Reduced trends of annual growth of Indonesian *Porites* over ~20 years

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Abstract
Annual coral growth bands serve as an important indicator for detecting the response of coral reefs to environmental change, through the study of coral growth chronologies and geochemical analysis of the skeleton. In this study, we analyzed the annual linear growth rates of 10 *Porites* coral colonies from Indonesia. Samples were taken from Natuna (South China Sea), Wakatobi (Banda Sea), Maumere (Flores Sea) and Biak (Indo-West Pacific Sea). Each location, with the exception of Natuna, was represented by three colonies. Annual growth rates (linear extension) were determined from the annual high and low density banding patterns observed using X-ray techniques. Coral XDS was used to calculate annual linear extension. Average linear growth of *Porites* colonies ranged from 0.4 cm to 1.4 cm/year over the past ~20 years. Seven of the ten *Porites* from Indonesia have displayed reduced linear growth over the past~20 years. However, three colonies showed increasing linear growth, for example WDB (North Eastern Biak), SRM (Southern Biak) and MMR4 (Maumere coast). At the Wakatobi site, all three *Porites* colonies showed reduced linear growth.

Key words: Coral Porites**,** Linear growth, SST, Indonesia

Introduction

Indonesia is an archipelago country well known for the rich marine biodiversity of its coral reefs (Wallace et al 2003). Coral reefs are home to many different marine organisms, sea plants, and animals. Thus, healthy living corals play an important role supporting the economy of Indonesia. Corals are sensitive to the environmental changes of the ambient waters, particularly changes in sea surface temperature (SST). SST anomalies during El Niño and Indian Ocean Dipole events coincided with death of Mentawai corals (Abram et al., 2003) and bleaching of Seribu corals (Suharsono 1998, Brown & Suharsono 1990).

Corals precipitate carbonate ions (CO_3) from seawater to build their $CaCO_3$ skeletons. The rate of coral calcification is calculated from the average coral density and annual linear growth (Felis & Pätzold 2004; Helmle et al., 2002; Lough and Cooper 2011). Some recent studies provide evidence of recent declines in massive coral calcification rates that may be related to recent changes in SSTs (e.g. De'ath et al., 2009; Cantin et al., 2010; Tanzil et al 2009; Cooper et al., 2008). A study of coral linear growth from Seribu Islands Indonesia suggests that during the last 20 years warming SSTs have negatively affected coral growth by about 8-9% (e.g. Cahyarini, 2008; Purnamasari et al, 2009). Offshore corals have also been influenced by changes in SST (Purnamasari et al., 2009).

In this study, linear growth rates of *Porites* corals from Natuna islands, Maumere, Biak and Wakatobi were analyzed. Trends of coral linear growth were compared with annual variations of SSTs.

Material and Methods

In this study, we used *Porites* coral from Natuna Islands, Maumere, Biak and Wakatobi (Figure 1). *Porites* usually grows about 1-2 cm/year. Massive *Porites* corals were cored in 2011 using a pneumatic drill powered by scuba tank. Cores were 3 cm in diameter and obtained in lengths of 30 cm. Coral cores were cut into 5 mm thick slabs and rinsed using an ultrasonic bath. Coral slabs were then X-rayed and the digital image used as input to the Coral X-radiograph Densitometry System (Coral XDS).

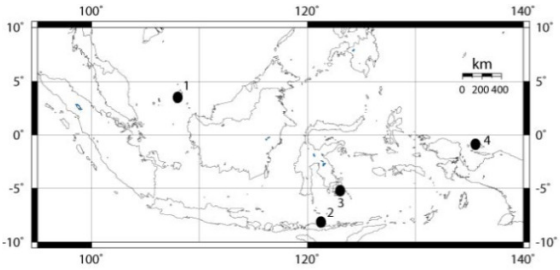

Figure 1. Study area and coral sites: 1. Natuna, 2. Maumere-Flores, 3 Wakatobi-Sulawesi Tenggara, 4. Biak-Papua.

