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Community change and evidence for variable warm-water temperature adaptation of corals in Northern Male Atoll, Maldives

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ABSTRACT

This study provides a descriptive analysis of the North Male, Maldives seven years after the 1998 bleaching disturbance to determine the state of the coral community composition, the recruitment community, evidence for recovery, and adaptation to thermal stress. Overall, hard coral cover recovered at a rate commonly reported in the literature but with high spatial variability and shifts in taxonomic composition. Massive *Porites*, *Pavona*, *Synarea*, and *Goniopora* were unusually common in both the recruit and adult communities. Coral recruitment was low and some coral taxa, namely *Tubipora*, *Seriatopora*, and *Stylophora*, were rarer than expected. A study of the bleaching response to a thermal anomaly in 2005 indicated that some taxa, including *Leptoria*, *Platygyra*, *Favites*, *Fungia*, *Hydnophora*, and *Galaxea astreata*, bleached as predicted while others, including *Acropora*, *Pocillopora*, branching *Porites*, *Montipora*, *Stylophora*, and *Alveopora*, bleached less than predicted. This indicates variable-adaptation potentials among the taxa and considerable potential for ecological reorganization of the coral community.

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1. Introduction

The warm phase of the 1998 El Niño Southern Oscillation was among the strongest warm water anomalies since instrumental records (Enfield, 2001). This created large-scale coral bleaching and mortality throughout the tropics and was most severe in many reef areas of the western Indian Ocean (Wilkinson et al., 1999; Goreau et al., 2000). Studies of coral cover shortly after this event found that Maldivian reefs were among the worst affected reefs globally with hard coral cover dropping to as low as 2% of the substratum (Goreau et al., 2000; McClanahan, 2000; Edwards et al., 2001), whereas cover estimates prior to the mid 1960s were typically over 50% of the substratum and dominated by large stands of *Acropora* (Scheer, 1971; Davies et al., 1971). Branching corals were the most affected by the bleaching events and some common taxa of branching corals such as *Stylophora*, *Seriatopora*, and some species of *Acropora* were not observed a year after the event (McClanahan, 2000).

Studies of coral recruitment found low to moderate numbers shortly after the disturbance and there was some indication of reduced recruitment and possible changes in taxonomic composition and dominance (McClanahan, 2000; Loch et al., 2002, 2004; Tkachenko, 2012). These studies indicate that the recovery potential of these reefs could be reduced, associated with changes in taxonomic composition arising from the different life history strategies and associated ecological processes and services (Darling et al., 2012). Consequently, there may be acclimation, community change, or adaptation processes emerging that may provide insights into the future of these and other coral reefs. This study provides a descriptive analysis of the coral community seven years after the 1998 disturbance to determine the state of the coral community composition, the recruitment community, evidence for recovery, and the responses of corals to post-1998 temperature anomaly in 2005. Our goal was to evaluate the ongoing changes and adaptation potential of these reefs.

2. Material and methods

2.1. Study sites

The Maldives is the most extensive area of coral reefs in the Indian Ocean, extending ~700 km and composed of 26 large atolls with ~1200 coral reef islands. Human influence is low in this country as only 200 of the islands are inhabited, only 185 km^2 of the land area is inhabited, and the people largely subsist on tuna fish and rice (Risk and Sluka, 2000). We studied eleven reef areas in the southern section of Northern Male Atoll where reefs were a combination of passages on the outer reefs and faroes or small atolls in the inner lagoons of the larger atoll (Table 1). We studied reefs in June 2005 with a depth range of 1–15 m and all areas were dominated by hard calcium carbonate substratum.

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Table 1
Study sites, sampling dates, GPS positions, and number of replicates for each of the measurements made during the survey of North Male Atoll, Maldives. ND – no position due to lack of functioning GPS unit during sampling.

Location	Dates	GPS	Substrate cover, 10 m	Coral genera count	Bleaching survey	Coral recruits
Angsana W	11/6/05	N 4.30601: E. 73.415055	3			
Angsana, E	4/6/05	N 4.306278: E. 73.417215	3	1	1	20
Furana	3/6/05	N 4.25259: E 73.547685	3	1		20
Galu Falhu	6/6/05	N 4.204786: E 73.502014		1	1	
HP Reef	8/6/05	N 4.317144: E 73.580445		1		
Kalhuga	10/6/05	ND	3	1	1	20
Kikki	7/6/05	N 4.28575 E 73.428517	3	1	1	20
Kodhiparu	9/6/05	N 4.309948 E 74.348006	3	2	1	20
Kudagiri	5/6/05	N 4.258921 E 73.359481		1		
Lions Head	7/6/05	ND		1		
Lohi Fushi	8/6/05		3		1	20
Lohi Fushi	28/5/05	N 4.348107 E 73.61606		2		
Lohi Fushi	29/5/05			1		
Maagiri	3/6/05	N 4.262674 E 73.512067	3	1		20
Rasfari	2/6/05	N 4.39087 E 73.351625	3	1	1	20
Thulgaari	5/6/05	ND	3	1	1	20
Vabbinfaru	31/5/05	N 4.307917 E 73.422166		1		
Vabbinfaru W	1/6/05	N 4.30948 E 73.422166	3	1	1	20
Vabbinfaru, E	1/6/05	N 4.309214 E 73.410316	3	1		20
Total			36	19	9	220

