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Large scale coral mortality in Barbados: a delayed response to the 2005 bleaching episode

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Abstract. Corals in Barbados suffered widespread bleaching during the high temperature event of 2005. Six reefs were monitored for one year (October 2005 – November 2006) to determine mortality impacts and rate of recovery from this bleaching event. Five 1 x 20 m band transects and five 20 m line transects were quantitatively surveyed at each site, every four months. Bleaching prevalence dropped from a mean of 71% of colonies in October 2005 to 38% in February, to 17% in June, before rising again to 25% in November 2006. Coral mortality remained low for five months (means: 3.8% colony surface dead; or 4.8% dead cover), but rose sharply after 10 months (means: 18.7% colony surface; or 25.9% cover), eventually declining after 15 months to near ambient levels (means: 2.0% colony surface; or 6.1% cover). Like other eastern Caribbean islands, recovery from bleached condition was slow and overall mortality impact was high on both deep and shallow reefs. In contrast were the delayed onset of mortality and low incidence of coral disease. High losses in live coral cover have significant economic implications for the island which derives a major proportion of its GDP from tourism, and relies heavily on healthy reefs for coastal protection.

Key words: coral bleaching, mortality, Barbados.

Introduction

Coral reefs across the Caribbean suffered extensive bleaching as a result of the record high temperature event of 2005 (Donner et al. 2007; Souter and Wilkinson 2008). In particular, the eastern Caribbean Lesser Antilles experienced unprecedented heating stress, and high levels of coral mortality were reported for several islands by early 2006 (Miller and Muller 2006; Bouchon et al. 2008; Morgan et al. 2008; Woody et al. 2008).

In Barbados, bleaching impact was very high, but the initial mortality response was low compared with early reports from other eastern Caribbean islands (Oxenford et al. 2008). Here we examine the cumulative mortality impact of the bleaching episode on Barbados reefs over the ensuing year.

Methods

Quantitative surveys were conducted at three shallow (<10 m) and three deep (>15 m) reef habitats along the west and southwest coasts of Barbados (see Oxenford et al. 2008 for reef study site locations and descriptions) every four months from September/October 2005 to November 2006. At each reef site, five haphazardly placed 1 x 20 m belt transects and five rapid assessment 20 m line intercept transects were surveyed.

Extent of bleaching was assessed along the belt transects by recording the number and species of all coral colonies and the number suffering partial or full bleaching. This was presented as transect mean percent colonies bleached for each reef site.

Coral mortality was assessed using two independent indices: 1) visually estimated percent of each colony surface recently dead (recorded for every colony encountered in the belt transects by species), and 2) percent of benthic coral cover recently dead (measured directly along the entire length of the line intercept transects without regard to species identification). Recently dead coral was identified by the presence of newly exposed white skeleton with or without a fine layer of green turf algae (see Lang and Marks 2006). This ‘state’ was observed to last only a matter of weeks in tagged corals before reverting to ‘old’ mortality (Oxenford, unpubl. data). Therefore, cumulative mortality (calculated as the sum of recent mortality recorded each survey) was used to represent the full mortality impact of the bleaching event. Mortality data were presented as transect means per site for both indices.

Species complexes *Montastrea* (*M. annularis, M. faveolata, M. franksi*) and *Agaricia* (*A. agaricites, A. humilis, A. lamarcki, A. grahamae*) whose individual species could not be reliably identified by all observers, were treated as single species (*Monastrea* spp. complex and *Agaricia* spp. complex respectively) in the analyses.

