

Observations of reef conditions on central Maldives reefs, 2005

(surveyed from 23 June to 7 July 2005,
with additional notes from 10-21 January 2005)



**A report by the Marine Conservation Society in
collaboration with Maldives Scuba Tours**



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Summary

The Marine Conservation Society in collaboration with the liveaboard dive operator Maldives Scuba Tours, carried out a survey of 24 reefs in June and July 2005 in order to assess the status of reefs and fish populations in Ari and North Male atolls. The survey used the ICRI post-tsunami rapid assessment methodology developed in 2005, along with Reef Check at two sites. The survey found that coral cover was low, averaging around or less than 10% with the greatest live coral cover in waters shallower than 12m dominated by *Pocilloporidae* and *Acroporidae* corals. The majority of reefs surveyed appeared to have been significantly affected by the bleaching event of 1998. Very little structural damage as a result of increased wave surge was observed both inside and outside these two atolls. Upper surfaces of thallas were dominated by mixed opportunistic benthic species such as the corallimorph *Discosoma* and the ascidian *Didemnum* sp.. A previous survey by the Marine Conservation Society in mid-January 2005 reported damage in the eastern channels of Felidhe atoll, consistent with the findings of the AUSAID survey of January 2005. Surveys of fish populations found that predatory commercial species were generally more abundant inside protected areas than outside from visual assessment methods. As a whole the fish populations of the Maldives on a regional scale are relatively healthy, with most families, and trophic levels well represented in terms of biodiversity and abundance.

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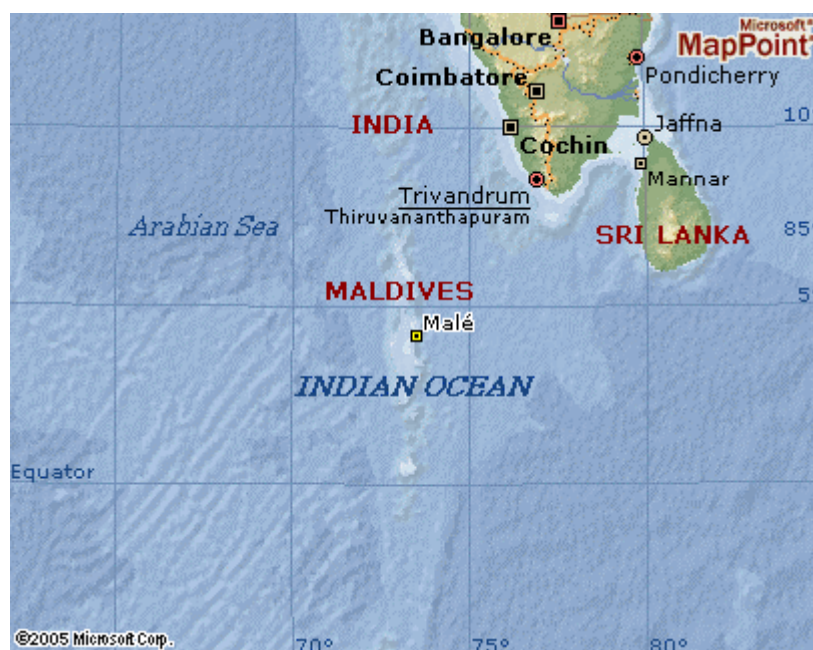
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Introduction

Introduction to the Maldives

The Maldives archipelago lies in the heart of the Indian Ocean approximately 300nm SSW of the southern tip of India. The archipelago comprises approximately 700 atoll islands lying on a raised oceanic ridge, which is approximately 900km long, and straddles the equator between 00 45.00 °S (Addu atoll) to approximately 07 06.00 °N (Ihavandhippolhu atoll). The chain of atolls is relatively narrow (approximately 150km wide), with the capital Male situated in the centre of the archipelago at 04 10.00 °N and 073 32.00 °W.

Map 1. Location of the Maldives in the central Indian Ocean



The Maldives in relation to the Indian Ocean Tsunami of 26.12.04

The islands lie approximately 1000nm miles to the west of the epicentre of the initial submarine earthquake that occurred on Boxing Day, 2004. This eruption lasted at least 20 minutes, and locally raised the seabed in the vicinity of Banda Aceh, west of the island of Java, western Indonesia. The tsunami wave created by the disturbance to the seabed took approximately three hours to reach the Maldives, by which time the initial tidal wave had hit parts of India, Sri Lanka, Bangladesh, Thailand, the Andaman and Nicobar Islands, and Indonesia. Initially, the damage to coastal habitats and human populations was related to the distance from the epicentre of the earthquake, the incident angle of the coast to the tidal wave, the extent of natural and man-made barriers at the land-sea interface (eg. Mangroves, man-made sea defences), and the extent of shallow water near to the affected land mass.

On a regional scale, the nearer to 90° the angle of the coast to the wave, and the shallower the slope / shelf offshore, the greater the impact of the wave (CSIRO, 2005). Areas where there was mangrove clearance (much of southern Sri Lanka) were

also more severely damaged than in areas where mangrove forests were dense, as these natural barriers are able to absorb a considerable proportion of the wave energy.

The Maldives reportedly suffered around 80 mortalities from the tsunami wave which measured 180cm above the expected sea level. Most of the atolls above sea level were inundated by seawater. This led to damage caused to infrastructure, destruction of crops and food, and some people being carried away from land by the surge, where they subsequently drowned in deeper waters. Many of the fresh water wells within the sand islands of the Maldives were contaminated by seawater, and freshwater had immediately to be sourced elsewhere. The estimated financial damage from the tsunami to the Maldives was in the order of \$US 400-1000 million (CSIRO, 2005).



Plate 1. Damage to Maldivian islands included flooding and the destruction of key infrastructure.

The Australian rapid assessment report

A team of Australian biological and social scientists was assembled to gauge the impact of the tsunami on the biological resources (coral reefs and bait fish populations) of the Maldives (CSIRO, 2005). Surveys were carried out over 17 days from January 23rd 2005.

Reef surveys were carried out by using the ‘manta tow’ technique, where snorkel divers are towed in shallow waters from the back of a small boat, and every two minutes record the cover of benthic lifeforms down to a depth of approximately 5m (English *et al*, 1997). This is a useful method to record broadscale biotic and abiotic information whilst covering a large survey area, which was necessary given the considerable length of reef needed to be surveyed, and short timescale of the project. Line intercept transects (English *et al*, 1997) were also carried out at three sites where permanent monitoring stations were already established prior to the tsunami event. Most of these in-water surveys were carried out on the eastern side of the archipelago where the wave first hit the Maldivian islands. A third assessment was made by circulating a questionnaire to dive operators around the islands to gather qualitative information based on the perceived extent of damage to marine habitats from the tsunami. Bait fish populations (fished for supplying bait to the deepwater tuna fishing industry) were also assessed using qualitative questionnaires.

Observations from quantitative and qualitative surveys revealed that only slight damage occurred as a result of the tsunami. More worrying to the long-term health of

Maldives reefs is the persistent low coral cover recorded on the reefs, which ranged from 5 to 15% depending on site visited. Fish populations were relatively high at most sites, compared to many other Indian Ocean nations, suggesting that algal overgrowth isn't necessarily a problem to coral recruitment and settlement success. (This is corroborated by the surveys outlined in this report). The low live coral cover in the Maldives is most significantly related to the worldwide mass coral bleaching event of 1997-8 which decimated many coral reefs of the world (Wilkinson *et al*, 2004).

The global coral bleaching event of 1997-8

The status of the coral reefs of the Maldives has been significantly affected by the bleaching event of 1998 (Wilkinson *et al.*, 2004). Between April and June 1998, temperatures remained above 30⁰ Celcius, even down to 30m depth. 30⁰ is broadly regarded as the upper lethal limit for many scleractinian hard corals before bleaching occurs. High temperature coupled with a long duration of high temperature waters being in contact with coral reefs appears to act synergistically to increase bleaching effects. Bleaching was even recorded down to 50m. Up to 40% of the surface area of live corals were bleached in the 20-30m depth zone (the area of highest biodiversity on most coral reefs). Southern atolls were generally less affected than more northern reefs. Minor coral bleaching was also subsequently observed in Ari atoll in 2003, although at a much smaller scale than that of the 1998 event. The 1998 bleaching event also initially changed the dominant assemblages of live coral from branching *Acropora* colonies prior to the bleaching event, to bleaching-resistant massive forms in many countries (with lower biodiversity), such as *Porites*, *Favia* and *Favites* (Marshall and Baird, 2000). However, from our observations even these massive reef-building genera appear to be relatively rare in Maldives waters. It appears that coral recovery (and recruitment) since the initial bleaching event has been spatially and temporally patchy, and that many areas have partially recovered with a large number of shallow reefs now covered by numerous small *Acopora* colonies.

Protected Marine Areas (PMAs)¹

There are 25 PMAs in the Maldives, where commercial fishing of any sort (for either bait fish for the offshore tuna fishery, or predator fish) is banned. 15 areas were announced by the government in 1995, with a further nine added in 1999. However, the active management of the site including monitoring and enforcement has been described as inadequate (Wilkinson, 2004). The sites are often frequented by the dive tourist industry, which could be used to report incidents of encroachment and poaching on an *ad hoc* basis. One of the key recommendations of the CSIRO post-tsunami Australian assessment of the Maldives reefs was to create more PMAs, and to increase the scientific capacity of the nation in order to effectively survey and monitor the islands in case of future perturbations.

¹ Called Marine Protected Areas in most other countries, but PMAs in the Maldivian literature

Methods

Four different surveys were carried out during the 14-day trip:

1. **ICRI Tsunami Rapid Assessment;**
2. **Commercial (predator) fish species and number counts;**
3. **Reef Check (at two sites); and**
4. **January 2005 visual assessment.**

1. ICRI Tsunami Rapid Assessment

The ICRI Tsunami Rapid Assessment technique was designed by an international group of marine scientists in early 2005 in order to assess immediate impacts, and monitor long term changes as a result of the Asian tsunami of 26.12.04.

The ICRI methodology was adapted to be compatible with the dive limits associated with diving with Maldives Scuba Tours. Semi-quantitative (1-5) scale assessment of reef type and damage parameters were recorded every 2 minutes of a dive, in this case between a depth of 28m (or where the base of the reef meets sand habitat, which is particularly relevant for the thillas²), and the top of the reef in waters between 3 and 8m deep. Approximately 15 minutes of each dive occurred in the 28-20m depth zone, 30 minutes in the 19-12m depth zone, and 10 minutes in waters between 11 and 5m, so for each site, a true representation of the range of depth affected habitats was recorded.

Benthic categories

Live Hard Coral
Recently Killed Coral
Indication of different (live) coral lifeforms present
Filamentous algae
Thick or fleshy algae
Rock and bare substrate
Rubble

Damage to corals

Overall damage to corals
Up-turned coral
Broken coral
Recently killed coral (standing)
Recently killed coral (upturned)
Coral lifeforms (damaged)

The other three major categories to be recorded were **Damage (waves); Damage (backwash) and Other (including qualitative information on fish)**. None of these categories were recorded during the surveys, as there was no apparent damage from these effects.

