The Relationship between Temperature and Precipitation to Ba/Ca of *Porites lutea* in Andaman Sea

ความสัมพันธ์ระหว่างอุณหภูมิและน้ำฝนต่อ Ba/Ca ในปะการัง *Porites lutea* ในทะเลอันดามัน

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ABSTRACT

Corals are very sensitive to climate change and surrounding environment change. Scientists use coral to study climate and environmental conditions from the past. This study quantified Ba/Ca ratios of *Porites lutea* from Racha Island in Phuket Province, Andaman Sea. The aim of this study is to analysis the variability and correlation between of Ba/Ca ratio of *Porites lutea* and historical climate factors consisting of temperature and precipitation for 58 years, between 1952-2009. Coral banding alternates between white band and dark band which from growth during summer season and rainy season respectively. Analysis of Ba/Ca ratio found that Ba/Ca ratios have positive correlation with temperature and negative correlation with precipitation. This result may suggest that high temperature can cause stress in coral, resulting in higher Ba accumulation. Since southern Thailand always has heavy rainfall almost year round, it is more difficult to correlation precipitation to Ba/Ca. Higher precipitation in rainy season may cause dilution of the sediment which may result in lower Ba in water, and thus lower Ba accumulation in corals in some cases.

บทคัดย่อ

ปะการังมีความไวมากต่อการเปลี่ยนแปลงของสภาพภูมิอากาศและสภาพแวดล้อมโดยรอบ มีนักวิทยาศาสตร์หลายท่านนำปะการังไปใช้ในการศึกษาเกี่ยวกับสภาพภูมิอากาศ และสภาพสิ่งแวดล้อมที่ผ่านมา ในการศึกษานี้เราได้ทำการเก็บตัวอย่างปะการัง *Porites lutea* จากเกาะราชา จังหวัดภูเก็ตในทะเลอันดามัน จุดประสงค์คือ ศึกษาความแปรปรวนและความสัมพันธ์ระหว่างอัตราส่วนของ Ba/Ca กับปัจจัยทางอากาศ ประกอบด้วยอุณหภูมิ และปริมาณน้ำฝนเป็นระยะเวลา 58 ปี ตั้งแต่ปี 1952-2009 ทั้งนี้สามารถแบ่งความหนาแน่นของแถบปะการังได้ 2 ส่วนคือ ส่วนสีขาวกับสีดำที่เกิดขึ้นในช่วงฤดูแล้ง และฤดูฝน ตามลำดับ และได้ทำการวิเคราะห์อัตราส่วน Ba/Ca พบว่าแปรผันตรงกับอุณหภูมิ และแปรผกผันกับปริมาณน้ำฝน ซึ่งคาดได้ว่าอาจเนื่องมาจากช่วงที่อุณหภูมิสูงนั้นทำให้ปะการังเกิดความเครียด และทางใต้ของประเทศไทยมีฝนตกหนักเกือบตลอดทั้งปี ในช่วงปริมาณน้ำฝนสูงขึ้นจึงอาจทำให้เกิดการเจือจางของตะกอน ส่งผลให้มี Ba ในน้ำและในแนวปะการังลดลงได้

Keywords: Climate change, Rainfall, Sediment

คำสำคัญ: การเปลี่ยนแปลงสภาพภูมิอากาศ ปริมาณน้ำฝน ตะกอน

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Introduction

Climate change is a major environmental problem occurring worldwide. It has been caused by rising fossil fuels usage and land-use changes which led to increasing quantities of greenhouse gases into the Earth's atmosphere (Royal Society, 2014). The main characteristics of climate change includes an increase in average global temperature (global warming) (Venkataramanan, Smitha, 2011), changing precipitation patterns (Dore, 2005), and an increase in ocean temperatures and ocean acidity (Royal Society, 2005). These phenomena affect the environment, socio-economics, water resources, agriculture, food security, human health, terrestrial ecosystems, biodiversity and coastal zones (UNFCCC, 2007).

