LONG-TERM CHANGES IN CORAL REEF BENTHIC COMPOSITION OF TUBBATAHA REEFS: RESPONSE TO BLEACHING IN 1998 AND PROTECTION

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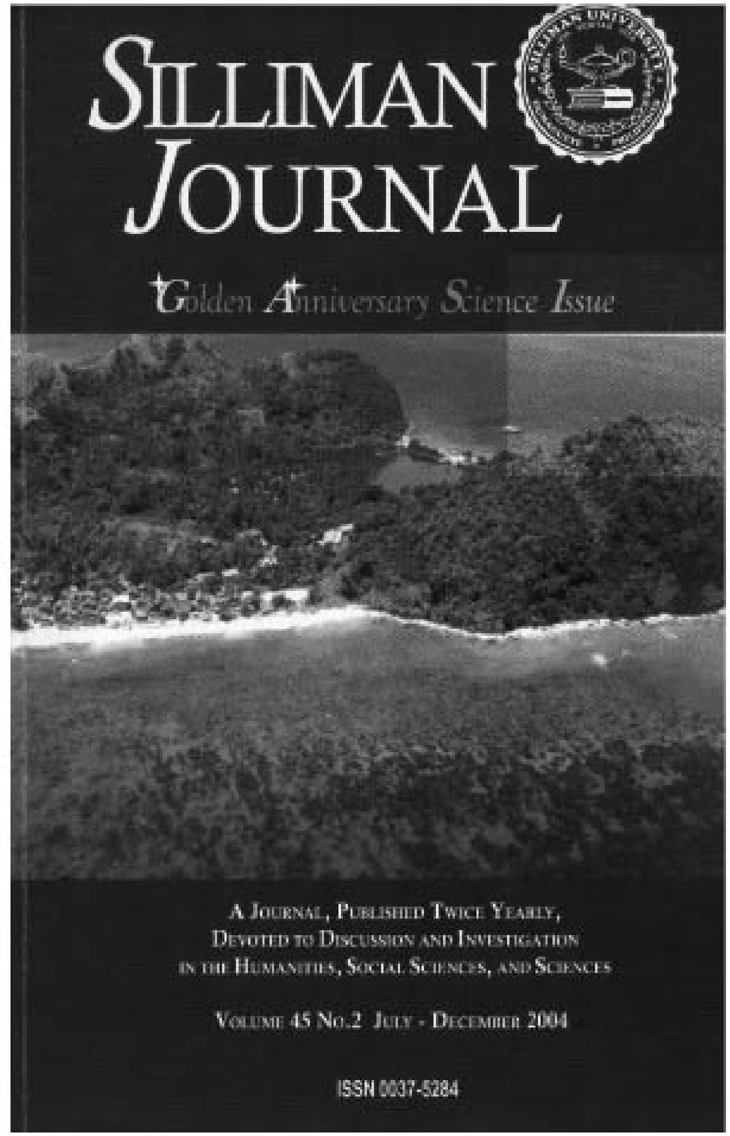
ABSTRACT

The benthic community of Tubbataha Reefs is dominated by hard corals that were severely impacted by the 1998 bleaching event and by lack of protection before 1992. The bleaching episode caused major changes in community structure. In this paper we provide details of the changes of benthic composition of selected sites in Tubbataha Reefs from 1984 to 2004. Our results show that coral bleaching and the post-bleaching responses of reefs can vary spatially within a small reef system such as Tubbataha Reefs. Four post-bleaching responses were documented: (1) recovery in terms of increase in live hard coral cover; (2) no recovery or change in live hard coral cover; (3) phase shift in the living substrate composition from hard live coral to soft coral and vice versa; and (4) no significant change in live hard coral cover. It is also suggested that the responses of the benthic community after 1998 are affected by active reef protection, whereas in the period of 1984 to 1992, reef management had not yet been instituted. This may partly explain the decline in hard coral cover in these years. Consequently, the need for sustained management, protection, and regular monitoring of this reef system has been recommended. This study is part of the Saving Philippine Reefs Project, whose long-term goal is to assist in Philippine coral reef management and conservation.