Benthic water temperatures were recorded *in situ* at

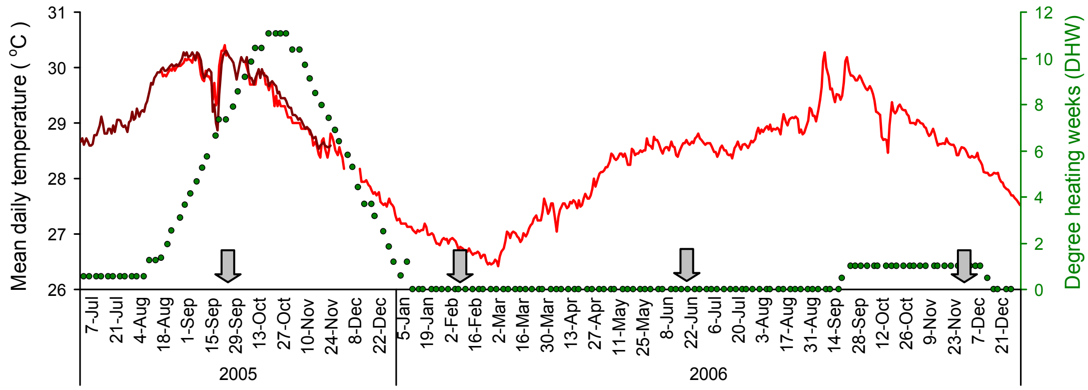

Figure 1. Benthic water temperatures recorded at two reef sites in Barbados, shown together with NOAA/NESDIS computed degree heating week data for the island. Dates of coral surveys are indicated by filled arrows.

deep and shallow sites every 4 h using HOBO® Water Temp Pro data loggers fixed in the reef. Computed mesoscale (50 km grid) degree heating week (DHW) data (Liu et al. 2006) were accessed from the archived NOAA/NESDIS Coral Reef Watch database at http://coralreefwatch.noaa.gov/satellite/hdf/index.html.

Results

The benthic water temperature and DHW time-series experienced by Barbados corals during late 2005 through 2006 are shown in Fig.1. In 2005 benthic water temperatures had exceeded 29.5 °C by the first week in August 2005 at both deep and shallow sites and persisted for almost three months. By comparison, in 2006 benthic water temperatures rose to 29.5 °C by the first week in September, but lasted for less than one month (Fig. 1). Heating stress was first apparent in Barbados in late May 2005, with values of 0.55 DHW persisting from May 24 - August 9. Heating stress rose sharply thereafter, reaching record highs of 11.05 DHW in the second half of October, and persisted through early January, 2006 (Fig. 1). The summer of 2006 was cooler with relatively low heating stress (1 DHW) occurring from late September to early December.

Bleaching was severe from late 2005 into 2006, affecting both shallow and deep reef habitats, virtually all hard coral taxa and the majority of colonies (see Oxenford et al. 2008), and persisted over the full year of study (Table 1). Bleaching prevalence gradually declined from a high of 70.6% of all colonies across all reefs in late September/early October 2005 to 17.1% in June 2006, 10 months after the initial onset of bleaching. Prevalence then rose again to 25.3% in November 2006 after summer warming (Table 1, Fig. 1).

Shallow reefs suffered significantly higher levels of bleaching than deeper reefs initially (Mann-Whitney: $U = 18$, $n = 30$, $P < 0.001$), showed no statistically significant differences in February or June ($U > 69$, $n = 30$, $P > 0.200$ in both cases), but by November the situation had reversed, with deep reefs suffering on average significantly more bleaching than shallow reefs ($U= 55$, $n = 30$, $P = 0.017$; Fig 2).

Table 1: Summary of bleaching prevalence of surveyed reefs shown as mean percent of all colonies that were fully or partially bleached along five 1x20 m belt transects at each reef site. SE in parentheses.

