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BLEACHING SUSCEPTIBILITY AND GROWTH CHARACTERISTICS OF *PORITES LUTEA* FROM THE ANDAMAN SEA, SOUTH THAILAND

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ABSTRACT: This paper reports the results of an initial follow-up investigation on the growth characteristics and bleaching susceptibility of the massive coral *Porites lutea*, together with an examination of the differences in growth rates between severely bleached (all virtually white in colour) and partially bleached (pale) colonies following the extensive seawater warming and bleaching event around Phuket in 2010. Prior to bleaching (Dec 2008–Nov 2010), linear extension and polyp density did not differ between colonies which later suffered severe compared to partial bleaching. In the post-bleaching period (Jun 2010–Jan 2011), linear extension rates were significantly reduced in both partially and fully bleached corals, compared with pre-bleaching values. Linear extension fell dramatically by 27.6% (± SE 3.0%) in severely bleached compared to 7.2% in partially bleached (± SE 5.8%) colonies.

INTRODUCTION

In late April of 2010, the coral reefs around Phuket, South Thailand suffered a widespread and severe seawater temperature bleaching event. Shallow water (~2–3m at mid-tide) instantaneous hourly temperatures occasionally reached >33 ºC, well above the average summer maximum of 31 ºC (Tudhope *et al*., 1992), with warming extending for ~7 weeks between April–June around Phuket (Fig. 1). The effects of such bleaching events on scleractinian corals – ranging from reduced growth rates, biomass, photosynthetic rates, reproductive output, to total mortality – have previously been extensively documented (see review in Baker *et al*., 2008). The response to bleaching events can vary greatly between coral taxa, with 'sensitive' types (e.g. *Acropora*, *Pocillopora*) widely reported to suffer from significant mortality rates while more 'resilient' ones (e.g. *Diploastrea*, *Porites*) show high survival and recovery rates (Baird and Marshall, 2002, McClanahan and Maina, 2003, Baker *et al*., 2008). However, susceptibility to bleaching within taxa is less well documented, with such intraspecific differences in response attributed to the possibility of varying assemblage/s of symbiotic zooxanthallae hosted, or genetic variation (by the coral animal and/or its symbiotic zooxanthallae) (Jokiel and Coles 1990; Glynn *et al.* 2001).

During the 2010 bleaching episode, varying degrees of bleaching between adjacent colonies of *Porites lutea* within the same reef were noted, similar to earlier observations by Tudhope *et al.* (1992) during the extensive bleaching event of 1991 at Phuket. It has since been found that *P.lutea* around Phuket almost specifically hosts the clade C15 zooxanthallae (LaJeunesse *et al*., 2010), leading to the possible rationale that the variation in bleaching seen may be due to differences in micro-environment, or is perhaps genetically controlled by either host and/or algal symbionts. Tudhope *et al*. (1992) had speculated a possible relationship between the large variation in growth rates between adjacent massive *Porites* colonies, as an expression of genetic variation or colony 'health' and bleaching susceptibility. Tudhope *et al*. (1992) found no significant differences in growth characteristics between bleached and unbleached colonies during pre-bleaching years, though they noted from qualitative observations of alizarin stain uptake that unbleached corals were growing faster than extensively bleached corals during the bleaching event. The present paper represents a preliminary follow-up investigation of growth characteristics and bleaching susceptibility of the massive coral *P. lutea*, as well as an examination of the differences in growth rates

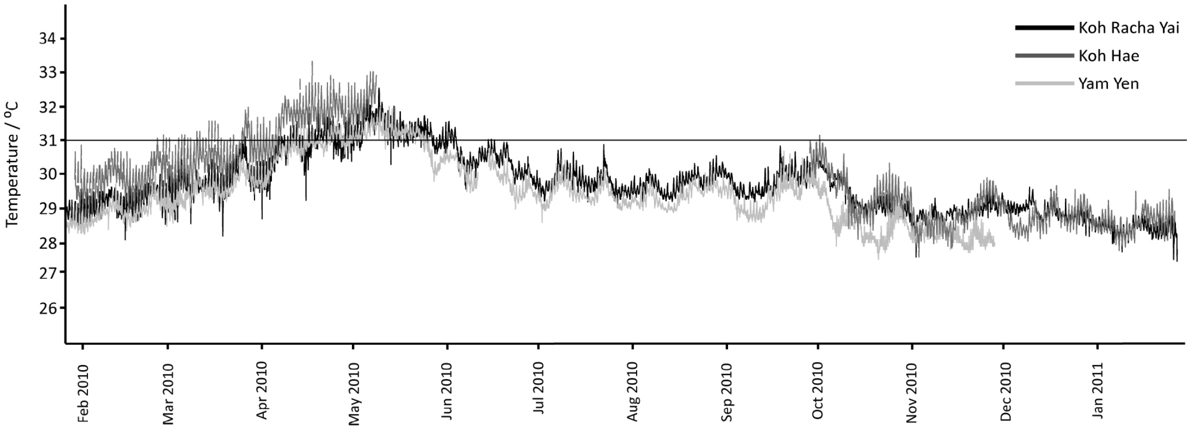

Figure 1. Instantaneous hourly measurements of shallow sea temperatures (depth 2–3m at mid-tide) at three sites around Phuket, South Thailand – Yam Yen (07°48.16'N, 098°24.17'E), Koh Hae (07°44.47'N, 098°22.24'E) and Koh Racha Yai (07°36.42'N, 098°22.14'E)

