Coral Reef Monitoring in Marine Reserves of Northern Madagascar

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keywords: Madgascar, coral reef monitoring, coral bleaching, marine protected areas

ABSTRACT

This study has provided detailed biophysical information on shallow to mid-depth coral reef habitats for the existing National Marine Parks at Masoala and Mananara and for the recently designated Sahamalaza National Park, all located in northern Madagascar. Data indicates that large scale disturbance events such as severe tropical storms are a major influence on shallow and mid-depth coral reef habitats in the marine parks. Differences in benthic composition were also governed by differences in marine habitat according to exposure gradients. A preliminary investigation of the effects of management practices on coral reef fauna did not reveal any significant differences between park zones, such as higher reef fish biomass in protected compared to unprotected reefs. Low to moderate fishing pressure on reefs adjacent to marine parks is likely to be a primary contributing factor to this lack of difference in marine resource availability between management zones.

INTRODUCTION

Considering the length of the Malagasy coastline,

Figure 1. Map of Madgascar, showing the MPAs monitored in the text: 1) Sahamahalaza, 2) Masoala (containing the 3 reserves Tanjona, Cap Masoala and Tampolo), and 3) Mananara Nord.

estimated to be more than 5000 km (Cooke et al., 2003) there are very few marine protected areas in Madagascar. At the national level, Madagascar currently has only two fully established national parks with a marine element to them; Nosy Atafana marine reserve in the Mananara Nord Biosphere Reserve and Masoala National Park which contains three marine reserves; Tampolo, Masoala and Tanjona. There are other smaller marine reserves at Nosy Ve in the south-west and Nosy Tanikely near Nosy Be in the northwest. However Nosy Ve is not yet recognised at the national level although it is protected by local law (Dina). Nosy Tanikely has some national conservation status in that fishing is prohibited within 300 metres of the island but this is poorly enforced with infringements known to occur (Cooke et al., 2003). Monitoring of coral reefs in and around these protected areas has varied. The most comprehensive programme is in the Masoala National Park conducted by the National Parks Authority (ANGAP) in collaboration with the Wildlife Conservation Society (WCS). Monitoring of one or two sites in each of the three reserves at Masoala began in 1998 and was expanded from 2002 onwards. At other sites patchy data has been recorded and some baseline assessments completed (Wilkinson 2000, Randriamanantsoa and Brand 2000).

As part of the National Environmental Action Plan (NEAP) three further marine parks were designated for establishment at the end of 2005. One of these is the Sahamalaza marine park which already has UNESCO Biosphere Reserve status. The others are Nosy Hara archipelago in the far north-west and Nosy Ve, near Anakao in the south-west of Madagascar. The proposed parks will be managed by ANGAP in collaboration with the following international NGO's and national institutions; SAGE at Sahamalaza, WWF at Nosy Hara and IHSM at Nosy Ve. The primary aim of this study was to expand coral reef monitoring in Madagascar at two of the existing and one of the proposed marine reserves and to extend monitoring to deeper depths. This paper summarizes some of the main points of the full monitoring report (Harding and Randriamanantsoa, 2006). Socio-economic monitoring from the same sites is also reported in Cinner et al. 2006 (and Cinner & Fuentes, 2008).

Coral reefs in Madagascar are under threat from climate change induced events such as mass coral bleaching and more direct anthropogenic induced impacts of sedimentation and overfishing. Corals on shallow reefs (<10 metres depth) in south western Madagascar were dramatically affected by the 1998 bleaching event, north-western Madagascar was not significantly affected and the north-east was intermediate between these (McClanahan and Obura, 1998). The main large scale disturbance events that occur in northern Madagascar are severe tropical storms which mainly occur between December and April, affecting both eastern and western sides. There have been three major cyclones in the north of Madagascar since 2000: Hudah (April 2000), Gafilo (March 2004) and Indlala (March 2007).

METHODOLOGY

Study site locations were selected so that surveys were conducted both within marine protected areas of each marine park or reserve and in unprotected areas open to fishing pressure adjacent to the marine parks. In Sahamalaza 12 sites were sampled, mostly on offshore submerged barrier reefs at 11-13 m depth, with one site each on inshore patch and island fringing reefs at shallower depths. At Tanjona, Cap Masoala and Tampolo in Masoala 4-5 sites each were sampled on the seaward spur and groove and fringing and patch reef areas at 5-10 m depth. At Mananara Nord 4 sites were sampled on fringing reef areas at 8-12 m depth.

Ecological monitoring of coral reefs and associated systems followed standard methodology as used by the Global Coral Reef Monitoring Network (GCRMN) and outlined in Hill and Wilkinson (2004). The majority of sites were assessed using fixed, haphazardly placed transects for benthic composition, reef fish biomass and invertebrate density.. Benthic cover was recorded using the point intercept transect method (PIT, 20 cm between points) on 4 replicate transects

Table 1. Benthic composition at marine park locations in northern Madagascar (mean values of percentage cover + standard error. n = 16).