Corals have been a part of the Earth's oceans for millions of years and are very sensitive to changes in climate and surrounding environment. When the coral grows, it creates annual bands (Lough, 2008). This is caused by the accumulation of $CaCO_3$, which crystalline couplets of high and low density bands represent the span of one year. Isotopic analysis of these density bands provides a sensitive reconstructive tool for paleoclimatology and paleoecology (Hill, 2010). The geochemical record contained in annual bands of coral can be used to reconstruct past climate variability at weekly, seasonal, inter-annual, decadal and even secular time-scales. (Francus et al., 2002; Horta-Puga, Carriquiry, 2012). Scientists can use coral to study past climate from the past hundreds or even thousands of years at high resolution.

One proxy to study these past climate conditions is coralline ratios of Ba/Ca (Horta-Puga, Carriquiry, 2012). In the part of Barium, it will be affecting to growth rate of coral as Ba^{2+} forms an isostructural carbonate, and likely substitutes for Ca^{2+} in coralline aragonite. Its skeletal concentration faithfully records the concentration of Ba^{2+} in the ambient ocean (Sinclair, McCulloch, 2004; Sinclair, 2005).

Phuket has experience more and more intense urbanization and tourist pressure over time which likely impact its environment (Panjarat, 2008; Sompongchaiyakul et al., 2011). This study aims to reconstruct environmental condition using Ba/Ca from coral colony from Phuket. Therefore can help understand how past environment and climate have changed over time in this area and it might be useful toward future planning against climatic and anthropogenic changes.

Objective of the study

To identify how climatic factors especially precipitation and temperature affect Ba/Ca in *Porites lutea* from Phuket, Thailand.

Materials and methods

1) Study area and coral sample collection

A living and healthy colony of the hermatypic coral *Porites lutea* were collected in during January 2011. The study site was selected on the outer of the Racha Island located in the Andaman Sea, Phuket, Thailand (Figure 1).

The hermatypic coral *P. lutea* was cored using a submersible hydraulic drill and coral cores were slabbed longitudinally into 1 cm thick slabs. Coral samples were washed in ultrasonicator to clean fine particles and then were dried in a laminar flow cupboard.

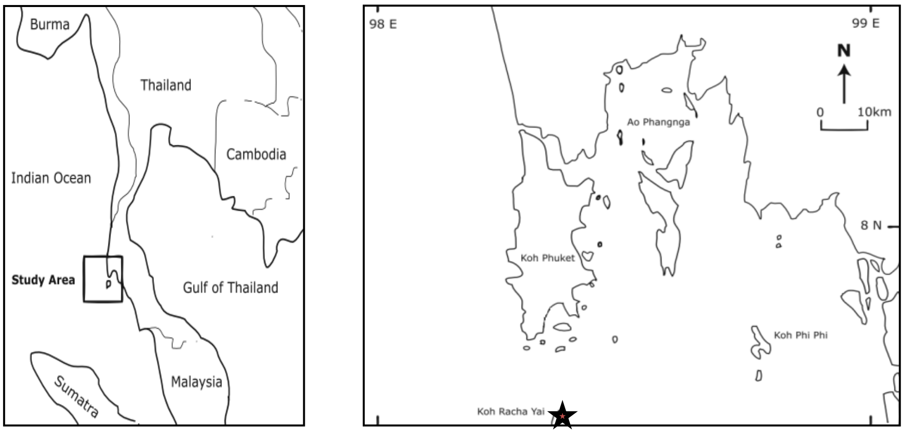

Figure 1 Coral sampling site in South Thailand.

2) Annual banding study

Cleaned coral samples were taken to X-ray and width measurement in order to determine density banding pattern of skeletal growth and age model of the coral colony by assigning calendar years to each band couplet when counting backwards from the band-couplet/year of collection (Figure 2).

3) Sample treatment

The correlation between annual banding of coral and the Ba/Ca coral record were obtained with a rotary tool equipped with a diamond-cutting wheel from each annual skeletal band. Afterwards, samples were cleaned with DI water for remove particulates and dried in lamina flow bench for 48 hours. Samples were crushed in acid cleaned agate mortar and pestle, sieves to produce size fraction between 297-550 µm, and thoroughly cleaned in oxidizing reagent (1:1 mixture of % H_2O_2:0.2 N NaOH) and 0.15 N HNO_3 to remove contamination from organic in the samples.

