Impact of the 2005 coral bleaching event on *Porites porites* and *Colpophyllia natans* at Tektite Reef, US Virgin Islands

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Received: 7 August 2006 / Accepted: 19 April 2007 / Published online: 6 June 2007
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Abstract A thermal stress anomaly in 2005 caused mass coral bleaching at a number of north-east Caribbean reefs. The impact of the thermal stress event and subsequent White-plague disease type II on *Porites porites* and *Colpophyllia natans* was monitored using a time series of photographs from Tektite Reef, Virgin Islands National Park, St. John. Over 92% of the *P. porites* and 96% of the *C. natans* experienced extensive bleaching (>30% of colony bleached). During the study, 56% of *P. porites* and 42% of *C. natans* experienced whole-colony mortality within the sample plots. While all whole-colony mortality of *P. porites* was directly attributed to coral bleaching, the majority (82%) of the *C. natans* colonies that experienced total mortality initially showed signs of recovery from bleaching, before subsequently dying from White-plague disease type II.

Keywords *Porites porites* · *Colpophyllia natans* · Coral bleaching · Disease · Mortality

Introduction

Coral bleaching occurs when coral polyps lose pigment or expel zooxanthellae due to physiological stress, which recently has been most often related to high water temperatures and high solar radiation (Brown 1997; Winter et al. 1998; Santavy et al. 2005). Since the 1980s, reports of coral bleaching in the Caribbean have increased, with major Caribbean-wide bleaching occurring in 1997–1998 (Hoegh-Guldberg 1999; Aronson et al. 2000; Gardner et al. 2003). Approximately 43–47% of coral tissue bleached at two St John, US Virgin Island study sites during the 1998 mass coral bleaching event (Rogers and Miller 2001), which resulted in low subsequent mortality (J. Miller, personal observation). However, two lagoonal reefs in Belize experienced substantial bleaching related mortality (Aronson et al. 2000).

Coral bleaching differentially affects coral species (Marshall and Baird 2000), coral morphology types (finger corals having higher mortality than mounding corals) (Loya et al. 2001), and colony size-frequency distributions by removing larger sized colonies (Hoeksema 1991; Loya et al. 2001; Shenkar et al. 2005). Recently, Ritchie (2006) showed the loss of antibodies in *Acropora palmata* mucus during 2005 summer bleaching in the Florida Keys. This suggests that stressed corals (i.e., bleached corals) may be more susceptible to disease and therefore that the combined effects of bleaching and disease need investigation. Elevated water temperatures predicted for the future may increase the interaction between coral bleaching and coral disease prevalence, exacerbating the impacts on the coral reef community.

This study investigated the impact of the 2005 mass coral bleaching on *Porites porites* (Pallas) (Club finger coral) and *Colpophyllia natans* (Houttuyn) (Giant brain

Communicated by Environment Editor R. van Woesik.

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coral or Boulder brain coral) 18 weeks prior to and 18 weeks after maximum water temperature. This study sought to determine overall bleaching impact and whole-colony mortality for both species and subsequent disease impact on *C. natans*.

Materials and methods

Tektite Reef is located adjacent to an undeveloped watershed within the boundary of Virgin Islands National Park on the south shore of St. John, US Virgin Islands. Surveys were conducted along the same transects established for long-term monitoring of coral disease on Virgin Island reefs (Miller et al. 2003). In February 2005, the specific study area within Tektite reef had high coral cover (35.8% SE 1.4) and was predominately comprised of *Montastraea annularis* (91.8%), *P. porites* (4.2%) and *C. natans* (1.8%) (National Park Service, unpublished data). *P. porites* and *C. natans* were the focal species of this study due to the relative ease in repetitively locating these coral colonies in photographs.

Surveys were conducted along eight parallel, 10 m transects with depths ranging from 7 to 10 m. A 1 m² PVC quadrat (gridded into 100 equal squares) deployed on each side of the transect produced a 10 m × 2 m belt transect. Each 1 m² PVC quadrat was photographed (from approximately 1.5 m distance) using a Sony DSC T33 or Olympus E20 so that the quadrat filled the image. Photographs of all quadrats were taken in February, April, May, and monthly from July to December in 2005, with final photographs

taken in January 2006. There were ten sampling events for each of the 160 quadrats, totaling 1,600 photographic records.