² - A thilla is a patch reef or 'bommie' rising from the seafloor inside the body of a coral lagoon to at or near the surface. These generally start at 25-30m, and extent to within 5m of the water surface.

Data were recorded semi-quantitatively every two minutes for approximately 10-20m of swim distance. Different scale categories of cover or damage were entered on a standard 1-5 semi-quantitative scale (English *et al.*, 1987).

1 (0-10%); 2 (11-30%); 3 (31-50%); 4 (51-70%); 5 (71-100%)

Fuller details of the ICRI/ISRS tsunami rapid assessment methodology can be found at www.icrforum.org.

This survey was only carried out by Jean-Luc Solandt (JLS), as it was thought that this would allow homogenous replicated comparison of data between sites, and that it was necessary for an experienced surveyor to gather this information, especially to compare natural and storm damage with post-tsunami assessment damage. Maldives Scuba Tour guides Dave and Lisa Alison were consulted where there was possible post-tsunami impact at each site, immediately after each dive.

2. Commercial fish species and number counts

During and between the tsunami rapid assessment surveys, counts were made of the estimated number of predator fish from approximately 30 species from 10 families. Numbers and species were estimated visually. Care was taken to avoid repeat counts of schooling fish which were particularly abundant, such as blue-lined snapper (*L. kasmiri*) and red snapper (*L. bohar*).

The commercial fish species and number counts were carried out by JLS alone, as considerable experience was necessary to name and quantify species and numbers of fish, particularly given the large numbers associated with the popular dive sites visited during the expedition.

3. Reef Check

Reef Check was carried out at two sites – one thilla at southern Ari Atoll, and at a drop off outside the reef at Rasdhoo-Madhivaru. International reef check protocol methods and results can be found at www.reefcheck.org. The former site was chosen as it represented a site that could always be visited regardless of current or wave conditions. The latter site was chosen, as it was representative of the best site (for benthic cover) during the two week trip.

Reef Check survey methods were taught to the whole dive team and carried out on Saturday July 2nd (at Kahanbu thilla) and Tuesday July 5th (at Rasdhoo-Madivaru). An introduction talk to Reef Check results and global initiative was given on Wednesday June 29th, and slides were shown of the target fish and invertebrates for the dive team prior to the start of the surveys. The full training presentation (as regards transect deployment, timing and order of surveys) was given on Friday 30th, and a refresher presentation made on the morning of Saturday July 2nd prior to the survey dive. The benthic survey for both sites was carried out by JLS, fish counts by Winn Walker and Joe Mercer. Invertebrate counts were made by David Alison and Melanie Bostick. Paul Underwood and Chris Bostick provided movie and stills footage. The remaining divers were used to lay out the transect line, and attach marker buoys for the start and end of the transects.

Data have already been validated and sent to Reef Check headquarters in the USA.

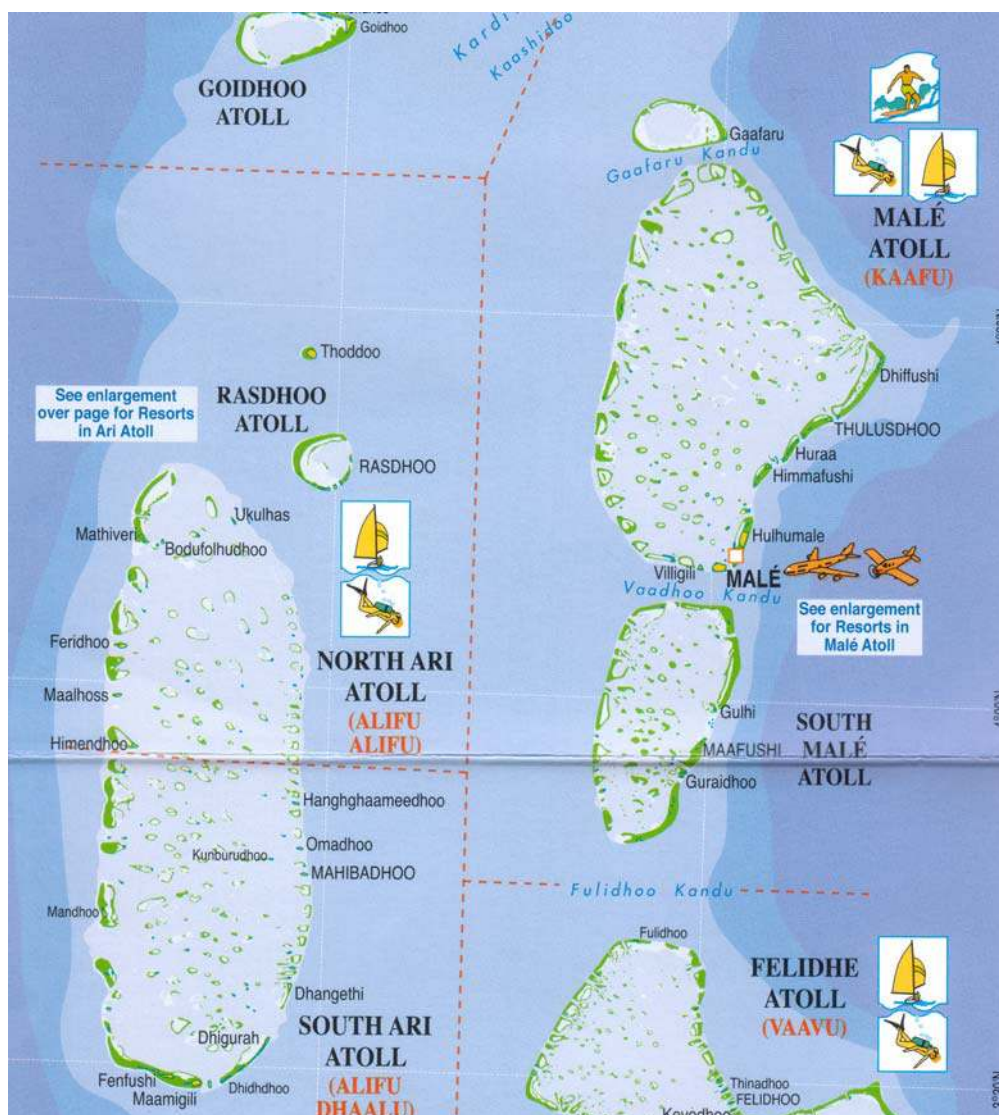
4. January 2005 visual assessment

In addition to the survey in June/July an MCS team was in the Maldives from 10-21 January, some 2 weeks after the tsunami. At that time the extent of damage was not known and the work of the CSIRO team had not commenced, nor was the ICRI rapid assessment technique available.

However, notes and photographs were taken by Chris Wood of damage observed at sites visited in Ari, Felidhe and South Male atolls, and are included in this report.

Survey Sites

Map 2. Location of dive sites visited during the surveys³.



Surveys were carried out initially at two sites in North Male atoll – Lankanfinolhu and Nassimo thilla. These two sites are found on the south east of the atoll.

One dive was then carried out at Rasdhoo-Madivaru, followed by twelve further tsunami / fish surveys which were carried out in Ari atoll between 29 June and 4 July. Surveys between 5 and 8 July were carried out in North Male atoll at the west, south and southeast parts of the atoll.

In January the sites visited were in Rasdhoo, North Ari, South Ari, Felidhe and South Male atolls.

³ - Map reproduced from 'Atlas of the Maldives – a reference for travellers, divers and sailors' (4th edition), Atoll editions, 2004, Victoria, Australia. Maps also reproduced on pages 10 and 11.

Table 1: Table of survey sites, general location, date surveyed, and Atoll.

Survey Site	Survey type	PMA?	Date	Atoll
1. Lankanfinolhu	tsunami/fish	no	27.6.05	North Male
2. Nassimo thilla	tsunami/fish	yes	28.6.05	North Male
3. Madivaru	Coral Watch	no?	28.6.05	Rasdhoo
4. Bathalaa Maagaa thilla	tsunami/fish	no	29.6.05	Ari
5. Maaya thilla	tsunami/fish	yes	29.6.05	Ari
6. Fish Head	tsunami/fish	yes	30.6.05	Ari
7. Kalhahandi Kandu	tsunami/fish	no	30.6.05	Ari
8. Angaga thilla	Coral Watch	no	1.7.05	Ari
9. Kudarah thilla	tsunami/fish	yes	1.7.05	Ari
10. Kahanbu thilla	Reef Check	no	2.7.05	Ari
11. Broken Rock	tsunami/fish	no	3.7.05	Ari
12. Kudadhoo thilla	tsunami/fish	no	3.7.05	Ari
13. Ellaidhoo	tsunami/fish	no	3.7.05	Ari
14. Makuru thilla	tsunami/fish	no	4.7.05	Ari
15. Kari Beyru thilla	tsunami/fish	yes	4.7.05	Ari
16. Bathalaa Island resort	fish	no	4.7.05	Ari
17. Madivaru	Reef Check	no	5.7.05	Rasdhoo
18. Bodu Hithi thilla	tsunami/fish	no	5.7.05	North Male
19. Rasfari	tsunami/fish	yes	6.7.05	North Male
20. Vashimas	tsunami/fish	no	6.7.05	North Male
21. Kuda Faru (Finger Point)	tsunami/fish	yes?	6.7.05	North Male
22. Okobe thilla	tsunami/fish	no	7.7.05	North Male
23. Lankanfinolhu	Coral Watch	no	7.7.05	North Male
24. Thunburudhoo Corner	tsunami/fish	no	8.7.05	North Male

Survey site locations

Map 3: (south) North Male Atoll.



Map 4: (north) North Male Atoll.



Map 5: (north) Ari Atoll.



Map 6: (south) Ari Atoll.



Results

Tsunami surveys

Only 3 sites showed coral cover over 10% (data pooled from all depths) - Madivaru, Kalhahandi and Kuda Faru (Finger Point). The substrate of many survey sites inside atolls was dominated, in the 25-35m depth band, by rock and *Tubastrea micrantha*, sponge and sand. Sand was particularly apparent inside the atolls (in and around the thillas) at around 25m, as this is the area of sediment accumulation around the base of the thillas.



Plate 2. Showing deep reef communities dominated by *Tubastrea micrantha*, rubble, sand, sponge and azooxanthellate coral species.

Between 25 and 15m, benthic species diversity increased, with more sponge and soft corals, hydroids, sponges, anemones and hard coral diversity. Coral families including *Favia*, *Favites*, *Pocillopora* start to pepper the benthos, although overall, cover of live hard corals from all surveys was low (<10%).



Plate 3. Diverse substrate on left including *Didemnum* ascidians, *Tubastrea* corals, encrusting sponge and algae, *Porites* branching corals and a young *Acropora* recruit. On the right is *Lobophytum* coral and a young *Pocillopora eydouxi*, another abundant species of coral in Maldives waters.