Benthic Category	Sahamalaza		Tanjona		Cap Masoala		Tampolo		Mananara	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sand	8.2	2.0	1.1	0.5	0.9	0.4	9.3	1.9	4.1	1.0
Bedrock	5.8	1.6	2.3	0.6	2.4	0.6	1.9	0.4	1.3	0.2
Rubble	6.8	1.8	0.3	0.1	2.2	0.5	0.9	0.3	3.9	0.7
Turf Algae	24.9	2.6	20.4	1.7	30.7	2.3	36.4	1.6	28.6	3.0
Macroalgae	2.3	0.8	9.7	2.0	0.8	0.2	4.8	1.1	2.4	0.7
Calcified Algae	16.4	1.8	29.9	2.7	36.7	2.4	10.6	1.4	34.9	2.8
Sponge	2.6	0.5	0.6	0.2	0.8	0.3	1.7	0.5	1.6	0.3
Other Invertebrates	0.6	0.3	0.4	0.2	1.5	0.9	1.1	0.5	0.4	0.2
Soft Coral	14.1	2.2	23.0	2.7	10.8	1.1	7.8	2.3	8.9	1.7
Acropora Corals	1.7	0.5	1.4	0.4	4.3	1.3	1.1	0.5	0.6	0.3
Non-*Acropora* Corals	14.8	2.4	10.7	1.2	8.6	0.9	23.2	3.4	12.8	1.7
Live Hard Coral	16.4	2.5	12.1	1.1	13.0	1.6	24.3	3.5	13.4	1.7

of 20 metres in length. Sessile organisms were recorded to genus ‘in situ’ when possible and confirmed using digital photographs using Veron (2000), Fabricus and Alderslade (2004), Littler and Littler (2003) and Richmond (2002).

Sixteen fish families were selected for monitoring, representing the main trophic groups of reef fish occurring in the study regions and the main fish families targeted by local fishers. At each site two replicate belt transects 50 metres in length, 5 metres wide and 5 metres deep were used. Individual fish were recorded in 5 cm size classes between 0 and 50 cm total length (TL) or 10 cm size classes between 50 and 100 cm TL. Fish length estimation at Sahamalaza and Tanjona used slightly different size class categories. For these sites fish were counted into six size categories as follows: 0-20 cm, 20-35 cm, 35-50 cm, 50-65 cm, 65-80 cm and more than 80 cm TL. Biomass for each family was calculated using biometric equations derived from moderately fished reef fish populations sampled in Kenya (McClanahan, unpublished) and converted to kilograms per hectare of reef area. Selected macro-invertebrates were recorded in the 50 x 5 metre belt transects, identified to species when possible. Commercially harvested (sea cucumbers, octopus, lobster), rare (large gastropod molluscs) or ecologically significant (herbivorous urchins) invertebrates were the main taxa selected for monitoring.

RESULTS

Between October 2005 and February 2006 a total of 24 sites were surveyed using fixed transects at the three national parks. Sites were located both within the marine protected areas of the reserves and in adjacent unprotected areas. At Masoala National Park and Sahamalaza, sites inside the parks were positioned in the core 'no-take' areas where all fishing is prohibited. For inter-park comparison 4 survey sites were selected at each park that represented the main reef type assessed for each park location in this study. For intra-park comparisons the four sites were then split into two groups depending on their location either inside or outside the marine park (see Harding and Randriamanantsoa, 2006 for details).

Benthic Composition

Benthic composition varied considerably between parks and often between sites within the same marine park location. Sahamalaza was characterised by relatively high levels of abiotic substrata (20.8%) consisting mainly of sand and coral rubble (Fig. 2, Table 1). Turf and calcified algae were the main components of the benthos with a combined cover of 41.2%. Macroalgal cover was low at the four sites combined (2.3%) but higher on the inshore patch reef (Site 1) at 20.5%. Coral cover on the top of the submerged barrier reef was just over 30% of the available substratum and was evenly split between hard (16.4%) and soft (14.1%) corals.

Marine parks on the more exposed east coast of Madagascar, with the exception of Tampolo, were characterised by a high cover of calcified algae mainly crustose coralline algae (CCA) but also branching calcified reds which included *Amphiroa Lithophyllum* and *Neogoniolython* spp. Calcified algae cover ranged between 29.9% and 36.6% for marine park locations at Mananara, Cap Masoala and Tanjona (Fig. 2, Table 1). The second largest component of the benthos was turf algae ranging between 20 and 30%. Macroalgal cover was low at both Mananara and Cap Masoala and did not exceed 3%. Higher cover of macroalgae was

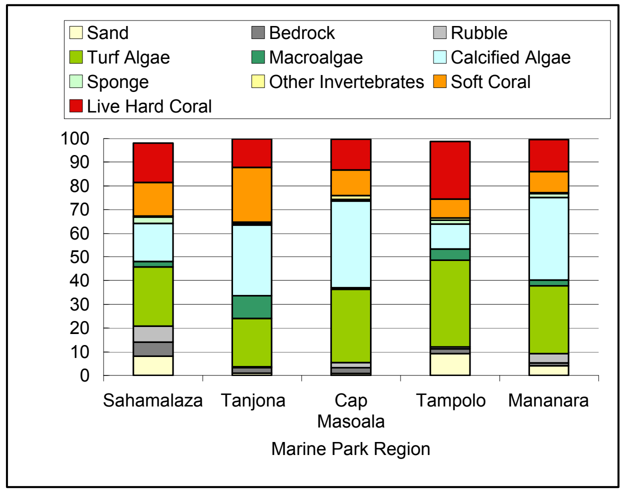

Figure 2. Benthic Composition at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

recorded at Tanjona (10.0%) and was mainly attributed to loosely attached spherical clumps of the red alga *Galaxaura subverticillata*.