In 2005, at St. John Virgin Islands, the daily average water temperatures were greater than 29°C from 17th June to 4th November with daily average water temperatures above 30°C from 4th September to 2nd October. The week of 27th September to 1st October had a daily average temperature of 30.5°C, the peak in the thermal anomaly, and was referred to as the maximum temperature week (MTW). Each photographic sampling event was referenced relative to MTW (Table 1).

Photographs were examined using Adobe® Photoshop CS2 Version 9, both uncorrected and after compensating for red wavelength loss in the underwater image by using the “underwater image enhancement action” (James Connell, Adobe Studio Exchange, 16 October 2003). The photographs were viewed to determine the presence of *P. porites* and *C. natans* colonies.

Each colony was numbered and allocated to a size class and a condition status. Colonies were classified in one of three size classes (determined using the gridded quadrat as a reference marker, Fig. 1): (1) small < 1,500 cm²; (2) medium = 1,500–3,000 cm²; (3) and large > 3,000 cm². The degree of maximum area bleached on each coral colony was defined as: (1) *no bleaching*—showed no signs of bleaching; (2) *minor bleaching*—less than 30% of the lateral surface area was bleached; (3) *severe bleaching*—30 to 99% of the lateral surface area was bleached; (4) and *complete bleaching*—100% of the lateral surface area was bleached.

Table 1 Timing of coral bleaching for *Porites porites* (*n* = 88) and *Colpophyllia natans* colonies (*n* = 26)

Sampling date	Water (°C)	Weeks from MTW	<i>Porites porites</i> (<i>n</i> = 88)			<i>Colpophyllia natans</i> (<i>n</i> = 26)			
			Initial	Peak	Recovery	Initial	Peak	Recovery	Disease ^a
27 May 2005	28.6	−18	3						
No sample June 2005									
31 July 2005	29.2	−8	61	4					
29 August 2005	29.8	−4	7	8		8			
29 September 2005	30.5	MTW	9	65		15	16		
31 October 2005	29.1	5	2	5	2	3	9	1	2
28 November 2005	28.1	9	1	1	2		1	12	7
31 December 2005	26.7	14			1			1	
31 January 2006	26.4	18			29			1	
<i>n</i>			83 ^b	83 ^b	34 ^b	26	26	15	9

Definition of initial, peak, recovery classification defined in the text. Water temperature is daily average (°C), St. John Virgin Island, 2–5 sensor at reef depth reporting. Weeks from the thermal anomaly maximum temperature week (MTW) of 27 September 2005 to 1 October 2005 (daily average temperature for the week was 30.5°C).

^a Date of recovery for *C. natans* colonies which eventually died from White plague type II disease

^b Five *P. porites* colonies did not bleach during the study

Fig. 1 *Porites porites* colony with both unbleached and bleached branches. Photograph was taken at Tektite Reef, US Virgin Islands on 29 September 2005 at the height of the coral bleaching event. The entire colony recovered from the 2005 bleaching event

Additionally, the month of initial bleaching and the month of peak bleaching for each colony were determined. Initial bleaching was defined as initial paling or color loss. Peak bleaching corresponded with maximal surface bleached. Recovery was defined as the re-coloring of the bleached colonies. Bleaching mortality was described as loss of the entire colony, if the coral had been discolored. Coral disease, White-plague type II followed criteria defined by Richardson (1998). Coral-disease mortality was differentiated from bleaching mortality by a progression of the mortality ‘line’ rather than whole-colony mortality.

Colony survival was determined using photographs taken in January 2006. Colonies were classified as alive, if any portion of the colony was alive in January 2006. Hence, this was a conservative estimate of total colony mortality from the 2005 coral bleaching event, since mortality from coral bleaching has been reported to occur up to 40 weeks after bleaching (Baird and Marshall 2002).

Pearson Chi-square test was used to investigate if there was an association: (1) between size class and bleaching status or mortality for *P. porites*, (2) between bleaching status and disease for *C. natans*, and (3) between mortality and severity of bleaching status for both species.