At 15m many thillas are undercut by caves and overhangs. One theory is that this was the sea level prior to the last ice age, and that coral growth stopped at this location. Subsequent growth above this level occurred in relation to sea level rise. The cave systems and walls of the Maldives are dominated by *Tubastrea faulkneri* and *Dendronephthya* soft corals, and large numbers of tube and branching sponges.

Encrusting sponges, and calcifying *Spondylus* (the latter growing attached to seafans) are also common features underneath the overhangs.



Plate 4. Mid-water communities were dominated in many areas (particularly thillas), by overhangs or cave systems. (Clockwise from top left) channel at Broken Rock (10m); undercut cave (16m); rubble, and small branching *Acropora* at bottom of a wall (12m); gentle gradient exposed reef with abundant *Dendronephthya* soft corals and *Tubastrea* (11m).

Between 14m and the surface, *Acropora* branching coral forms are more numerous, particularly in thillas and inner reefs. Ramose and digitate *Acropora* are more prevalent on the outside of reefs (outer reef walls in exposed locations). One reef flat at Kalhahandi had a reef table dominated by large numbers of *Acropora clathrata*.

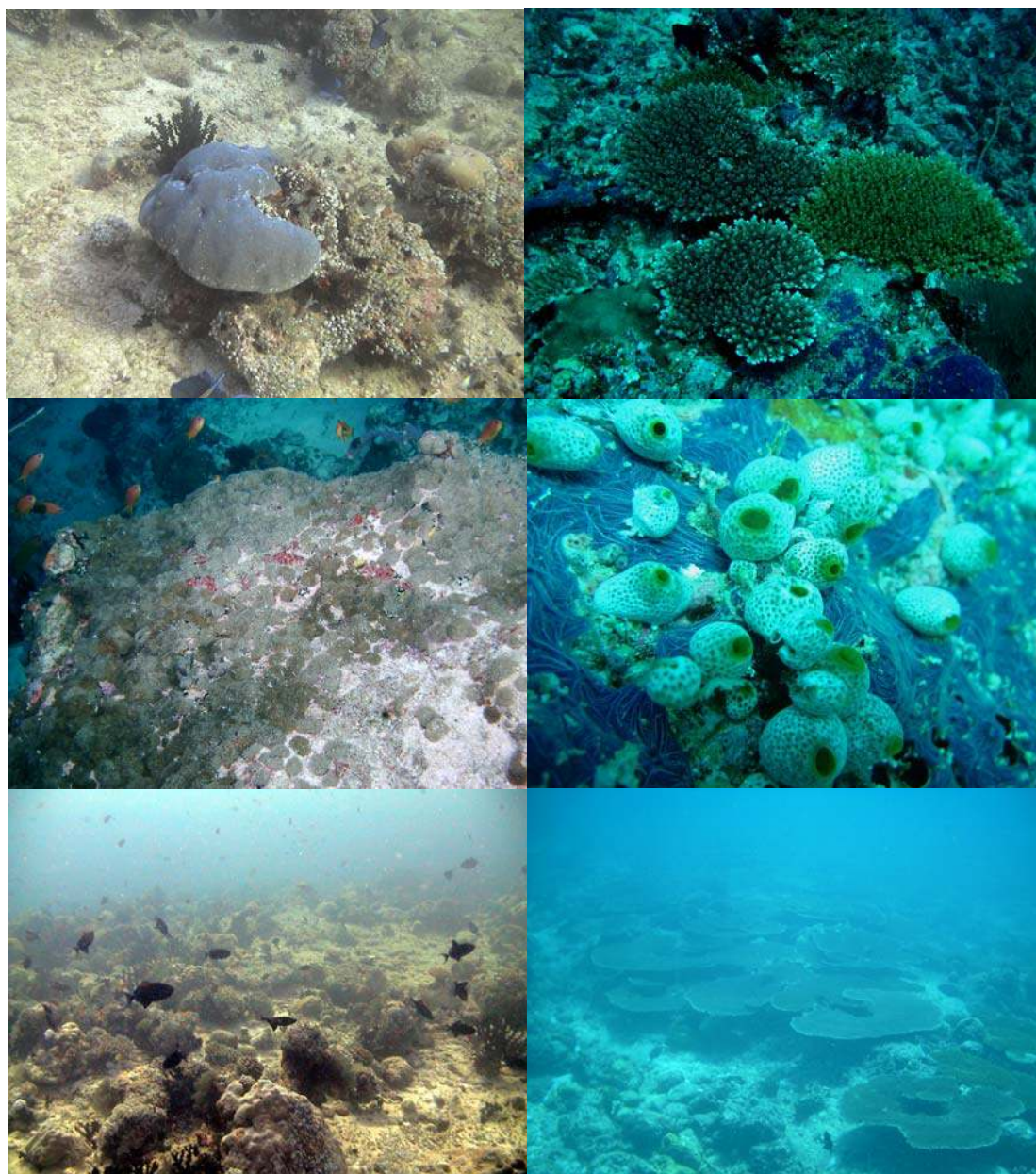


Plate 5. Shallow reef communities (clockwise from top left), dominated by small *Porites* colonies on exposed outer reefs; small branching *Acropora* colonies (recruited since the 1998 bleaching event); *Didemnum* ascidians and sponge covering the upper surface of dead coral rock; shallow spur and groove/table *Acropora* corals at Kalhahandi; thilla tops dominated by small coral mounds (*Porites* and *Favia*); *Discosoma* covering considerable areas of thilla surfaces.

Many more sheltered thillas including Maayaa, Fish Head, and Kahanbu had high cover of opportunistic *Discosoma* corallimorpharians that had settled 'free space' left after the coral bleaching. Similar high cover of the solitary ascidian *Didemnum* was a feature of many of the more exposed reefs. The dominance of these two *r*-strategist (high fecundity, low life span, fast growth) species at many of the upper (<12m) surfaces of reefs is likely to be because of the absence of coral competitors. The cover of reef building corals in areas/sites dominated by these lifeforms was rare (around 5%) indicating a shift from coral / hard bottom dominated substrate to a corallimorph / opportunist dominated substrate.

Table 2: Table of relative levels of substrate cover and perceived overall structural damage.
(1 = 0-10%; 2 = 11-30%; 3 = 31-50; 4 = 51-70; 5 = 71-100%).

Survey Site	Coral Cover	Fleshy algae	Rock	Rubble	Overall Damage
1. Lankanfinolhu	1.067	1.267	2.800	1.067	0.000
2. Nassimo thilla	1.182	0.545	2.182	0.545	0.273
3. Madivaru	2.750	0.000	1.500	1.750	0.750
4. Bathalaa Maagaa thilla	1.000	0.833	2.333	1.250	0.083
5. Maaya thilla	1.143	1.857	1.286	1.286	0.000
6. Fish Head	0.818	2.636	3.818	0.273	0.000
7. Kalhahandi Kandu	1.231	0.833	4.154	1.846	0.538
8. Angaga thilla	1.000	0.909	3.818	1.364	0.091
9. Kudarah thilla	1.375	0.250	3.250	1.375	0.000
11. Broken Rock	2.000	0.333	3.889	0.667	0.222
12. Kudadhoo thilla	3.308	0.308	4.923	1.000	0.231
13. Ellaidhoo	2.375	0.000	5.000	0.000	0.000
14. Makuru thilla	2.182	0.273	2.273	2.273	0.273
15. Kari Beyru thilla	1.818	0.909	4.545	1.273	0.091
18. Bodu Hithi thilla	1.333	0.000	4.833	0.500	0.000
19. Rasfari	1.500	0.250	4.000	1.875	0.000
20. Vashimas	3.200	0.000	5.000	0.000	0.000
21. Kuda Faru (Finger Point)	1.000	0.429	3.571	1.571	0.571
22. Okobe thilla	2.455	0.273	4.091	0.636	0.000
24. Thunburudhoo Corner	1.125	0.375	4	0.875	0.125
Overall mean	1.693	0.614	3.563	1.071	0.162

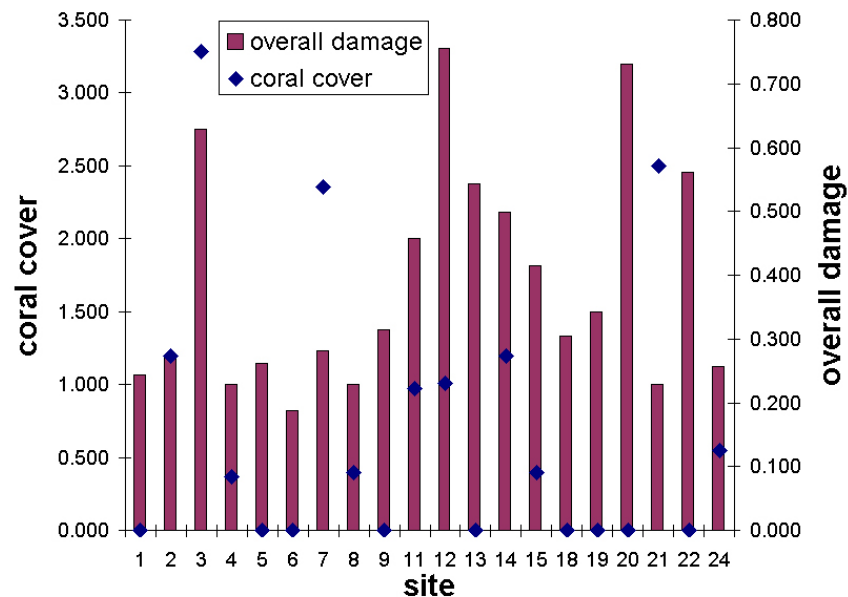


Figure 1. Coral cover and overall structural damage at sites surveyed for tsunami damage (data from all depths is pooled).

Commercial fish populations

Table 3: Commercial fish populations were surveyed from the following species list (grey cells are the larger number for that species). 68% of recorded commercial fish species were found to be more abundant inside PMAs than outside PMAs. [Data is pooled from all depths at each site, then averaged for PMA and non-PMA sites.]