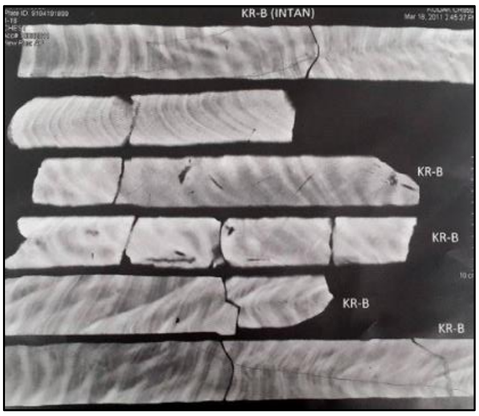

Figure 2 X-radiograph of the *Porites lutea* colony from the Racha Island located in the Andaman Sea, Phuket, Thailand.

4) Instrumental analysis

The Ba/Ca molar ratios were determined using an inductively coupled plasma atomic emission spectroscopy (ICP-OES) with a charge injection solid-state detector, coupled to an ultrasonic nebulizer. All instrumental parameters were adjusted for the highest sensitivity and stability. The instrument was calibrated by the intensity ratio method using the spectral lines with the best stability (i.e. Ba 455.4 and Ca 373.6 nm), and with standard solutions prepared with a known Ba/Ca molar ratio of 2.5-9.0 µmol/mol. To improve the accuracy of the Ba/Ca measurements a standard solution was measured every five samples and a correction factor was calculated for each sample bracketed between measured standard solutions in order to eliminate the effects of instrumental drift, similar to the method proposed by Schrag (1999). Routine instrument precision during the analysis was 4.0%.

5) Data analysis

Annually bands of *Porites lutea* will be studied from X-ray image. The correlation between Ba/Ca ratio and climate data of Phuket Province collected from Meteorological Department were used to analyze for the correlation by Microsoft Excel Software 2013 and correlation between Ba/Ca ratio and climate data were checked using linear regression by IBM SPSS Statistic 20.

Results and Discussions

The Ba/Ca ratio of *Porites lutea* collected from Racha Island, Phuket, the Andaman Sea have upward to trend and over approximately the past 58 years, encompassing the period from 1952-2009. X-ray radiography can be divided in two sessions, show alternating white band and dark band, which a couple of white and black bands represent 1 year of growth (Helmle, Dodge, 2010). White bands from during the summer season probably between December-March. White bands have an average Ba/Ca of 2.91 ± 0.72 µmol/mol, within the range 1.46-4.54 µmol/mol. Dark band happened during the rainy season, probably deposited between May-June. Dark band have average 3.15 ± 0.48 µmol/mol, within the range 2.28-4.26 µmol/mol.

Usually, Ba/Ca ratios has been used as an effective proxy for local precipitation and freshwater runoff (McCulloch et al., 2003; Horta-Puga, Carriquiry, 2012) temperature (Chen et al., 2011; Lea et al, 1989) and land use change (McCulloch et al., 2003). This study was conducted to compare the Ba/Ca ratios with environmental factors, including temperature and precipitation.

Relationships between Ba/Ca ratios of white band and temperature as well as precipitation in summer season (December-March) are shown in Figure 3. Ba/Ca ratios have positive correlation trend with temperature (Figure 4). Ba/Ca ratios have negative correlation trend with precipitation. Correlation of Ba/Ca ratio and temperature and precipitation are obvious especially in 1958, 1968, 1978, 1991, 1995 and 1998.

