly dominated by small, rock-boring *Echinostrephus molaris* urchins, and patch reefs being dominated, to a lesser extent, by individuals from the *Diadema* genus. The overall density of the three large algae grazing sea urchins found in the Andavadoaka region (~400 urchins per ha) is similar to those encountered on protected sites in Kenya and Tanzania (~430 urchin per ha) and 6 times lower then on unprotected, over fished sites in the same region (~2500 per ha ;McClanahan et al. 1999). The extreme density of sea urchins encountered on unprotected sites in Kenya and Tanzania was explained by the excessive removal of their predators (e.g. triggerfish) by fishing. The relatively low densities of sea urchin on the three reef systems in Andavadoaka thus suggests that urchin populations are appropriately regulated by the presence of a sufficient abundance of key predators and is an indication that these reefs are not yet clearly over fished.

No significant differences were detected between barrier, fringing and patch reefs in the abundance of the 3 commercial invertebrates sampled (sea cucumbers, triton shells and giant clams). Patch reefs have a very low fishing pressure and should have almost natural abundances of these invertebrates; the fact that barrier and fringing reefs have similar densities suggests that these species are not yet over fished on these reefs. Finally, the coralivorous crown-of-thorns starfish *Acanthaster planci* was found almost solely on fringing reefs (50 per ha), with no sightings on barrier reefs and only a few on patch reefs (5 per ha). The overall density of *Acanthaster* in the region (~15 per ha) can be considered high compared to the typically low concentrations found elsewhere in the Indian Ocean (~0.2 per ha; McClanahan 2000). This is no serious cause for concern since *Acanthaster* densities are not currently excessive, even on fringing reefs, and triton shell gastropods, its natural predator, are still commonly found on all types of reef, as discussed previously. Furthermore, major crown-of-thorns outbreaks are rare in the western Indian Ocean and have never been recorded in Madagascar (McClanahan 2000).

Reef fish

Unsurprisingly, the high coral cover patch reefs also harbour the highest fish densities, including the highest density of coralivorous butterflyfish (Chaetodontidae) which, as was previously shown, are a reliable indicator of reef health in the region (see Fig 12). More surprisingly, barrier reefs, which are the most heavily fished (Blue Ventures, unpublished data) and have relatively low coral covers, only have slightly lower fish densities then on patch reefs (~155 per 100 m^2 versus 180 per 100 m^2). The fringing reef sites, which are also heavily fished and have the lowest coral cover, have half the reef fish densities present on the two other reef systems (80 per 100 m^2). The higher densities of fish on barrier and patch reefs are mostly due to a higher concentration of planktivores (e.g. fusiliers) and omnivores (e.g. surgeonfish). These densities compare very favourably with those measured on both protected and unprotected coral reefs in Kenya and Tanzania, which were similar to the low levels found on Andavadoaka's fringing reefs at around 90 fish per 100 m^2 (McClanahan et al. 1999). This suggests that the relatively heavy fishing pressure on barrier reefs has not yet significantly affected their reef fish population.

The difference between reef types in fish diversity was less clear. The only significant difference was in family richness per transect between fringing reefs (~7 families per transect) versus barrier and patch reefs (~10 per transect). Barrier reefs had the highest species richness per transect and highest H`, although both these indexes were not significantly different between systems. The absolute number of species in the region can be estimated using Allen (1998)'s species diversity regression formula: number of species = 3.39 (CFDI) – 20.595, where CFDI is the Coral Reef Fish Diversity Index, which is simply the total number of species in 6 key families (Chaetodontidae, Pomacanthidae, Pomacentridae, Labridae, Scaridae and Acanthuridae). The total number of species estimated with this formula for the Andavadoaka region is 430, which is close to the number estimated in an in-depth survey of northwest Madagascar (576 species; (McKenna & Allen 2003). Andavadoaka, and Madagascar in general, have a similarly high reef fish diversity as the Indian Ocean islands of the Seychelles and Maldives or, for example, French-Polynesia islands in the Pacific (McKenna & Allen 2003).

The threats

The three principal factors currently or potentially threatening Malagasy coral reefs are: bleaching from abnormally warm surface waters, excessive terrigenous sedimentation and over fishing (Gabrié et al. 2000). The reefs in the region were severely affected by warm waters during the 1998 El Niño event and will no doubt be affected again in the next few decades. Encouragingly, the reefs around Andavadoaka seem to be at lower risk from coral bleaching since they were not affected in March 2005 when a bleaching event was reported in the northeast of the island (S. Harding, pers. comm.). Furthermore, the reefs in the region are not seriously affected by terrigenous sedimentation, the closest river being at least 100 km away to the north (Mangoky River) or south (Manombo River). This is confirmed by a preliminary sedimentation analysis that shows that most settling particles are grains of sand from the lagoon (BV, unpublished data). The main manageable threat to the reefs of Andavadoaka in the foreseeable future is over fishing from the traditional Vezo fishermen in the communities of Andavadoaka, Ampasilava and Nosy Hao. By most accounts, the reefs in the region appear to be relatively unaffected by over fishing (see previous section). However, the population of Andavadoaka, now at 1200 with 350 fishermen (60% of the active population), is growing at a high rate of 4% a year (FID 2003) and signs of over fishing will no doubt start appearing in the next few decades, as in the rest of the region (Laroche et al. 1997) and most coastal areas in the western Indian Ocean. Furthermore, the recent arrival of collection companies, paying a higher price for marine products and introducing a new, lucrative market for marine products, has created a major incentive to increase individual fishing efforts (pers. observ.).

