Maldives Reef Survey - June 13-30th 2008

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1. Introduction

The Maldives archipelago lies in the heart of the Indian Ocean approximately 300nm SSW of the southern tip of India. The archipelago comprises approximately 1190 islands lying on a raised oceanic ridge, which is approximately 900km long, and straddles the equator between 00 45.00 ^{0}S (Addu atoll) to approximately 07 06.00 ^{0}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 N 04 10.00^{0}; E 073 32.00^{0}.

The reefs and islands of the Maldives are entirely comprised of raised reef limestone, built over thousands of years by billions of tiny corals laying down of calcium carbonate. There are 26 major atolls comprising a total of some 1190 islands – all entirely built by corals.

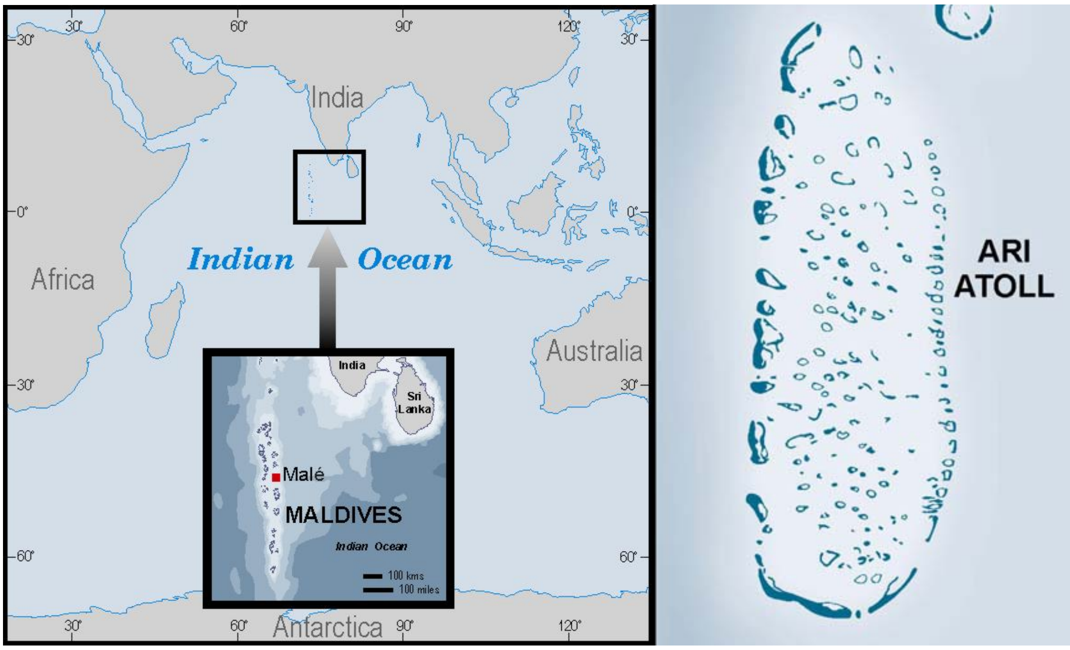

Figure 1. Location of the Maldives in the central Indian Ocean (left), and Ari atoll (right) showing the variety of coral reefs found within any one atoll. (Maps by Steve Frampton)

The structures these corals have created can broadly be divided into three geo-morphological features:

i. Inner atoll reefs – (Thillas, Faros and Giris)

Thillas are submerged reefs found in the middle of the atolls – which reach depths of around 80m in the largest lagoons, and rise to between 15 and 5m of the surface. Giris are simply small thillas which reach the surface, whilst Faros are larger thillas, usually assuming the shape of a small atoll within the atoll (fig. 1).

A common feature of thillas is a cave or overhang system at 15-20m depth. The various changes in sea level over thousands of years has contributed to these features. The last ice age finished between 8 and 10,000 years ago whereupon large volumes of water were released relatively quickly into the oceans. Prior to the melting of the huge amount of ice, sea level used to be at current depth of the Maldives caves and overhangs, which is remarkably consistent (15-20m). The increase in sea level rise was then accompanied by an increase in the vertical growth of the corals on top of the reefs over the ensuing 10,000 years, creating a further layer of reef above these overhangs. Some of the overhangs are precarious, with many periodically collapsing under the weight of corals on the tops of reefs, combined with storm surges.

The overhangs attract cave-dwelling species such as soldierfish and glass fish. Large sea whips, Tubastrea corals, and sponges also dominate these overhangs. As such, they provide their own micro-community to the coral reefs of the Maldives.

ii. Outer reefs

Outer exposed reefs usually feature a large reef flat which grows horizontally over thousands of years to dominate the outer rim of the atoll (see the west-facing outer reef ring of Ari atoll in figure 1). Reef flats and reef crests absorb energy from oceanic swells, and are therefore dominated by small stubby growth forms such as coralline algae, and robust coral species (eg. digitate *Acropora*). The outer deeper reefs are generally comprised of a number of ledges after which the reef plummets to deep waters (over 1,000m) at the outer edge of the archipelago.

iii. Channels between outer reefs and inner atolls.

Channel mouths to lagoons tend to be where large apex predators congregate where large numbers of their fish prey can feed on plankton passed into and out of the reef by immense currents. The reason as to why currents are so great is related to the structure of the atolls. Channels lie on the outer edge of the atolls, where the deep wide oceanic water is continuously either entering or leaving the atoll with the tide. The channels effectively act as a bottleneck through which millions of tones of seawater pass during each tidal cycle between the relatively shallow waters of the inner atoll basin to the open ocean outside the atoll plate. The restricted channel mouths (which usually measure between 500-1000m wide by 30-70m deep (such as at Guraidhoo Channel, South Male atoll) funnels all this water, and therefore the currents pick up the nearer one dives to the channel entrance.

2. Marine Resource Use in the Maldives

Fisheries

i. Reef fish for artisinal use and tourist resorts

The fishery for reef fish is thought to be relatively sustainable. Biomass estimates of predatory (target) reef fish such as grouper, snapper and scrombids from most Maldivian reefs are broadly high relative to other Indo-Pacific reefs. The massive development of the tourist industry since the 1970s, coupled with the demand for reef fish may have led to a change in reef fish assemblages on some reefs close to tourist resorts and near to the more populated atolls. As such, the Maldivian government introduced 10 Marine Protected Areas in 1995 and a further 10 in 1999 to stop all reef fishing (whilst fishing for bait fish such as caesionids is still permitted). However, efforts to enforce these protection measures are weak, with limited government support available to fund patrols, or appropriate infrastructure to accommodate and supply rangers near to the sites.

ii. Bait fish fishery on inner atoll reefs.

The Maldivian baitfish fishery use small-mesh nets to capture Caesionidae (fusiliers), Apagonids (cardinalfish) and Clupeids (spreats) to use as bait for the offshore tuna fishery (fig 2).

Figure 2. Live baitfish (caesionids) in a holding pen at Male harbour beside the fish market

iii. Offshore tuna fishery

The tuna fishery is (along with the tourist industry) the primary source of GDP for the Maldives. Tuna are caught in many places close to offshore Fish Aggregation Devices (FADs), which are used to attract principally yellowfin tuna, but bluefin tuna are also captured. Yellowfin tuna are graded depending on freshness and quality. Those of the highest grade are flown to Japan for sale as sashimi. Lower grade (b and c) are sold to Europe (including the UK), for restaurants and supermarkets. Skipjack tuna are also caught within and outside of atolls for the canning industry, and for supply to the local population (Fig. 2).

Figure 2. Skipjack tuna (left) and low-grade yellowfin tuna and marlin fillets (right) on sale in Male fish market.

Figure 3. A yellowfin tuna aboard a tuna-fishing vessel in Male harbour, adjacent to the fish market.

Figure 4. The deck of a Maldivian tuna fishing boat. Vessels can be out to sea for a week. Note the large freezer containers for storing the fish.

iv. Long-lining for pelagic species

The Maldives currently sells licenses to other states, which allows foreign fishing vessels to fish within its 200nm EEZ waters. Unfortunately this results in many long-lining vessels operating adjacent to the atolls. These vessels often target hotspots for pelagic species, and sharks constitute a considerable proportion of the catch. The main economic demand for the shark fishery comes from the sale of shark fins to Fareast Asia for the shark fin soup trade. One estimate is that between 400 and 800kg of shark fins are exported per week from the Maldives (Tim Davies, pers. comm.). This has prompted the Maldives Fishermen Union on July 24th 2008 to call for a ban on shark fishing in Maldivian waters.

Figure 5. Beruwela fish market, Sri Lanka with finned sharks – a common site amongst tropical developing country fish markets. The provenance of the sharks in these photos is unknown, but could quite feasibly be from the Maldives.

3. Aims and background of MCS/MST surveys

The Marine Conservation Society and Maldives Scuba Tours have surveyed the atolls of the central Maldives since 2005. The first survey trip using the Reef Check method was carried out in July 2005, with subsequent survey visits in Jan 2006, Jan 2007 and June 2008.

The first Reef Check survey of the reefs in 2005 was carried out in order to set up permanent monitoring stations at popular dive sites regularly visited by Maldives Scuba Tours, and in areas where the coral reefs appear to be relatively healthy and diverse. The site chosen was Rasdhoo. The June 2005 survey trip also monitored the impacts of the Asian Tsunami (of 24.12.04) on the reefs of the Maldives, where little impact was recorded (Solandt and Wood, 2005).

The Marine Conservation Society has been the Reef Check Co-ordinator for the Maldives since 2006, and co-ordinates the activities of other survey teams, ensuring that data is quality assessed, and regularly passed on to the ReefCheck HQ in California.

Since 2004, there has been limited published data from reef monitoring carried out in the Maldives (Table 1) although the Maldives government Marine Research Centre is carrying on with subtidal reef monitoring (Liz Wood, pers comm.). The work carried out between 1998 and 2004 recorded the recovery of Maldivian reefs at different locations to the impact of the global coral bleaching event of 1998.