Fish species	Mean # per site	
	PMA	Non-PMA
<i>Plectorhinchus orientalis</i> (oriental sweetlips)	4.75	10.9
<i>Plectorhinchus chaetodontoides</i> (spotted sweetlips)	1	0.5
<i>Lutjanus bohar</i> (red snapper)	31.875	14
<i>Lutjanus gibbus</i> (paddletail snapper)	37.5	39.25
<i>Lutjanus monostigma</i> (onespot snapper)	7.625	0.5
<i>Lutjanus fulvus</i> (blacktail snapper)	1	0
<i>Aprion viriscens</i> (green jobfish)	1.125	0.416667
<i>Aphareus furca</i> (small jobfish)	0.25	0.333333
<i>Macolor macularis</i> (midnight snapper)	3.75	1.333333
<i>Macolor niger</i> (black and white snapper)	3.75	3.083333
<i>Lutjanus kasmira</i> (bluestripe snapper)	675	130.8333
<i>Lethrinus erythracanthus</i> (yellow tail emperor)	1.25	0.25
<i>Lethrinus olivaceus</i> (long-nosed emperor)	0	0.166667
<i>Lethrinus xanthurus</i> (yellow lip emperor)	0.625	0.083333
<i>Carangidae</i> (trevally)	17.625	28.16667
<i>Gnathodentex aurolineatus</i> (gold lined sea bream)	27.5	3.833333
<i>Monotaxis grandoculis</i> (humpnose bigeye bream)	0.875	4.25
<i>Chelinus undulatus</i> (humphead wrasse)	1.75	0.583333
<i>Traienodon obesus</i> (whitetip reefshark)	1.875	1.75
<i>Carcharhinus amblyrhynchus</i> (grey reef shark)	1.25	0.583333
<i>Carcharhinus albimarginatus</i> (silvertip shark)	0.25	0
<i>Variola louti</i> (lunar tail grouper)	0.875	1.25
<i>Plectropomus laevis</i> (coral trout)	1.75	1.17
<i>Aethaloperca rogaa</i> (redmouth grouper)	0.375	0.75
<i>Epinephelus</i> spp.	1.25	0.416667
<i>Anyperodon leucogrammicus</i> (slender grouper)	1	0
<i>Gymnosarda unicolor</i> (dogtooth tuna)	1.125	0.583333
<i>Thunnus albacares</i> (bluefin tuna)	0.125	0.25

Fish numbers were compared between Protected Marine Areas and outside Protected Marine Areas. Overall, 11 non-PMA sites were dived, and 8 PMA sites. There were not any statistically significant differences in populations between these two different areas, however, for many of the species, there were greater numbers in PMA dive sites than outside these sites. Overall, species from the snapper family were more abundant in PMAs than outside PMAs.

The most numerous species was *Lutjanus kasmira* which was prevalent near to the coral reef itself, alongside walls, or in sheltered areas. They occurred in very large schools, often numbering many hundreds of individuals. *Lutjanus bohar*, *Macolor macularis* and *Macolor niger* were often associated with more exposed outer reefs, swimming higher in the water column than *L. kasmira*.

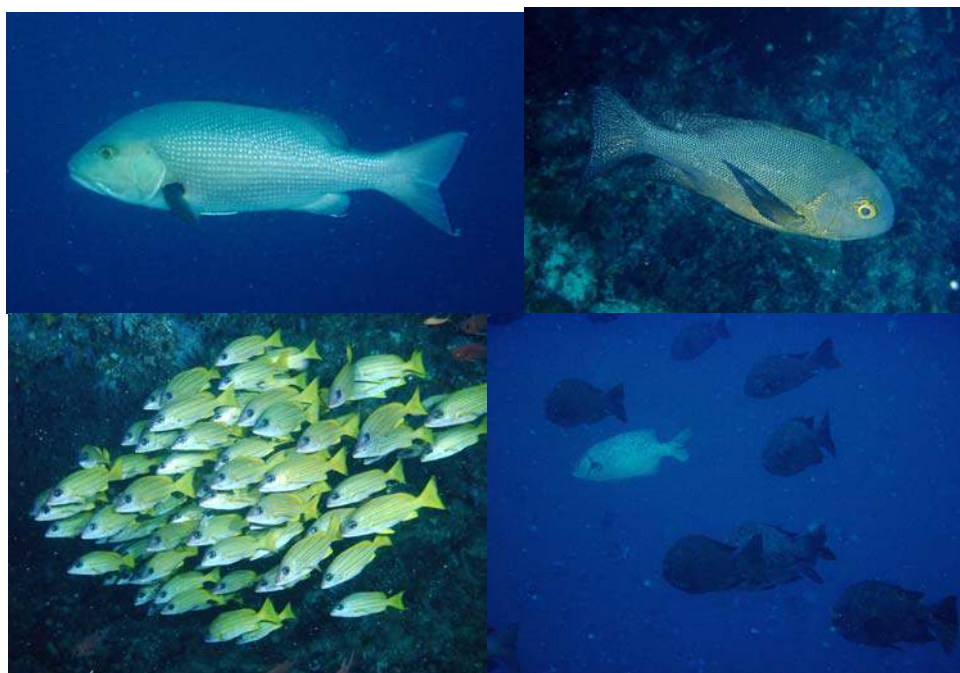


Plate 6. Snappers were generally more abundant in protected areas than outside protected areas.

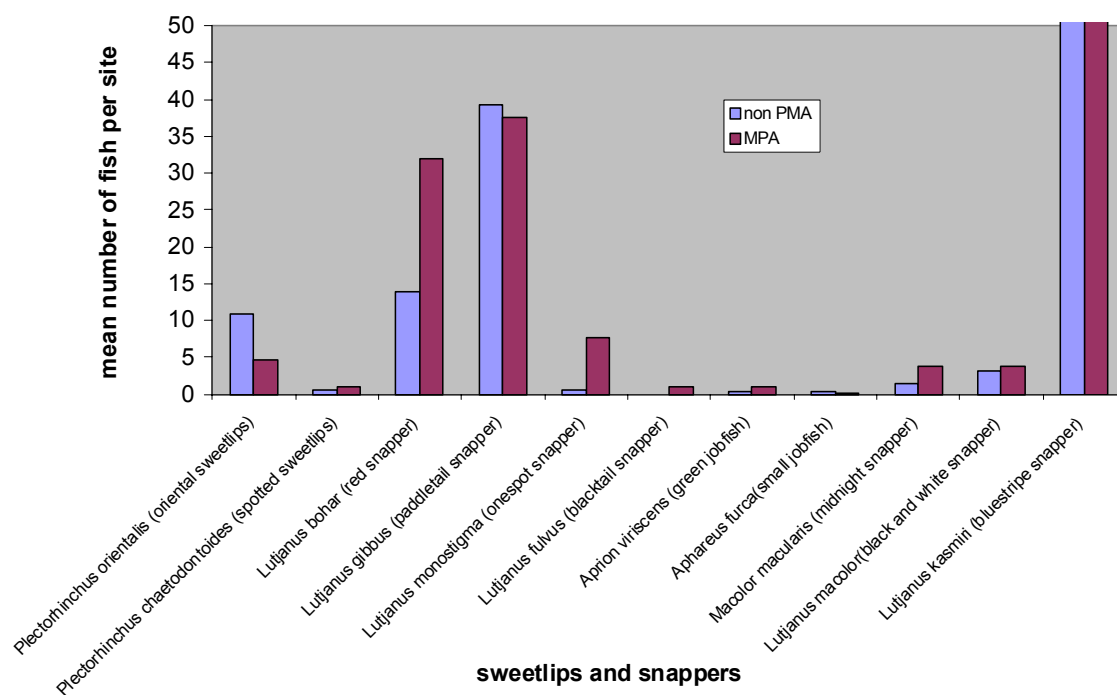


Figure 2. Mean numbers of snappers and sweetlips inside and outside Protected Marine Areas. 8 out of 11 snapper species were more abundant inside PMAs than outside PMAs.

Other commercial fish species such as *Cheilinus undulatus* (the humphead wrasse) were more abundant inside PMAs than outside (Fig. 3). These species can be targeted for the live fish trade in Far East Asia in countries such as Taiwan, Hong Kong, China and Indonesia.

Twelve out of the 19 sites recorded humphead wrasse, with 75% of PMA sites having at least one resident fish. Five humphead wrasse were seen at Kari Beyru on the north east of Ari Atoll on one dive. Four of these were swimming together 3m above the coral reef, with approximately 3m between individuals. They measured approximately 70-100cm, so were not likely to be fully grown.

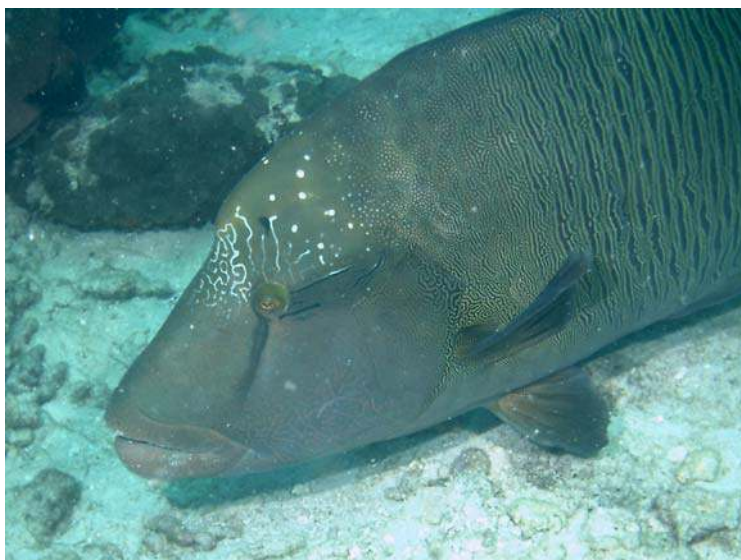


Plate 7. The humphead wrasse was observed at most sites. Thillas usually had one or two residents observed during surveys.

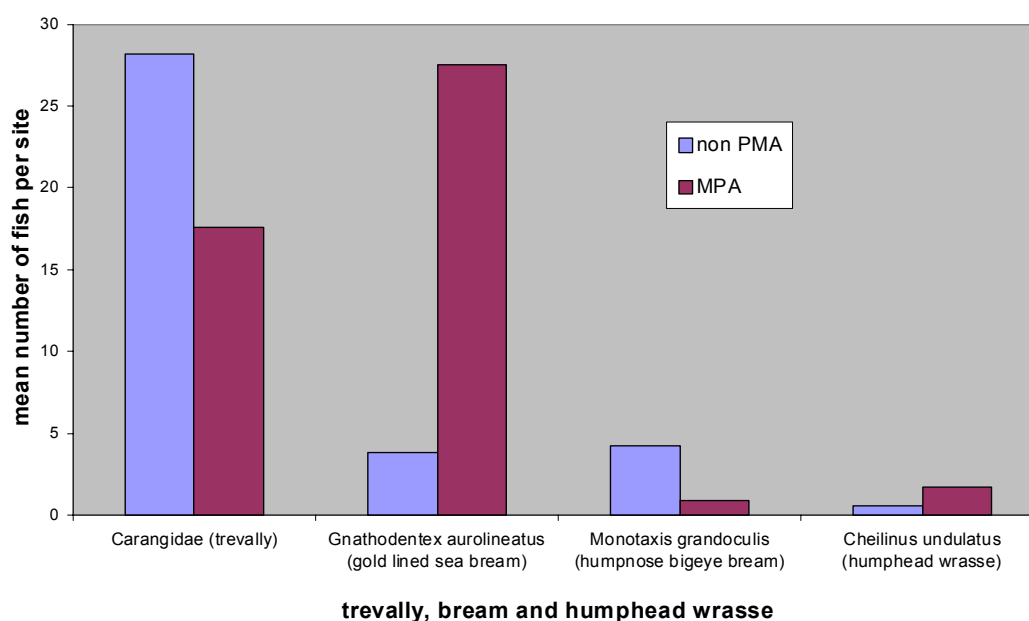


Figure 3. Trevally, brems and humphead wrasse inside and outside PMAs.