2.2. Benthic field measurements

Three types of surveys were completed in each of the study sites: (1) 10 m benthic line-intercept surveys, (2) coral recruitment in 0.25 × 0.25 m quadrats, and (3) haphazard searches for coral taxa and their bleaching status (Table 1). At each study site three to six 10-m line transects were haphazardly placed and the distance of each gross functional group and taxa were measured to the nearest centimeter (McClanahan and Shafir, 1990). Corals and algae were identified to the genus and coral crown lengths were used to estimate average coral size (McClanahan et al., 2008). We present the percent cover of the benthic functional groups and coral taxa, absolute coral cover, and average coral lengths by coral taxa. A search sampling method was also used to identify and count coral taxa (mostly genera). During the search sampling, an observer swam haphazardly along a reef and recorded the first time an individual coral genus (colony size >5 cm diameter) was observed for a search interval of 40 min. The relative abundance that was assumed to be inversely related to the time taken to observe the first individual of a given genera was presented for each coral taxa encountered. Coral recruit quadrats were haphazardly tossed twenty times in each site and the number of recruits in two size classes (0.4–2 cm and 2–5 cm lengths) within the quadrats were identified to the genus and counted (McClanahan, 2000) and the average abundances for each coral taxa in these size classes presented.

2.3. Bleaching surveys

The survey of bleaching was undertaken just after a peak period of a weak HotSpot formation (~1 °C above the warm-water mean, McClanahan et al., 2007a,b). Coral bleaching was measured by haphazardly selecting coral colonies within a 2-m radius and categorizing the colony bleaching response into one of seven categories scaled from normal to bleached using methods developed by Gleason (1993) and modified by McClanahan et al. (2007a). Each colony was identified and classified according to the bleaching response c1 = normal, c2 = pale live coral, c3 = 0–20%, c4 = 20–50%, c5 = 50–80%, c6 = 80–100% bleached, and c7 = recently dead. The sampling was repeated many times at a site for a period of ~ 40 min. The bleaching response of individual coral genera in the Maldives was correlated against the bleaching response of ~40,000 corals collected between 1998 and 2005 in seven other countries in the Indian Ocean (McClanahan et al., 2007a,b). This comparison was done to evaluate the potential difference and test for adaptation of Maldivian corals to previous and more widespread responses of corals to temperature anomalies.

3. Results

3.1. Benthic substrate

On average, algal turf dominated the benthic substrate covering 60% of the substratum, followed by hard coral at 20%, and coralline red algae at 16% (Table 2). Calcareous green algae, soft coral, and sponge were rare components of the substratum occurring on average at 1% or less of the substratum. There was a weak positive relationship between hard coral cover and algal turf cover at the sites ($r = 0.74$; $p = 0.025$; $n = 9$) and no statistically significant relationship between hard coral cover and coralline algae ($r = 0.28$) or with calcareous algae ($r = 0.004$). There were large differences in the components of the benthic substratum between reefs and the difference was especially prominent in hard coral cover that ranged from 5% at Furana to more than 40% at Angsana west. Algal turf cover was particularly high at Lohi Fushi (80%) and less than 40% at Angsana west while coralline algae ranged from 14% to 29% at 6 of the 10 sites surveyed. Sand was not an important component of the substratum except at Kodhiparu where it consisted of 13% of the substratum while fleshy algae were only recorded at Vabbinfaru west at a very low cover (0.1%).

3.2. Coral community

A total of 26 genera were recorded at all the reefs during the benthic line transect surveys (Table 3) and the number of genera was highest at Angsana east (18), Vabbinfaru (17) and Kalhuga (12) and lowest at Lohi Fushi (6) and Kikki (5). On average, the coral assemblage was dominated by massive *Porites* and *Pavona* that together contributed more than 44% of the total coral cover at all sites combined, but there were also large differences in the hard coral assemblage between reefs (Table 3). *Porites* and *Pavona* were found at all sites except Furana where massive *Porites* was absent. *Pocillopora*, *Acropora*, *Montipora*, and *Goniastrea* were also relatively common occurring at 7–8 of the 10 reefs surveyed. Differences in

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