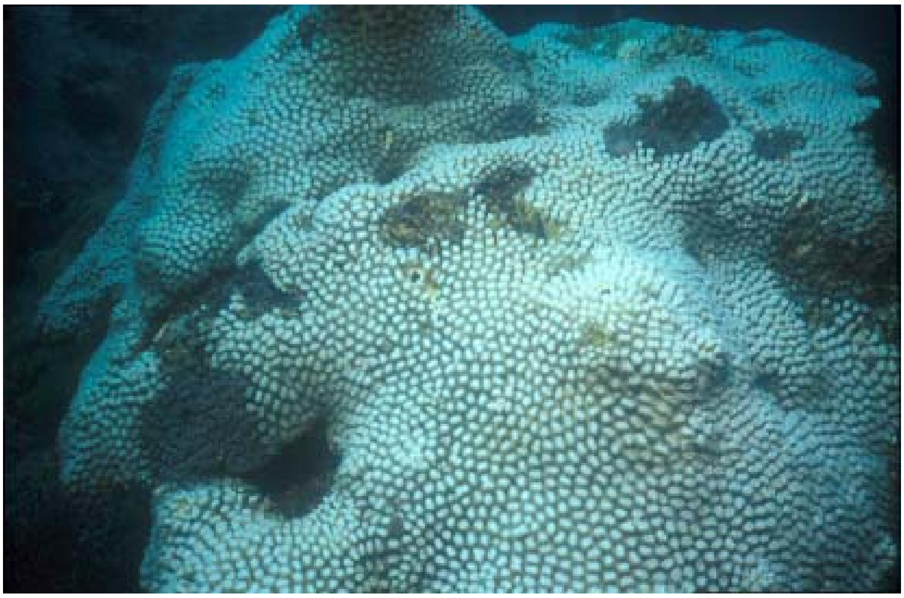

Figure 6: Bleached *Galaxea fascicularis* coral colony.

The bleaching event was caused by unusually high water temperatures in the region – where monthly mean Sea Surface Temperature was 1.2 – 4 degrees Celsius above the 1950-1999 average for the region (Edwards *et al.*, 2001). The greatest temperatures were recorded in May 1998, reaching +2.1^{0}C above mean SST. The El-Nino Southern

Oscillation[1] drove temperatures up in many other coral reef regions of the world in 1997-998 (NOAA, Fig 9). The recovery of reefs to the bleaching event of 1998 has been variable both across the Indian Ocean and within the Maldives (Fig. 6). It appears that southern reefs of the atoll chain were less affected than northern reefs (Table 1).

[1] El Nino leads to warm surface water conditions in central - western Pacific regions, a slowing down or cessation of the cold Humboldt Current in Peru, floods in Pacific South American states, and drought in the western Pacific Rim because of the eventual reversal, or slowing down of the westerly equatorial currents.

Table 1: Percent cover of live coral from 19 Maldives reefs between 1998 and 2004. (Source: Wilkinson *et al* (2005), Status of the coral reefs of the World, *Global Coral Reef Monitoring Program*).

Reef Sites	1998	1999	2000	2002	2003	2004
Reef flat (1-2 m)	% cover	% cover	% cover	% cover	% over	% cover
Hondaafushi	1.6	0.5	0.9	1.7	3.1	n/m
Finey	0.7	0.1	0.3	1.4	2.5	n/m
Hirimaradhoo	0.7	0.3	0.4	1.1	1.1	n/m
Feydhoofinolhu	1.7	2.3	1.8	1.9	n/m	n/m
Bandos	1.9	7.6	5.0	6.9	n/m	n/m
Udhafushi	1.3	1.5	2.1	2.9	n/m	n/m
Fesdhoo	3.3	3.8	9.9	22.1	n/m	27.2
Maayaafushi	0.6	0.9	1.5	2.7	n/m	4.8
Velidhoo	0.2	0.2	0.7	2.3	n/m	2.3
Ambaraa	1.2	0.9	3.2	2.9	4.8	n/m
Wattaru	2.8	2.4	2.7	3.7	5.0	n/m
Foththeyo	5.0	2.7	4.1	5.0	9.7	n/m
Gan	4.0	4.5	5.0	12.9	n/m	17.0
Villingili	4.3	n/m	9.2	13.2	n/m	n/m
Kooddoo	1.0	2.3	n/m	6.0	n/m	n/m
Reef flat (3 m)						
Hithadhoo				51.6	59.1	32.0
Reef slope (7 m)						
Gan				42.8	n/m	n/m
Reef slope (10 m)						
Villingili				54.3	n/m	61.4
Hithadhoo				40.9	62.6	51.7

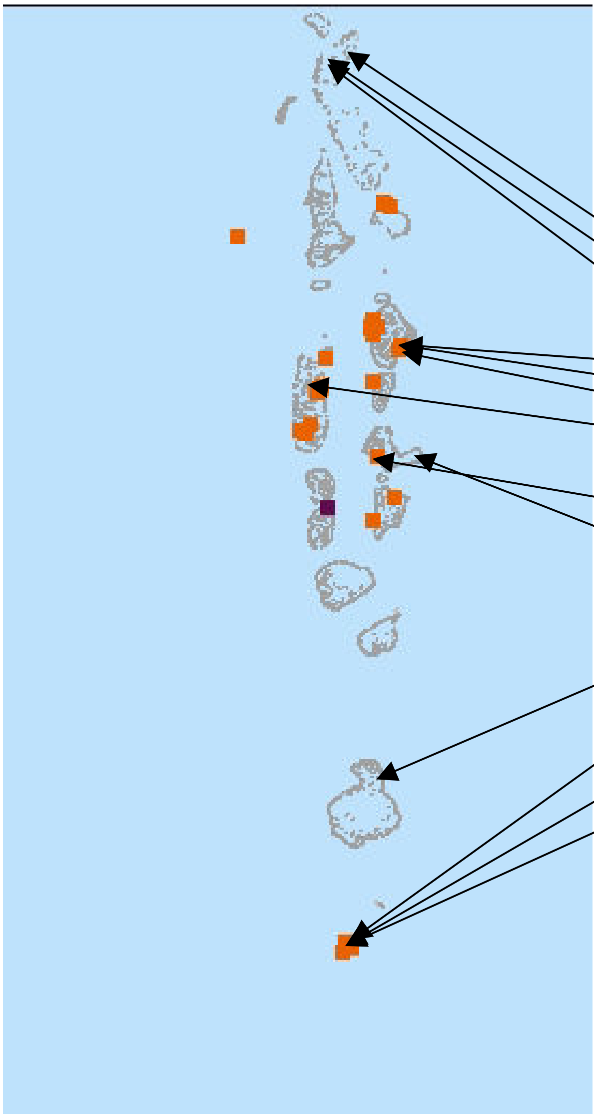

Figure 7. Survey sites carried out to investigate the effects of the 1998 bleaching event on Maldivian coral reefs. (Results are in Table 1).

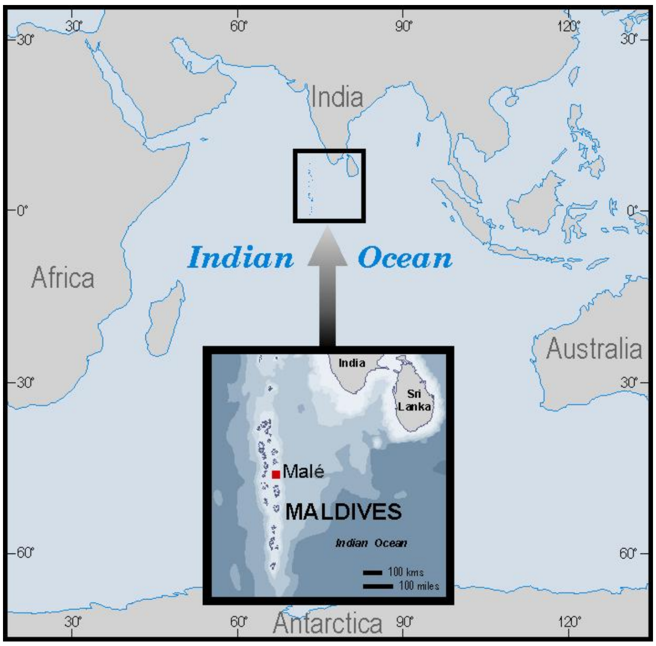

Figure 8: Location of the Maldives in the Indian Ocean. (Map by Steve Frampton).

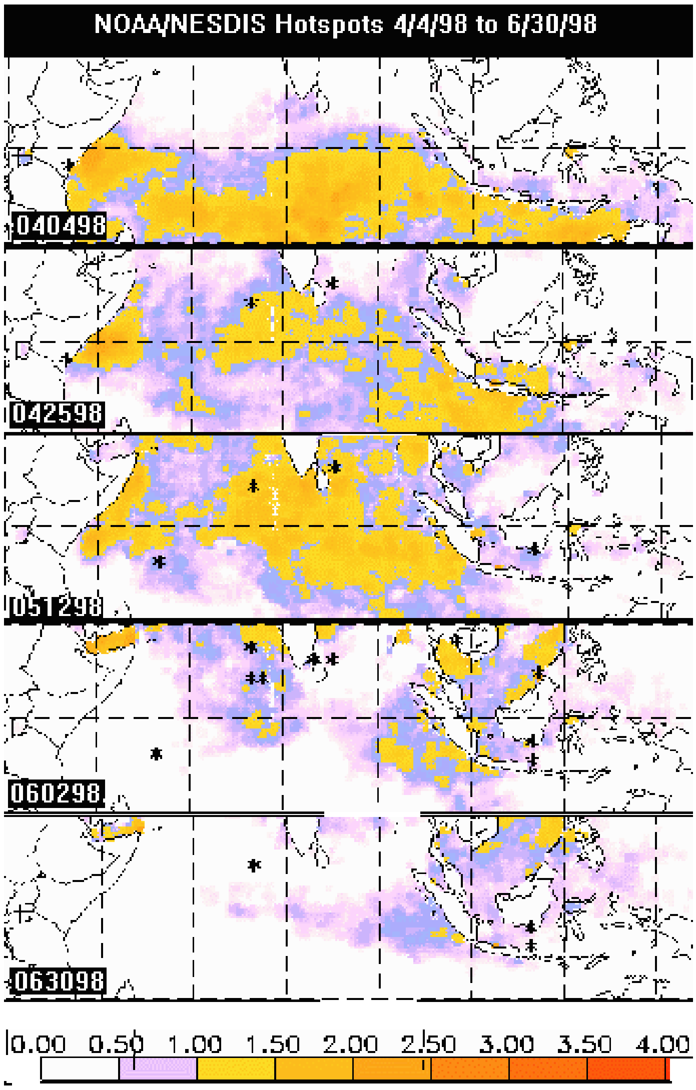

Figure 9. NOAA satellite image of the Sea Surface Temperature temperatures above the seasonal averages from the Indian Ocean in April, May and June 1998. This shows a significant anomaly of warm water directly over the Maldives.