Other aggregations of commercial predator fish species were also observed. The black-saddled coral trout, *Plectropomus laevis*, commonly a solitary species, was also observed aggregating at Bathalaa Maagaa thila in northeast Ari atoll, where ten

individuals were seen in dark colouration indicating that breeding may have been imminent. The individuals were seen in groups of 3-4 animals no more than 3m apart at about 12-15m depth. Mating behaviour of coral trout (chasing nose to tail in a small area) was also observed at Kari Beyru thilla, where a very large individual (about 70cm) was pursuing a smaller individual (about 30cm) in 30m of water.



Plate 8. Coral trout were large, at most sites exceeding 30cm, and growing up to 70cm in some areas.

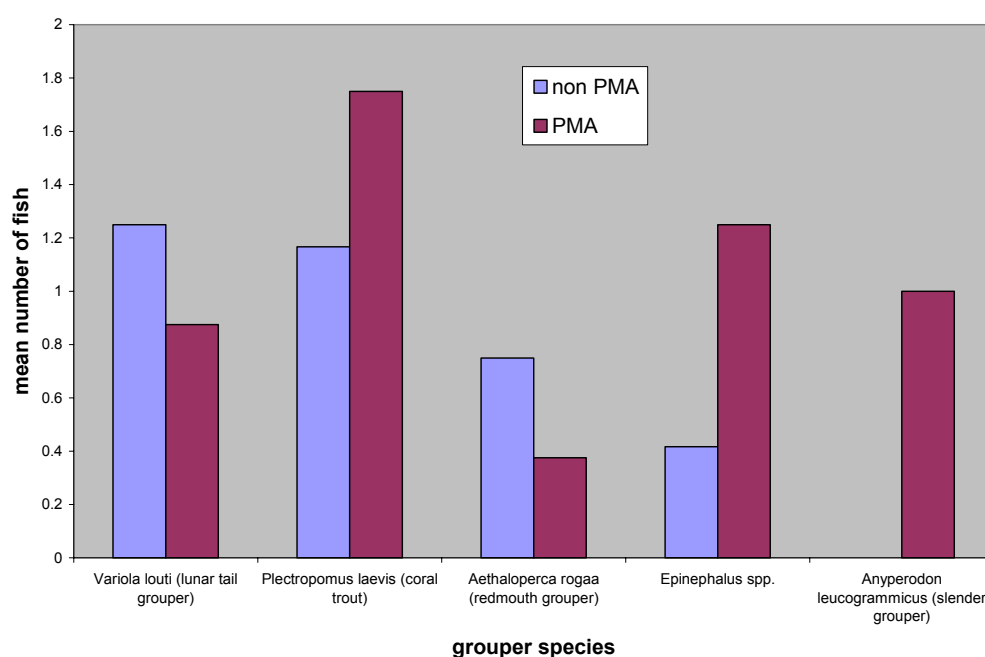


Figure 4. Grouper numbers inside and outside PMAs.

Other species (elasmobranchs, invertebrates and turtles)

Sharks and rays

Sharks were generally more abundant on outer reefs than on inner thilla reefs, and the three commonly observed predatory sharks (greys, whitetips and silvertips) were observed in greater numbers in PMAs than outside PMAs. Some sites had considerable shark numbers occurring regularly at current points. Vashimas had 7 grey reef and 6 whitetip reef sharks, all at 30m at the current point. The upwelling at this site was recorded by the considerable drop in water temperature from ambient surface conditions at 28⁰ to 26⁰ at 30m – this distinct thermocline was not recorded

from any other dive sites. Whitetip reef sharks were observed on most dives, and silvertip sharks at 2 sites – Rasfari and Fish Head. Two whale sharks were spotted on the survey (at the surface with snorkel, and not on dives), one at Dhidhoo Finolhu barrier reef at the south west of Ari atoll on the outer barrier reef. This was a 5m specimen. The other was spotted near to Kuda Rah thilla at the surface, and measured approximately 8m. Only two blacktip reef sharks (*Carcharhinus melanopterus*) were spotted by the survey team, and Madivaru is known for a resident population of scalloped hammerheads (*Sphyrna lewini*) at 30m, although none were seen on our survey.

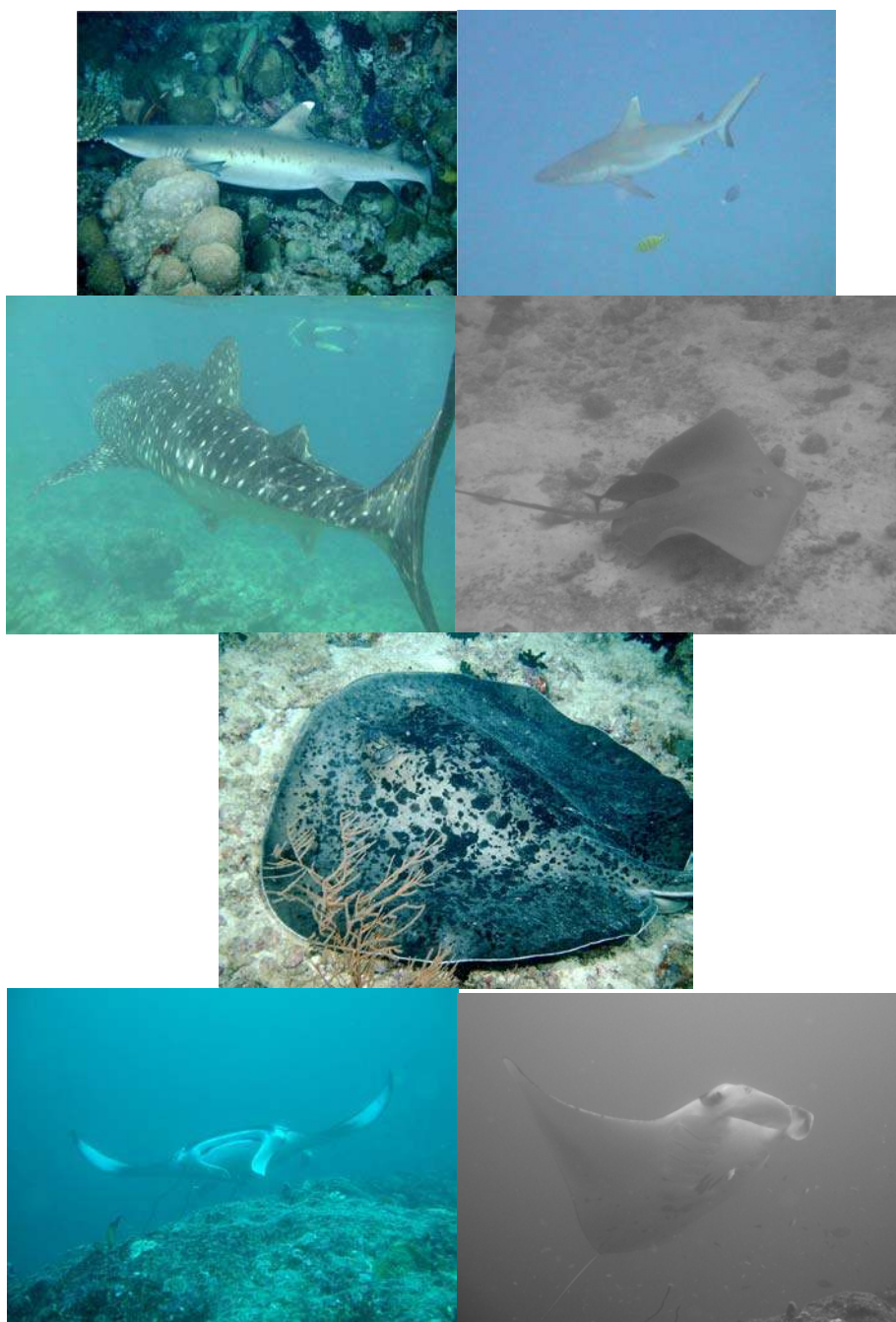


Plate 9. Elasmobranchs encountered on the survey trip.

Most rays encountered on surveys were whiptail rays, and a well-known manta ray feeding station was visited twice at Lankanfinolhu, where up to 19 rays were seen on a single dive.

Reef Check

Reef Check surveys were carried out at Adhureys Rock in South Ari atoll – a sheltered thilla; and at Rasdhoo Madivaru, on the exposed south-facing outer reef of an atoll.

1. Adhureys Rock

Benthic Cover

Adhureys Rock was covered in *Discosoma* to a large extent, especially in the deeper surveys (at 12m). There was a large patch (approximately 25m²) of soft coral (*Sarcophyton* sp.) on the shallow dive at Adhureys Rock, and in another part of the shallow dive, there was a large patch of *Goniopora* coral about 4m² in area. Between dead coral heads covered by *Discosoma* were large areas of sand and rubble, the latter principally comprised of dead *Acropora* coral branches.

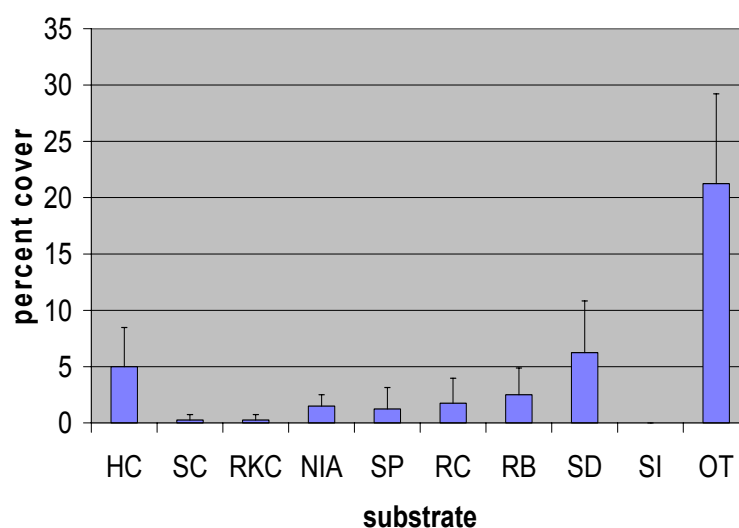


Figure. 5 Benthic cover at the deep (12m) transect at Adhureys Rock. Coral cover is around 5% (or 1 in 20 data points along the transect). The 'other' category is dominated by *Discosoma* (see plate 5).