between severely bleached and partially bleached colonies following the bleaching.

MATERIALS AND METHODS

A total of 20 *Porites lutea* colonies were tagged within the bleaching period in 11–14 Jun 2010, and later sampled between 26–30 Jan 2011 from three reefs around Phuket – Yam Yen (YY), Koh Hae (KH), and Koh Racha Yai (KR) (Fig. 2). At each site, colonies in a size range of ~1–2m diameter and at a depth of ~2–3m were randomly selected from a stretch of reef 30–50m wide. A 5cm diameter core was taken from the top of each colony for analysis of growth characteristics. Of the 20 colonies, 10 were severely bleached (virtually all white in colour) and 10 were partially bleached (evenly pale; scoring 2–3 out of 6 against the CoralWatch coral health chart; Siebeck *et al.* 2008). Subsequent microscopic examination of corallite structure revealed two colonies that were grossly different from the rest and these were excluded from further analyses. Several of the colonies (2 of the severely and 3 of the partially bleached) had previously been stained with Alizarin red S on 25 Jan 2009, and provided a suitable reference to validate the fluorescence banding pattern used here to delineate growth increments. Linear extension rates were obtained using similar techniques described in Tudhope *et al.* (1992) for the 'normal' growth period Dec 2009–Nov 2010 (pre-bleaching period) and the 8–month period post-bleaching in Jun 2010–Jan 2011 (post-bleaching period).

Statistical analyses

An unbalanced 2-way analysis of variance (ANOVA) was used to detect differences in pre-bleaching and post-bleaching linear extension rates between bleaching groups (severely vs. partially) and across study sites. Between group differences for polyp density, and pre- to post-bleaching percentage change in linear extension were examined using two-tailed T-tests. Assumptions of normality and homogeneity of variance of data were investigated using the Kolmogorov-Smirnov and Bartlett's tests respectively. The Ryan F-test (Welsch, 1977) was used to investigate any post-hoc differences.

RESULTS

All linear extension data sets met the assumption of homogeneity of variance, but some