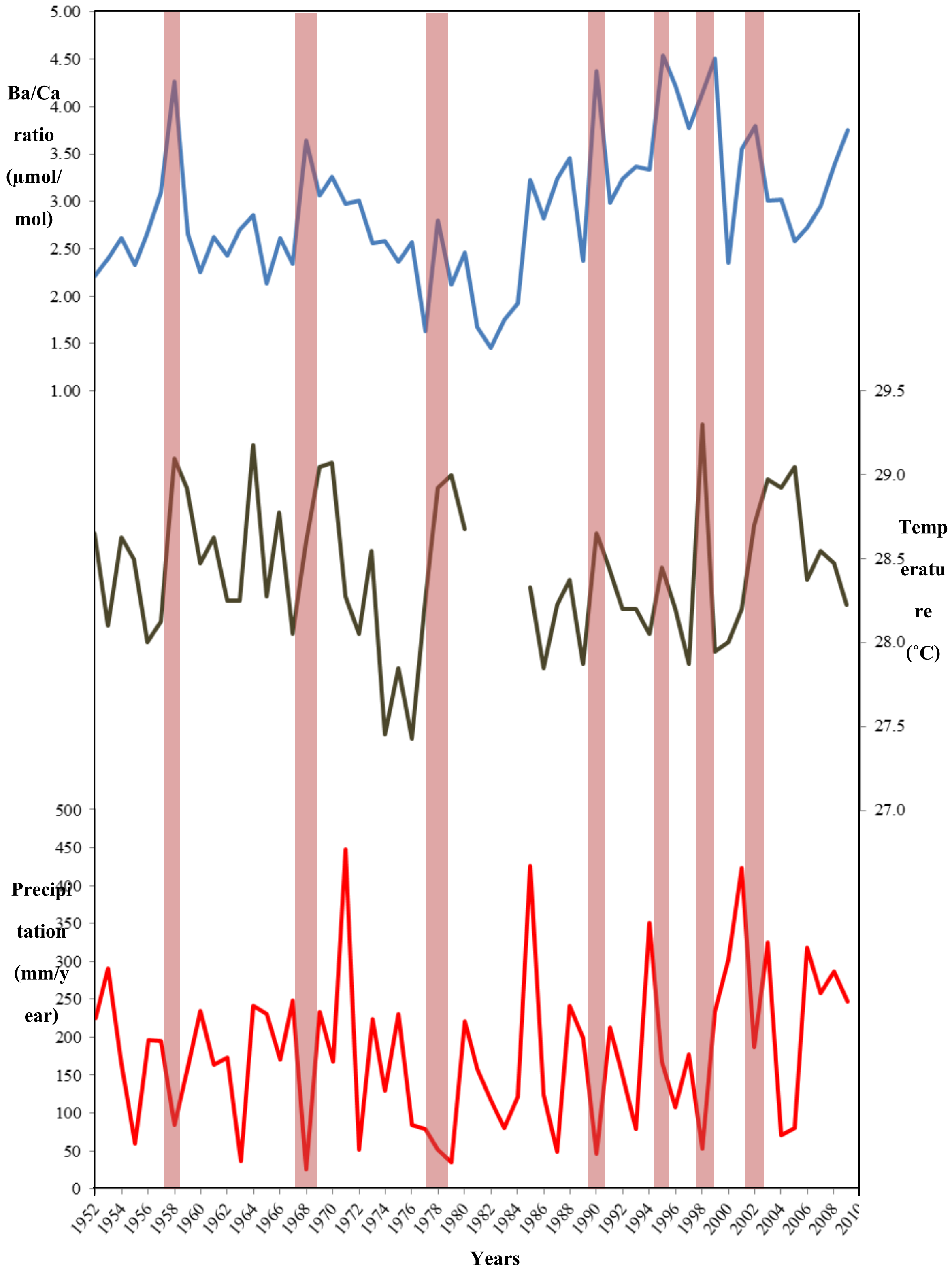

Figure 3 Time series for coral Ba/Ca ratios in white band of *Porites lutea* against temperature and precipitation in December-March since 1952 to 2009.

