

Status of the Coral Reefs of Maldives

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INTRODUCTION

Conservation, sustainable use and management of coral reef resources are among the national priorities in the Maldives, the country's economy being dependent on the health and function of the coral reefs. Degradation of coral reef resources because of natural and/or human impacts has been felt more frequently and intensively in recent years. This paper reports on the national coral reef monitoring programme that began after the severe bleaching in 1998 that led to high mortality of the reefs in the Maldives. Monitoring of selected sites was conducted in 1998, 1999, 2000, and 2002 to assess the status of the coral reefs and the recovery processes after the mass bleaching and mortality of corals in 1998. The aim of this monitoring exercise is to quantitatively document the post-bleaching status of the shallow-water coral communities on the reefs of the north, central and southern regions of Maldives.

METHODS AND SURVEY LOCATIONS

Site Selection

The reef area of Maldives is enormous and the resources available for monitoring it are small. The sampling sites were chosen in the following regions (Fig. 1 on next page):

- *Haa Dhaal* (north, and a regional development target);

- *Male* (east central, with intensive tourism and other commercial activities);
- *Ari* (east central, with intensive existing tourism development);
- *Vaavu* (south central, with a community-based integrated island resource management project underway);
- *Addu-Gaaf Alif* (south, and a regional development target).

In each of these regions three reefs were selected, including reefs that had been surveyed in the recent past and thus providing baseline data against which monitoring data could be compared.

All of the quantitative surveys were conducted on the reef tops, since this has been the case for virtually all of the previous studies, and for logistical efficiency. Surveys were also confined to inner reefs within the atolls, because this is where past surveys had been conducted, and also because the surge caused by oceanic swells ensures that working in shallow water on outer reefs is usually impossible.

Survey Method

On each surveyed reef, data from three line intercept transects of 50 m (English *et al.*, 1997) were recorded in areas near the location of past survey sites, and where physical conditions such as wave action permitted. Oc-

asionally, when it was judged efficient to do so, a 50 m long line point insect transect was used. A pilot study was done in 1998, and surveys were repeated in the same sites in 1999 and 2000 as part of a monitoring programme to provide an insight to the processes of reef recovery especially after the bleaching in 1998. After a data gap of one year (2001) reef surveys at these sites resumed during 2002.

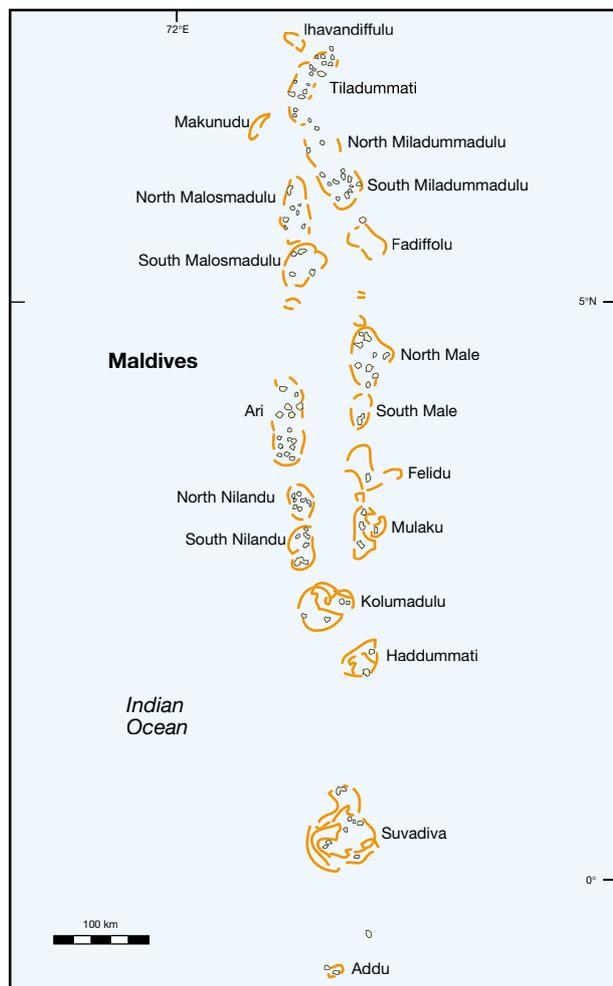


Figure 1. The reef area of Maldives with each survey site illustrated.