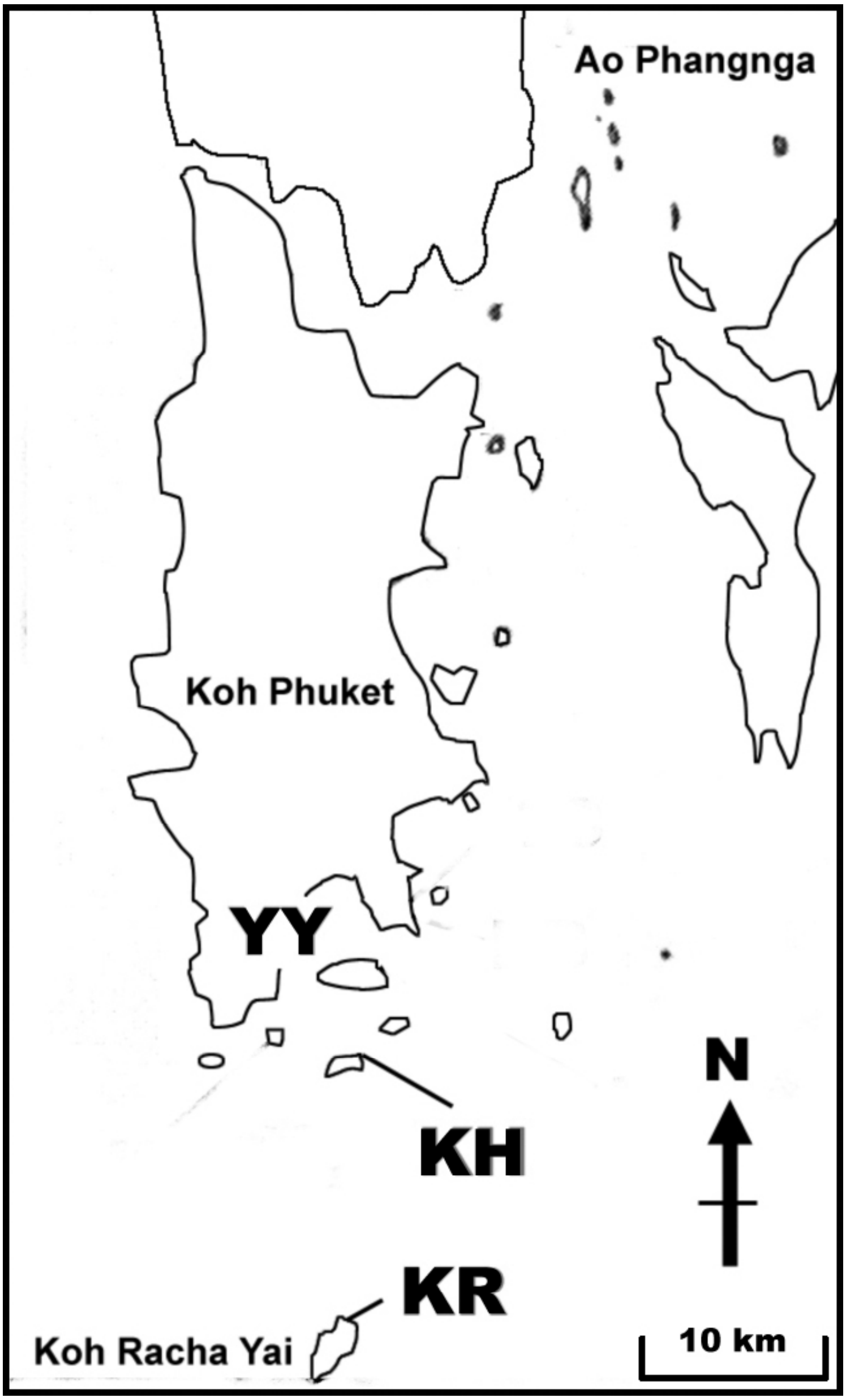

Figure 2. Location of the study reefs around Phuket, South Thailand – Yam Yen (YY), Koh Hae (KH) and Koh Racha Yai (KR)

data were non-normal. Given the robustness of ANOVA to this latter assumption (Underwood, 1997), it was decided to continue to use a 2-way ANOVA. For the pre-bleaching linear extension rates, there was no interaction between bleaching group and site treatments ($F_{[2,12]}$=2.89, *P*=0.94); extension rates between the severely and partially bleached colony groups did not differ ($F_{[1,12]}$=0.095, *P*=0.76); whilst between study sites, KR had a lower extension rate compared to YY or KH, which did not differ from one another ($F_{[2,12]}$=5.39, *P*=0.021, Ryan F-test *P*<0.05). Post-bleaching, there was again no interaction ($F_{[1,6]}$=2.68, *P*=0.15) with the severely bleached colony group suffering significantly lower extension rates compared to the partially bleached group ($F_{[1,6]}$=16.03, *P*=0.007). Site differences in extension rates remained ($F_{[2,6]}$=6.67, *P*=0.03) but post-hoc comparisons were not possible due to the limited sample numbers for some of the data. The percentage change in average monthly linear extension rates from pre- to post-bleaching was significantly larger (–27.6 ± SE 3.03%) in the severely bleached colony group (two-tailed T-test T=–3.81, *P*<0.01) compared to the partially bleached (–7.2 ± SE 5.8%) (Table 1). Polyp densities did not vary significantly between bleaching groups (two-tailed T-test T=0.10, *P*=0.92).

Monitoring carried out in Sept. 2010 showed that all colonies at KR and KH and partially bleached colonies at YY had regained colour ~3 months post-bleaching, though most were still considered pale (score of 3–4 on the CoralWatch coral health chart) compared to their 'normal' coloration (score of 5). Severely bleached colonies at YY still showed patches of white. No whole colony mortality was observed at this stage, with partial mortality of up to 30% noted only at YY. By Jan 2011, 80% of the 20 colonies tagged survived, of which ~44% showed no significant mortality (<5%) (Table 1). All 4 colony deaths reported occurred at YY.

DISCUSSION

The current study found a significant difference in the post-bleaching linear extension rates of severely (1.13 ± 0.06cm) vs. partially bleached colonies (1.47 ± 0.29cm) that is consistent with previous observations of adverse effects of bleaching on skeletogenesis (Goreau and Macfarlane 1990;, Leder *et al*., 1991; Tudhope *et al*., 1992; Mendes and Woodley, 2002). Although post-bleaching linear extension rates for the current study were obtained by averaging an 8-month period, we assume that rate of extension through a 'normal' year is linear and have no reason to believe that the measured decrease in growth rate post-bleaching is an artifact of changing linear extension rates through an annual cycle of growth. Tudhope *et al*. (1992) reported calcification to have all but ceased during a 3-week period immediately following the 1991 bleaching event around Phuket. During the Caribbean-wide bleaching event of 1987–1988, Goreau and Macfarlane (1990) and Leder *et al*. (1991) both reported a two-thirds reduction in the extension rate of bleached colonies of *Montastraea annularis* compared to unbleached colonies in Jamaica and Florida respectively. Mendes and Woodley (2002) reported a similar trend during the 1995–1996 bleaching events around Jamaica, with a reduction in extension rates of ~40%.