Introduction

Long-term data sets documenting detailed changes in coral reef benthic community composition and fauna are rare. However, such information is needed for sustained coral reef management. In the Philippines, where 50% of animal protein is derived from marine fisheries and aquaculture (White and Cruz-Trinidad, 1998), support for coral reef conservation and management has been growing over time. But despite the growing number of measures to reduce anthropogenic threats to coral reefs, the impact of coral bleaching since the 1998 El Niño Southern Oscillation (ENSO) event remains a global concern.

The impact of coral bleaching varies from physiological changes in individual corals such as reduced growth and reproductive output and increased mortality (Marshall and Baird, 2000) to a spatially extensive reduction in coral cover and changes in fish composition (Fujiwara *et al.*, 2000). More seriously, it has been considered as a factor damaging the fragile economies of many developing countries and the livelihood of their people (Douglas, 2003).

Bleaching events are predicted to increase in frequency and severity (Hoegh-Guldberg, 1999). Bleaching is induced by a variety of stressors, of which thermal stress has been implicated in most large-scale bleaching events (Brown, 1997; Douglas, 2000). Elevated sea water temperature, often combined with increased solar irradiance, has been linked with long-term changes in global climate and compounded by ENSO events (Stone *et al.*, 1999). Factors affecting bleaching susceptibility and severity in corals include the molecular ecology of the zooxanthellae, the ecophysiology of corals (Douglas, 2003), and presence of bacteria which can cause bleaching (Kushmaro *et al.*, 1998; Ben-Haim *et al.*, 2003).

This study is part of the Saving Philippine Reefs Project, whose goal is to assist in Philippine coral reef management and conservation. In this report, we document the long-term changes in the benthic communities of Tubbataha Reefs and the differential

post bleaching responses of various reef sites in the context of reef protection in the last ten years.

Methods

Study site

The Tubbataha reef system lies in the middle of the Sulu Sea. Its structure is that of a classic atoll with both fringing and atoll reefs facing the open sea outside the atoll lagoon (White *et al.*, 2003; Fig. 1, next page). Continuous reef platforms, 200-250 m wide, completely enclose sandy and coral substrate lagoons that range from 1 m - 24 m in depth. At extreme low tide, portions of the atolls' shallow reef platforms are exposed (NRMC, 1983). Tubbataha Reef was declared a National Marine Park in 1988 through a presidential decree, and as a UNESCO World Heritage site in December 1993 by the World Conservation Union (White *et al.*, 2003).

Data were gathered from six selected sites (Fig. 1) from 1984 to 2004, by scientists and trained volunteers of the "Saving Philippine Reefs (SPR) Earthwatch Expedition." These six sites are within the protected area of the Tubbataha Reef National Marine Park (TRNMP):

1. NR1 (North Reef): Amos Rock or Malayan Wreck (8°53.5 17' N, 119° 53.338' E)
2. NR2 (North reef): Ranger Station (8°55.5 22' N, 120° 0.327' E)
3. NR5 (North reef): Bird Islet (8°55.594' N, 120° 0.338' E)
4. SR1 (South Reef): Lighthouse (8°44.348' N, 119° 48.089' E)
5. SR3 (South Reef): Black Rock (8°47.842' N, 119° 50.352' E
6. SR4 (South Reef): Northwest corner of South Atoll (8°48.604' N, 119° 48.462' E)