Total coral cover (octocorals and hexacorals) for east coast parks ranged from 22.3% at Mananara to 35.1% at Tanjona. The latter location differed from other marine parks on the east coast by having a higher proportion of soft coral cover than hard coral. Soft corals made up 23% of the benthos while hard coral cover was 12.1% at Tanjona. Hard coral cover at Cap Masoala (13.0%) and Mananara (13.4%) was similar to levels recorded at Tanjona. Tampolo sites had the highest hard coral cover of any park location (24.3 %) but also highest standard error (3.5) indicating that inter-site variation was greatest at this location.

Cover of other sessile invertebrates was low across all marine park locations. Sponge cover was highest at Sahamalaza (2.6%) and less than 2 % at all other parks. Cover of other sessile invertebrates (zooanthids, anemones, coralliomorphs, giant clams and ascidians) ranged between 0.4 and 1.5%.

Closer examination of hard coral cover reveals that the genus *Acropora* was occasionally or rarely recorded on transects at the marine park locations (Table 1, Fig.

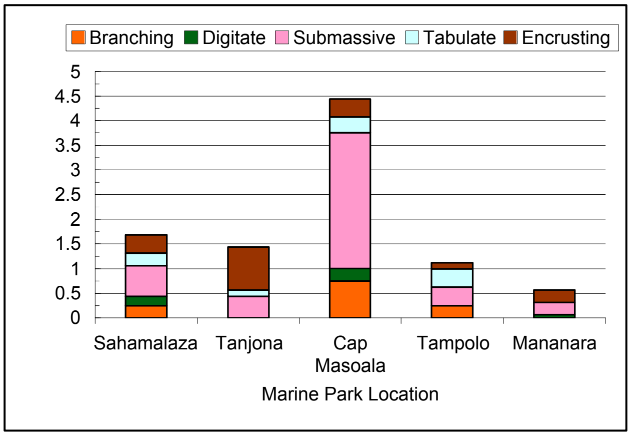

Figure 3. Percentage cover of *Acropora* lifeforms at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

3). Mean *Acropora* cover was less than 1.7% at all marine parks with the exception of Cap Masoala (4.5%). The main *Acropora* lifeforms present were submassive and encrusting and were more prominent at the more exposed locations of Mananara, Cap Masoala and Tanjona. Non-*Acropora* corals made up the bulk of hard coral cover at all sites but total cover for this category varied considerably between marine park locations (Table 1, Fig. 4). Mean total cover remained between 8 and 15% for all park locations

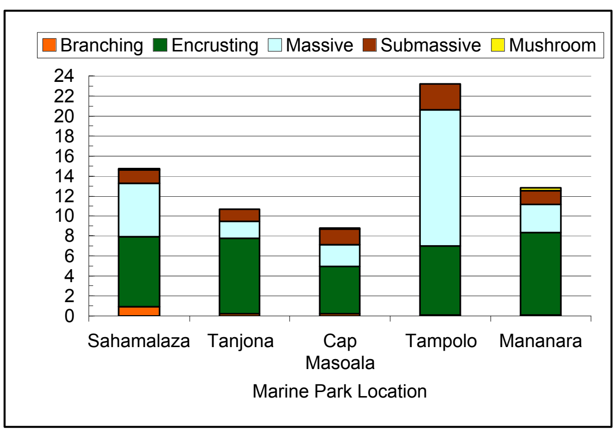

Figure 4. Percentage cover of Non-*Acropora* lifeforms at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

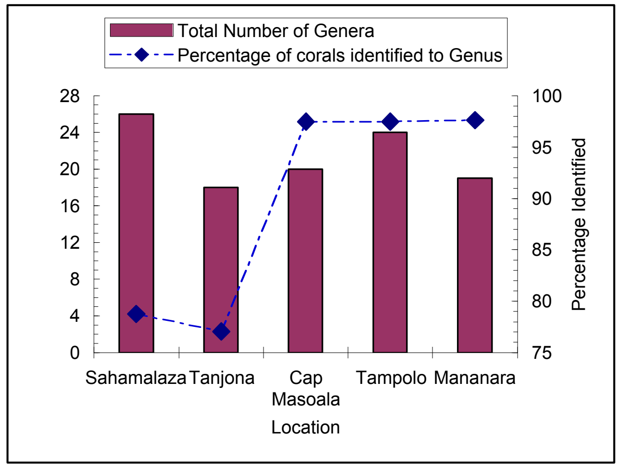

Figure 5. Comparison of hard coral diversity between marine park locations.

except for Tampolo (23.2%). The vast majority of non-*Acropora* corals were either encrusting or massive forms with submassive colonies also recorded at all locations. Branching lifeforms were rarely recorded, with a maximum cover of 0.9% at Sahamalaza but were present at all locations.