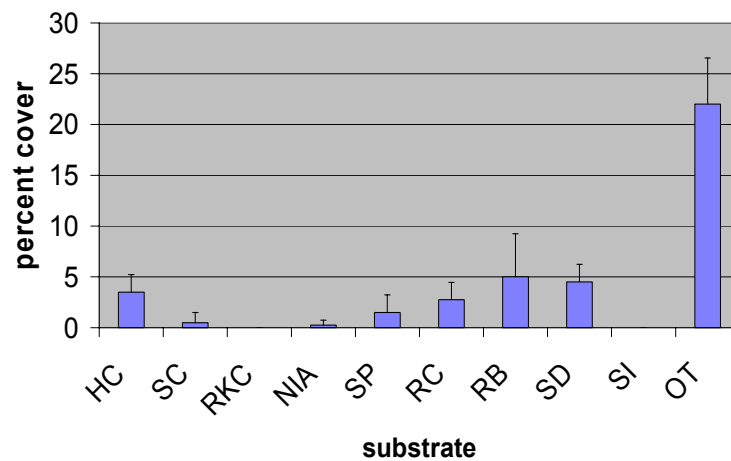


Figure 6. Benthic cover at the shallow (5m) transect for Adhureys Rock reef. Note the low coral cover again, and the high cover of 'other' (>20%) representing high cover of *Discosoma* corallimorpharians.

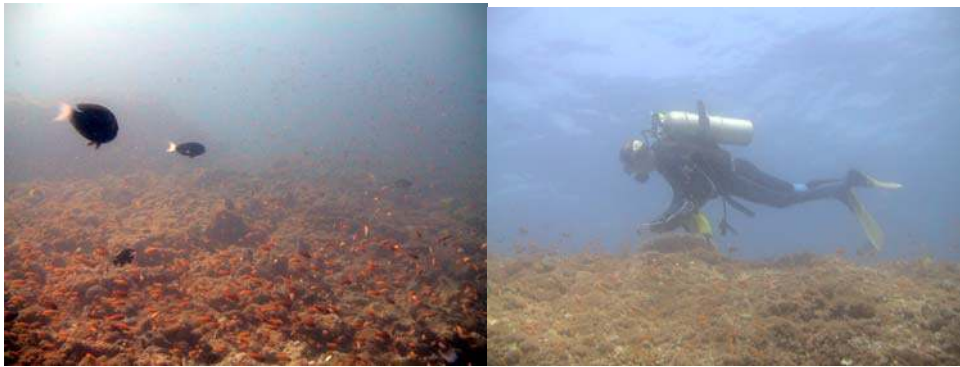


Plate 10. *Discosoma* dominated shallow reef at Adhureys Rock. Corallimorphs were so dominant in some areas, that the reef surface resembled a 'brown carpet'. In these areas, there didn't appear to be any free space for colonisation by corals, or other sessile organisms.

Fish populations

Fish populations were fairly poor in trophic diversity and biomass at Adhureys Rock. Dominant assemblages were *Anthias*, damselfish, and red-tooth triggerfish, none of which are commercial species on the reef check fish species list.

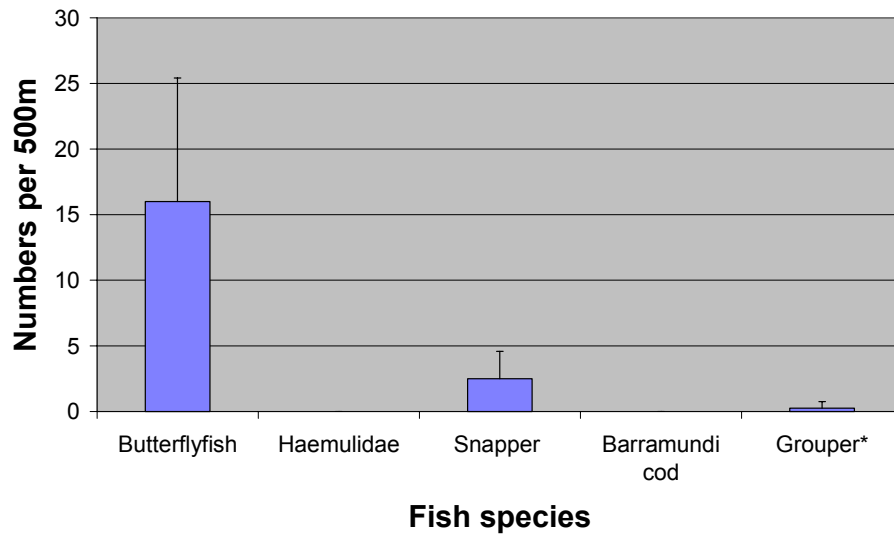


Figure 7. Reef fish populations along the deep (12m) transect. Note the dominance of butterflyfish and the lack of many other commercial species, be they open water (such as many snapper species), or crevice-dwelling, such as moray eels.

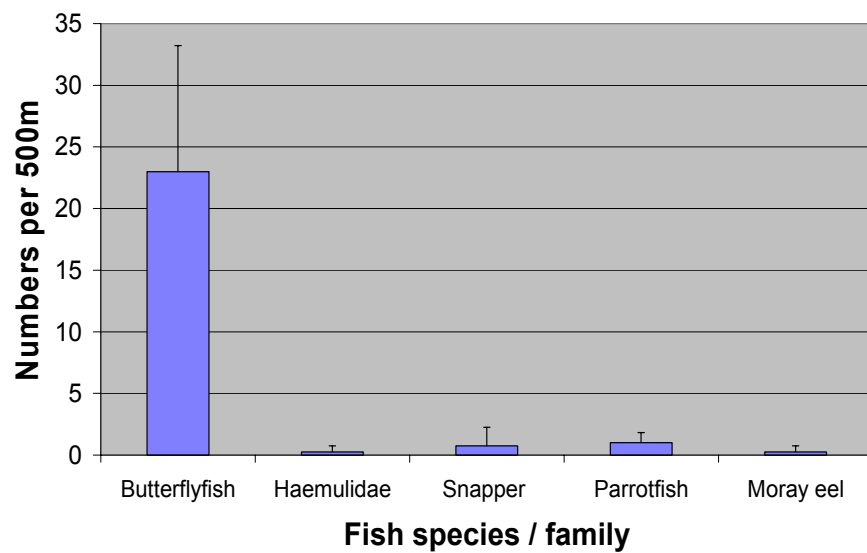


Figure 8. Reef fish populations at shallow Adhureys Rock reef, Ari Atoll. The shallow transect has greater diversity of reef fish, but very low numbers with grouper absent, and snapper and grunt (*Haemulidae*) numbers very low.

Invertebrate populations on the reef check transect were dominated by detritivorous sea cucumbers of the genus *Pearsonothuria graeffei* and giant clams (*Tridacna* sp.).

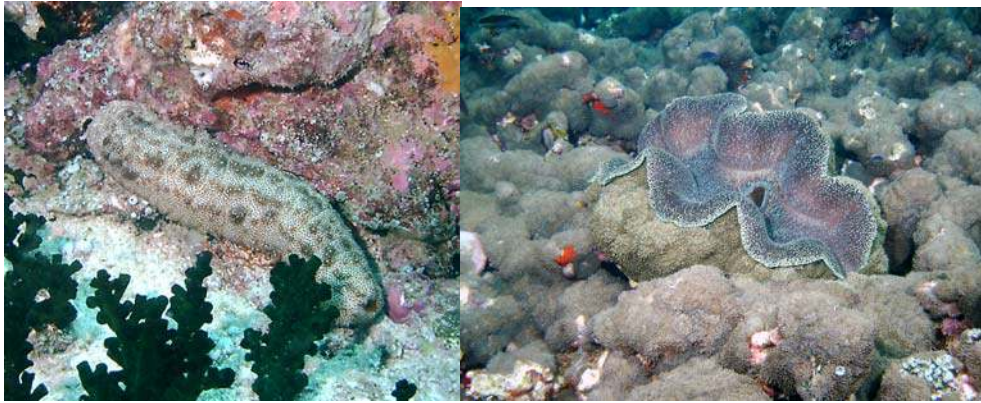


Plate 11. Commonly occurring invertebrates found on the shallow reefs of the Maldives include *P. graeffei* and *Tridacna* sp. of giant clams. Note that the outer shell of the clam is totally covered by *Discosoma*, and in some cases has led to partial mortality of the clams.

2. Rasdhoo Madivaru

Benthic Cover

Coral cover at Rasdhoo was approximately three times higher than that of Adhureys Rock, and other *Discosoma*-dominated thillas in Ari atoll (Fig. 8 and 9). The angle of slope of the reef was approximately 45° on this seaward reef, and most of the substrate other than coral consisted of ephemeral algae (there was low cover of macroalgae), and some sand and rubble.

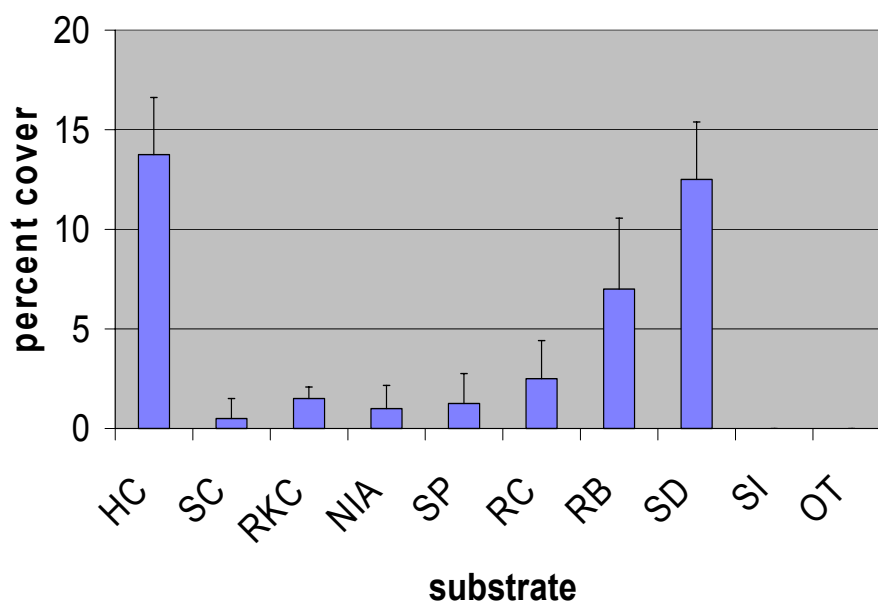


Figure 9. Benthic cover at the deep (14m) transect at Rasdhoo. Hard coral, rubble and sand are the dominant benthic cover types.

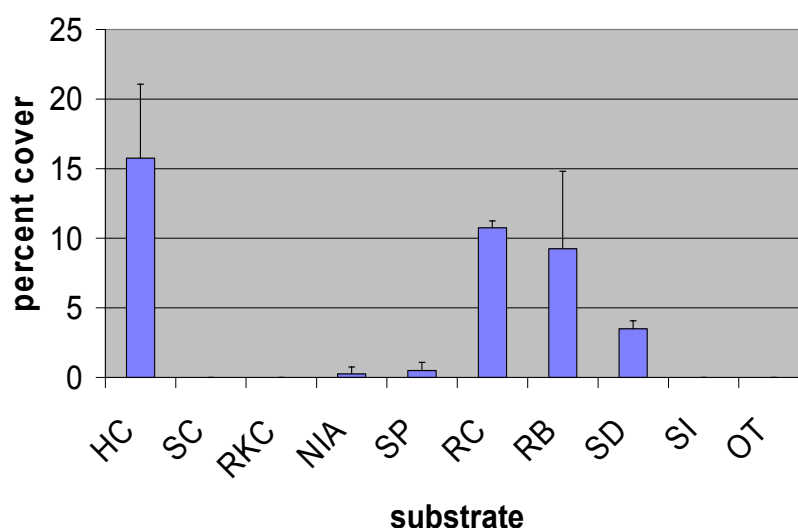


Figure 10. Benthic cover at shallow (5m) Rasdhoo. Substrate cover is similar to the deeper reef, however coral cover is greater, and there is considerably more free space for settlement in the form of coral rock (RC) than in slightly deeper waters.