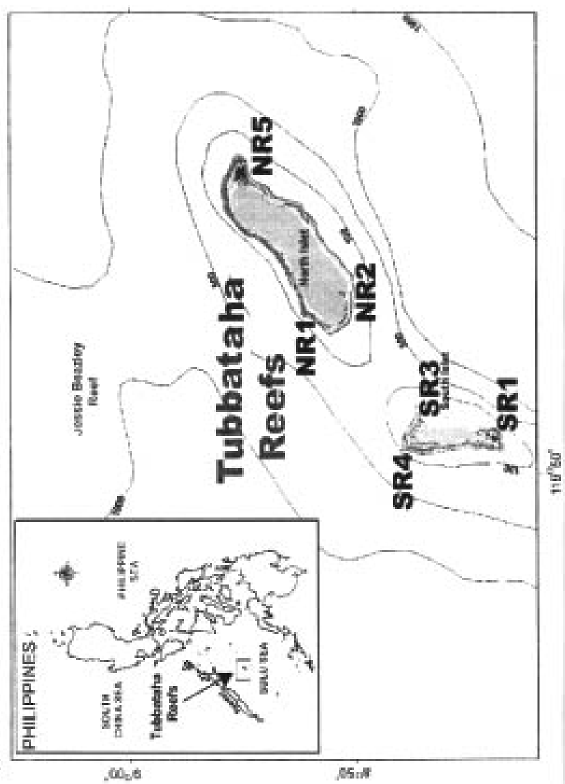


Figure 1. Study sites (NR1, NR2, NR5, SR1, SR3, SR4) on Tubbataha north and south atolls (modified from WWF Philippines).

Data collection

Scuba surveys were carried out at 7-9 m depth parallel to the reef crest using a systematic point-intercept method. Transects were laid on sections of a reef flat, reef crest, slope, or wall. Substrate was noted at 25 cm intervals along 50 m transects (no.= 1984=1; 1992=3-4; 1996=4-8; 2000 =11-22; 2004 =16-17). Distance between transects averaged 5-10 m. Survey sites were relocated yearly using GPS. Data gathered during SCUBA surveys were: (1) percent cover of living coral (hard and soft); (2) percent cover of non-living substrate (e.g., rock, rubble, sand, dead coral); (3) percent cover of living substrate (e.g., seagrass, algae, sponges); (4) numbers of indicator species (e.g., butterflyfish, giant clams, lobsters, Triton shells, Crown of Thorns starfish, and other invertebrates); (5) presence of large marine life (e.g., sharks, manta rays, Humphead wrasses, sea turtles, whales, dolphins, and others); (6) types of reef damage; and (7) fish species and densities. In this paper, we report only the substrate changes over time and the rest of the collected data were excluded but available in a separate report (White *et al.*, unpubl.).

Data analyses

Substrate categories were regrouped for comparison into total live hard coral, soft coral, rubble, dead coral (white dead standing coral, dead coral colonized by algae) and non-living substrate (rock and block, sand and silt), and presented graphically. Each category was compared within site between years using a One-Factor Analysis of Variance. Surveys from previous years with low replication ($n<3$) were excluded from statistical analyses, so T-tests were used to analyze sites with only two survey years available. All percentage data were log transformed. Normality was tested using Kolmogorov's Test for normality and Levene's Test for homogeneity of variances.

Results

The benthos of Tubbataha Reef was dominated by live hard coral (LHC) prior to the 1998 ENSO bleaching event (Figs. 2-5) with the exception of site SR3, which was primarily a soft coral reef (Fig. 1, 5). LHC fell within the "fair" to "good" categories (27.4 – 54.1%; as described in Gomez *et al.*, 1994) in all sites in 1984 and 1992 (Table 1). By 1996, LHC cover at site NR1 significantly increased (55.9±7.6%; Table 2). No significant changes were observed in other sites, though cover remained relatively high. By 2000, the immediate impacts of the 1998 ENSO were reflected in the significant ($p<0.05$) decline of LHC and/or soft coral (SC) cover in all sites except SR4 and SR1, where no significant change was detected (Table 2).

By 2004, distinct changes in the benthic composition of most sites were observed. NR2 LHC cover increased from 12.9±2 % in 2000 to 41.9±4.2% in 2004. Similarly, NR5 LHC cover also significantly increased from 18.5±2% in 2000 to 35.7±2.8% in 2004 (Table 1). The increase in LHC in both sites were coupled by decreases in non-living substrates (e.g., dead coral, sand/silt; Fig. 2), suggesting hard coral growth. In contrast, no recovery in LHC was observed in NR1; LHC cover in 2000 (23±3.4%) was not significantly different from 2004 (18±2.4%). Alternatively, SR1 and SR3 benthos exhibited phase shifts in dominant substrata (Fig. 4). In SR1, LHC still dominated in 2000 and 2004 over the rest of the substrate. Although changes in LHC between 2000 and 2004 were not significant, a decline in LHC corresponded to a significant increase in soft coral cover (Table 2, Fig 4). In SR3, the dominant soft coral substrate was replaced by LHC after the 1998 ENSO mass bleaching. No significant change in LHC was observed between years at the SR4 site, suggesting that LHC was not severely affected by the 1998 ENSO.