Table 2: Summary of MCS Reef Check surveys of coral reef live coral cover (%) 2005-2008. (N/m – Not monitored) (See fig. 10 for a map of the sites).

Site	June 2005	Jan 2006	Jan 2007	Jan 2008	June 2008
Rasdhoo (14m)	34.4	16.25	33.1	18.75	33
HP reef (14m)	N/m	17.5	36.9	N/m	19
Niumath (15m)	N/m	10	N/m	10.75	N/m
Dega Giri (2m)	N/m	N/m	N/m	N/m	66.9
Adhureys Rock (10m)	12.5	N/m	N/m	N/m	N/m

The aim of the June 2008 survey was to:

1. Survey Dega Giri shallow waters to gather baseline data on the coral cover and species composition of a relatively mature growth coral reef.
2. To carry out a quantitative assessment of predatory reef fish between different dive sites.

4. Methods

4.1 Reefcheck

Reef Check was carried out at one site at Dega Giri on 8 June 2008 (World Oceans Day). International reef check protocol methods and results can be found at www.reefcheck.org. The site was chosen for its exceptional coral cover in shallow waters, first noticed by JL Solandt in January 2007, however it wasn't possible to survey it that year due to low water (the site is inaccessible at low water). It also wasn't accessible at this shallow depth in January 2008, because of heavy wave action over the top of the reef making the snorkel surveys impossible to carry out.

Normally Reefcheck is carried out at between 5 and 8m for the shallow transect, and 10-15m for the deep transect to record reef health in the most productive, shallow habitats of coral reefs. A further reason to carry out the surveys in relatively shallow water is to ensure that surveyors can accomplish lengthy surveys within the safety margins of SCUBA diving. However, with regard to Dega giri, an exception to this rule was made because of the exceptional coral colony size and cover in shallow water (1-3m).

Reef Check survey methods were taught to the volunteer surveyors aboard the MV SeaSpirit and carried out on June 8th 2008. An introduction talk to Reef Check results and the Global Coral Reef Monitoring programme was given on June 3rd. A practice in-water survey was carried out with the survey team on June 4th in order to get volunteers accustomed to the methodology, and carrying out data collection in the field for the first time. Further ID presentations were given on Reefcheck on June 7th and 8th.

Ali Naseer carried out Benthic surveys, fish counts by Rob Andrews and Kim Bonham, with invertebrates recorded by Judy England. JL Solandt (team leader) and Judy England 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 by JL Solandt and sent to Reef Check headquaters in the USA.

4.2 Fish surveys

Fish surveys aimed to gather detailed information on the density and biomass of predatory fish species (higher trophic level) (listed in table 3), and an estimate of the abundance and biomass of non-predatory fish families (listed in table 4). Fish were recorded onto underwater sheets with the species and family list, within 10cm size ranges (11-20; 21-30; 21-30 etc.).

Fish were recorded along 50m transect laid out at between 10 and 14m depth. Divers recorded fish at 5m intervals - 0; 5; 10; 15; 20; 25; 30; 35; 40; 45; 50. Each 5m recording interval was effectively a volume of 5m (length) x 5m (width) x 5m (height) = 125m^2 blocks – the whole transect thus covering an area of 1250m^2. Divers made sure that individual fish recorded in each 125m^2 block weren't recounted in subsequent blocks. Fish surveys were carried out by JL Solandt (recording predatory fish species and size) and Judy England (other families).

Table 3. Predatory species recorded in the fish surveys.

snapper	
Aphareus furca	smalltooth jobfish
Aprio viriscens	green jobfish
Lutjanus bohar	red snapper
Lutjanus gibbus	paddletail
Lutjanus monostigma	one spot
Ltjanus kasmira	blue lined
Macolor macularis	midnight
Lutjanus fulvus	blacktail
Macolor niger	black and white
Emperor	
Lethrinus conchyliatus	redaxil emperor
Lethrinus erythracanthus	yellowfin
Lehtrinus microdon	smalltooth
Letrhinus olivaceus	longnose
Lethrinus miniatus	red spotcheeck
Lethrinus xanthochilus	yellowlip
Monotaxis grandoculis	bigeye bream
Gnathodentex aurolineatus	goldspot emperor
Grouper	
Aethaloperca rogaa	redmouth
Anyperodon leucogramma	slender grouper
Cephalophis argus	peacock
Cephalophis miniata	coral hind
Epinephalus spp.	
Plecropomus laevis	saddleback
Plectropomus pessuliferus	coral trout
Varoila louti	lunar tail
Jacks	
Caranx sexcfasciatus	bigeye trevally
Carangoides fulvoguttatus	yellowspot trevally
Caranx ignobilis	giant trevally
Caranx melampygus	bluefin jack
other jack	
sharks	
Carchahinus albimarginatus	silvertip
Carchahinus amblyrhinchus	grey reef
Triaenodon obesus	whitetip reef
Other	
Tuna	
Euthynnus affinis	mackeral tuna
Gymnosorda unicolor	dogtooth tuna
Thunnus albacores	yellowfin tuna
sweetlips	
Diagrama pictum	painted sweetlips
Plectorhinchus vittatus	oriental sweetlips
Plectorhinchus chaetodonoides	harlequin sweetlips

Table 4. Non-predatory fish (recorded by family).

other species	
Murainidae	moray eels
Scaridae	parrotfish
planktivorous *balistidae*	triggerfish
other *balistidae*	triggerfish
planktivorous *acanthuridae*	surgeonfishes
other *acanthuridae*	surgeonfishes
planktivor Chaetodontidae	butterflyfish
other *chaetodontidae*	butterflyfish
Caesionidae	fusiliers
Mullidae	goatfish
Pommacanthidae	angelfish
Pommacentridae	damselfish
Holocentridae	soldierfish
Sphyraena barracuda	great barracuda
Sphyraena jello	picklehandle
Tylosaurus crocodilus	needlefish
Cheilinus undulatus	humphead wrasse
other *labridae*	wrasse
Siganidae	rabbit fish
Other	anthias

Habitat surveys were carried out using the Line Intercept Transect (LIT) methodology at 0.5m intervals (Table 5).

Table 5. Benthic categories recorded on LIT surveys at each fish survey site.

Hard coral
Soft coral
Recently killed coral
Nutrient impact algae
Sponge
Rock
Rubble
Sand
Silt
Other

5. Survey sites:

5.1 Reefcheck survey sites (2005-2008)

Sites are all located within the central atolls of the Maldives (Fig 10). Reefs surveyed using Reef Check methodology varied from outer atoll reefs (Rasdhoo); inner Giris (Dega giri); thillas (Adhureys Rock and Niumath), and channel reefs (HP).