Results and discussion

Porites porites

A total of 88 *P. porites* colonies were identified and monitored. Sixty-one of the *P. porites* colonies showed signs of initial bleaching –8 MTW (Table 1). Peak bleaching for 65 of the colonies was observed at MTW; however, colonies showed peak bleaching as early as –8 MTW to as late as 9 MTW. Of the 39 colonies that survived, 29 showed signs of recovery at 18 MTW (Table 1).

The small-size class comprised the majority of the colonies (70%), followed by medium (19%) and large (10%) size classes. Sixty-seven colonies experienced complete bleaching, 14 experienced severe bleaching, two experienced minor bleaching, and five experienced no bleaching (Table 2). Over 92% of the *P. porites* population that was monitored experienced extensive (severe to complete) bleaching. The five colonies that did not show any signs of bleaching were not isolated from the other colonies and presumably experienced similar environmental conditions (irradiance and water temperature). Some sections of partially bleached coral colonies showed no signs of bleaching (Fig. 1).

Overall, 56% of *P. porites* colonies died from bleaching; 61% of the small colonies, 53% of the medium colonies, and 22% of the large colonies (Table 2). Colonies that were completely bleached had the highest mortality (48 of 67 = 72%), and this mortality was concentrated in the small and medium sized colonies (74 and 75%, respectively, Table 2). Only 7% of colonies that experienced severe bleaching died. There was no mortality observed for the two colonies that experienced minor bleaching and the five colonies with no bleaching. There was no evidence of coral

Table 2 Counts of *Porites porites* colonies by size class and degree of maximum surface area bleached followed by counts of colonies which died during the study and the percent mortality by size class and degree of maximum bleaching

Bleaching status	Total colonies (counts)				Mortality (counts)				Mortality (%)			
	Small	Medium	Large	Total	Small	Medium	Large	Total	Small	Medium	Large	Total
None	4	1	0	5	0	0	0	0	0	0	0	0
Minor	1	1	0	2	0	0	0	0	0	0	0	0
Severe	7	3	4	14	1	0	0	1	14	0	0	7
Complete	50	12	5	67	37	9	2	48	74	75	40	72
Total	62	17	9	88	38	9	2	49	61	53	22	56

Table 3 Counts of *Colpophyllia natans* colonies by degree of maximum surface area bleached followed by counts of colonies which died during the study from bleaching, disease (White plague type II), and combined mortality

Bleaching status	Total (<i>n</i>) colonies	Mortality bleaching (counts)	Mortality diseased (counts)	Combined mortality (counts)	Mortality bleaching (%)	Mortality disease (%)	Mortality combined (%)
None	0	0	0	0	0	0	0
Minor	1	0	0	0	0	0	0
Severe	8	0	3	3	0	38	38
Complete	17	2	6	8	12	35	47
Total	26	2	9	11	8	35	42

Percentage for each cell is within each bleaching status

disease on the *P. porites* colonies monitored during this study.

Baird and Marshall (2002) reported no association between colony size class and bleaching mortality for scleractinian coral of reproductive size at two locations on the Great Barrier Reef. In contrast, Shenkar et al. (2005) reported that large *Oculina patagonica* coral colonies had higher mortality from bleaching than small colonies, which were less likely to bleach for a site in the Mediterranean Sea. Hoeksema (1991) reported a similar result for Fungiidae corals in the Java Sea. In this study, no association was found between *P. porites* colony size and bleaching status or between size and colony mortality, although there were few large colonies. Interestingly, the five *P. porites* colonies that did not bleach were either small or medium sized.

Colpophyllia natans

A total of 26 *C. natans* colonies were identified and monitored. Eight of the *C. natans* colonies showed initial signs of bleaching by –4 MTW, and 15 additional colonies show initial signs of bleaching at MTW; therefore, approximately 88% of the population showed signs of bleaching by MTW (Table 1). Twenty-five of the 26 colonies (96% of the population) had reached peak bleaching by 5 MTW, with peak bleaching for 16 colonies occurring by MTW, and nine additional colonies had reached peak bleaching at 5 MTW. Overall, 92% (22 colonies) of the *C. natans* colonies began to show signs of apparent recovery (re-coloring) from the bleaching event by 9 MTW, including the nine colonies that eventually died from White-plague disease type II (Table 1).