Data are summarized over time for all sites in Fig. 6. Percent change from 1984 to 1992 is +13.38% and from 2000 to 2004, is +37%. Although these changes are not significant (ANOVA) due to site variability, they indicate probable trends in the reef condition.

A decreasing trend in live hard coral reef is exhibited as indicated by a regression line (Fig.6).

Figure 2. Changes in benthic composition of NR2 and NR5 showing recovery of live hard coral cover after the ENSO bleaching event.

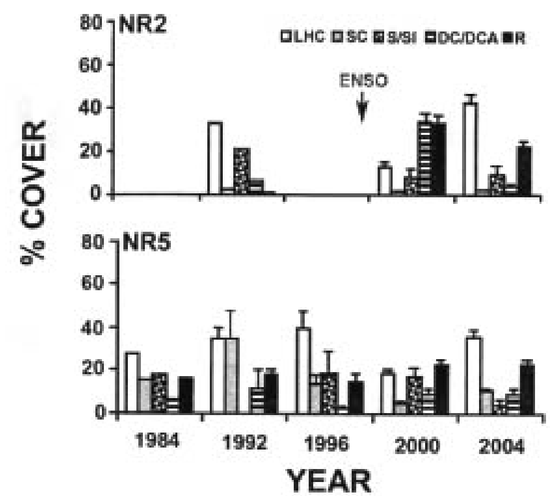


Figure 3. Changes in benthic composition of NR1 showing no recovery in live hard coral cover after the ENSO bleaching event.

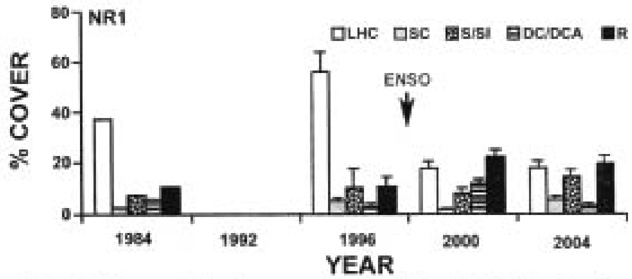


Figure 4. Changes in benthic composition of SR1 and SR3 showing phase shifts in the dominant substratum. SR1: continued decline in live hard coral cover and simultaneous increase in soft coral cover. SR3: replacement of a previously soft coral-dominated reef to a hard coral reef.

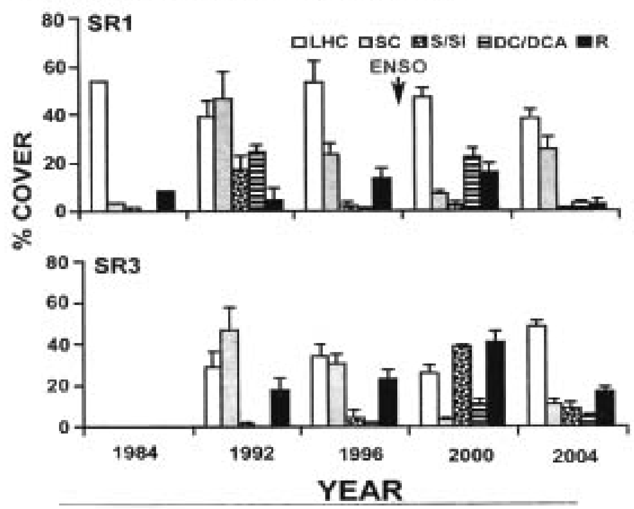


Figure 5. Changes in benthic composition of SR4 showing no significant change in live hard coral cover after the 1998 ENSO coral bleaching.

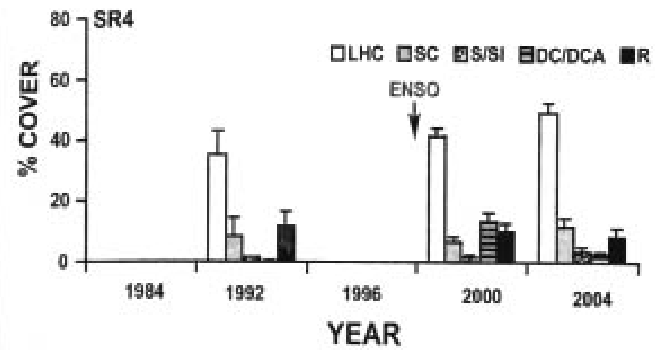


Figure 6. Changes in mean (± SE) overall live hard coral (LHC) cover of Tubbataha Reef showing a decreasing trend from 1984 to 2004. Straight line through graph indicates overall mean.