Reef site		Survey Dates							
		Oct-05		Feb-06		Jun-06		Nov-06	
Type	Name	15 Sep – 6 Oct		6 Feb – 9 Feb		20 Jun – 22 Jun		27 Nov – 7 Dec	
Deep (> 15 m)	Welcome Inn	59.4	(6.8)	43.1	(3.0)	18.8	(3.6)	36.9	(5.7)
	Atlantis	63.0	(3.8)	43.7	(6.7)	25.2	(6.9)	37.0	(5.7)
	Maycocks	59.1	(2.1)	32.6	(2.7)	16.9	(2.7)	20.7	(4.4)
Deep reefs mean		60.5	(2.5)	39.8	(2.8)	20.3	(2.7)	31.5	(3.5)
Shallow (< 10 m)	Coconut Court	86.0	(1.3)	19.9	(1.5)	7.3	(2.6)	8.8	(3.9)
	Batts Rock	73.8	(6.7)	46.0	(1.7)	21.5	(3.7)	25.2	(4.1)
	Bellairs	82.0	(3.1)	39.7	(8.7)	13.1	(5.6)	23.5	(9.0)
Shallow reefs mean		80.6	(2.7)	35.2	(4.1)	14.0	(2.7)	19.2	(3.8)
All reefs mean		70.6	(2.6)	37.5	(2.5)	17.1	(2.0)	25.3	(2.8)

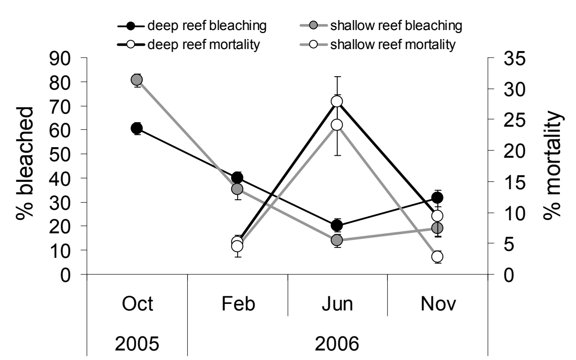

Figure 2. Mean bleaching and mortality responses of corals on deep and shallow reefs in Barbados to the 2005 hot water event. Bleaching is shown as mean % of coral colonies affected; mortality is shown as mean % of recently-dead benthic coral cover; bars show standard error.

The two coral mortality indices were highly correlated ($R^2 = 0.904$, n = 36), showing the same patterns among reef sites and the same trend over time (Fig. 3). However, the belt transect method, measuring whole coral colony surface, consistently estimated slightly lower mortality values than the rapid assessment, line intercept method measuring benthic coral cover (Fig. 3).

Bleaching-induced mortality, when first examined in February 2006, was relatively low across all reefs (mean % colony surface recently dead: 3.8% ±0.1 SE; mean % benthic coral cover recently dead: 4.8% ±1.0 SE), but rose sharply after 10 months (June 2006 – mean colony surface: 18.5% ±2.5 SE; mean cover: 25.9% ±3.2 SE), eventually declining after 15 months to near ambient levels (November 2006 - mean colony surface:2.0% ±0.4 SE; mean cover: 6.1% ±1.8 SE). Cumulative mortality impacts of the bleaching event are therefore estimated at approximately 24.3% loss in live coral colony surface or 36.8% loss of live coral benthic cover.