Of the 26 *C. natans* colonies monitored, 24 were small, while two were medium sized. Because 92% of the *C. natans* colonies were in the small-size class, there was no possible comparison across size classes. All colonies in this study experienced some level of bleaching: 17 colonies experienced complete bleaching, 8 colonies experienced severe bleaching, and 1 colony experienced minor bleaching (Table 3). Overall, 96% of the *C. natans* population that

was monitored experienced extensive (severe to complete) bleaching.

Nine *C. natans* colonies appeared to have partially recovered from bleaching at the November sampling; however, this was followed by the onset of White-plague disease type II resulting in total colony mortality (Table 1). Of the nine colonies that suffered total coral mortality from this disease, six colonies experienced complete bleaching and three severe bleaching (Table 3). Only two colonies died as a result of bleaching; both of which had experienced complete colony bleaching. Overall, 42% of the original 26 *C. natans* colonies died. Of the colonies that died, 82% died from disease after partially recovering from bleaching. Only 8% of the *C. natans* colonies died without showing signs of disease (Table 3).

Comparing species response

Porites porites and *C. natans* exhibited differential bleaching. According to the photographs, the first signs of bleaching for *P. porites* were observed to occur at –18 MTW, while *C. natans* bleaching was not evident until –8 MTW, some 2 months later. Bleaching substantially affected *P. porites* for over 7 months, whereas the *C. natans* colonies were generally affected for only 4 months (Table 1). Species specific bleaching has been previously reported by Baird and Marshall (2002).

Bleaching mortality was also species specific in this study. These results support the findings of others (Marshall and Baird 2000; Loya et al. 2001; Baird and Marshall 2002; Kayanne et al. 2002) that direct bleaching mortality of the fast growing branching corals species (*P. porites*—56% whole colony mortality) was greater than the slow growing massive species (*C. natans*—8%). Coral mortality has been associated with bleaching severity (Marshall and Baird 2000; Baird and Marshall 2002). In this study, mortality was also associated with severity of bleaching (bleaching status) for *P. porites* ($\chi^2 = 29.1$ $df = 3$, $p < 0.005$) but not for *C. natans* colonies. Interestingly, the severity of bleaching did not differ between the two species studied. Additionally,

for both species studied, individuals that experienced complete bleaching were able to recover (28% for *P. porites* and 88% for *C. natans*). This recovery has been reported by a number of other authors from different geographic areas (Porter et al. 1989; Suzuki et al. 2003).

Although mortality directly resulting from coral bleaching was seen in only two of the *C. natans* colonies, the majority of colonies died of disease after partially recovering from bleaching. The White-plague type II disease mortality was not associated with the bleaching status of the *C. natans* colonies. Previous work on these same transects found that White-plague disease type II affected unbleached *P. porites* and *C. natans* colonies at a similar rate (2 and 3%, respectively, Miller et al. 2003). One possible explanation for the differential response of these two species found in this study is that the longer duration of bleaching of *P. porites* compared to *C. natans* (26 compared to 9 weeks of bleached colonies, respectively) caused the *P. porites* colonies to succumb to bleaching due to the extended length of time without zooxanthellae. For *C. natans*, bleaching duration was much shorter thus allowing for “recovery from bleaching” but eventual death from the disease that followed. Thus, the *C. natans* population still contained essentially weak members that were more susceptible to White-plague disease type II.

The 2005 bleaching event caused a substantial reduction in live *P. porites* and *C. natans* colonies and provided an opportunity for White-plague disease type II to affect weakened *C. natans* colonies. Under current global warming scenarios, with increasing frequency and severity of bleaching (Hoegh-Guldberg 1999), the long term survival of these slow-growing coral species will be tenuous, especially when challenged by the combined impacts of bleaching and coral disease which can result in >40% whole-colony mortality in less than 6 months.

Acknowledgments This study is indebted to Rob Waara for field assistance, Judd Patterson for Photoshop assistance; Chris Ringewald for editorial improvements; O. Sanchez was supported by the Undergraduate Independent studies program from the Department of Environmental Studies, Florida International University. This is South Florida/Caribbean Network publication number SFCN-06-1.

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