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Status of Maldivian reefs eight years after the 1998 coral mass mortality

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Episodes of coral bleaching and mortality have occurred with increasing frequency over the past two decades, often followed by proliferation of non-constructional organisms leading to a 'phase shift' in reef ecosystems. As the Maldives were severely affected by the 1998 episode, concern raised about the possibility of a phase shift there. The status of Maldivian reefs was surveyed eight years after the mass mortality of 1998; the percentages of biotic and abiotic benthic categories were estimated in both lagoon and ocean reefs. Hard coral cover did not exceed 37%, but no threat was recognized of a phase shift toward the dominance of soft corals, algae or sponges (7% on average). The high percentage of bare coral rock (up to almost 50%) and the local variability of living benthic cover suggest that Maldivian reefs were still in a re-colonization phase. Monitoring of their evolution is in progress.

Keywords: coral reefs; benthic categories; phase shift; Maldives

1. Introduction

During the last two decades coral reefs have experienced an increase in the number of environmental disturbances linked to global changes in temperature [1,2]. In 1998, the high sea surface temperature (up to 34°C) associated with a strong ENSO event, led to the largest bleaching episode on a worldwide scale, followed by massive coral mortality [3]. After a major die-off of corals, fast-growing organisms (i.e. algae and soft-bodied invertebrates) can increase in abundance and occupy the newly available benthic space [4,5]. The dominance of these organisms can lead to a 'phase shift' of coral reef ecosystems, after which coral re-establishment may be difficult [6,7].

The 1998 bleaching episode affected severely most Indian Ocean reefs [3]; the Maldives, in particular, suffered of 90% coral mortality in the central atolls [8]. Before this mass mortality, hard coral cover was generally between 30 and 60%, often reaching 100% in shallow water [9]. One year after coral cover had decreased to less than 8%, and reefs were dominated by algae [10–12].

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In April 2006, eight years after the 1998 coral mass mortality, we re-examined the status of the Maldivian reefs, focusing on the benthic composition to evaluate the possible change in dominance from hard corals to non-constructional organisms such as soft corals, algae or sponges.

2. Materials and methods

2.1. *Study area*

The Maldives form the central part of the Chagos-Maldives-Laccadive ridge in the central Indian Ocean, stretching in a north-south direction from about 7°07′ N to 0°40′ S in latitude. They are comprised of 22 atolls and around 1120 islands forming a single atoll chain in the north and in the south, and a double atoll chain in the central part [13,14]. While recent descriptions of the Maldivian coral reefs are available [15–17], thorough studies on coral communities before the 1998 mortality event date back to the Xarifa expedition in the late 1950s [18 and references therein]. The data presented in this study were collected during a scientific cruise in the three central atolls of South Malé, Felidhoo and Ari.

2.2. *Field activities*

Scuba dives were carried out in a total of eight randomly selected sites belonging to two typologies: four lagoon reef sites and four ocean reef sites (see Figure 1). Benthic data were visually estimated using the plan view technique [19] at 4–6, 10–12, 16–18 m depth. This technique involved the diver hovering 1–2 m above the bottom and estimating percentage cover of benthos and substratum categories in a 5 m × 5 m area; at each depth, 12 estimates were obtained. A total of 6 categories