The highest number of hard coral genera (26) was recorded at Sahamalaza (Fig. 5) even though the proportion of colonies identified to genus at this location was low (78.8%) compared to other parks (except Tanjona). On the east coast of Madagascar hard coral generic diversity was similar at Mananara, Tanjona and Cap Masoala (18-20 genera) while Tampolo had a higher diversity with 24 genera recorded. Porites was the most abundant genus at Sahamalaza, Tampolo and Mananara and dominated the hard coral fauna at Tampolo. Large *Porites* massive colonies were frequent at Tampolo but encrusting forms were dominant at Mananara and Tanjona. Branching forms of *Porites* were rare but were recorded more often at Sahamalaza. Faviids (*Favia*, *Favites* and *Platygyra*) were a regular and significant component of the hard coral fauna at all park locations and were particularly prominent at Mananara and Tampolo. Mussids such as *Lobophyllia* were also important components at these two

Table 2. Reef fish biomass at marine park locations in northern Madagascar (Mean values of kg/ha. + standard error). N = 8 x 50 m transects except Sahamalaza (n = 6) and Cap Masoala (n = 4 x 100 m transects).

Family	Sahamalaza		Tanjona		Cap Masoala		Tampolo		Mananara	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Acanthuridae	441.5	240.6	258.6	40.2	144.8	48.4	312.4	111.6	261.0	62.8
Balistidae	13.4	2.7	9.3	9.9	9.1	8.5	0.9	1.0	2.3	1.6
Caesionidae	193.7	119.6	35.9	37.8	32.4	37.4	51.6	20.3	65.2	34.3
Carangidae	20.5	19.2	0.0	0.0	0.0	0.0	59.5	61.8	0.0	0.0
Chaetodontidae	23.9	14.4	13.4	7.0	4.0	1.7	5.4	0.9	10.7	1.9
Haemulidae	11.8	9.6	0.0	0.0	0.0	0.0	7.0	4.9	5.5	4.7
Labridae	73.1	13.0	69.9	18.8	69.0	20.5	71.4	27.9	96.5	13.2
Lethrinidae	33.1	19.2	1.0	0.5	0.0	0.0	2.2	2.3	2.8	2.3
Lutjanidae	14.4	11.0	0.0	0.0	0.0	0.0	1.2	0.7	0.0	0.0
Mullidae	6.5	2.2	0.6	0.4	0.6	0.6	4.1	2.6	6.2	2.7
Pomacanthidae	14.4	7.1	6.7	6.2	18.8	13.3	16.4	6.9	3.5	3.4
Pomacentridae	6.8	1.0	17.8	4.9	18.5	4.8	19.7	3.9	23.2	4.6
Scaridae	54.5	16.6	121.5	42.7	44.2	5.8	25.2	12.3	95.1	35.7
Serranidae	5.7	4.2	51.3	46.8	133.4	88.9	27.0	16.9	47.8	17.6
Siganidae	15.6	10.0	0.0	0.0	0.5	0.5	21.6	12.1	14.2	10.2
Total	**929.0**	**252.0**	**585.9**	**110.5**	**475.1**	**95.7**	**625.6**	**163.4**	**634.0**	**102.4**

locations. *Acropora* was the most commonly recorded genus at Cap Masoala and also notable at Tanjona and Sahamalaza. The latter two park locations contained the highest cover of *Turbinaria* spp. Encrusting forms of *Millepora* were a prominent part of the hard coral fauna at Tanjona. *Galaxea* was most often recorded at the three park locations around the Masoala Peninsula.

Reef Fish Biomass

Reef fish biomass was calculated for six size categories (0-20 cm, 20-35 cm, 35-50 cm, 50-65 cm, 65-80 cm and > 80 cm). Mean values of total reef fish biomass for 15 families combined were higher on the west coast of Madagascar at Sahamalaza (929 kg/ha) than at east coast locations on the Masoala Peninsula and Mananara (475–634 kg/ha). However, a large variance between sites was found at both Sahamalaza (s.e. = 252) and Tampolo (s.e. = 164), and total biomass estimates were not statistically different between marine park locations (Oneway ANOVA on log(x) transformed data). Cap Masoala had the lowest total biomass values for the 15 recorded families, but the highest biomass for groupers (Serranidae) although variation between counts for this family was also high (Table 2).

Highest biomass was recorded for Acanthurids (144 – 441 kg/ha), which made up 40-50% of total biomass at four of the five park locations and more than 30% at Cap Masoala (Table 3). The second largest component of fish biomass varied between marine park locations and consisted of Caesionids at Sahamalaza, Groupers (Serranids) at Cap Masoala, Labrids at Tampolo and Mananara and Scarids at Tanjona. Biomass of Labrids was similar across all marine park locations (69-96 kg/ha) and this family was consistently ranked highly, as were Scarids and Caesionids (Table 3). Scarid biomass was more variable with highest values recorded at Tanjona (121 kg/ha) followed by Mananara (95 kg/ha). Biomass of