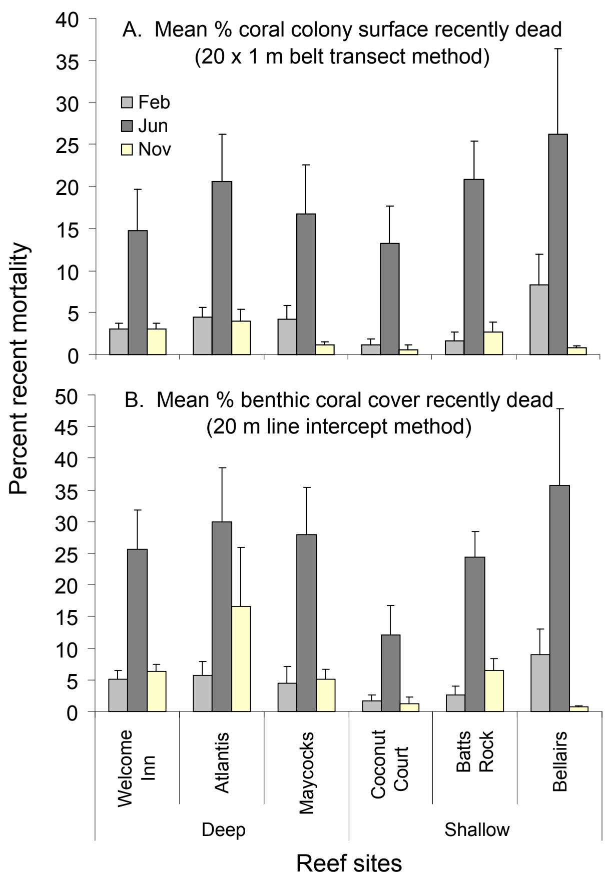

Figure 3: Mean percent loss of live coral at reef sites in Barbados following severe bleaching event of summer 2005, shown by two indices; A – mean estimated % of coral colony surface recently dead, and B – mean percent of benthic coral cover recently dead.

Similar to the trends in bleaching, mortality impacts did not differ significantly between shallow and deep reefs in February nor June 2006 ($U > 86$, $P > 0.05$ in both cases), but appeared greater on deep reefs than shallower reefs by November 2006, at least for the benthic coral cover index (Mann Whitney for coral cover: U = 54.5, n = 30, P = 0.015, Fig. 2; cf. colony surface: U = 70, n = 30, P = 0.078).

The severity of mortality impacts differed among coral species, but the trend was similar (Table 2). All species experienced the highest levels of mortality in June 2006, with the exception of *Favia fragum, Siderastrea radians* and *Millepora complanata* (Table 2). *F. fragum* and *S. radians* suffered very high levels of bleaching but low mortality throughout, whilst the milleporids suffered high levels of bleaching and very high early mortality, with *M. squarrosa* eventually disappearing completely from survey transects (Table 2).

Bleaching response was not always indicative of the longer term mortality response across all species. For example, among the most commonly observed species, *Agaricia agaricites*, *Montastrea annularis*, *Porites porites* and *Millepora alcicornis,* all suffered initial bleaching of more than 70% of all colonies and cumulative mortality in excess of 30% of colony surface (Fig. 4). In contrast, *Diploria strigosa* and *Favia fragum* experienced more than 70% bleaching but cumulative mortality was less than 12% for these two species, and *Colpophyllia natans* had very low level of bleaching (< 10%) but more than 30% mortality (Fig. 4).

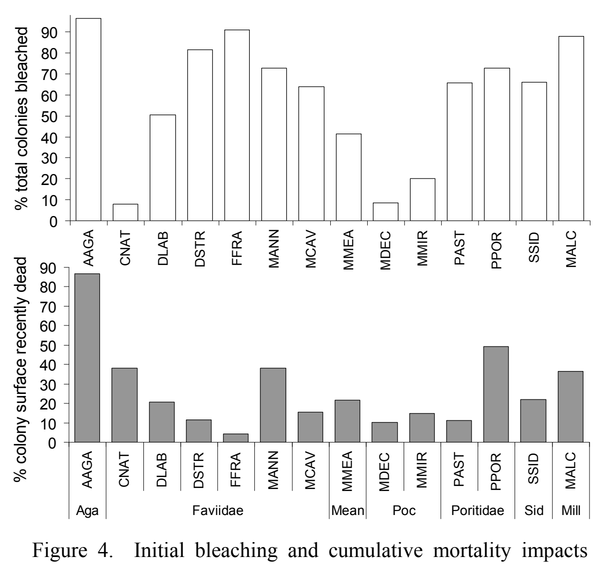

Figure 4. Initial bleaching and cumulative mortality impacts shown for the most common coral species (> 50 colonies per survey) over the period September 2005 to November 2006, grouped by family. Initial bleaching was recorded in September/October 2005. Cumulative mortality represents the sum of 'recently-dead' colony surface recorded in February, June and November 2006. Species codes are given in Table 2.