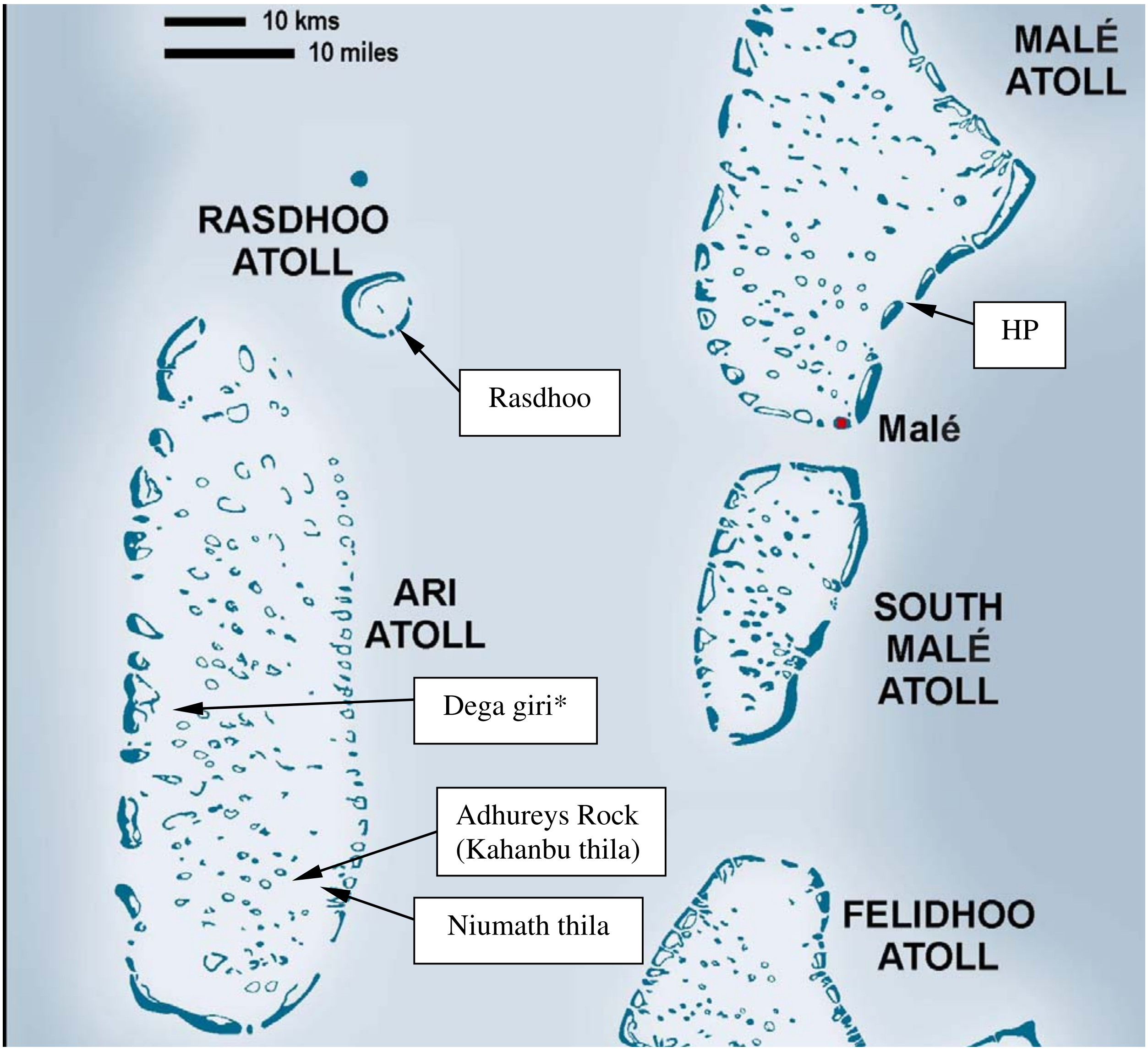

Figure 10: Location of Reefcheck permanent monitoring sites of central Maldives reefs. Sites were surveyed between June 2005 and June 2008. (* only site surveyed in June 2008 – Dega Giri). (Map by Steve Frampton).

5.2 Fish Survey sites

In June 2008, nine fish surveys were carried out to record the individual abundance, size and species of predatory reef fish, and the size and abundance of other reef fish families (Fig. 11). Sites were at 3 inner atoll thillas (Maya; Okobe and Angaga); 3 outer channel reefs (HP; Bodhu hithi; Kudarah); and 3 outer reef walls (Aquarium; Rasdhoo; Bathaalaa Maagaa).

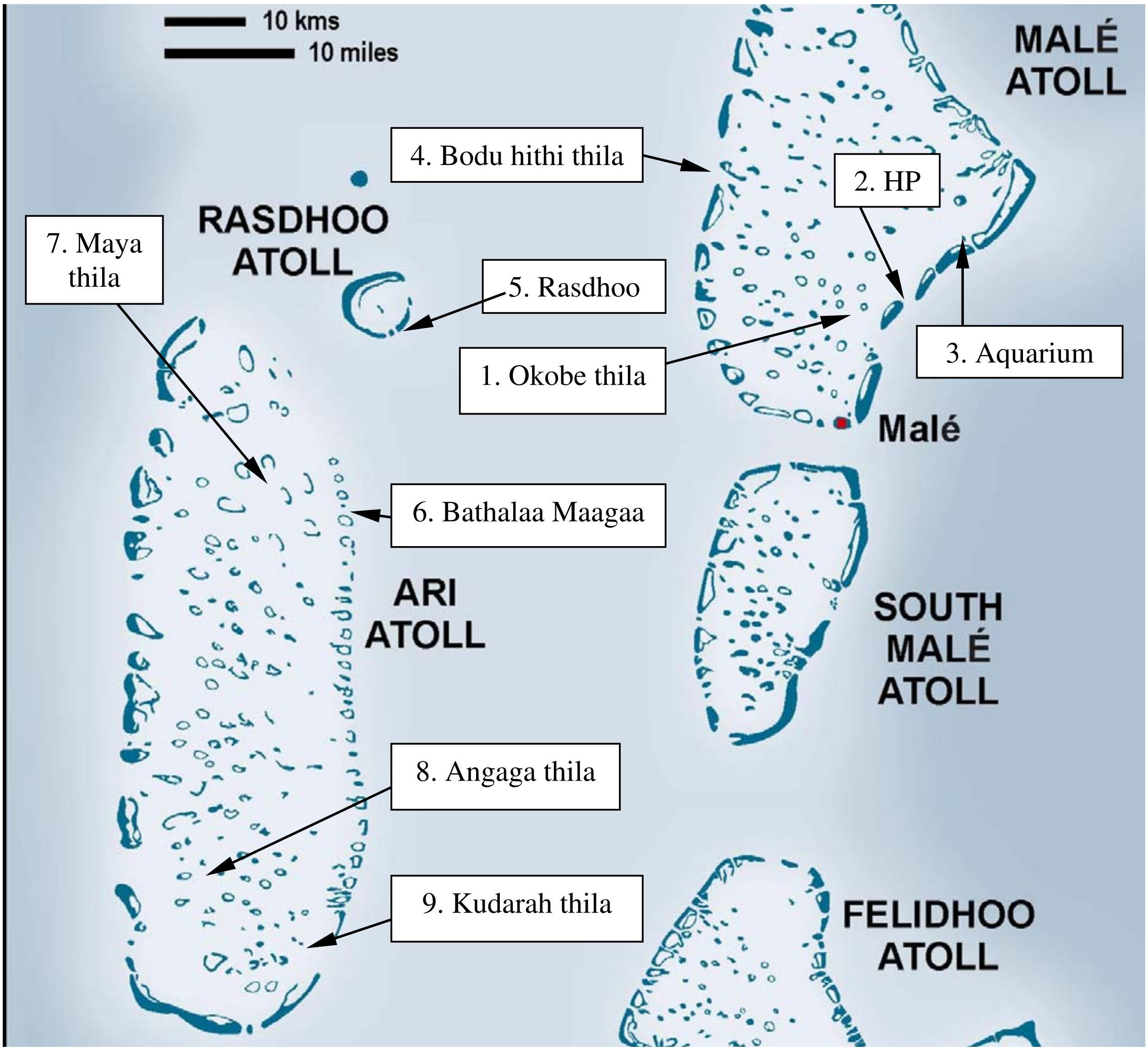

Figure 11. Fish survey sites: 1 Okobe thila; 2 HP reef; 3 Aquarium; 4 Bodhu hithi thila; 5 Rasdhoo; 6 Bathalaa Maagaa thila; 7 Maya thila; 8; Angaga thila; 9 Kudarah thila. (Map by Steve Frampton).

6. Results:

6.1 Reefcheck at Dega thila

6.1.1 Fish populations

Fish recorded at Dega were dominated by butterflyfish and parrotfish species. The other families observed on the survey were acanthurids (surgeonfish), siganids (rabbitfish) and mullids (goatfish), which exploited the rapid ephemeral algal growth on the reef top, whilst the mullids were found in the shallow sand patches in the centre of the giri (Fig. 12).

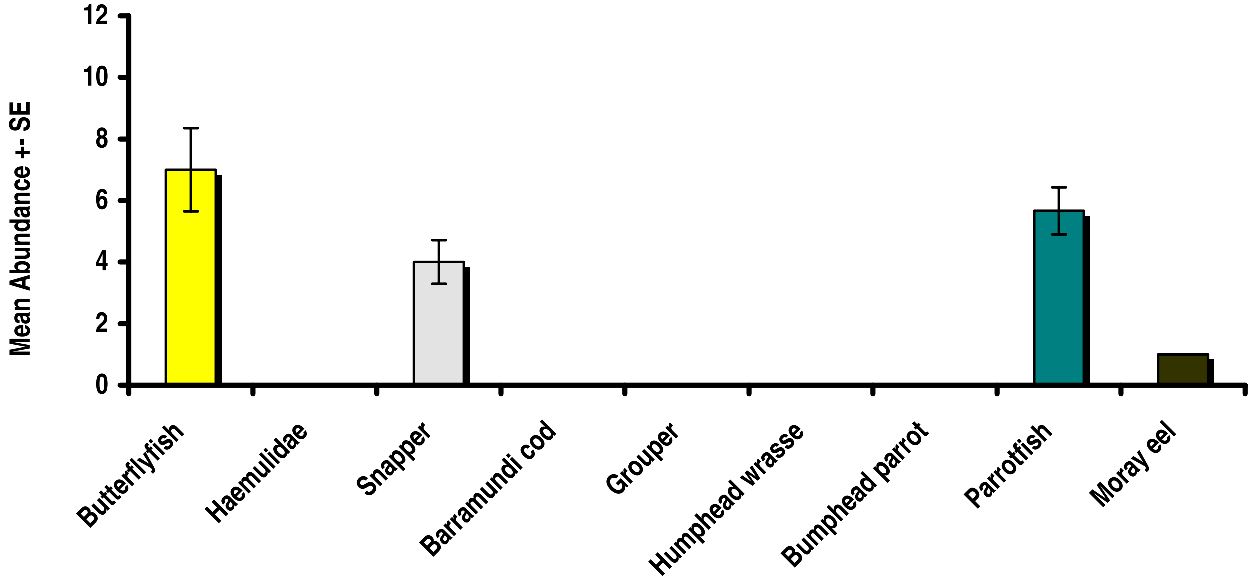

Figure 12: Fish recorded at Dega Giri using the ReefCheck methodology.

6.1.2 Invertebrate populations

Invertebrates at the site were dominated by sea cucumbers and giant clams. The complex nature of the reef flat would mean that many crevice-dwelling invertebrates such as *Diadema* echinoids wouldn't be easily recorded, as they were likely to be found deep within the coral framework (Fig. 13).