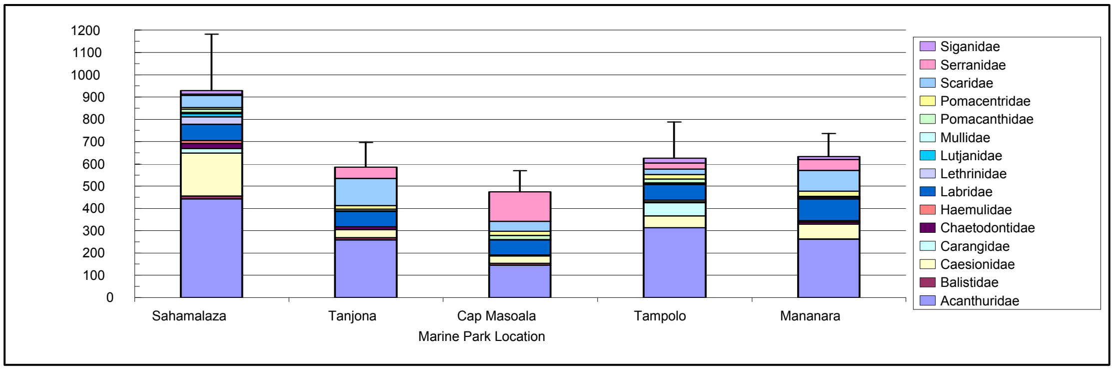

Figure 6. Reef Fish Biomass for Selected Families at Marine Park Locations in Northern Madagascar (Mean values of kg/ha. with standard error shown for total biomass).

Table 3. Percentage contribution of fish families to total recorded biomass and ranking (in brackets).

Family	Sahamalaza	Tanjona	Cap Masoala	Tampolo	Mananara
Acanthuridae	47.53 (1)	44.14 (1)	30.48 (1)	49.94 (1)	41.16 (1)
Balistidae	1.44 (11)	1.58 (8)	1.91 (8)	0.15 (15)	0.36 (13)
Caesionidae	20.85 (2)	6.12 (5)	6.81 (5)	8.24 (4)	10.28 (4)
Carangidae	2.21 (7)	0 (12=)	0 (12=)	9.51 (3)	0 (14=)
Chaetodontidae	2.58 (6)	2.29 (7)	0.84 (9)	0.87 (11)	1.68 (8)
Haemulidae	1.27 (12)	0 (12=)	0 (12=)	1.11 (10)	0.86 (11)
Labridae	7.87 (3)	11.93 (3)	14.51 (3)	11.41 (2)	15.23 (2)
Lethrinidae	3.57 (5)	0.17 (10)	0 (12=)	0.34 (13)	0.45 (12)
Lutjanidae	1.55 (9)	0 (12=)	0 (12=)	0.20 (14)	0 (14=)
Mullidae	0.70 (14)	0.09 (11)	0.12 (10)	0.65 (12)	0.98 (9)
Pomacanthidae	1.55 (10)	1.15 (9)	3.96 (6)	2.62 (9)	0.55 (10)
Pomacentridae	0.73 (13)	3.03 (6)	3.89 (7)	3.15 (8)	3.61 (6)
Scaridae	5.87 (4)	20.74 (2)	9.30 (4)	4.03 (6)	15.00 (3)
Serranidae	0.61 (15)	8.75 (4)	28.08 (2)	4.32 (5)	7.54 (5)
Siganidae	1.68 (8)	0 (12=)	0.10 (11)	3.46 (7)	2.25 (7)

Pomacentrids was considerably lower at Sahamalaza than at other marine park locations (Table 2, Fig. 6). Highest biomass of Chaetodontids, Balistids, Lethrinids, Lutjanids and Haemulids were all recorded at Sahamalaza. The latter three families were not recorded often at sites on the east coast of Madagascar.

Macro-Invertebrates

Herbivorous urchins in three genera (*Diadema*, *Echinothrix* and *Echinometra*) were not recorded at all on submerged barrier reef sites at Sahamalaza but were present on inshore reef sites where *Diadema* was the

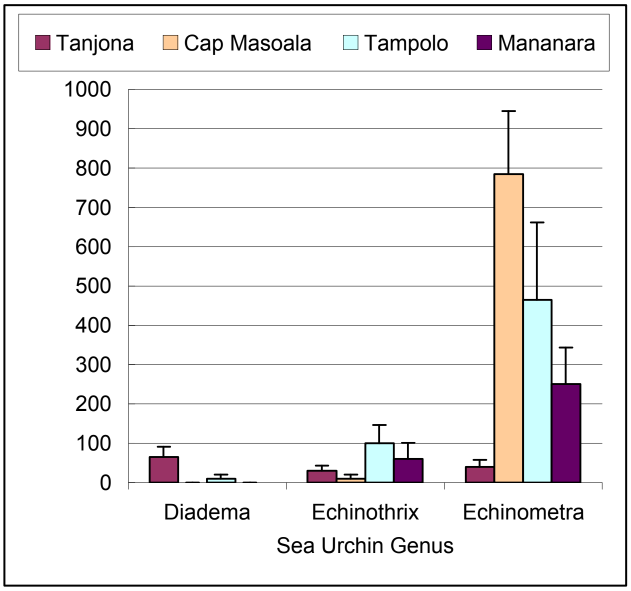

Figure 7. Herbivorous Urchin Densities at Marine Park Locations in Northern Madagascar (Mean values + SE, n = 8).