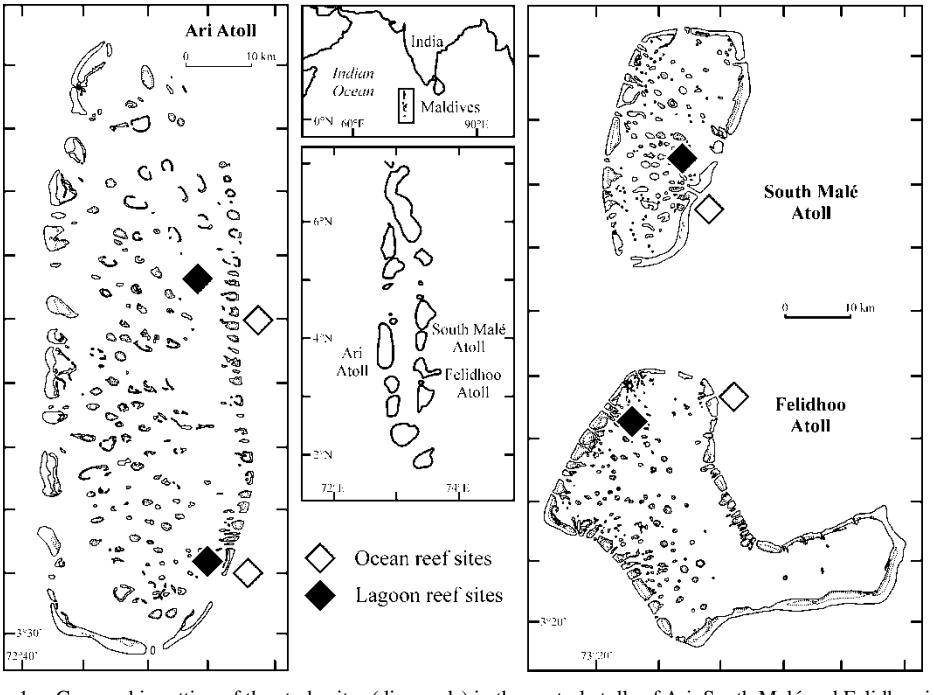

Figure 1. Geographic setting of the study sites (diamonds) in the central atolls of Ari, South Malé and Felidhoo in the Maldives.

(four biotic and two abiotic) was considered: (i) live hard corals, (ii) soft corals, (iii) algae, (iv) sponges, (v) coral rock, (vi) rubble and sand.

2.3. *Data treatment*

Differences among the percentages (mean ± standard error) of the six categories were analysed by 3-way ANOVA with 'reef typology' (RT) as fixed factor, 'site' (S) as random and nested factor within 'reef typology', and 'depth' (D) as fixed and orthogonal factor (see Figure 2). Homogeneity of variances was tested by Cochran's *C*-test, and data were arcsin $\sqrt{(x/100)}$ transformed when necessary to assure homogeneity [20].

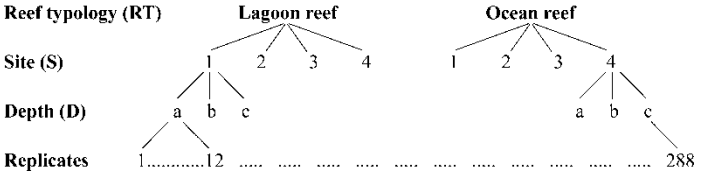

Figure 2. Hierarchical sampling design used in this study. Letters identify the three depths considered (a = 4–6 m, b = 10–12 m, c = 16–18 m), whilst numbers indicate sites. Depths are orthogonal to sites, which are nested within reef typologies. Twelve replicates were obtained at each depth.

3. Results

Eight years after the 1998 coral mass mortality, hard coral cover varied from 12% to 37% depending on individual sites; the lowest values were found in shallow ocean reefs (see Figure 3a). Cover of soft corals (see Figure 3b), algae (see Figure 3c) and sponges (see Figure 3d) was comparatively low (approximately 7% on average). Coral rock percentage decreased with depth, ranging from 25–50% at shallow sites on ocean reefs to less than 20% in deep and/or lagoon sites (see Figure 3e). Percentages of coral rubble and sand ranged from 15% to 65%, inconsistently with typologies, sites or depths (see Figure 3f).

No significant difference in the percentages of benthic categories was found between reef typologies, with the only exception of coral rock. Differences among depths were significant only for hard corals, algae, sponges and coral rock. Most interactions among factors were significantly different, suggesting that there was not a clear pattern with either depth or typology in benthic categories percentages (see Table 1).