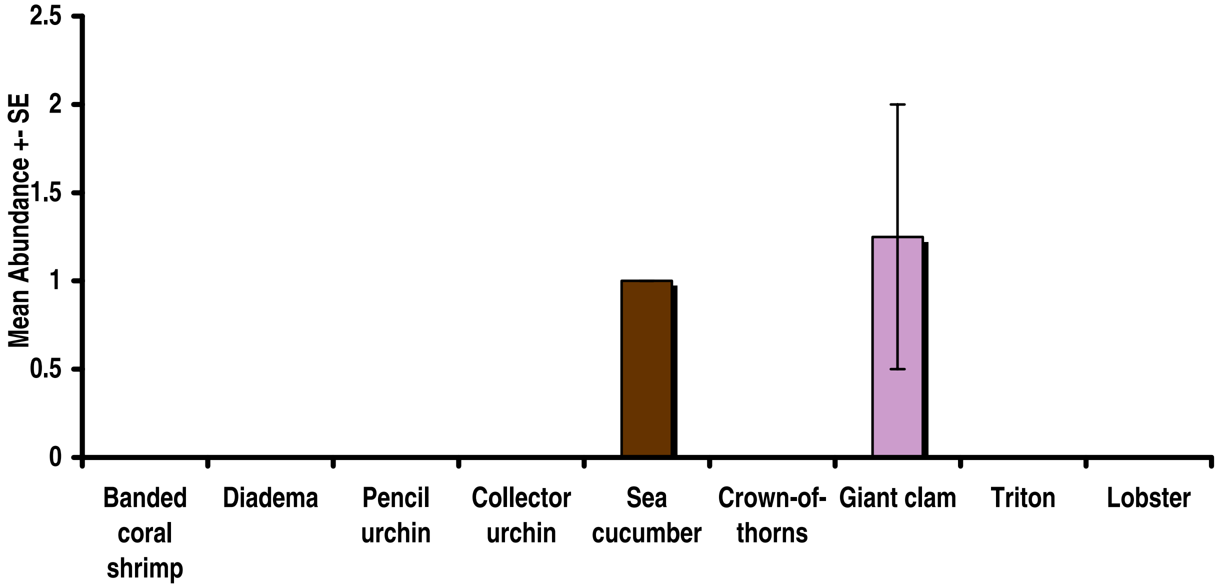

Figure 13: Invertebrates recorded out at Dega Giri using the ReefCheck methodology.

6.1.3 Giant clam size

The surveys recorded relatively small giant clams, with 3 animals recoded in the 10-20cm range, with one below and one above this size class (Fig 14).

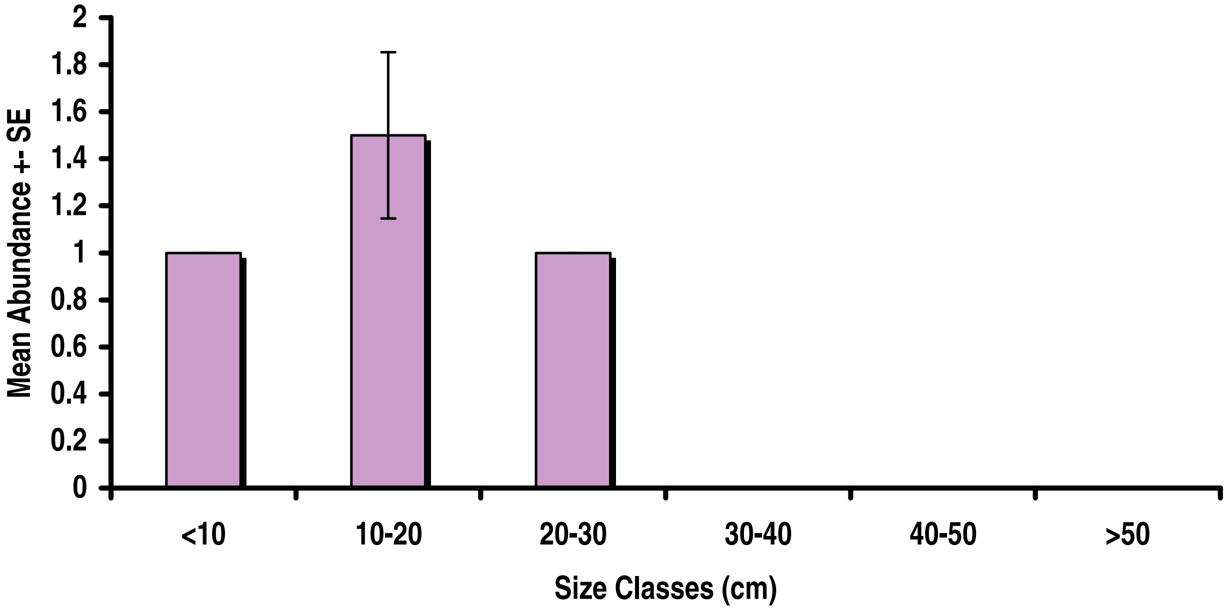

Figure 14. Clam sizes recorded at Dega Giri.

6.1.4 Damage recorded at the site

There was very little damage. A single patch on the transect could have been damaged by anchor, but this was inconclusive (Fig. 15).

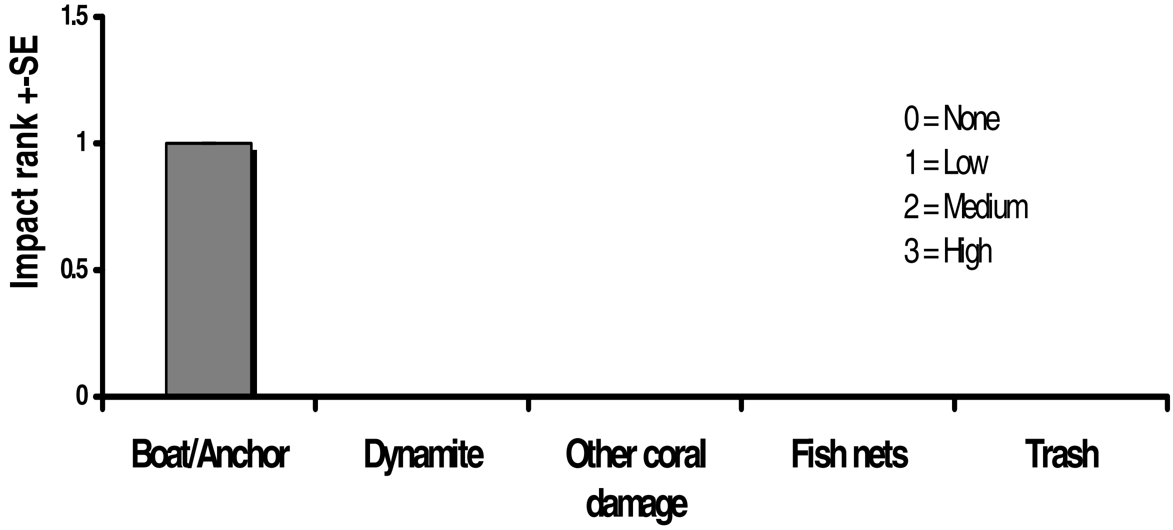

Figure 15. Damage recorded at Dega Giri.

6.1.5 Substrate cover at Dega Giri.

The substrate was dominated by mature colonies of fast-growing table *Acropora* coral (Fig 16 and 17). The survey was laid from the outer edge of the giri (in 3m water) to the inner central area of the giri, adjacent to a sand patch. Coral cover decreases with distance along the transect from the outer edge of the giri towards the centre. Coral cover over the first 20m section was 87.5% the second section was 62.5, the third 57.5, with the lowest cover at the centre of the giri of 60% which was linked to the fall in table Acropora cover from the outer to inner area of the giri over the transect (Fig. 18).

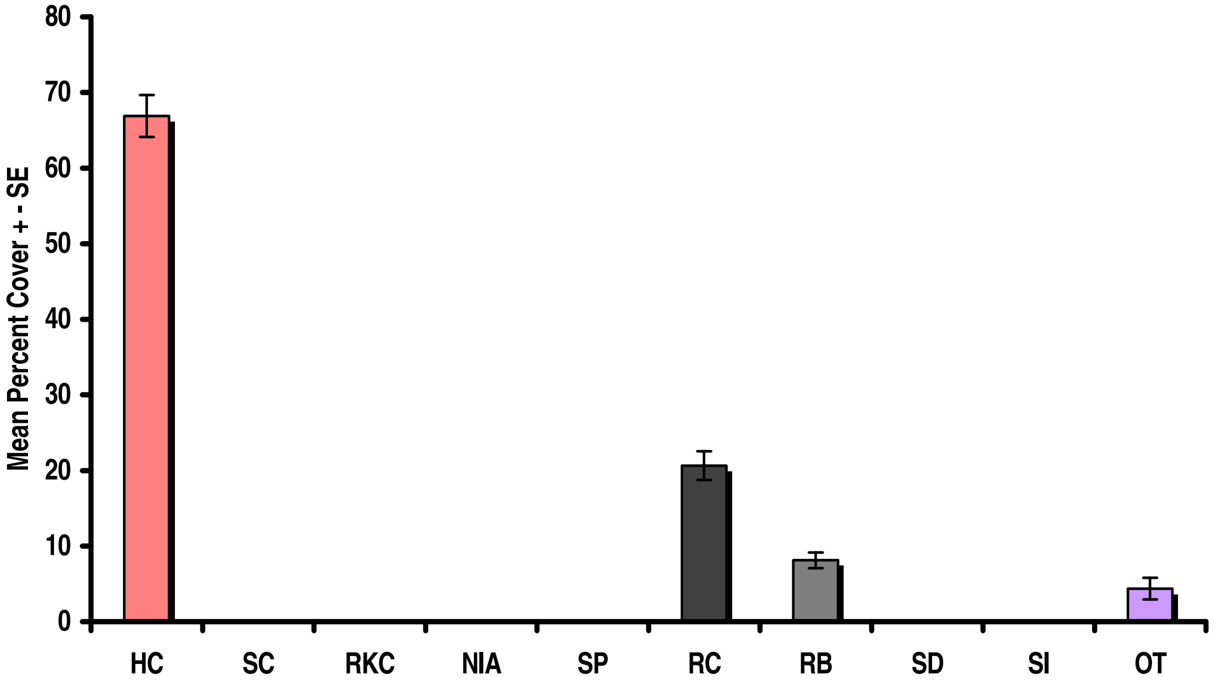

Figure 16. Relative substrate cover recorded at Dega Giri using the ReefCheck methodology.