Table 2: Summary of bleaching and mortality census data for six reefs in Barbados shown for all colonies by species. Data were collected along five 1x20 m belt transects at each reef and are presented as percent of total colonies bleached by species, and percent of colony surface recently dead over all colonies by species.

Class	Family	Code	Species	Sept/Oct-05		Feb-06			Jun-06			Nov-06		
				n	% bleached	n	% bleached	% mortality	n	% bleached	% mortality	n	% bleached	% mortality
Anthozoa	Acroporidae	ACERV	*Acropora cervicornis*	0	-	0	-	-	1	0.00	0.00	0	-	-
	Agariciidae	AAGA	*Agaricia* spp. complex	1322	96.60	166	62.65	31.87	282	23.40	50.90	139	38.13	3.92
		LCUC	*Leptoseris cucullata*	1	100.00	3	33.33	0.00	2	0.00	2.50	10	20.00	0.00
	Astrooeniidae	SBOUR	*Stephanocoenia bournii*	0	-	0	-	-	6	33.33	0.00	0	-	-
		SINT	*Stephanocoenia intersepta*	18	38.89	35	25.71	1.00	41	36.59	5.34	46	41.30	0.87
	Caryophylliidae	EFAST	*Eusmilia fastigiata*	12	16.67	18	55.56	5.56	20	20.00	15.75	22	22.73	5.68
	Faviidae	CNAT	*Colpophyllia natans*	64	7.94	89	15.73	2.00	142	6.34	30.83	95	9.47	5.35
		DCLIV	*Diploria clivosa*	5	80.00	28	39.29	3.75	5	20.00	10.00	4	0.00	0.00
		DLAB	*Diploria labyrinthiformis*	75	50.67	85	31.76	2.16	106	14.15	17.53	113	22.12	1.14
		DSTR	*Diploria strigosa*	277	81.59	311	32.48	2.21	402	14.68	8.75	414	22.22	0.46
		FFRAG	*Favia fragum*	11	90.91	95	93.68	3.84	131	41.22	0.38	128	56.25	0.00
		MANN	*Montastrea* spp. complex	489	72.60	858	58.28	2.16	971	33.47	31.92	690	46.38	4.05
		MCAV	*Montastrea cavernosa*	238	63.87	386	26.17	1.15	431	10.44	12.65	577	18.89	1.79
	Meandrinidae	DCYL	*Dendrogyra cylindricus*	15	100.00	0	-	-	7	14.29	38.57	1	0.00	0.00
		DSTOK	*Dicocoenia stokesii*	10	30.00	10	10.00	0.50	10	10.00	11.00	15	26.67	3.33
		MMEAN	*Meandrina meandrites*	92	41.30	185	43.78	5.04	209	37.80	15.36	204	41.18	1.35
	Mussidae	IRIG	*Isophyllastrea rigida*	1	100.00	0	-	-	0	-	-	0	-	-
		MANG	*Mussa angulosa*	2	100.00	4	0.00	0.00	2	50.00	5.00	-	-	-
		MYCET	*Myceptophillia* spp.	2	0.00	3	33.33	0.00	4	0.00	0.00	5	0.00	0.00
		SCOLY	*Scolymia* sp.	1	0.00	0	-	-	0	-	-	0	-	-
	Pocilloporidae	MDEC	*Madracis decactis*	59	8.47	116	12.93	0.93	286	2.80	8.17	223	7.62	0.98
		MMIR	*Madracis mirabilis*	55	20.00	74	4.05	4.19	94	0.00	10.63	97	2.06	0.10
	Poritidae	PAST	*Porites astreoides*	1084	65.59	853	12.66	2.85	1553	5.54	7.51	1309	4.97	0.90
		PFUR	*Porites furcata*	0	-	0	-	-	0	-	-	17	0.00	0.59
		PPOR	*Porites porites*	250	72.80	138	26.81	16.74	268	2.24	31.48	162	3.70	1.00
	Siderastreidae	SRAD	*Siderastrea radians*	20	70.00	18	72.22	5.00	6	33.33	0.83	13	100.00	4.62
		SSID	*Siderastrea siderea*	318	66.04	238	76.47	2.49	333	42.04	15.80	337	68.25	3.71
Hydrozoa	Milleporidae	MALC	*Millepora alcicornis*	83	87.95	41	26.83	9.51	68	4.41	22.90	41	7.32	4.15
		MCOM	*Millepora complanata*	40	90.00	23	0.00	46.09	40	0.00	25.93	45	0.00	5.56
		MSQU	*Millepora squarrosa*	58	75.86	12	8.33	90.83	111	0.00	96.40	0	-	-
	Stylasteridae	SROS	*Stylaster roseus*	3	0.00	22	0.00	0.00	8	0.00	0.00	14	42.86	0.00