Plate 12. Benthic cover photographs at Rasdhoo showing small *Acropora*, high biodiversity of invertebrates, and some evidence of line fishing (bottom left, diver holding a fishing weight).

Fish survey

Reefcheck fish populations at Rasdhoo were considerably more abundant and diverse than at Adhureys Rock, in shallow and deeper zones of the reef (Fig. 10 and 11).

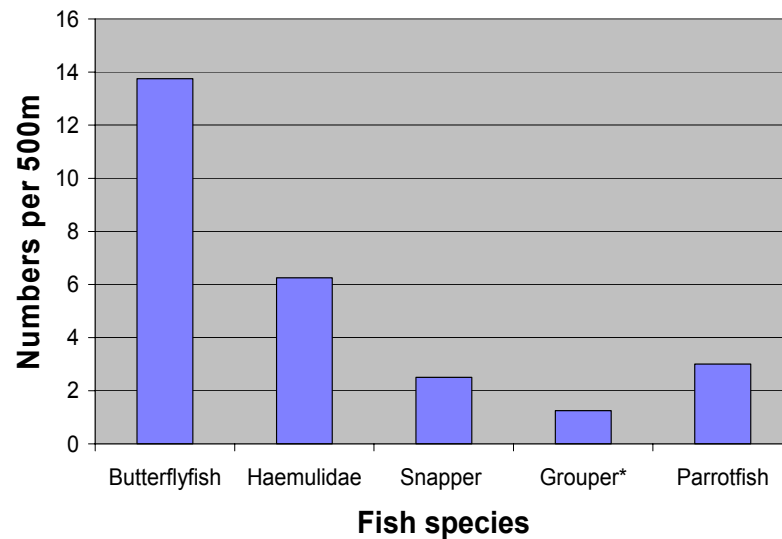


Figure 11. Fish populations at Rasdhoo on the deeper transect (12m). Larger numbers of snappers, sweetlips and other target species, such as the humphead wrasse, were seen at this site slightly off transect, including whitetip reef sharks, whiptail rays, eagle rays and more saddleback grouper.

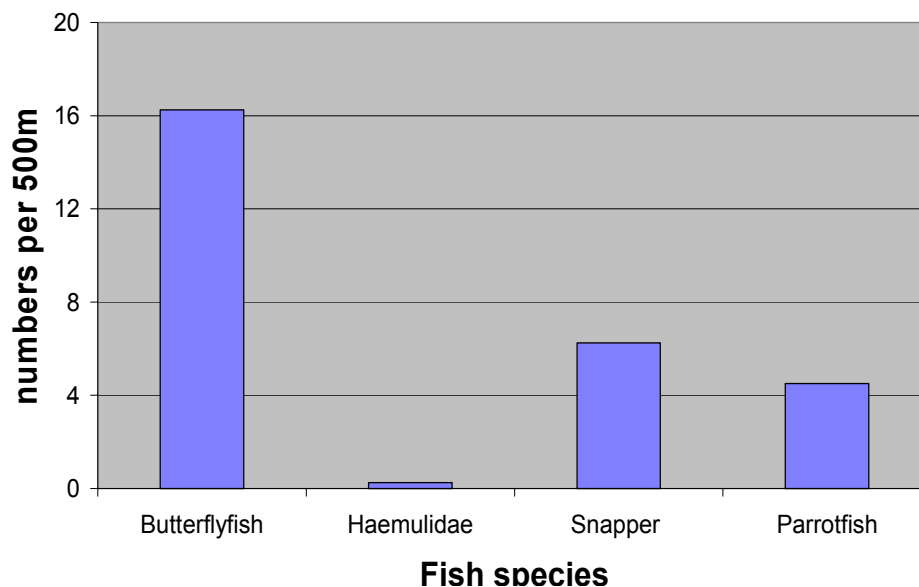


Figure 12. Fish populations at shallow (5m) transect. Diversity (number of target species and families) is lower, but abundance of snapper and parrotfish is slightly higher.

Invertebrate populations

Invertebrate populations at Rasdhoo were dominated by small giant clams in deep and shallow waters (possibly either *Tridacna maxima* or *T. crocea*). Abundance of clams was approximately three times higher along the shallow depth contour of the survey, than in deeper reef areas. Slate pencil urchins and *Diadema* urchins were also recorded at this site.

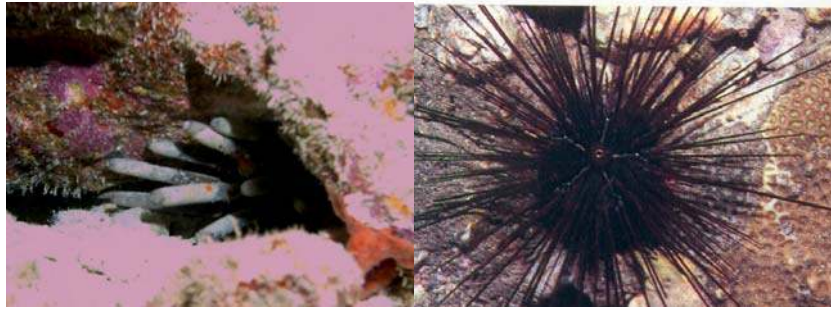


Plate 13. Echinoids found at shallow Rasdhoo. Slate pencil urchin – probably *Phyllacanthus imperialis* (left) and the long-spined urchin, *Diadema setosum* (right).

Immediate post tsunami records from January 2005

Rasdhoo Atoll

Site dived Madivaru 12 & 13/01/05

No visible impact from the tsunami. See Reef Check surveys carried out above.

North Ari Atoll

Sites dived	Eillaidoo Wall	10/01/05
	Mushmasmingili (Fish Head)	11/01/05
	Makuru Thilla	11/01/05
	Maaya Thilla	11 & 12/01/05
	Bathala Thilla	12/01/05
	Maalhoss Thilla	13/01/05
	Bathala Maagaa Kanthilla	14/01/05
	Donkarlo Ridge	14/01/05

This atoll was protected from the effects of the tsunami by North and South Male atolls to the east. Underwater visibility was unusually poor (10-12m) for the first few days, which may have been due to disturbance by the tsunami two weeks earlier, but other than that there were no signs of recent damage at any of the sites visited.

Maalhoss Thilla is one of the better thillas from the point of view of hard and soft coral cover on the upper surfaces, having largely escaped the 1998 bleaching because it is a little deeper than other sites. There was no sign of recent damage at this thilla.



Plate 14. Undamaged reef top at Maalhos Thilla, North Ari atoll, January 2005. (Photo: C. Wood).

South Ari Atoll

Sites dived	Dega Thilla	14/01/05
	Kalahandi Huraa	15/01/05
	Thundufushi Thilla	15/01/05
	Madivaru	15 & 16/01/05
	Broken Rock	16/01/05
	Kudarah Thilla	17/01/05

South Ari atoll was also protected from the direct effects of the tsunami by the atolls to the east. The tsunami was experienced here as a rolling wave on the surface and significant downcurrent on the western (outflowing) side of the atoll, accompanied by disturbed water and poor visibility. By the time of our visit some 3 weeks later visibility had returned to normal.

Some signs of recent damage were observed:

Thundufushi Thilla: The reef top here had very low coral cover, with extensive areas of bare eroded rock with a few colonies of *Pocillopora* and small massive corals. There were no *Acropora* table or branching corals. The dive guides reported that this site had been significantly damaged with the loss of many of the small corals, however little rubble was visible and must have been washed off the thilla to the west. There were large areas of light sandy coloured rock with no life on them, which contrasted with older bare rock with sparse algal cover, which made up much of the surface.

Kalahandi Huraa: The reef top at this site is characterised by a series of coral tables on eroded rock which have presumably grown since the 1998 bleaching event. There was no sign of damage to these tables (Plate 14).



Plate 15. Table corals at Kalahandi Huraa in January 2005, which have grown since the 1998 coral bleaching event. (photo: C. Wood).

Broken Rock: The site is in the south-east of the atoll and in the centre of a wide channel leading into it. It would have faced the tsunami related wave. There were clear signs of recent damage in the form of broken 'pipes' of *Tubastrea micrantha* and *Acropora* branches, together with some whole colonies. There was a large detached sea fan lying on the sea bed. However, the upper reef slopes contained much

living coral, especially *Tubastrea micrantha* ‘trees’ and branching *Acropora*. The limited effects of the tsunami seem likely to be rapidly masked by new growth.



Plate 16. Broken *Tubastrea micranthata* corals at Broken Rock, South Ari atoll in January 2005. (Photo: C. Wood).

Felidhe Atoll

Sites dived:	Fulidhoo Caves	17/01/05
	Kahanbu Thilla	17/01/05
	Miyaru Kandu	18/01/05
	Golden Wall	18/01/05
	Fushi Falhu Wall	18/01/05
	Fotteyo Kandu	19/01/05

Felidhe Atoll is one of the eastern line of atolls and therefore its east side directly faced the origin of the tsunami in Sumatra. All of the sites dived were facing either north or east, and most were in or adjacent to kandus or channels into the atoll.

Fulidhoo caves: an outer, north facing reef which was in poor condition with a low living cover. However much of the rubble was covered with *Halimeda* and other algae, and was clearly not recently damaged.

Kahanbu Thilla: the ocean side reef face was in generally good condition with many *Tubastrea micrantha* ‘trees’ which had survived any tsunami effect. However, the reef top was almost all rubble or bare coral rock, presumably largely the result of 1998 bleaching and/or storms. There had clearly been some re-growth of *Pocillopora* and *Acropora* colonies, but much of this had been recently damaged, presumably by the tsunami.



Plate 16: Large overturned table coral at Kahanbu thilla, Felidhe atoll, January 2005. (Photo: C. Wood).

Miyaru Kandu: an east facing channel into the atoll, which would have felt the direct effects of the tsunami. The reef slope consisted of broken bare rocks with only occasional small living corals. Whilst there may have been some additional impact from the tsunami, the main damage to this reef was much older.

Golden Wall: this is a northerly facing narrow channel into the atoll, with a vertical wall of short orange *Scleronephya* soft corals giving it its name. The outer reef corner appeared to be undamaged, however the slopes of the channel itself were badly affected, with recent rubble slides and much broken coral. Much of the vertical *Scleronephya* wall had survived.