Coral *XDS* from NSUOC (National Coral Reef Institute Nova South Eastern University Oceanographic Center) (http: // www. nova. edu/

ocean/ coralxds/) was used to calculate annual linear extension in each core (Helmle et al., 2002). These quantities are determined from the annual high-density and low-density bands. In this study, we used the extension/luminance mode of CoralXDS to measure annual linear extension. This mode requires only a coral X-ray image and knowledge of the scaling parameter (pixels per centimeter) used for the image.

Annual linear extension rates were compared to annual SST obtained from the Extended Reconstructed Sea Surface Temperature (ERSST) dataset (Reynold et al., 2008; Xue et al., 2003) version 3b.

3. Results and Discussion

3.1 *Porites* coral linear growth

Annual linear extension rates obtained from the 10 coral cores were between 59 years (BSN2) and 10 (FLR1) years in length (Table 1). For the common time period, 1993-2011, coral linear extension rates varied between 0.7 and 1.8 cm/yr (Table1). Figure 2 shows the average coral growth, which ranges from 0.59 to 1.33 cm/yr for the period of 1993-2011.

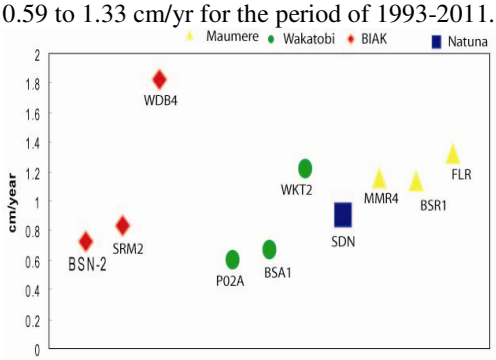

Figure 2. The average of linear growth rate of *Porites* corals during the period 1993-2011

3.1.1 Natuna Islands

Based on annual banding analysis, the chronology of SDN core extends from 1973 to 2011 (Figure 3). The linear growth rate is about 0.96±0.23 cm/year. The decreasing (not significant) trend of annual linear growth of SDN coral is shown for the period 1973-2011 (i.e. 2 cm in 10 yrs) (Figure3).

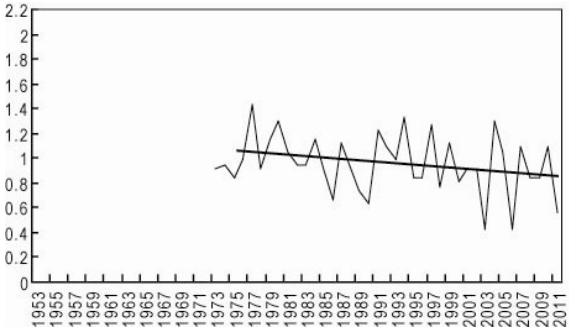

Figure 3. Annual variation of linear growth of *Porites* coral from Sedanau (SDN) Natuna Islands showing decreasing trend over the period 1973-2011.

3.1.2 Maumere-Flores Nusatenggara Timur

Three *Porites* cores were analyzed from Maumere bay (Table 1). BSR1 (significant) and FLR1 (not significant) corals show a decreasing trend of annual linear growth rate. Decreasing linear growth of BSR1 in 19 years (i.e. for the period of 1992-2011) is about 0.43 cm, while in 9 years (for the period 0f 2002-2011) decreasing FLR1 is 0.22 cm. MMR4 shows a non-significant increase of 0.08 cm in 19 years (i.e. 1992-2011) (Figure 4).

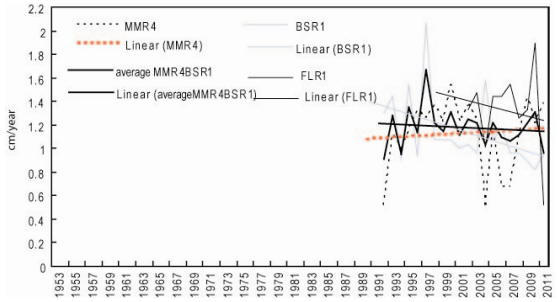

Figure 4. Annual variation of linear growth of *Porites* corals from Maumere and the linear trend: MMR4 (dashed line), BSR1 (grey line), FLR (dark line) and average of BSR1 and MMR4 (dark bold line).