RESULTS

A summary of post-bleaching data in 1998 shows that the mean cover of live coral was 2.1% and ranged between 1.0% and 3.1% among the different atolls surveyed (Table 1) which is comparable to MRS Reef Check estimates of 1.7% (Table 2). This is in stark contrast with pre-bleaching levels of 46.5% (Table 2) and 37.4% (Table 3) (Fig. 2). Although the cover of live coral is uniformly low, there is a suggestion of slight difference among atolls. Members of the family Acroporidae, excluding *Astreopora*, were rarely seen on the reef top, whereas poritiids and agariciids, despite suffering

Table 1. Summary data from transects surveyed between August and October, 1998. Estimates for each reef comprises three transect surveys which are pooled to calculate the aggregate estimates.

Regions surveyed	Reef Number			Aggregate
	1	2	3	
Vaavu Atoll				
Mean % cover	2.8	1.3	4.7	2.9
Standard deviation	0.92	0.42	1.69	1.82
No. of transects	3	3	3	9
Ari Atoll				
Mean % cover	0.5	2.1	0.2	1.0
Standard deviation	0.38	2.03	0.28	1.36
No. of transects	3	3	3	9
Haa Dhal Atoll				
Mean % cover	0.4	1.6	0.8	1.0
Standard deviation	0.49	0.19	0.94	0.75
No. of transects	3	3	3	9
Addu & Gaaf Atolls				
Mean % cover	3.9	4.3	1.0	3.1
Standard deviation	1.81	2.54	0.24	2.21
No. of transects	3	3	3	9
North & South Male Atolls				
Mean % cover	1.4	5.3	1.0	2.6
Standard deviation	0.82	3.21	1.09	2.71
No. of transects	3	3	3	9
All Transects, All Atolls				
Mean % cover				2.1
Standard deviation				2.06
No. of transects				45

Table 2. Reef Check data showing 1997 and 1998 coral cover at three permanent transect sites. Source: Marine Research Centre

Reefs	1997 Transect Estimates						1998 Transect Estimates					
	Ta	Tb	Tc	Td	Mean	SD	Ta	Tb	Tc	Td	Mean	SD
Patch Reef, Vaavu	60.0	57.5	65.0	47.5	57.5	7.36	0.0	0.0	0.0	0.0	0.0	0.0
Thuvaru	22.5	22.5	22.5	45.0	28.1	11.25	0.0	0.0	0.0	0.0	0.0	0.0
Maduvvaree	70.0	50.0	50.0	45.0	53.8	11.09	10.0	7.5	0.0	2.5	5.0	4.56
Grand Mean	46.5						1.7					
SD	16.39						3.43					

Table 3. Estimates of live hard coral cover prior to bleaching. Source: Marine Research Centre and Naeem et al., 1998.

Reef	Atoll	Date	Transects									
			1	2	3	4	5	6	7	8		
Gan	Addu	29/09/97	60.0	45.0	57.5	30.0	35.0	22.5				
Khoothoo	Gaaf Alifu	15/04/98	22.5	42.5	35.0	50.0	12.5	22.5	22.5	45.0		
Bandos	N. Male	05/05/98	28.4	45.1	38.8	36.7						
Udhafushi	N. Male	29/06/98	51.5	26.4								
Kudahaa	N. Male	30/06/98	45.1	30.0								
Rasfari	N. Male	01/07/98	44.5	48.5								
Embudhu Finolhu Far	S. Male	05/07/98	31.0	44.3								
Grand Mean	37.4											
SD	12.05											

high mortality, survived the mass bleaching best. Results from the 1999 surveys showed a mean cover of live coral of 1.9% ranging between 0.33% and 3.04% among the atolls surveyed (Table 4 on next page). The results from the 1998, 1999, 2000, and 2002 surveys are shown in Fig. 3 (next page). Recovery is slow but evident at all regions, although variable between regions. Reef recovery (live coral cover) has been recorded highest in Addu followed by Ari region but highly variable within regions (e.g. large standard deviations).