4. Discussion and conclusion

Hard coral cover had increased tremendously with respect to the values observed short after the 1998 mass mortality episode [10–12,21]. A recent inventory of coral species showed that their number is larger than that known before 1998 [22]. The threat of a phase shift, as observed for instance in southern Taiwan [4], the US Virgin Islands [23], the Seychelles [24] and the Great Barrier Reef [25], seems to be averted in the Maldives, as the cover of soft corals, algae and sponges was usually much lower than that of hard corals. This notwithstanding, hard coral cover was still scarce when compared with pre-mortality values [26,27], and the proportion of bare coral rock was always high, especially in shallow ocean reefs. Extensive bare rock in shallow ocean

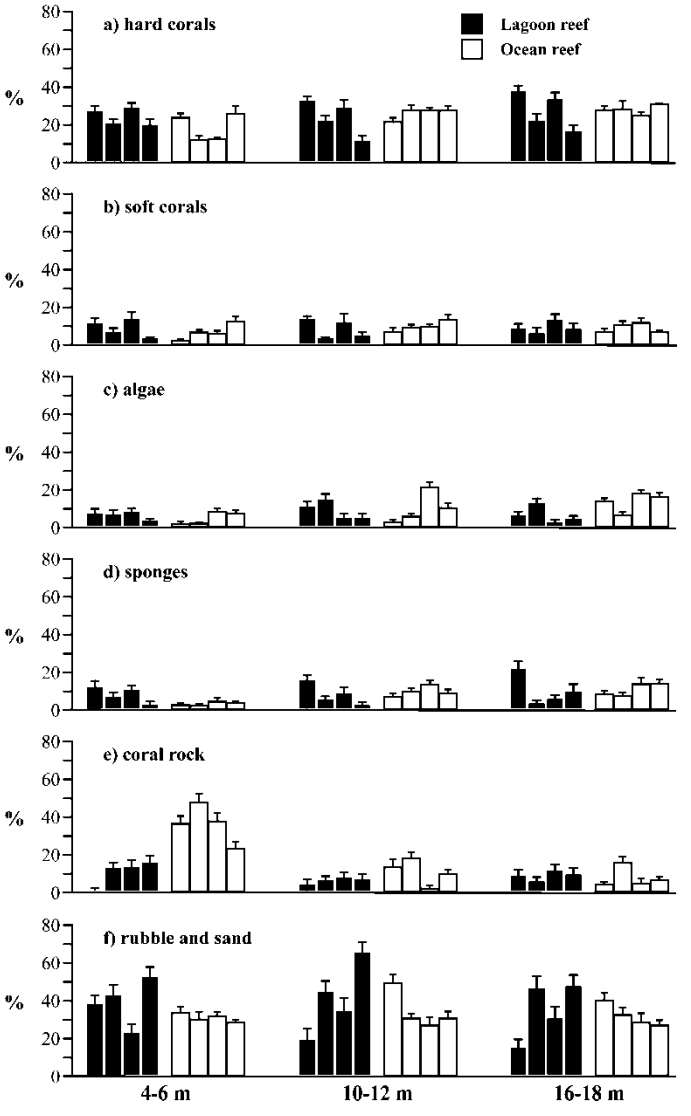

Figure 3. Mean (+ standard error) percentages of biotic and abiotic benthic categories at four sites and three depths from two reef typologies.

reefs might indicate that physical disturbance by oceanic waves is limiting coral growth, as the highest coral mortality in 1998 had been observed, on the contrary, in lagoon reefs [28].

The abundance of bare rock and loose material derived from dead coral breakage (namely, rubble and sand), was consistent with the loss of 3D structure in Maldivian coral reefs [8,9,12]; substrate smoothing is known to represent an impediment to coral recruitment [21,29].

The high variability of living benthic cover among sites suggests that in 2006 the Maldivian reefs were still in an ongoing process of re-colonization. It will probably take several years before a living reef structure is re-established in the central atolls of the Maldives: continued monitoring of reef recovery is in progress to track their future evolution.

Table 1. Results of 3-way ANOVA on biotic and abiotic benthic categories: RT-reef typology; S-site; D-depth. NS-not significant. $*P < 0.05$; $**P < 0.01$.