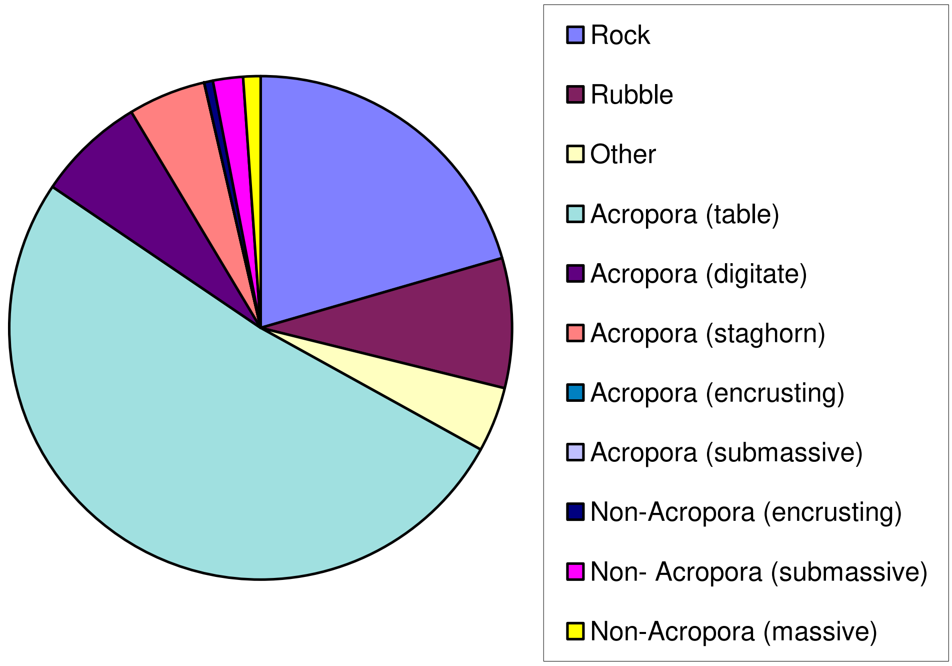

Figure 17. Relative representivity of different coral lifeforms and benthic features recorded at Dega Giri.

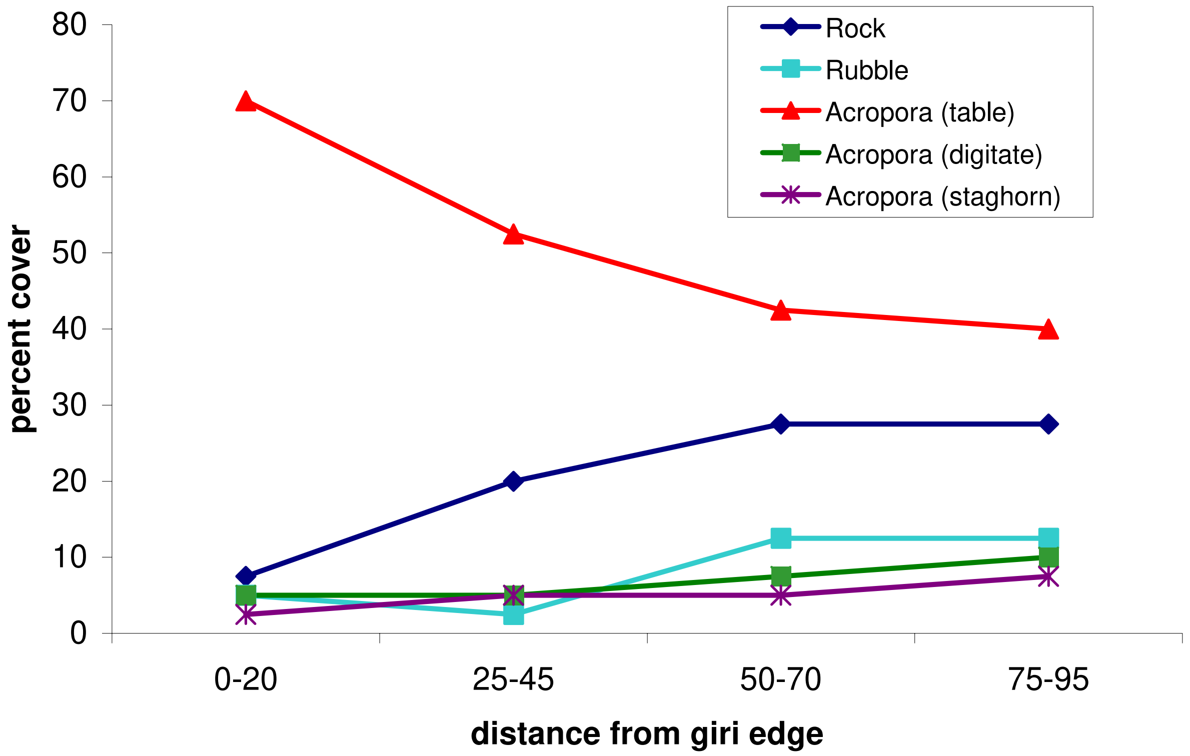

Figure 18. Relative change in the most dominant coral lifeforms and substrate with increasing distance from the outer edge of Dega Giri.

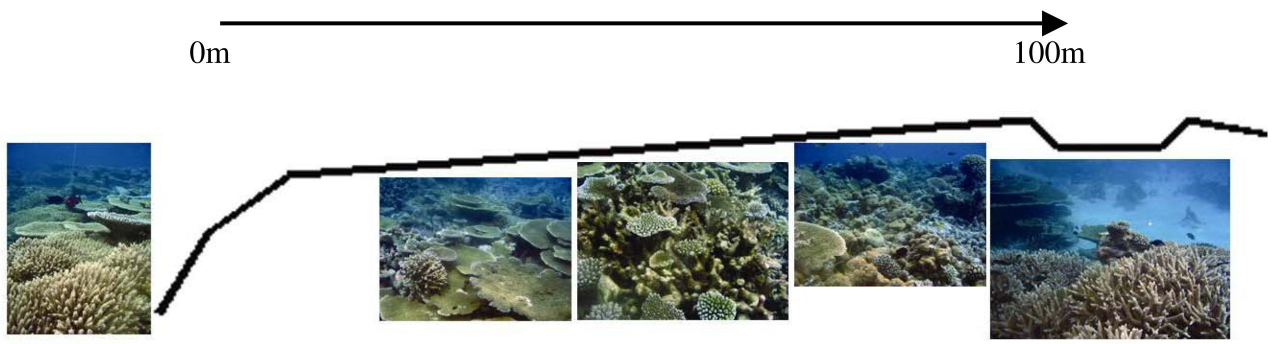

Figure 19. Schematic cross-section of the reef from the outer edge (left) to centre (far right).

Coral species identified at Dega giri by Professor Doug Fenner (Department of Marine and Wildlife Resources, American Samoa) were *Acropora nobilis, A. cytherea, A. muricata (formosa), A palifera* and *Gardineroseris planulata.*

6.2 Fish surveys

Fish were randomly distributed by site. There was no significant difference in predatory fish family or species density between sites surveyed (Fig. 19). Two of the MPs surveyed – Maya thila in Ari atoll and HP reef in North Male atoll had a higher abundance of carangids (jacks) than in other locations. Other MPAs such as Kudarah in SE Ari atoll channel had considerable number of dogtooth tuna (*Gymnosorda unicolor*). Most sites surveyed had one or more individual humphead wrasse (*Chelinus undulatus*).

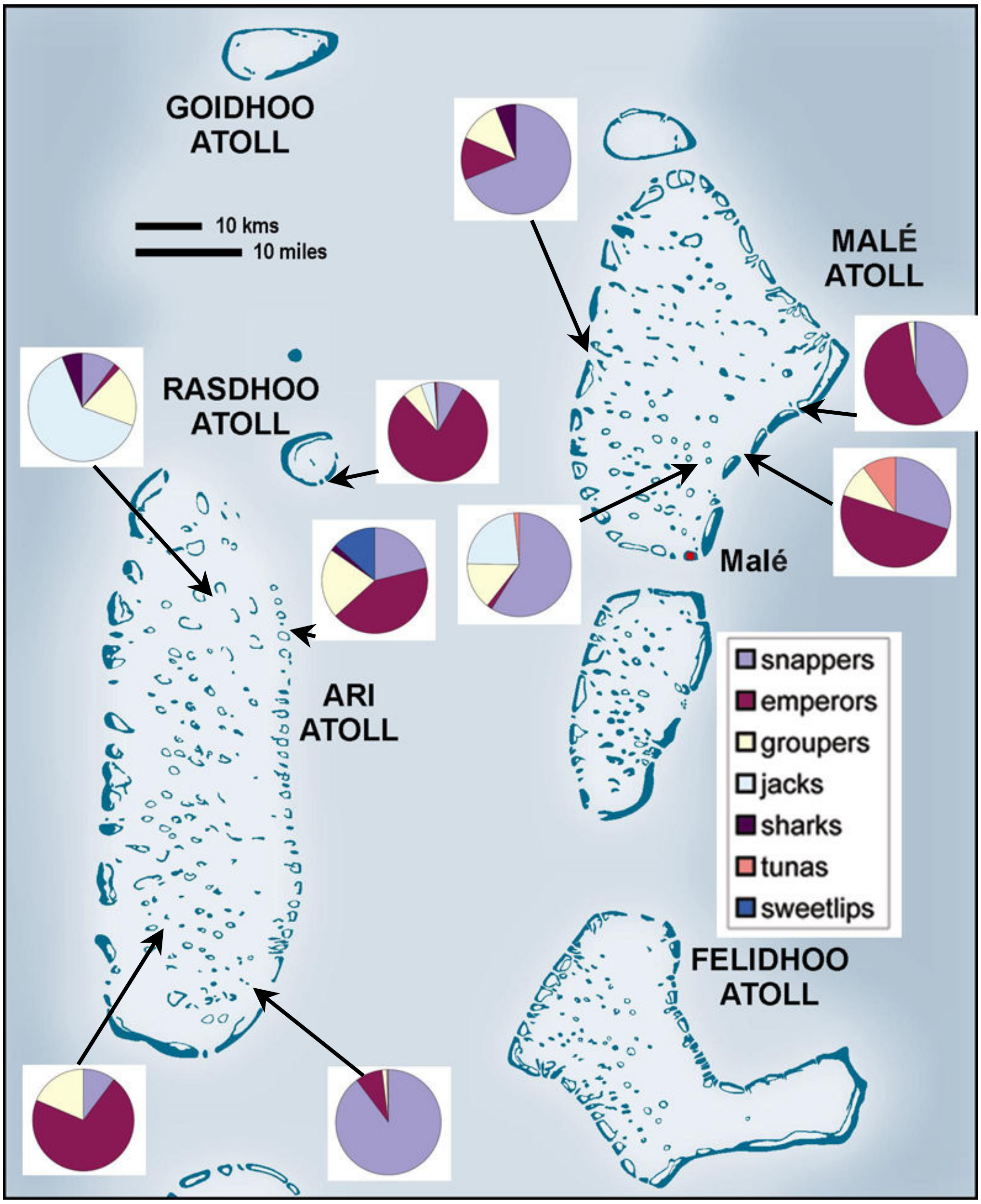

Figure 20. Relative abundance of predator fish families at nine sites around the central Maldives. (Map by Steve Frampton).