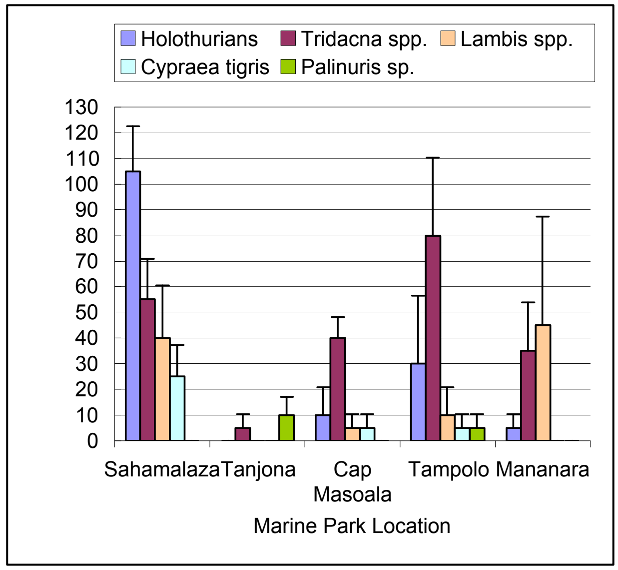

Figure 8. Invertebrate Densities at Marine Park Locations in Northern Madagascar (Mean values + SE, n = 8).

most abundant genus. On east coast sites *Diadema* and *Echinothrix* densities were low, with less than 100 per ha (Fig. 7). Considerably higher densities of *Echinometra* were recorded at most east coast parks, particularly at Cap Masoala and Tampolo where mean densities ranged from 465 to 785 ha^{-1} with high variation between sites and transects. The small burrowing urchin *Echinostrephus molaris* was present at all locations and often at high densities but was not recorded in this study. Densities of holothurians also varied considerably between park locations (Fig. 8). Holothurians were the most abundant and diverse at Sahamalaza on the submerged barrier reef with a mean density of 105 ha^{-1} and a total of five genera recorded. Densities at the other locations did not exceed 30 ha^{-1} with only one or two genera recorded at each park. Mean densities of giant clams (*Tridacna* spp.) were similar at Sahamalaza, Cap Masoala and Mananara (35-55 ha^{-1}). Highest densities were found at Tampolo (80 ha^{-1}) with few individuals recorded at Tanjona. High densities were also seen at the shallow inshore site on Nosy Berafia at Sahamalaza, where numerous small individuals of *Tridacna squamosa* were present.

Conch shells (*Lambis* spp.) were recorded more often at Sahamalaza and Mananara than at the three locations on the Masoala Peninsula. Tiger cowries (*Cypraea tigris*) were not seen on transects at Mananara or Tanjona, occasionally recorded at Cap Masoala and Tampolo and most abundant at Sahamalaza. Lobster (*Palinurus* sp.) were recorded at low densities at Tanjona and Tampolo but not on transects at the other three park locations.

Other invertebrates not recorded in transects were *Acanthaster plancii* and *Cassis cornuta*. *Charonia tritonis* was observed in Sahamalaza on two occasions on inshore sites (Sites 1 and 5). Another rare species also seen at Sahamalaza but not on transects was *Heterocentrotus mammilatus*.

Marine Park Zones Comparison

There were few significant differences in benthic cover, reef fish biomass and invertebrate density between sites inside the marine protected areas where fishing is either officially restricted (Mananara-Nord

Table 4. Statistical comparison of coral reef indicators inside and outside of marine parks in northern Madagascar (Two-sample T-test on transformed data). Data Transformations used: Arcsin for Benthic Percentage Cover, Log(x) for Fish Biomass and Square-root (x + 0.5) for Invertebrate Densities. Significance levels: * = $p< 0.05$, ** = $p< 0.01$, n.s. = not significant, n.t. = not tested, I>O = greater inside MPA than outside, I<O = greater outside MPA than inside.

	Sahamalaza	Tanjona	Cap Masoala	Tampolo	Mananara
Benthic					
Hard Coral	* I>O	n.s.	n.s.	** I<O	** I<O
Soft Coral	n.s.	* I<O	n.s.	* I>O	n.s.
Turf Algae	n.s.	n.s.	n.s.	n.s.	n.s.
Calcified Algae	n.s.	** I>O	n.s.	n.s.	n.s.
Abiotic Cover	n.s.	n.s.	n.s.	n.s.	n.s.
Reef Fish					
Acanthuridae	n.s.	n.s.	n.s.	n.s.	n.s.
Balistidae	n.s.	n.t.	n.t.	n.t.	n.t.
Chaetodontidae	n.s.	n.s.	n.s.	n.s.	n.s.
Labridae	n.s.	n.s.	n.s.	n.s.	n.s.
Mullidae	n.s.	n.t.	n.t.	n.t.	n.t.
Pomacentridae	n.s.	n.s.	* I<O	n.s.	n.s.
Scaridae	n.t.	n.s.	n.s.	n.s.	n.s.
Serranidae	n.t.	n.s.	n.s.	n.s.	n.s.
Total Biomass	n.s.	n.s.	n.s.	n.s.	n.s.
Invertebrates					
Holothurians	n.s.	n.t.	n.s.	n.s.	n.s.
Tridacna	n.s.	n.s.	n.s.	n.s.	n.s.
Echinometra	n.t.	* I>O	n.s.	n.s.	n.s.

Biosphere Reserve) or prevented (Masoala National Park marine reserve no-take zones) and outside of the marine parks, where there are no fishing restrictions (Table 4). Most of the statistical differences were found for benthic categories. Hard coral cover was significantly higher in the core marine park zones of the submerged barrier reef at Sahamalaza than at sites in the controlled fishing zone. However the opposite was found at Tampolo and Mananara with higher hard coral cover outside of the marine parks. Soft coral cover was higher in the no-take zone at Tampolo than outside the marine reserve. Conversely soft coral cover was significantly greater outside the marine park at Tanjona than in the no-take zone. Significantly higher cover of crustose coralline algae (mainly CCA) was recorded in the no-take zone at Tanjona than for seaward reef sites outside the marine park.