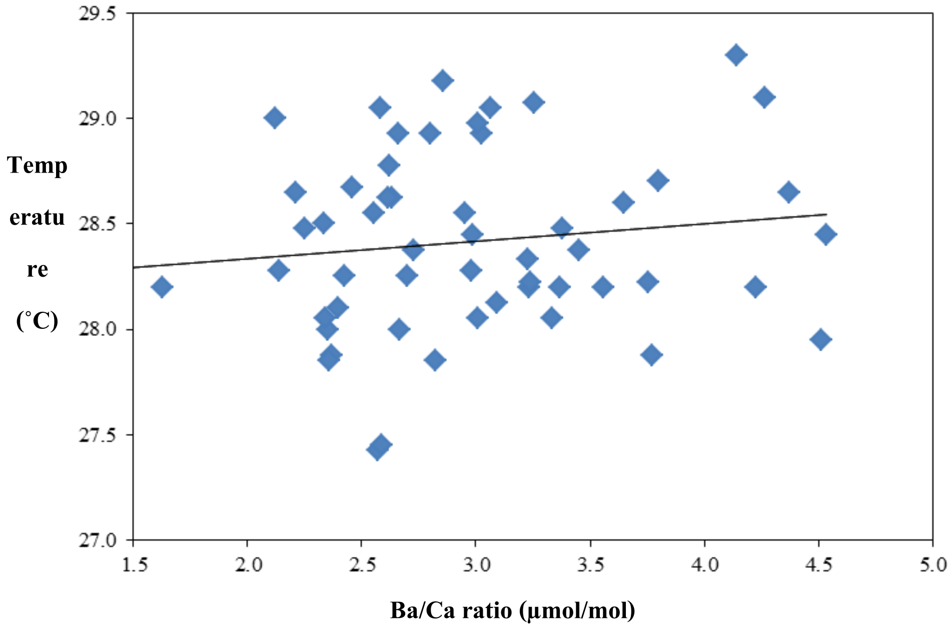

Figure 4 Plot of Ba/ Ca ratios in white band of *Porites lutea* against the temperature in summer season (December-March) since 1952 to 2009.

Relationships between Ba/Ca ratios of dark band and temperature as well as precipitation in rainy season (May-June) are shown in Figure 5. Ba/Ca ratios have positive correlation trend with temperature (Figure 6). Ba/Ca ratios have negatively correlation trend with precipitation. Correlation of Ba/Ca ratio and temperature and precipitation are obvious especially in 1957, 1959, 1970, 1979, 1987 and 1991.

In comparison to other studies, Chen et al. (2011) studied anomalous Ba/Ca signals associated with low temperature stresses in *P. lutea* from Daya Bay, northern south China Sea. They found that the maximum of Ba/Ca appeared to occur coinciding with the winter minimum temperature, suggesting that the anomalous high Ba/Ca signals were related to winter-time low temperature. They concluded that Ba/Ca ratio in relatively high-latitude corals could be a potential proxy for tracing the low temperature stress (11.5 ˚C) as the coral uptakes more Ba/Ca under chilling stress. Since Thailand is located in the equator area with high temperature, it is possible that high temperature stress may be affect coral growth rate and accumulation of trace element in coral. Coral reefs grow best in warm water (21-29 ºC) (Coral Reef Alliance, 2014). When the temperature is very high, coral may be under stress. Suharsono and Brown (1992) mention that the increasing of temperature 1 ºC in the summer dry season will cause coral bleaching. It may be possible that increasing of temperature 1 ºC may be make coral growth rate and accumulation of trace element change. It can be seen for the high temperature year such as in 1991, 1995, 1998 and 2003 were when El Niño occurred. El Niño can result in higher temperature than normal in Thailand. There were reports of coral bleaching during those years with high temperature indicating that they were under stress. Under such condition of stress, growth rate of coral may be decrease and Ba/Ca accumulation may be higher, as shown in this study. From figure 4, the relationship between temperature and Ba/Ca seems linear, so the stress from temperature rise seems gradual.

We did not see a threshold of temperature that completely disrupts the pattern of Ba/Ca accumulation within the range of data from this study. Future study to find the relationship between temperature and growth rate will help to further identify how much temperature is causing stress in the coral.