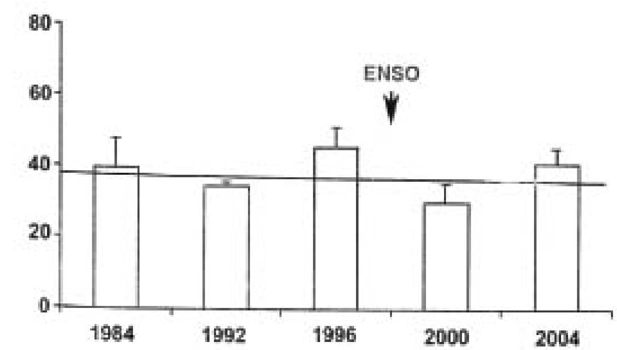


Table 1. Changes (% mean ± SE) in live hard coral cover (LHC) and soft coral cover (SC) from 1984 to 2004 in six selected sites at Tubbataha Reef.

Site/substrate	Year 1984	1992	1996	2000	2004
NR2					
LHC	no data	32.4	no data	12.9 ± 2.0	41.9 ± 4.2
SC	no data	1.8	no data	1.1 ± 0.4	1.7 ± 0.4
NR5					
LHC	27.4	34.9 ± 5	38.8 ± 8.7	18.4 ± 2.0	35.7 ± 2.8
SC	15.8	34.8 ± 13	13.9 ± 3.8	4.7 ± 1.0	10.1 ± 1.5
NR1					
LHC	37.3	no data	56.0 ± 7.6	23.0 ± 3.4	18.0 ± 2.4
SC	2.7	no data	5.3 ± 1	1.6 ± 0.5	5.5 ± 1.44
SR1					
LHC	54.1	38.9 ± 7.2	53.2 ± 9.2	47.2 ± 3.6	38.2 ± 3.8
SC	3.6	46.8 ± 11.6	23.4 ± 4.4	7.3 ± 1.4	25.4 ± 5.3
SR3					
LHC	no data	29.0 ± 7.2	33.7 ± 6.1	26.5 ± 3.2	47.9 ± 3.3
SC	no data	46.8 ± 11.6	30.7 ± 4.2	3.4 ± 0.9	11.4 ± 2.1
SR4					
LHC	no data	35.3 ± 6.9	no data	41.0 ± 2.7	49.0 ± 2.95
SC	no data	9.1 ± 5.2	no data	7.0 ± 1.8	11.7 ± 2.4
All sites					
LHC	39.6 ± 7.8	34.3 ± 1.4	45.4 ± 5.4	30.0 ± 5	41.1 ± 3.8
Overall LHC % change [(Year2/Year1)-1] x100		-13.38	+32.4	-33.9	+37

Table 2. Results of 1-Way ANOVA and T-test within substrate categories between years per site (á = 0.05). LHC = Live hard coral, SC = Soft coral, R = Rubble, NL = Non-living (sand and silt), DC = Dead coral.

North Reef

	NR1			NR2		NR5		
	1-ANOVA		Bonferroni post hoc	T-test		1-ANOVA		Bonferroni post hoc
Substrate	p	F		p	Ranking	p	F	
LHC	≤ 0.0001	20.7772	1996>2000=20004	≤ 0.0001	2004>2000	0.0004	7.497	1992=1996=2004>2000
SC	0.0.03	4.4966	1996=2000>2004	NS		NS		
R	NS			0.016	2000>2004	0.0009	6.5659	2000>2004=1996
NL	0.047	3.3595	NS	NS		≤ 0.0001	17.046	2000>1992>1996>2004
DC	< 0.003	11.16	2000>1996=2004	≤ 0.0001	2004>2000	0.013	4.05	2000>1996