3.1.3 Biak-Papua

Three coral cores from Biak Island were analyzed for annual linear growth (Table 1). WDB4 (not significant) and SRM2 (significant) corals show an increasing trend of annual linear growth rate, while BSN2 coral shows a significant decreasing trend (Figure 5). The average linear growth rate of WDB4 is faster than Biak corals

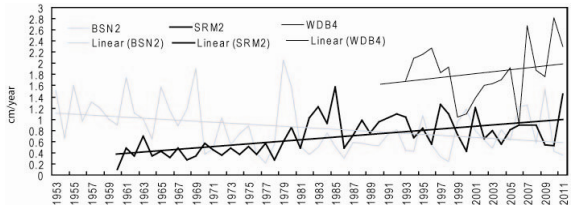

Figure 5. Annual variation of linear growth of *Porites* coral from Biak, BSN2 (grey line), SRM2 (black bold line) and WDB4 (black line) and bold lines show the linear trend.

3.1.4 Wakatobi-Sulawesi Tenggara

Three coral cores from Wakatobi sites were analyzed for linear growth (Table 1). Significant decreasing coral growth during their record period was shown by core P02A (Figure 6), BSA1 coral shows a non significant decrease while WKT2 shows a non significant increase.

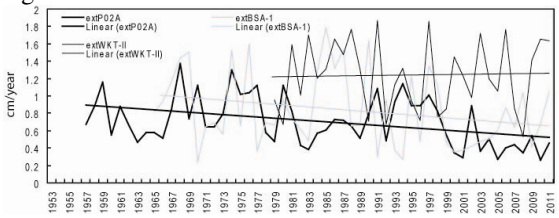

Figure 6. Variation of annual linear growth rate of Porites coral from Wakatobi i.e P02A (black bold line), BSA1 (grey line) and WKT2 (black thin line) and its linear trend (bold line).

3.2 Linear growth rate of *Porites* coral and sea surface temperature.

Based on linear growth rate analysis of *Porites* coral from Natuna, Wakatobi, Maumere and Biak the average of linear growth rate ranges from 0.7 cm/year to 1.8 cm/year (Table 1).

Table 1. The average of *Porites* coral growth rate and correlation coefficient between linear growth and SST (confidence level of 95%).

Coral site	Core ID	Period	Mean growth rate ± sd (cm y^{-1})	R value of SST vs. linear growth
Natuna	SDN	1973-2011	0.96 ± 0.23	R=0.05
Maumere	MMR4	1992 – 2011	1.12 ± 0.30	R= 0.15
	FLR1	2002 – 2011	1.33 ± 0.36	R =0.51
	BSR1	1992 – 2011	1.14 ± 0.30	R=0.43
Wakatobi	**P02A**	**1957-2011**	**0.71 ± 0.30**	**R= 0.40**
	BSA1	1965-2011	0.83 ± 0.40	R= 0.26
	WKT2	1979-2011	1.24 ± 0.40	R= 0.15
Biak	WDB4	1993-2011	1.82 ± 0.50	R= 0.04
	SRM2	**1960-2011**	**0.70 ± 0.30**	**R= 0.26**
	BSN2	**1953-2011**	**0.84 ±0.40**	**R=0.32**

Table 2. Trend of coral linear growth; values in bold are significant at 5% level.

Lokasi	Code	Slope	p-value
Biak	WDB4	+0.018	0.4119
	SRM2	**+0.012**	**<0.0001**
	BSN2	**-0.009**	**0.0057**
Wakatobi	**P02A**	**-0.007**	**0.0037**
	BSA-1	-0.008	0.0984
	WKT-2	+0.001	0.8907
Natuna	SDN	-0.005	0.1109
Maumere	MMR4	+0.004	0.7311
	BSR1	-0.023	0.0527
	FLR	-0.019	0.6555

Table 3. Trend of grid SST during period of 1992-2011; values in bold are significant at 5% level.