Table 6. Summary of fish family abundance at each site

Species / common name	Mean number of fish / 1250m^2	SD
lutjanidae (snapper)	149.1	383.0
lethrinidae (emperor)	50.9	61.4
serranidae (grouper)	9.6	5.3
carangidae (jacks)	6.1	10.5
carchahinidae (sharks)	1.0	1.0
haemulidae (sweetlips)	1.1	2.3
murainidae (morays)	0.9	1.7
Sphyraena (great barracuda)	0.1	0.3
Sphyraena jello (picklehandle barracuda)	0.0	0.0
Tylosaurus crocodiles	0.0	0.0
Cheilinus undulates (humphead wrasse)	0.6	0.5
scaridae (parrotfish)	11.7	8.2
planktivorous *balistidae* (triggerfish)	164.9	325.1
other *balistidae*	8.9	4.4
planktivorous a*canthuridae* (surgeonfish)	30.1	23.8
other a*canthuridae*	45.1	25.2
planktivorous c*haetodontidae* (butterflyfish)	12.7	8.3
other c*haetodontidae*	13.0	8.6
caesionidae (fusiliers)	75.7	42.2
mullidae (goatfish)	5.6	6.7
pommacanthidae (angelfish)	5.0	3.1
pommacentridae (damselfish)	83.9	105.4
*holocentridae (*soldierfish)	40.4	47.7
labridae (wrasse)	18.4	27.8
siganidae (rabbitfish)	12.3	26.4
other	84.3	148.4

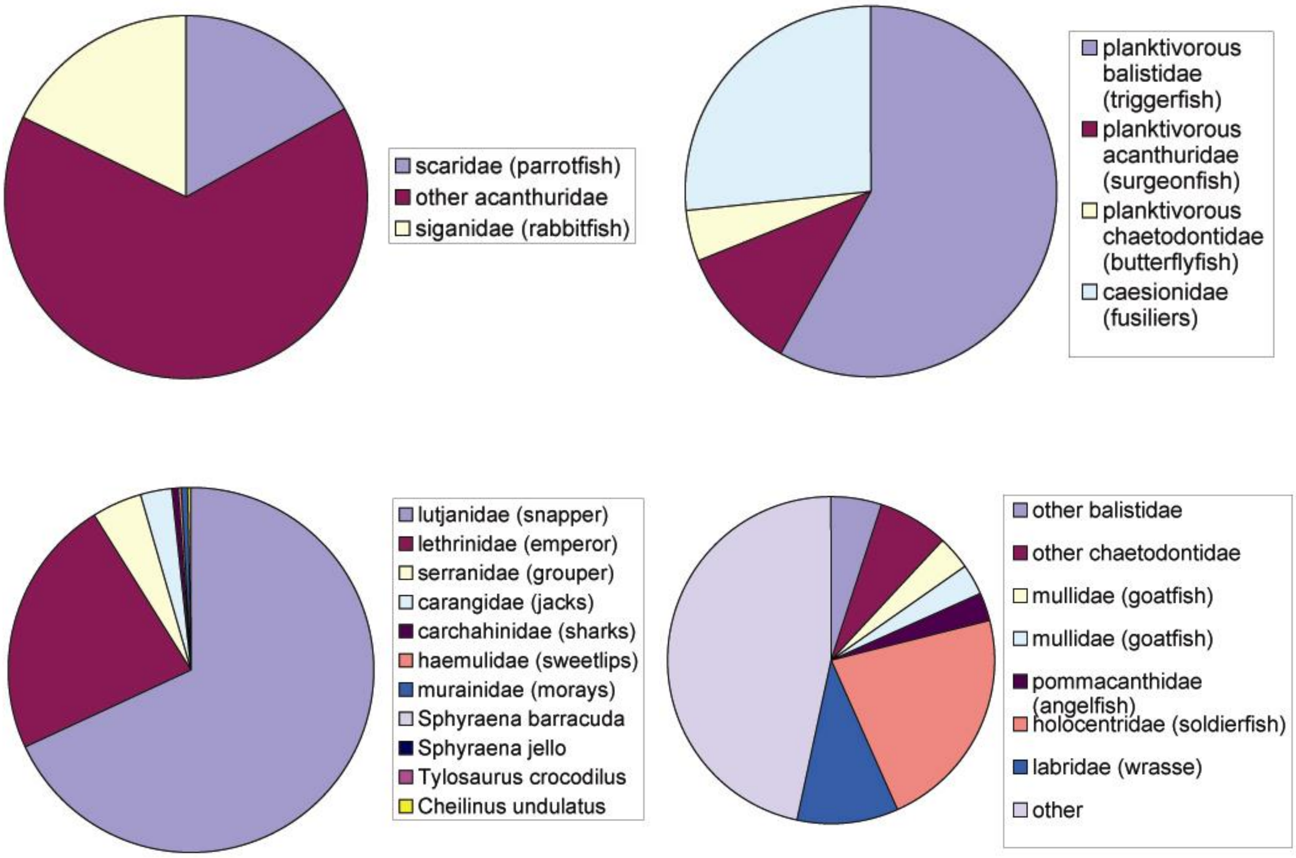

Figure 21. Mean relative abundance of fish per trophic level from all nine sites. (Clockwise from top left: herbivores; planktivores; omnivores; predators).

7. Discussion

7.1 Maldives Reef Health

An estimated 80% of Maldives reefs werekilled by the 1998 bleaching event (Wilkinson, 2004). The Global Coral Reef Monitoring Network (GCRMN) carries out an assessment of the health of Indian Ocean reefs every four years. The report is currently being compiled whilst a recent report has proved that the world's coral reefs are currently at a highly vulnerable stage, with a considerable threat of local extinction of some species (Carpenter et al., 2008). The next GCRMN report is due to out in 2008, which will put much of the data from the Maldives into a regional and global perspective. The average coral cover of Maldivian reefs visited by MCS/MST since 2005 of 25.7% is within the category of 'poor-fair' condition according to the GCRMN[2]. The data derived from MCS/MST surveys carried out in central atolls between 2005 and 2008, compared to that available between 1998 and 2004 would suggest that these central reefs continue to recover from the bleaching event of 1998.

7.1.1 Coral species diversity

Most deeper reefs (>15m deep) are dominated by mature colonies of *Tubastrea micranthata* in deeper reef waters, and acoporid and pocilloporid colonies in shallow waters (<15m), which grow to about 40cm diameter. The latter two families do not significantly contribute to the structural architecture of the reef, and cannot be described as 'reef building' corals such as those species within the massive *Porites, Pavona* and *Faviid* families. The recovery of reef-building species is very much slower, evinced by the common occurrence of small (<30cm diameter) *Porites* colonies present on many shallower (10-20m deep) reefs. Larger colonies of this family are probably survivors from the initial 1998 bleaching event (fig. 23). Clearly it is important to survey sites with slightly higher coral cover where species diversity is greater. Dega giri fits this description, as it is a site of higher diversity, and more mature colonies.

Figure 22. Mature (over 100cm diameter) reef-building corals such as *Porites* are rare on Maldives reefs (left), and tend to be less than 50cm diameter (right), indicating that most colonies completely died-off, or were partially bleached in 1998.

[2] GCRMN coral health categories: excellent = >75%; good = 50-75%; fair = 25-50%; poor = <25%

Figure 23. A large *Acropora cytherea* colony on the reef flat at Dega giri.

7.2 Fish families and trophic levels.

7.2.1 Planktivores:

A large number and biomass of planktivorous fish dominate Maldives reefs, including the red-toothed triggerfish, the chaetodontid pennant bannerfish, fusiliers and numerous small damselfish species. Fusiliers in particular are very commonly caught in reef areas for the live fish trade, along with apogonids (cardinalfish) and clupeidae (principally silver sprats).

The planktivorous fish dominate the outer walls of thillas and atoll outer rim reefs. The red-tooth triggerfish feed between 2 and 10m above the reef and tend to be fairly site attached, being faithful to a particular stretch of reef measuring less than 500m^2. Fusiliers, however have a more fusiform shape, and are a wider-ranging species and may move to where plankton feeding conditions are better.

7.2.2 Herbivores:

Herbivorous families were dominated by scarids, acanthurids and siganids. As observed with the planktivorous families, different species and families occupied different niches on the reef, with acanthurids feeding on floating zooplankton and phytoplankton in the water column, and foraging on the bottom amongst attached algae in shallow reef areas. Mixed herbivore schools commonly occur in and around Maldives reefs, where siganids, acanthurids and scarids along with wrasses and other families roam over expanses of reef flat, targeting areas rich in algal growth (fig 24). Occasionally these schools were observed feeding in areas of damselfish territories, where large standing crops of algae were present. Scarids were ever present on shallow fore and back reefs, with a number of species commonly represented on the surveys, at different growth / morphological stages.