Additional information on the reef status was also collected as part of the 2002 surveys to compare reef recovery at deeper reef areas. Surveys at several deeper locations in Addu region indicated a relatively higher live coral cover compared to shallow reef areas surveyed in that atoll (Fig. 4 on next page). Coral cover ranged from 41–54% on the reef slope (7–10 m) and 52% at 3 m (atoll outer reef). Villingili (1 m) and Villingili (10 m) are directly

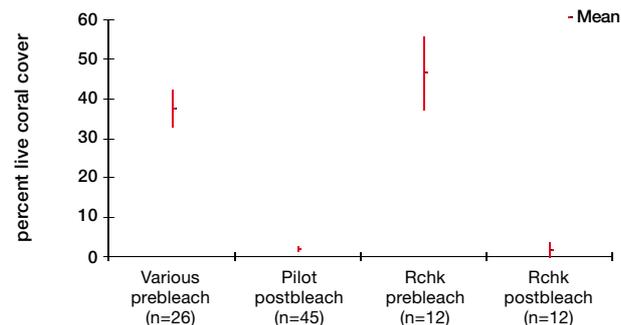


Figure 2. Estimates of live hard coral cover prior to and after the bleaching event plotted as mean bounded by upper and lower 95% confidence intervals on the mean. Pilot post-bleaching data from pilot project field work. Various pre-bleaching data from Coral Reef Research Unit, Riyaz et al. (1998). Rchk = Reef Check data (Hussein, et al., 1998) from MRC Reef Check surveys in August 1997 (pre-bleaching) and August 1998 (post-bleaching).

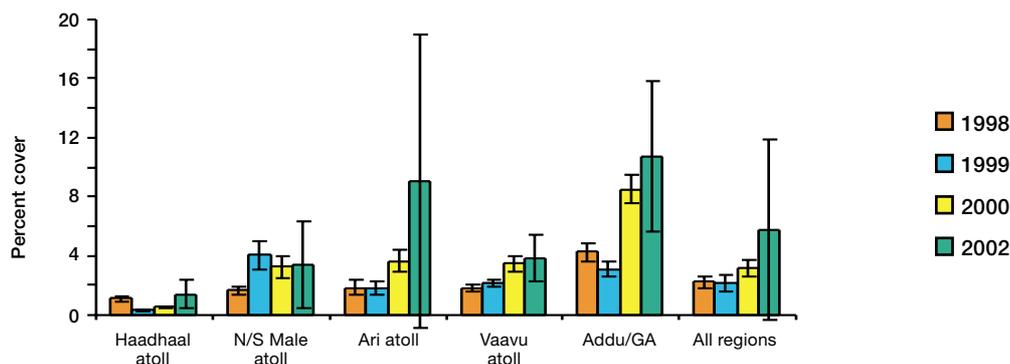


Figure 3. Comparison of estimates of the cover of live coral obtained immediately following the bleaching event (1998) and yearly surveys since then to present (no data for 2001). Values are mean coral cover and the error bars are standard deviation of the means.

Table 4. Summary data from transects surveyed from April to June 1999. Estimates for each reef comprise three transect surveys which are aggregated to calculate the aggregate estimates

Regions Surveyed	Aggregate
Vaavu atoll	
Mean percent cover	2.37
standard deviation	1.29
Number of transects	8
Haadhaal atoll	
Mean percent cover	0.33
standard deviation	0.41
Number of transects	9
Ari atoll	
Mean percent cover	1.62
standard deviation	2.18
Number of transects	9
Addu/Ga. Atoll	
Mean percent cover	2.28
standard deviation	1.92
Number of transects	6
N/S Male atoll	
Mean percent cover	3.04
standard deviation	2.67
Number of transects	9
All Transects (5 regions)	
Mean percent cover	1.931
standard deviation	2.047
Number of transects	41

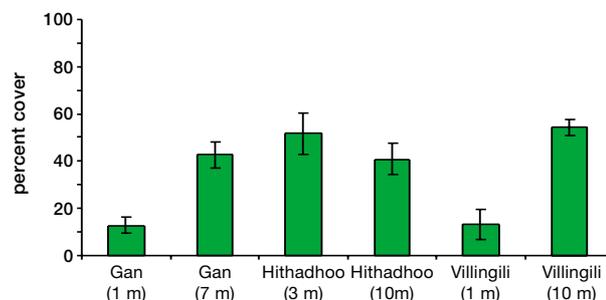


Figure 4. Reef surveys at Addu atoll in 2002, comparing the coral cover between shallow and deeper sites. Values plotted are means and error bars are standard deviation of the means.

comparable sites in Addu atoll clearly demonstrating the different levels of coral cover at this region (Fig. 4).