There were no significant differences in reef fish biomass between no-take zones and peripheral sites outside the parks with the exception of Pomacentrids at Cap Masoala where biomass for this family was higher outside the park than in the no-take zone.

Table 5. Summary of reef fish observations outside of survey transects at Marine Parks of Northern Madagascar.

Location	Date	Observation
Sahamalaza	17/10/05	1 *Charcharinus melanopterus*, 1 *Cheilinus undulatus*, 8 *Bolbometopon muricatum*
"	19/10/05	Five large Groupers (*Plectropomus* spp.) with three larger than 80 cm TL. Carangids and Haemulids also noted.
Tanjona	16/11/05	Three species of Scarid (*Scarus sordidus, S. niger* and *S. frenatus)* observed in a spawning aggregation.
Cap Masoala	12/02/06	Three large groupers (*Plectropomus laevis, P. punctatus* and *Epinephelus caerulopunctatus*).
"	12/02/06	School of 15-20 large *Scarus ghobban* 30-50 cm TL
"	14/02/06	Large *Plectropomus punctatus*
"	16/02/06	Large *Plectropomus punctatus*
Mananara	25/02/06	Large Groupers (*Plectropomus laevis, P. punctatus* and *Epinephelus caerulopunctatus*) and Haemulids (*Plectorhinchus playfairii*)
"	26/02/06	Large Groupers (*Plectropomus laevis, P. punctatus* and *Epinephelus caerulopunctatus*) and Haemulids (*Plectorhinchus gaterinus*)
"	27/02/06	Large Groupers (*Plectropomus laevis* and *P. punctatus*)

Similarly only one significant difference was found for invertebrates, where *Echinometra* densities were significantly higher inside the no-take zone of Tanjona marine reserve than on reefs outside the park boundaries. No significant differences in densities were found between managed and unmanaged reef sites for holothurians and giant clams at any marine park.

Other Observations

A number of observations were made during survey dives which should be noted. Firstly, although large reef fish such as Groupers were not recorded often on belt transects they were observed at a number of the study sites (Table 5).

DISCUSSION

The data presented in this report provide a detailed snapshot of the status of shallow to mid-depth coral reef habitats for three marine park locations in northern Madagascar. The majority of surveys were conducted at depth bands not previously assessed quantitatively at any of the marine parks thereby significantly adding to the biological and ecological information available for the park locations. Inter-park comparisons revealed notable differences in biophysical characteristics between locations, particularly between parks on the east and west coasts of Madagascar, but also between marine reserves on the east coast such as those located around the Masoala peninsula.

Mean levels of hard coral cover recorded at all marine park locations with the exception of Tampolo were rather low (10-20%) with a range of 2.75 – 23%. This is less than previous measures of hard coral cover for sites in northwest (Webster and McMahon, 2002; Wilkinson, 2002; 2004) and northeast (Wilkinson, 2000) Madagascar for reef slope habitats. A recent study in northwest Madagascar recorded a range of hard coral cover between 2.5 – 70.6% (McKenna and Allen, 2003) with almost two thirds (65.4 %) of sites between 12 and 16 m depth having more than 20% hard coral cover. Surveys on the outer reef slope at Antanambe and Nosy Atafana in 1999 (reported in Wilkinson, 2000) found hard coral cover levels of 83 and 85.7% respectively which differs markedly from our data for these locations where the range was 6-19.25%.

For all marine park locations in northern Madagascar it is likely that the three recent severe tropical storms have reduced hard coral cover in shallow and medium depths at both east and west coast locations. This is backed up by anecdotal observations at Sahamalaza, Mananara, Cap Masoala and Tanjona and evidence of drastic changes that occurred to the shallow marine environment as a result of recent cyclones (Toany and Rafenonirina, 2005). Coral bleaching was not observed during the study but previous bleaching events may have affected benthic composition at one or more of the marine park locations. The major bleaching event of 1998 affected coral reefs in southwestern Madagascar (Quod and Bigot, 2000; Cooke et al., 2003) and in the northeast (McClanahan and Obura, 1998) but was not thought to have influenced reef systems in the northwest of the country (Webster and McMahon, 2002). At the three marine park locations in northeast Madagascar we observed large old dead tabulate *Acropora* colonies in depths of 8–12 metres covered in CCA and fine algal turf. We speculate that the intact *Acropora* tabulate skeletons on seaward reef slopes at east coast sites were killed by an extreme event such as bleaching with 1998 the most likely year that this occurred. A mild bleaching event was also noted in Antongil Bay in March 2005 which affected many hard and soft coral species as well as anemones and giant clams (Jan and Harding, 2005) but subsequent mortality and recovery were not quantified. Low levels of coral bleaching have been reported in northwest Madagascar in recent studies (Webster and McMahon, 2002; McKenna and Allen, 2003).