The current study found similar results to those of Tudhope *et al*. (1992) in that there were no significant differences in linear extension rates in the pre-bleaching period between colonies which subsequently showed 100% or partial bleaching. The lack of relationship between growth characteristics and bleaching susceptibility might be partly attributed to the generally resilient nature of massive *Porites* species to bleaching, which has been observed to resist bleaching better and suffer significantly less bleaching-induced mortality compared to other species (Gleason, 1993; Hoegh-Guldberg and Salvat, 1995; Baird and Marshall 2002, McClanahan and Maina 2003, Baker *et al*., 2008). The present study reports a colony death rate of only 20% for the *P. lutea* sampled, all of which occurred at YY – the most turbid of the 3 study sites and one which was subject to high sedimentation (Scoffin *et al.*, 1992; Tanzil *et al*., 2009). Additionally, as of Jan 2011, all remaining live colonies had regained 'normal' colouration with coral tissue growing over dead surfaces. This

Table 1. Growth data from severely and partially bleached colonies at the 3 study sites prior to and following the 2010 bleaching event. All colonies had regained colour by Jan 2011 with varying degrees of mortality (NM=not significant (<5%) mortality, PM=partial mortality, M=whole colony mortality)

	Sample	Condition (Jan 2011) Jan 2011	Post-bleaching LE rate/cm Jun 2010–Jan 2011	Post-bleaching LE rate/cm Ave. monthly LE	Pre-bleaching LE rate/cm Dec 2008–Nov 2009	Pre-bleaching LE rate/cm Ave. monthly LE	%change in monthly LE post vs. pre bleaching	Polyp density/cm^2
Severely bleached (white)	KR-A	PM	8.53	1.07	16.15	1.35	-20.77	106
	KR-P6*	PM	-	-	14.47	1.21	-	60
	YY-A	M	-	-	20.85	1.74	-	117
	YY-B	M	-	-	24.23	2.02	-	80
	YY-C	M	-	-	22.55	1.88	-	-
	YY-P9*	M	-	-	24.19	2.02	-	-
	KH-A	PM	8.46	1.06	19.64	1.64	-35.39	71
	KH-D	NM	10.85	1.36	21.97	1.83	-25.92	64
	KH-F	NM	8.18	1.02	17.11	1.43	-28.29	72
Paritally bleached (pale)	KR-P2*	NM	9.04	1.13	12.54	1.05	8.13	85
	KR-P9*	NM	11.53	1.44	20.04	1.67	-13.70	90
	KR-B	NM	11.17	1.40	19.45	1.62	-13.86	108
	YY-D	PM	-	-	19.83	1.65	-	85
	YY-P8*	PM	8.6	1.08	17.46	1.46	-26.12	85
	KH-B	NM	14.54	1.82	23.22	1.94	-6.07	57
	KH-C	NM	14.06	1.76	20.45	1.70	3.13	63
	KH-E	PM	13.34	1.67	20.47	1.71	-2.25	69
	KH-G	PM	-	-	19.17	1.60	-	-

*Colonies stained with Alizarin Red S   LE=linear extension high survival rate of *P. lutea* following bleaching could perhaps be negating any selection pressure/s for colonies of particular growth characteristic/s.

The lack of sensitivity of growth characteristics as an indicator for bleaching susceptibility can also be seen in the disparity between the degree of reduction in linear extension and degree of bleaching. Fitt *et al*. (2000) showed that bleached corals would need to lose >50% of their zooxanthallae in order to appear visibly pale. Despite potentially suffering significant loss in zooxanthallae, post-bleaching extension rates of the pale colonies examined in the current study are not markedly different from 'normal' years, reduced only by an average of ~7% compared to the ~28% decrease seen in severely bleached colonies (Table 1). Previous studies have also documented a similar lack of sensitivity in linear extension and polyp density of massive *Porites* to other environmental stresses, such as eutrophication and sedimentation (Dodge and Brass 1984, Brown *et al.* 1990, Chansang *et al.* 1992, Edinger *et al.* 2000). Although the current study was not able to account for variation in all growth characteristics (e.g. bulk density, derived calcification, corallite morphology) between the severely and partially bleached groups across pre- and post- bleaching periods, we can conclude that linear extension rates and polyp densities are not sensitive enough parameters to be suitable indicators of bleaching susceptibility and stress.

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