	Hard corals			Soft corals			Algae		
Factor	*df*	*F*	*P*	*df*	*F*	*P*	*df*	*F*	*P*
RT	1	0.16	NS	1	0.14	NS	1	0.02	NS
S (RT)	6	12.78	**	6	7.73	**	6	18.57	**
D	2	4.20	*	2	0.61	NS	2	5.78	*
RT × D	2	2.64	NS	2	0.70	NS	2	5.74	*
D × S (RT)	12	2.27	**	12	1.86	*	12	3.19	**
Residual	264			264			264		
	Sponges			Coral rock			Rubble and sand		
Factor	*df*	*F*	*P*	*df*	*F*	*P*	*df*	*F*	*P*
RT	1	0.33	NS	1	7.07	*	1	0.73	NS
S (RT)	6	8.48	**	6	7.86	**	6	18.43	**
D	2	7.40	**	2	28.46	**	2	0.77	NS
RT × D	2	4.41	*	2	19.53	**	2	0.31	NS
D × S (RT)	12	2.10	*	12	2.39	**	12	2.59	**
Residual	264			264			264		

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References

[1] T.J. Goreau, T.R. McClanahan, R.L. Hayes, and A. Strong, *Conservation of coral reefs after the 1998 global bleaching event*, Cons. Biol. 14 (2000), pp. 5–15.
[2] A.D. Barton and K.S. Casey, *Climatological context for large-scale coral bleaching*, Coral Reefs 24 (2005), pp. 536–554.
[3] C. Wilkinson, O. Linden, H. Cesar, G. Hodgson, and A. Strong, *Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and warming of future changes*, Ambio 28 (1999), pp. 188–196.
[4] C.A. Chen and C.F. Dai, *Local phase shift from* Acropora-*dominant to* Condylactis-*dominant community in the Tiao-Shi Reef, Kenting National Park, southern Taiwan*, Coral Reefs 23 (2004), p. 508.
[5] K. Loch, W. Loch, H. Schuhmacher, and W.R. See, *Coral recruitment and regeneration on a Maldivian reef four years after the coral bleaching event of 1998. Part 2: 2001–2002*, PSZN: Mar. Ecol. 25(2) (2004), pp. 145–154.
[6] M. Scheffer and S. Carpenter, *Catastrophic regime shifts in ecosystems: Linking theory to observation*, Trends Ecol. Evol. 18(12) (2003), pp. 648–656.
[7] J.W. McManus and J.F. Polsenberg, *Coral-algal phase shifts on coral reefs: Ecological and environmental aspects*, Progr. Oceanogr. 60 (2004), pp. 263–279.
[8] C.N. Bianchi, C. Morri, M. Pichon, F. Benzoni, P. Colantoni, G. Baldelli, and M. Sandrini, *Dynamics and pattern of coral recolonization following the 1998 bleaching event in the reefs of the Maldives*, in *Proceedings of the 10th International Coral Reef Symposium*, Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya, eds, Tokyo: Japanese Coral Reef Society, 2006, pp. 30–37.
[9] C.N. Bianchi, M. Pichon, C. Morri, P. Colantoni, F. Benzoni, G. Baldelli, and M. Sandrini, *Le suivi du blanchissement des coraux aux Maldives: Leçons à tirer et nouvelles hypothèses*. Oceanis 29(3–4) (2006), pp. 325–354.
[10] T.R. McClanahan, *Bleaching damage and recovery potential of Maldivian coral reefs*, Mar. Pollut. Bull. 40(7) (2000), pp. 587–597.
[11] H. Zahir, *Status of the coral reefs of Maldives after the bleaching event in 1998*, in *Coral Reef Degradation in the Indian Ocean*, D. Souter, D. Obura, and O. Lindén, eds, Stockholm: Cordio, 2000, pp. 64–68.
[12] H. Schuhmacher, K. Loch, W. Loch, and W.R. See, *The aftermath of coral bleaching on a Maldivian reef – a quantitative study*, Facies 51 (2005), pp. 80–92.
[13] R.G. Price and S. Clark, *The Maldives*, in *Seas at The Millennium: An Environmental Evaluation*. Vol II, C.R.C. Sheppard, ed., Amsterdam: Elsevier Press, 2000, pp. 199–299.
[14] M.J. Risk and R. Sluka, *The Maldives: A Nation of Atolls*, in *Coral reefs in The Indian Ocean: Their Ecology and Conservation*, T.R. McClanahan, C.R.C. Sheppard, and D. Obura, eds, Oxford: Oxford University Press, 2000, pp. 325–351.