Discussion

Sea water temperatures and accumulated heating stress through the summer and fall of 2005 were unprecedented for the Caribbean region (Wilkinson and Souter 2008). Conditions in Barbados were no exception and resulted in the worst coral bleaching event ever recorded in this region (Oxenford et al. 2008). Similar claims have been made for other islands of the Lesser Antilles, where the hotspot developed and remained for many months (see NOAA/NESDIS archived database; Wilkinson and Souter 2008).

Although the initial mortality impact on corals was low in Barbados compared with many other locations (Oxenford et al 2008), prolonged bleaching resulted in delayed mortality with high losses of live coral, comparable to elsewhere in the Lesser Antilles (Bouchon et al 2008; Woody et al 2008).

The highest losses of live coral occurred 9 to 10 months after the initial onset of the bleaching event. Corals in Barbados did not appear to die as a result of any described syndrome. Incidence of coral disease was negligible throughout the surveys, in contrast with other reports from the Lesser Antilles (e.g. French West Indies and the US Virgin Islands) where infections were reported to be the primary cause of early bleaching induced coral mortality (Miller et al. 2006; Muller et al. 2008; Bouchon et al. 2008).

Differences in mortality estimates between the two indices used in this study and the delayed onset of mortality in Barbados compared with elsewhere serve to illustrate the importance of standardising methodologies and extending the time-frame over which reefs are surveyed when drawing conclusions about the impact of an event and/or making comparisons among geographically separated sites.

The difference among species in their bleaching and mortality response to the hot water event was marked, but relatively consistent among the few detailed reports from the region with *Agaricia agaricites*, *Colphyllia natans* and *Montastrea annularis* showing particularly high mortality (Woody et al. 2008). Differences in behavioural response such as the ability to increase the level of heterotrophic feeding (Grottoli et al. 2006), and in coral host and symbiont genetics (Berkelmans and van Oppen 2006) certainly contribute to the variation in resistance among species, but are not well understood.

This event marks the most extreme coral bleaching experienced by Barbados reefs on record and corroborates the prediction of more frequent and more severe mass coral bleaching events in the Caribbean with the current trend of global warming (e.g. McWilliams et al. 2005). The study also represents the first quantitative examination of mortality response to mass bleaching in Barbados and indicates the severe ecological impact with cumulative losses of 42.4% and 31.3% of live coral cover from deep and shallow reefs respectively. High losses in live coral cover have significant social and economic implications for Barbados, which relies on healthy reefs for marine-based tourism, coastal protection, and small scale reef-associated fisheries (NCSD 2004). The high coral mortality outcome certainly emphasises the vulnerability of tropical small island developing states (SIDS) like Barbados, with a high reliance on healthy marine ecosystems, to the progression of global warming. It further emphasises the urgency for improved national conservation and coral protection measures to mitigate local stressors and improve reef resilience, whilst continuing to lobby for international action to reduce climate change.

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