South Reef

	SR1			SR3			SR4		
	1-ANOVA		Bonferroni post hoc	1-ANOVA		Bonferroni post hoc	1-ANOVA		Bonferroni post hoc
Substrate	p	F		p	F		F	p	
LHC	NS			0.0018	6.163	2004>2000	NS		
SC	0.0167	4.1546	NS	0.8788	0.5236	1992=1996 >2000=2004	NS		
R	NS			0.0136	4.0981	2000>2004	NS		
NL	0.0031	5.8774	1992<2000=2004	0.0006	7.3274	1992>1996 =2000=2004	0.008	5.553	2004>1992=2000
DC	NS			NS			≤ 0.0001	13.41	2000>2004=1992

Discussion

Our surveys over a 20 year period indicated that the El Niño Southern Oscillation (ENSO) event contributed largely to the changes in Tubbataha coral reef substrate in 1988 and after. Although no visits were made to the reefs during 1998, our data suggest that the impact of the 1998 ENSO on Tubbataha reefs caused massive bleaching and death of the live hard corals (LHC) and soft corals (SC). This is reflected in the sharp declines of these substrata during the 2000 survey. Live hard coral cover was "fair" (25-49.9%) to "good" (50-74.9%). By 2000 and 2004 LHC declined to "poor" to "fair" (0 – 49.9%). In 2004, distinct differential responses were exhibited by various reefs in Tubbataha: (1) recovery in terms of increase in LHC: sites NR2 and NR5; (2) no change in LHC: SR1; (3) phase shift in the living substrate composition from soft coral to live hard coral or vice versa: NR1; (4) no significant change in LHC: SR4.

Coral reef recovery after bleaching was evident in two Tubbataha survey sites. NR2 and NR5 LHC declined by 20% in 2000, but significant increases in LHC were seen by 2004 in both sites. NR1, on the other hand, was apparently severely impacted by bleaching; LHC cover declined by 33% from 1996 to 2000. By 2004, NR1 showed the lowest LHC of all sites and no significant recovery was observed. These results indicate that coral recovery in NR1 is taking longer than other sites. Repeated bleaching episodes may result in the continued decline of coral cover at this site. It is interesting to note the spatial position of these three reefs (Fig. 1). Sites NR2 and NR5 are both on the eastern side of the atoll, while NR1 is on the western side. Possible difference in current patterns that drive the sea surface temperature (SST) differences between sites may have contributed to the differential responses to bleaching and subsequent recovery observed. Changes in community structure as a consequence of coral bleaching and death were seen in SR3 and SR1. A decline

in soft coral and hard coral cover was observed in SR3 from 1996 to 2000. By 2004, a phase shift had occurred, and LHC cover increased by 81%. This replaced most of the soft coral population dominating the area prior to the bleaching episode. A similar change was seen in Apo Island Marine Reserve, Central Philippines, documented by Raymundo and Maypa (2002; 2003). Soft coral cover steadily increased, while LHC cover decreased, after ENSO from 1999 to 2001. By 2002, LHC cover started to increase with a simultaneous decrease in soft coral cover. In SR1, LHC was still the dominant substratum but data suggest a decreasing trend. When combined with the continuing increase in SC cover, this suggests that a community shift from LHC to SC may be occurring. Continued monitoring can quantify this shift over time, and would provide valuable information regarding responses to bleaching within a pristine reef system. This shows that bleaching disturbances may promote changes in species dominance and diversity which are not immediately apparent and which may take several years to complete (Marshall and Baird, 2000).

SR4 LHC cover remained unchanged from 1996 to 2004, and thus was apparently not affected by the 1998 bleaching event. Factors that may have contributed to the high survival of corals at this site during sea water temperature rise may include: (1) the depth at which the corals thrive; (2) species composition of the reef; and, (3) the exposure of the reef to strong local currents which may have acted as a temporary buffering system for temperature change. It is interesting to note that SR4 is on the opposite side of the atoll from SR1 and SR3, and on the same side as NR1 (Fig. 1). According to Skirving (2004), there are four different mechanisms that can vertically mix the water column, wind, low frequency currents (e.g., East Australian current, Gulf Stream), high frequency currents (e.g., tides), and swell waves. Winds are effectively absent during a mass bleaching

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