Location	Slope	p-value
Biak	+0.009	0.29
Maumere	+0.017	0.09
Wakatobi	+0.012	0.20
Natuna	**+0.018**	**0.05**

During the last 20 years linear growth rate shows a statistically significant decreasing trend in 3 of the 10 corals analysed here (Table 2). Significant increasing linear growth rate trend is found for the Biak, coral (SRM), while non significant increase was found in Wadibu coral (WDB4), and Maumere coral (MMR4). It requires further analysis to understand whether this trend is correlated with natural or anthropogenic factors. Natural factors such as changes in SST influence coral growth (De'ath et al., 2009; Cantin et al., 2010). Increasing SST above some optimum temperature has coincided with decreasing calcification in coral (De'ath et al., 2009; Cantin et al 2010). In this study, linear growth rate was compared with SST. The results show that in most locations SST significantly increased and coincided with decreasing coral linear growth (Figure7, 8). However, in some colonies (e.g. MMR4 (Maumere), WDB4 (Wadibu-Biak) and SRM2 (Biak)) show increasing

linear growth coinciding with increasing SST. However, in these locations, SST shows a non significant increasing trend (Table 3).

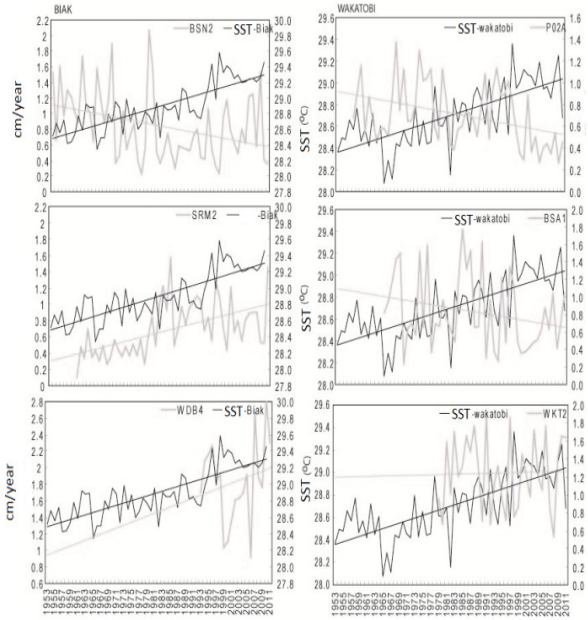

Figure 7. Comparison of annual sea surface temperature and linear growth trend of *Porites* coral from Biak (Left) and from Wakatobi (right). SST data is obtained from Extended Reconstructed Sea Surface Temperature (ERSST dataset) (Reynold et al., 2002; Xue et al., 2003).

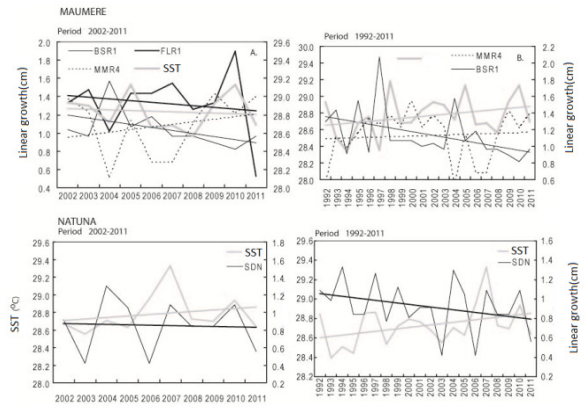

Figure 8. Comparison of sea surface temperature and linear growth trend of *Porites* coral from Maumere (upper) and from Natuna (bottom).

Correlations between annual coral linear growth (colony averaged for each coral site) and annual SST for the period of 1992-2011 shows that only the Wakatobi coral growth rates were significantly correlated with SST (R=0.50) (Table 4).

Table 4. Linear regression of linear growth (y) of averaged colonies and SST (confidence level 95% for all regression) for the period 1992-2011.

No	Location	Linear
1	Wakatobi	R= 0.50, $p < 0.05$
2	Maumere	R= 0.01, $p > 0.1$
3	Natuna	R=0.09, $p > 0.1$
4	Biak	R=0.1, $p > 0.1$

4. Conclusions

The average of linear growth rate of *Porites* coral from Natuna, Maumere, Wakatobi and Biak ranges from 0.7 to 1.82 cm/year. During the last 20 years the linear growth rate trend shows significant decreasing trend in 3 of the 10 and only one of the ten colonies shows a significant increasing trend. This study illustrates the complex responses of coral growth rates to environmental changes in Indonesia.

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