DISCUSSION

The post bleaching study data from 1998 show that only a small amount of live coral cover remained on the reef tops surveyed (Table 1). Qualitative observations made by many other people in other parts of the country are consistent with these quantitative surveys and lead to the conclusion that this was the general condition of reef tops throughout Maldives. Surveys conducted before and during the bleaching event indicate that live coral cover was approximately 20 times greater prior to the event



Figure 5. Large colonies of *Acropora* and *Porites* at Villingili (10 meters depth).

(Tables 2 and 3). Although quantitative data describing the abundance of *Acropora* and *Pocillopora* prior to bleaching are unavailable, it is well known that they were common. Indeed, *Acropora* was often the dominant coral on many reefs.

Repeated surveys of the same sites in 1999 indicated the cover of live coral remained very low at all sites. Indeed, each site surveyed, with the exception of Ari Atoll and North / South Male, possessed less live coral one year after the bleaching event than it did immediately after indicating subsequent mortality of corals and negligible recovery. Furthermore, it is suspected that Ari and Haa Dhal Atolls were affected more than the other regions surveyed and the low level of coral cover was consistent with consecutive sampling.

However, the survey team has observed new coral recruits at all sites. Re-colonisation of fast growing branching growth forms were observed ten months after the bleaching event, indicating that reef recovery processes were already underway (Clark *et al.*, 1999). Several observations bode well for the recovery of these reefs. For example, many of the new recruits belong to the genus *Acropora* which was the genus most seriously affected by the bleaching in 1998. In addition, on some reefs encrusting coralline algae are abundant providing potential areas for coral settlement and recruitment and



Figure 6. Reef survey location at Hithadhoo (10 meter depth). Large acroporids are common indicating less impact compared to shallow areas.



Figure 7. Tabulate acroporids in Hithadhoo (shallow, 3 meter depth) survey location, the most severely affected coral genus from the 1998 bleaching.

in some regions (e.g. Haa Dhaal) large *Acropora* tables that were believed to be dead are regenerating live tissue indicating prolonged recovery of some species of coral. Reef recovery has been reported to be highest in Addu atoll compared to other regions.

Comparison of the reef recovery at Addu region clearly demonstrated highly variable conditions at the surveyed sites. This high coral cover compared to other regions indicated that the severity of the impact of bleaching in 1998 was not as widespread as it has been

previously thought (Fig. 5–7). There was considerable evidence that the reefs in Addu were less affected compared to other regions surveyed in the country. Large colonies of acroporids were common in these reefs that have clearly survived and outlived the bleaching impact. More interestingly, corals of the genus *Seriotopora* and *Stylopora* were common in both atoll outer reef (Hithadhoo 3 m) and deeper reefs (Hithadhoo and Villingili) which were not recorded elsewhere during the past 4 years of reef surveys as part of this long term reef monitoring program since the bleaching in 1998.

On average, coral cover increased approximately 3% from 1998 to 2002 (see Fig. 3). However, it is evident that the rate of recovery is variable among and between sites, demonstrating the complexity of the reef recovery processes. Therefore, the impacts of the 1998 bleaching event will not be fully understood for some time. However, it is clear that reefs will be modified as a result of this bleaching event. In the short term (<5 years), reefs formerly dominated by branching species will be dominated by non-living substrate supporting only a low percentage cover of living corals of which the majority will be massive species. The consequences of bleaching for the reef framework will largely depend on the trans-

port and fate of calcium carbonate (CaCO_3) fragments. Where reef disturbance is severe, boring and grazing organisms may remove CaCO_3 faster than primary frame-builders can add to it. Such biogenic processes will determine whether the integrity of the reef structure will be compromised.

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