Ba/Ca ratios have negative correlation with precipitation with many Ba/Ca peaks (Figures 3 and 5). Thus low precipitation may affect the accumulation of Ba^{2+} in coral. Ba^{2+} is transported from land in river discharge to the ocean. Other studies usually identify that higher sediments, erosion or increase in precipitation can affect the amount of Ba^{2+} in the ocean, and thus in coral. Horta-Puga, Carriquiry (2012) studied coral Ba/Ca molar ratios as a proxy of precipitation in the northern Yucatan Peninsula, Mexico and found positive correlation between annual precipitation and Ba/Ca_{TC} time-series. Thus, Ba/Ca_{TC} ratio can be used as a proxy to reconstruct past precipitation. Likewise, the Ba/Ca_{TC} ratio can be used for the reconstruction of dissolved Ba in coastal seawater. In this study, the negative relationship between Ba/Ca and precipitation is observed. It should also be noted that there are various Ba/Ca peaks occurring during high precipitation. As southern Thailand always have heavy rain almost year round. In rainy season with higher precipitation, it may cause dilution of the sediment which may result in lower Ba in water, and thus lower Ba accumulation in corals in some cases. High erosion during drought may increase the amount of sediment in dry years.

In other aspects, we speculate that another major factor of the Ba/Ca ratios peaks is probably due to land use change or other environmental change that may affect Ba concentration.. The Ba/Ca profile from the coral in this study displayed a significant increase especially in 1981-2009. Such abrupt change may represent changes in environmental conditions such as land use change, population growth rate and freshwater management that may affect sediment supply. McCulloch et al. (2003) studied coral record and increased sediment flux to the inner Great Barrier Reef since European settlement at Havannah watershed in Burdekin River of Australia and found a significant increase in the Ba/Ca from baseline condition since around 1870 AD onwards. They identified that an increase in Ba/Ca is as a result of European settlement in Australia which changed land use practices through land clearing and overstocking. Such land use change resulted in a major degradation of the semi-arid river catchments which increase erosion and sediment load into the ocean. Phuket is highly developed and utilized and might have gone similar land degradation. For this study, we would need to further analyze to get better understanding of the process that affect coral's Ba/Ca in Thai Andaman Sea.