Figure 24. Mixed herbivore school of parrotfish, rabbitfish and surgeonfish.

The relatively common recording of ‘terminal phase’ parrotfish in Maldives reefs indicates that their population is in reasonable health (fig 25). The 1997-2001 Reef Check global assessment of Indo-Pacific coral reefs recorded an average abundance of 2 parrotfish/100m^2 (Hodgson and Liebler, 2002). Our study recorded a mean parrotfish abundance of 0.94 individuals /100m^2 from the nine reefs surveyed, less than half the Indo-Pacific average from the 1997-2001 Reef Check report. We also recorded a mean of 3.6 herbivorous acanthurids/100m^2 at the survey sites. Parrotfish have recently been proved to be essential in maintaining ecosystem equilibrium in coral reefs in order to maintain hard coral dominance (Mumby *et al.*, 2003), as they graze significant quantities of algal turfs and macroalgae. Furthermore, the importance of maintaining a suite of different herbivorous species is imperative to keep the standing crop of most algal species in check. The abundance and total biomass of these fish herbivores is particularly relevant in reef areas where the bleaching event of 1998 led to the creation of considerable free space after the die-off of most corals. If it weren’t for the activity of large numbers, diversity and biomass of grazers clearing ephemeral algae from the surface of the corals, the regeneration of the reefs which we are currently recording, would be significantly hampered by algal overgrowth.

Figure 25. Terminal phase female bicolour parrotfish (*Cetoscarus bicolor*) at HP reef (January 2007).

Figure 26. Sailfish surgeonfish (*Zebrasoma desjardinii*).

Another abundant reef fish family was the damselfish family, including territorial benthic omnivorous, planktivorous and herbivorous species. Territorial damselfish species were often found in aggregations of up to 15 individuals occupying areas of up to 100m^2 of reef. They can radically alter the natural ecological community of the reef by allowing space for algae to grow, which in turn provides habitat for invertebrates to occupy interstitial spaces between the algal fronds. They spend a considerable amount of time nurturing certain algal species to both provide a food source, and in order (in the case of territorial males) to make their patch more attractive to females, in which the females will lay their eggs on the substrate within the territories of the males. Successful males fertilize the eggs by swimming over them, releasing sperm, and guarding them (for approximately 1-2 weeks) before they hatch, and are released into the plankton.

The bleaching event of 1998 may have allowed many species to dominate areas of reef which they would otherwise not have had access to prior to the loss of healthy live coral cover. For example, the territorial damselfish species which dominates expose areas of loose reef and rubble, which would otherwise be dominated by widespred *Acropora* growth similar to that found at Dega Giri.

7.2.3 Predators:

Predatory fish species are dominated by omnivorous species such as *L monostigma* and *L. kasmira*, rather than large members of the grouper family. Some sites did however have large numbers of piscivores such as jacks, red snapper (*L bohar*) and grouper which were abundant or common at HP reef, Kudarah and Rasdhoo, which are also Marine Protected Areas.

There is concern that the increasingly expanding tourism sector (measured at 30% of GDP in 1997) and the indigenous population are combining to overfish some species of reef fish. Furthermore, a grouper fishery has was initiated in 1993 which targets the family not only for the Maldivian market, but for export to the far east, as a commercial fishery.

Sharks were not common on the dives, with the whitetip reef shark *Traeinodon obesus* the most commonly observed individual. Sites visited during the surveys were not the most suitable habitat for the grey reef shark, which tends to occupy deep channel reefs in large numbers, rather than the inner shallower patch reefs on which the surveys were carried out. In July 2008, the Maldivian fisherman's Union called for a complete cessation in the sale of shark fins from the Maldives to foreign markets. The continuing exploitation of Maldives waters by foreign vessels operating, under license, within the 200nm EEZ appears now to be accounting for the reduction in reef-associated shark species which would otherwise be available for consumption by local Maldives fishermen, but are of more value alive to the dive-tourist sector which attracts divers to many sites because of the guarantee of seeing sharks. If sharks aren't present at many sites (as could be the case), the Maldives will become less attractive to the dive-tourism market.

The reefs of southern atolls (over 300km south of Male) were less affected by the bleaching event than the central and northern atolls (see Table 1), and also are less heavily populated and developed (by the tourism industry) than the northern atolls. The population of Huvadhoo atoll is approximately 20,000 with a total area (land and sea) of 3,200km^2 (6.25 people/km^2) whereas the population of North and South Male Atoll is approximately 120,000 with a surface area of 3,600 (33 people/km^2)[3]. This would suggest that the reef fish populations of southern atolls are less affected by fishing because there is more limited exploitation, and the area of reef relative to local human population is high, and the level of commercial resource extraction, is relatively low compared to the rest of the archipelago.

Research carried out at the relatively isolated Northwestern Hawaiian Islands in the central Pacific has revealed a progression of increasing number of large predatory fish (principally sharks and jacks) in isolated coral atolls away from centers of human population (Friedlander and DeMartini, 2002), compared to near the heavily populated islands more

[3] Population statistics from Maldives Ministry of Planning and Natural Development (2006). Total Maldivian population estimated at 298,968. http://www.citypopulation.de/Maldives.html

familiar to the tourist industry (such as Oahu. Maui and Moloki). The density of predatory fish in isolated regions relative to the main island group was 11-1 (fig. 27).

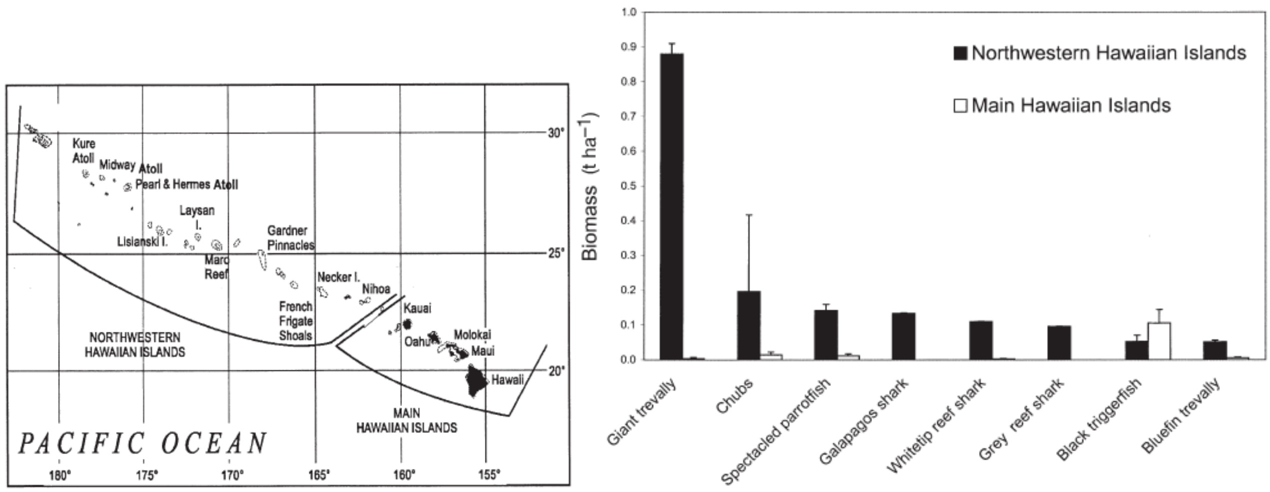

Figure 27. The northwest Hawaiian Islands (left) and the relative biomass of predatory and non-predatory fish recorded in the heavily-populated Main Hawaiian islands (clear bars) relative to the isolated Northwestern Hawaiian Islands (black bars). The number of apex predators (jacks and sharks) is greater in the isolated areas where population pressure is lower. (Reproduced from Friedlander and DeMartini, 2002).

8. Summary

8.1 Corals reefs

- The reefs of the central parts of the Maldives are recovering from the coral bleaching event of 1998, yet have not reached the coral cover, diversity and health of the reefs prior to the 1998 bleaching event.
- Reefs are mainly dominated by acropora and pocillopora families.
- Most reefs have patchy coral populations, but in the top 10m are dominated by small (average size 30-50cm) coral colonies.
- Many of the old structural reef-building colonies are dead. These are being succeeded by small isolated colonies, which have recruited since 1998.
- Dega giri is an anomalous reef where growth of delicate fast-growing acroporids is much more extensive (in coral cover and individual colony size) than was recorded at many other dive sites.
- The reefs from the southern atolls (principally Huvadhoo) are less affected by the bleaching event in 1998, and resemble unimpacted healthy coral communities.

8.2 Fish

- Fish surveys show relatively high numbers of apex predators in some MPAs (particularly at HP; Rasdhoo; Kudarah) compared to other Indo-Pacific reef regions.
- Predatory fish at MPAs are dominated by jacks (principally the bigeye jack *Caranx sexfasciatus*), and snapper (principally the red snapper, *lutjanus bohar*), and blue-striped snapper, *Lutjanus kasmira*.
- There was no significant different in fish assemblage between the different types of reef surveyed (inner reef thillas; channels and outer atoll walls).
- There appeared to be no significant difference in the fish populations surveyed between MPAs sites visited on the surveys and sites outside MPAs (t-test, $P >$ 0.005).

9. Recommendations

- MCS recommends greater enforcement of MPAs by outposted rangers to islands and communities adjacent to the sites trained in enforcement techniques.
- MCS recommends that the MPAs are regularly monitored by Marine Research Centre scientists in collaboration with the tourism sector (if there are no available funds to sponsor research from government sources).
- The survey and monitoring work carried out by the MCS in collaboration with the MST should continue for the long-term to record any changes to fish populations or coral health.
- New surveys on fish populations need to be carried out in the relatively undeveloped and lightly populated atoll of Huvadhoo as soon as possible before the tourist industry becomes well established in this area.

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