[15] G. Ciarapica and L. Passeri, *An overview of the Maldivian coral reefs in Felidu and North Malé atolls (Indian Ocean): Platform drowning by ecological crises*, Facies 28 (1993), pp. 3–66.
[16] C. Morri, C.N. Bianchi, and S. Aliani, *Coral reefs at Gangehi (North Ari Atoll, Maldive Islands)*, Publ. Serv. Géol. Luxembourg 29 (1995), pp. 3–12.
[17] C.N. Bianchi, P. Colantoni, J. Geister, and C. Morri, *Reef geomorphology, sediments and ecological zonation at Felidu Atoll, Maldive Islands (Indian Ocean)*, in *Proceedings of the 8th International Coral Reef Symposium*, H.A. Lessios and I.G. MacIntyre, eds, Panama: Smithsonian Tropical Research Institute, 1997, pp. 431–436.
[18] C.C. Wallace and H. Zahir, *The "Xarifa" expedition and the atolls of the Maldives, 50 years on*, Coral Reefs 26 (2007), pp. 3–5.
[19] S.K. Wilson, N.A.J. Graham, and N.V.C. Polunin, *Appraisal of visual assessments of habitat complexity and benthic composition on coral reefs*, Mar. Biol. 151 (2007), pp. 1069–1076.
[20] A.J. Underwood, *Experiments in Ecology. Their logical design and interpretation using analysis of variance*, Cambridge: Cambridge University Press, 1997, p. 504.
[21] K. Loch, W. Loch, H. Schuhmacher, and W.R. See, *Coral recruitment and regeneration on a Maldivian reef 21 months after the coral bleaching event of 1998*, PSZN: Mar. Ecol. 23(3) (2002), pp. 219–236.
[22] M. Pichon and F. Benzoni, *Taxonomic re-appraisal of zooxanthellate scleractinian corals in the Maldive Archipelago*, Zootaxa 1441 (2007), pp. 21–33.
[23] C.S. Rogers and J. Miller, *Permanent 'phase shifts' or reversible declines in coral cover? Lack of recovery of two coral reefs in St. John, US Virgin Islands*, Mar. Ecol. Prog. Ser. 306 (2006), pp. 103–114.
[24] M.H. Ledlie, N.A.J. Graham, J.C. Bythell, S.K. Wilson, S. Jennings, N.V.C. Polunin, and J. Hardcastle, *Phase shifts and the role of herbivory in the resilience of coral reefs*, Coral Reefs 26 (2007), pp. 641–653.
[25] T.P. Hughes, M.J. Rodrigues, D.R. Bellwood, D. Ceccarelli, O. Hoegh-Guldberg, L. McCook, N. Moltschaniwskyj, M.S. Pratchett, R.S. Steneck, B. Willis, *Phase shifts, herbivory, and the resilience of coral reefs to climate change*, Curr. Biol. 17 (4) (2007), pp. 360–365.
[26] W.R. Allison, *Changes in the Maldivian reef system*, Coast. Manag. Tropic. Asia 4 (1995), pp. 6–8.
[27] ———, *Degradation and recovery of Maldivian reefs*, Reef Encounter 17 (1995), pp. 6–7.
[28] C. Longo, P. De Mandato, M. Piscitelli, and G. Corriero, *Osservazioni preliminari sulla mortalità di madreporari ermatipici nell'arcipelago delle Maldive*, Biol. Mar. Medit. 7(1) (2000), pp. 686–690.
[29] R. Lasagna, I. Gattorna, G. Albertelli, C. Morri, and C.N. Bianchi, *Eterogeneità del substrato e relazione con il reclutamento dei coralli in scogliere coralline delle Maldive (Oceano Indiano)*, Biol. Mar. Medit. 13(2) (2006), pp. 88–89.