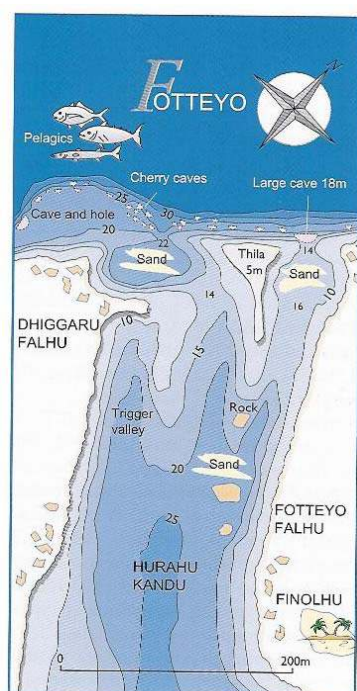


Plate 17. Broken corals at the base of the reef, Golden Wall, Felidhe atoll, January 2005. (Photo: C. Wood).

Fushi Falhu Wall: this is a northerly facing section of ocean-side reef close to a channel into the atoll. The latter was not visited as the current was too strong. There was a steep outer slope with a variety of small corals, sponges etc but with little vertical development and few large features. There were no signs of recent damage.

Fotteyo Kandu: this is also a northerly facing channel, characterised by two sandy channels either side of a small central thilla at the entrance. There are caves on the western side of the entrance, and a long ledge across much of the entrance with underhangs beneath it. There had clearly been a major impact at the entrance to the channel, and much of the central thilla had disappeared leaving a mound of broken coral rock. Across the entrance the long ledges were covered in sand and broken corals, however the caves on the west side were undamaged.

Map 7 (below left) shows the site pre tsunami (from Tim Godfrey, Dive Maldives 1996) and Map 8 (below right) is taken from Chis Wood's dive notes made on January 19th 2005.



Significant damage post tsunami:

- deep caves unaffected
- ledges with sand & broken coral
- underhangs OK
- central thilla very broken up.

Map 7 and 8. Map and sketch of Fotteyo Kandu, January 2005. (Sketch by C. Wood).

South Male atoll

Sites dived:	Guraidhoo Corner	19 & 20/01/05
	Heart Thilla	19 & 20/01/05
	Cocoa Thilla	20/01/05
	Kuda Giri	21/01/05

All of the sites dived were on the east side of South Male atoll and thus exposed to the direct effects of the tsunami. Two of them are open to the ocean and the other two

sheltered by islands and reefs. The island of Guraidhoo suffered badly from the wave which had demolished a swathe of buildings along the eastern side, despite the presence of a shallow lagoon and reef offshore.

Guraidhoo Corner: This site is on the southern side of a relatively narrow kandu leading into the atoll, and is subject to strong currents. The ocean-facing reef, though not particularly varied, had not suffered any discernable damage. However, along the south side of the kandu the reef face, which had comprised a series of overhangs and caves with large numbers of sea fans and sea whips had been significantly damaged. The situation was patchy and some of the caves and overhangs remained, whilst others had collapsed.

Heart Thilla: This is a more sheltered site and there were no visible impacts from the tsunami.

Cocoa (Kandooma) Thilla: This is a thilla in the centre of the channel to the north of Guraidhoo and is often subject to strong currents. It has a minimum depth of 13m and has a varied cover on the top. There were signs of recent damage, with a small number of overturned tables, but in general the reef top remained in good condition. There were a large number of *Tubastrea micrantha* 'trees' present, which we would expect to have been damaged if the tsunami had had much impact on the reef.

Kuda Giri: A more sheltered site which did not show any signs of recent damage.

Discussion

Tsunami damage

The observations made in January, immediately after the tsunami, suggest that the direct physical effects were concentrated on the kandus or channels into and out of the atolls with the greatest impacts on the east side of Felidhe and South Male atolls. Here the concentration of water moving through had stripped walls and created rubble slopes in a number of places. These are all areas where there are naturally strong currents, and may well be the areas from which rubble would soon be removed and the opportunities for re-colonisation will be greatest.

Even in these areas deeper reefs and the open reefs directly facing the tsunami appeared to have been unaffected.

Surveys of the reefs of Ari and North Male Atolls (particularly in June and July 2005) revealed that damage to these sites from surge or large wave action appeared to be minimal. There were areas which had broken, overturned or damaged colonies, but not on a scale to suggest that the tsunami had destroyed large swathes of live coral. This may of course be because the standing live coral cover of the Maldives is considerably lower than it was prior to the 1998 bleaching event, and many of the colonies affected by this mass mortality would already have been killed, and eroded through boring and encrusting fauna and flora. In time, these skeletal colonies would have broken up, and littered many areas of the reef with rubble fields. Indeed, many of the shallow sites had 'scree' slopes of coral rubble, where unconsolidated branches of predominantly branching *Acropora* species were seen to litter the seabed, upon which little grew.



Plate 18. Table *Acropora* (probably *A. hyacinthus*), and rubble scree at 15m on a seaward slope.

Only one site had considerable growth of large coral colonies. This was at Kalhahandi Kandu, which had high shallow-water cover of table *Acropora* (plate 14). However, species diversity was low, and this is a fast growing colony relative to many reef-building corals such as *Porites* spp, and may well have grown to this size since the bleaching event of 1998, even from being a recruit. Most other sites were notable for cover of small (<30cm diameter) colonies of branching *Acropora* and *Pocillopora* corals in waters above 15m depth, but again, relatively devoid of large areas, or numbers of reef-building corals.

Kalhahandi Kandu was also noted for a huge 30 x 30 x 30 m section of reef, which had broken off from the main framework of the whole superstructure of the coral reef. This area of coral had collapsed into deeper waters (around 50m seaward of the original reef area), and used to be in an area of an extensive overhang. Subsequent phone calls made by Maldives Scuba Tours staff to other dive operators in the area revealed that the collapse had occurred in the week preceding our visit. It is not known if this damage was caused by wave action from natural storms, or if the tsunami event in any way weakened the structure of the entire reef. Similarly, the bleaching event may have increased the capacity of coral borers (generally marine worms and bivalves) to bioerode the reef framework, which would make the reef prone to structural weakness in the face of wave action and tidal erosion.



Plate 19. Damage to reef at Kalhahandi Kandu. Left - photo shows the cleanly cleaved fresh coral framework, and the living reef on top (depth 23m). Right - picture is of a section of the broken reef lying seaward in 27m.

Reef fish populations

Fish counts of commercial (predator) species of fish on the coral reefs of the Maldives show that in a global context, populations are high for most families. Highest abundance of fish were observed in the schooling species such as the snapper and jack families. The planktivore biomass was also very high, with considerably large numbers of red-tooth triggerfish and fusiliers recorded at every dive site.

Many of the sites visited were Protected Marine Areas (PMAs). The majority of these sites support greater numbers of commercial species than in other sites, but it is not known if this is as a result of protecting the sites, or if they have been chosen because they naturally support greater populations of commercial species. Greater monitoring of these sites is recommended to establish these patterns over a long timescale.

Many dives sites had at least one or two large grouper observed during the surveys (generally either large coral trout, saddleback or lunar tail grouper), often at least one large mature humphead wrasse. It was common to observe whitetip reef sharks on all dives, and larger sharks on all sites where they are known to occur. Therefore relatively speaking, from sites we visited, it appears that the coral reefs of the Maldives support healthy numbers and biomass of large predator species, which are often missing from other exploited reefs in the Indian Ocean. It is also particularly important that grouper populations are maintained, and that many individuals are

allowed to grow to full size because larger individual females of this family will produce disproportionately large numbers of eggs. Also, as with other sequential hermaphrodites, it is important that they are allowed to attain the size at which they change sex (into males within the grouper family), in order to create the right natural male-female ratios to maintain a critical self-sustaining level of reproductive output.

Reef Check

Reef Check was carried out at two very different sites – one site was chosen for being a sheltered thilla, where fish populations were relatively low (for all sites visited), and benthic cover was dominated by *Discosoma* corallimorphs. The other site (Madivaru) was an exposed atoll outer reef where fish populations (both species assemblages and numbers) are more representative of many of the Maldives more famous dive sites. The Reef Check transect at Madivaru yielded unexceptional counts of reef fish for both shallow and deep transect, however eagle rays, whitetip sharks and whiptail rays were all regularly spotted in and around this dive site.

Conclusions

It is clear from the surveys undertaken that the tsunami has had a limited impact on the Maldives reefs surveyed in this study. The areas significantly damaged are some of the kandus in Felidhe and South Male atolls as they lie in the area of the Maldives directly in line with the initial wave. Whilst there was some damage to other sites in these atolls and to the sites visited in North Male and Ari atolls this was not significant, and it is clear that the 1998 bleaching event had a much greater and long lasting impact on the shallow Maldives reefs than did the tsunami.

Reef fish populations appear relatively healthy in a bioregional context from the sites visited during these surveys, although it would be beneficial to have further surveys such as this carried out to establish any change in numbers and biomass of target commercial species, particularly with regard to the PMAs. Compared to observations of reefs of the Caribbean, East Africa, Philippines, Australia and Fiji over a ten year period, Maldives reefs have a remarkable consistency in the biomass and diversity of predatory commercial species (authors personal observations).

The low hard coral cover, lack of large numbers of old colonies (particularly from the genera *Poritidae*) indicates that the bleaching impact of 1998 has had a long-term deleterious impact on the ecological stability of much of the Maldives. Recruitment of faster growing *Acropora* coral appears to have been significant at most sites, although only in the upper waters (usually shallower than 12m). Many reef areas below 15m suffer from very poor coral cover and species diversity, with azooxanthellate species such as *Tubastrea* spp. dominating the benthos (where they dominated the coral cover before the 1998 bleaching event, as they grow well in areas of high current). The preponderance towards sponge, filter feeders and azooxanthellate benthic species over much of the reef area of the Maldives may also indicate the productivity of the archipelago being driven in large part by bottom-up (nutrients and plankton) processes, rather than the dominant coral-zooxanthellae driven systems of areas such as eastern Africa. Observations from other researchers have indicated out that soft corals such as *Sarcophyton* and *Lobophytum* used to be very common on shallow

reefs pre-1998, but the bleaching event has significantly reduced these populations (Liz Wood, pers comm).

Recommendations

- Commercial fish counts need to be repeated inside and outside PMAs in order to monitor fish population changes.
- PMAs and other regularly visited dive sites of the Maldives should be monitored for fishing impacts (number of boats seen fishing).
- Maldives tour operators should charge a tax on divers (perhaps \$10 per visitor) to pay for this surveying and analysis to be carried out by the Marine Research Institute to monitor coral reefs, commercial fish populations, and important invertebrates on a wider scale.
- Resorts which operate diving trips should all be trained in Reef Check methods and encouraged to annually survey one or two 'house reefs'.
- Liveaboard dive trips should be encouraged to follow the example of Maldives Scuba Tours and encourage Marine Biology trips in collaboration with scientists in order to gather time-series data on the status of Maldives reefs.

Acknowledgements

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