Conservation

As discussed above, the three reef systems present in the Andavadoaka region are in mostly pristine conditions, but at risk from a rapidly increasing population of the still traditional but very skilled Vezo fishermen. These results are not entirely surprising: the low population density, lack of major rivers and general remoteness of these coral reefs are what attracted the attention of NGOs (BV, WCS, WWF), research institutes (IHSM, IRD, ARVAM, SAGE) and the Malagasy government (MAEP, CSP) in the first place. There is a genuine concern amongst these partners and the local community for the future of the coral reefs of Andavadoaka and major conservation efforts are currently underway to ensure the safeguarding of this exceptional ecosystem. One of the proposed projects is the creation of a system of marine protected areas (MPAs) to manage and restrict fishing on certain reefs. Despite the paucity of properly controlled long-term experiments demonstrating their effectiveness in conserving natural riches and enhancing local fisheries, MPAs are generally viewed as the only viable and moral management option for subsistence fisheries (Russ 2002, Sale 2002).

Based on the findings presented in this report, we believe the best location for a MPA network would be on both barrier and patch reefs. The patch reefs near the southern end of Nosy Hao (Fig. 1) are the healthiest in the region and are relatively unexploited, which would make their designation as a no-take zone easily accepted by the local communities. Since these reefs represent only a few hectares, a significant portion of the barrier reef system would also need to be included in the marine reserve plan. The most convenient option would be to designate a major section of the southern tip of the Nosy Hao reef (including the Shark Alley survey site) as part of a continuous no-take zone with the patch reefs also located in this area. This would also include the stunningly beautiful seascape of the spur & groove zone called Yellow Brick Road, located on the south west tip of the reef (see YBR on map, figure 1), which would undoubtedly attract recreational divers . The Nosy Hao reef flat in this zone could also be included in the reserve but probably not as a strictly no-take zone, since it is an important octopus fishing area. Coral cover on the reef flat is very low (<1%) and it is unlikely that completely closing this area would have any significant conservation effects. In addition to this suggested no-take zone nucleus, adjacent areas could be designated as restricted fishing zones where, for example, only line fishing would be permitted. Regardless of the nature and shape of the proposed marine reserve, the interest and enthusiasm displayed by international, national and local community partners in this project will hopefully lead to the long-term preservation of one of Madagascar's richest and most beautiful marine environments.

Literature cited

Ahamada S, Bigot L, Bijoux J, Maharavo J, Meunier S, Moyne-Picard M, Paupiah N (2002) Status of coral reefs in the south west Indian Ocean island node: Comoros, Madagascar, Mauritius, Reunion and Seychelles. In: Status of the coral reefs of the world

Carreiro-Silva M, McClanahan TR (2001) Echinoid bioerosion and herbivory on Kenyan coral reefs: the role of protection from fishing. J. Exp. Mar. Biol. & Ecol. 262:133-153

Cooke A, Ratomahenina O, Ranaivosoin E (2000) Madagascar. In: Sheppard CRC (ed) Seas of the Millenium. Elsevier Science press

FID (2003) Plan communal de développement : Befandefa, Commune de Befandefa, Toliara

Gabrié C, Vasseur P, Randriamiarana H, Maharavo J, Mara E (2000) The Coral Reefs of Madagascar. In: McClanahan T, Sheppard CRC, Obura DO (eds) Coral Reefs of the Indian Ocean. Oxford University Press, New York

Hughes T, Szmant AM, Steneck R, Carpenter R, Miller S (1999) Algal blooms on coral reefs: what are the causes? Limnol. & oceanogr. 44:1583-1586

Hughes TP (1994) Catastrophes, phase shifts, and large scale degradation of a Caribbean coral reef. Science 265:1547-1551

Laroche J, Razanoelisoa J, Fauroux E, Rabenevanana MW (1997) The reef fisheries surrounding the south-west coastal cities of Madagascar. Fish. Manag. Ecol. 4:285-299

McClanahan T (2000) Coral reef use and conservation. In: McClanahan T, Sheppard CRC, Obura DO (eds) Coral reefs of the Indian Ocean. Oxford University press, New York

McClanahan T, Obura DO (1998) Monitoring, training and assessment of the coral reefs of the Masoala Peninsula, Wildlife Conservation Society, Madagascar

McClanahan TR (1998) Predation and the distribution and abundance of tropical sea urchin populations. J. Exp. Mar. Biol. & Ecol. 221:231-255

McClanahan TR, Muthiga NA, Kamukuru AT, Machano H, Kiambo RW (1999) The effects of marine parks and fishing on coral reefs of northern Tanzania. Biol. Conserv. 89:161-182

McKenna SA, Allen GR (2003) A rapid marine biodiversity assessment of northwest Madagascar, Vol 31. Conservation International, Washington, DC

Pichon M (1971) Comparative study of the main features of some coral reefs of Madagascar, La Reunion and Mauritius. Symp. Zool. Soc. Lon. 28:185-216

Roberts C (1995) Effects of fishing on the ecosystem structure of coral reefs. Conserv. Biol. 9:988-995

Russ GR (2002) Yet another review of marine reserves as reef fishery management tools. In: Sale PF (ed) Coral Reef Fishes. Academic Press, San Diego

Sale PF (2002) The science we need to develop for more effective management. In: Sale PF (ed) Coral Reef Fishes. Academic Press, San Diego

Webster FJ, McMahon K (2002) An assessment of coral reefs in northwest Madagascar, Unpublished report

Appendix