Reef fish biomass estimates from this study are similar to those recorded for offshore barrier reef sites in southwest Madagascar at Andavadoaka (Harding et al., 2006) and Beheloka (Woods-Ballard et al., 2003) and for moderately fished inshore reefs in East Africa (McClanahan, 1994; McClanahan et al., 1999). The higher biomass recorded on the west coast at Sahamalaza than at east coast locations may be a true result in that the reef fish fauna is generally more abundant on the more extensive west coast reefs than on the east coast, however the difference was not statistically significant.

Measurements of fishing effort by subsistence fishers at the park locations indicate that overall effort is low to moderate (100-400 fishing trips/week) with higher reliance on fishing at Tanjona and low reliance at Mananara and Tampolo (Cinner et al., 2006). At Cap Masoala and Tanjona fishing effort is concentrated on the more sheltered back reef and lagoon habitats with fishing on the outer reef slopes restricted to occasional trips when weather conditions permit. At Mananara, fishing around Nosy Atafana has decreased since a ban on octopus fishing was introduced by ANGAP (J. Brand pers. comm.). In addition to subsistence fishing there are artisanal fishers targeting sharks and Holothurians in all the locations visited during this study. The higher densities of Holothurians recorded at Sahamalaza compared to east coast locations are likely to be attributed to differences in habitat rather than to fishing pressure. The more exposed shallow seaward reefs on the east coast are not a preferred habitat of sea cucumbers compared to the mixed sand and coral habitat in deeper water on the submerged barrier reef at Sahamalaza.

Surveys of target invertebrates indicate that densities of potential pest organisms such as *Acanthaster plancii* are very low for the areas assessed and do not currently pose a management problem. Herbivorous urchin densities were also generally very low with one exception; the shallow fringing reef on Nosy Berafia in Sahamalaza where *Diadema* density exceeded 2000 individuals per hectare. However this density is still considerably lower than densities recorded in East Africa (McClanahan and Shafir, 1990).

Comparison of coral reef criteria measured both inside and outside the existing marine parks did not reveal many significant differences for benthic cover, reef fish biomass or invertebrate density (Table 4). In particular reef fish biomass was not statistically different for populations in the no-take zones and those recorded outside the marine parks. As mentioned earlier, overall fishing effort is low to moderate at the park locations, coupled with the fact that the majority of sites surveyed are not visited often by fishers due to their more exposed position on the seaward outer reefs (Cap Masoala and Tanjona) or their distance from the coastal fishing communities (Sahamalaza and Nosy Atafana, Mananara). At Tampolo where shallow fringing reefs are more accessible to fishers the number of resident fishers and fishing effort is very low compared to other marine park locations, at <100 fishing trips per week (Cinner et al., 2006).

The high variance between counts and the low number of replicates for reef fish and invertebrate assessments also makes it more difficult to identify any potential differences in abundance or biomass between park zones. There is also the question of whether enforcement of marine park regulations is fully effective at the parks where management is in place (Masoala and Mananara). When the surveys were conducted, Sahamalaza, as a newly designated marine park, did not have a full complement of park management staff in place. Therefore we should not expect there to be major differences in the abundance or biomass of mobile coral reef fauna between the recently designated marine management zones at Sahamalaza.

Although statistical differences in benthic composition were found between management zones at some marine parks these are more likely to be related to differences in site location and aspect coupled with habitat patchiness than to effects of management practices. This is especially so for Tampolo where sites outside the marine park were more sheltered with higher hard coral cover than those within the no-take zone on the more exposed Tampolo Point. Large scale disturbance events such as the intense cyclones in the last decade are likely to exert the greatest influence in shaping the shallow to mid depth (5-15 m) coral reef habitats of northern Madagascar at the present time.

RECOMMENDATIONS

Based on the findings above, a number of recommendations can be made relating to future monitoring and management of these marine parks:

Monitoring of coral reef habitats assessed in this study needs to be continued on an annual or semi-annual basis. The monitoring program should also be expanded to incorporate particular survey methods such as the Timed Swim survey for all marine parks and increase the sampling effort to assess more sites across a range of reef and habitat types (e.g. seagrass beds).

Ongoing monitoring of environmental parameters such as water temperature at the sea surface and at set depth(s) should be instigated at all marine parks using data loggers. Installation of sediment traps on inshore and lagoonal reefs is recommended to determine sedimentation rates and characteristics which can then be compared to land-use practices.

Inshore reefs at Sahamalaza require further investigation to determine whether anthropogenic impacts such as sedimentation are causing habitat degradation. Once impacts are identified then measures need to be taken to mitigate their effect on the inshore marine habitats of coral reefs and seagrass beds.

Existing biophysical data should be combined with socio-economic information to provide a more rounded assessment of the marine parks and the fishing communities that live within them.

It is important to maintain the interest and involvement of the coastal communities within or adjacent to the marine parks in the management process of these coastal regions. Regular meetings and discussions with the communities should go hand in hand with long-term environmental education and awareness initiatives.

ACKNOWLEDGEMENTS

Funding for this assessment was supplied by CORDIO and the Wildlife Conservation Society. The authors would like to thank WCS staff in Antananarivo and Maroantsetra and ANGAP staff in Maroantsetra and Mananara for logistical support and assistance. Many thanks also to Sebastien Jan, and Frederic Ramahatratra, Roberto Komeno and Etienne Bemanaja of IHSM for their assistance in data collection at Masoala and Mananara Marine Parks. Reef fish biomass conversion factors were kindly provided by Tim McClanahan.

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