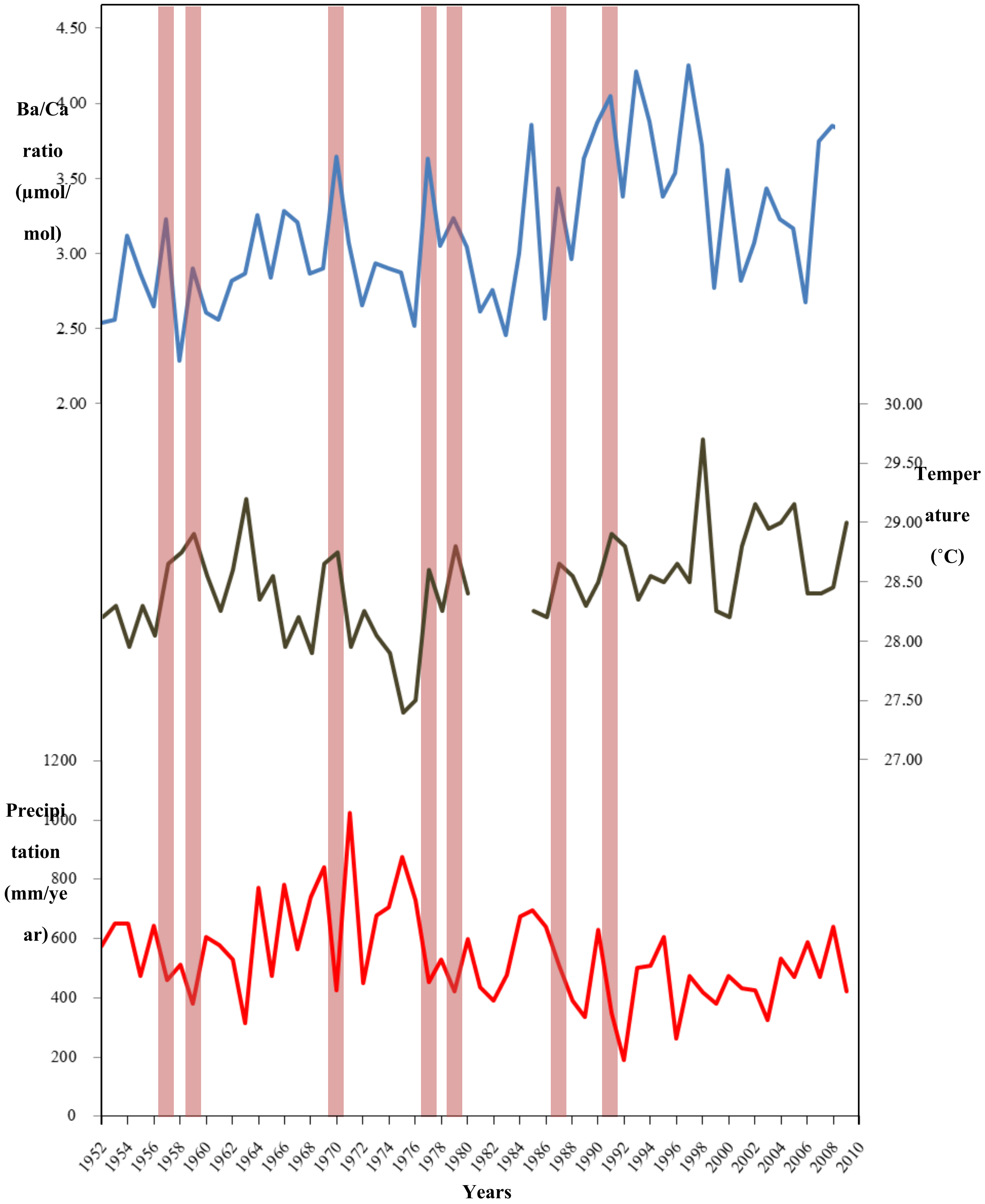

Figure 5 Time series for coral Ba/Ca ratios in dark band of *Porites lutea* against temperature and precipitation in May-June since 1952 to 2009.

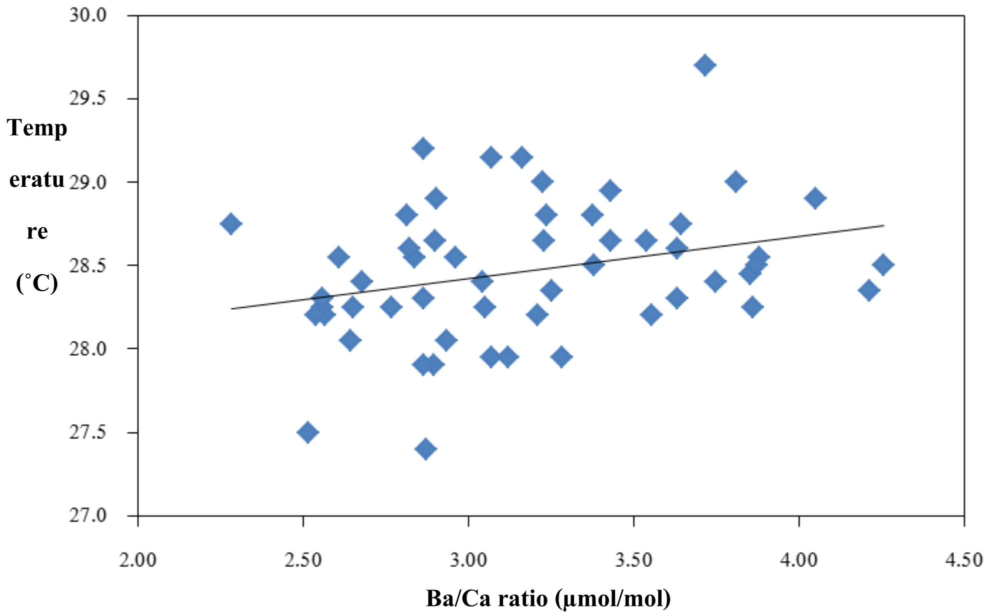

Figure 6 Plot of Ba/Ca ratios in dark band of *Porites lutea* against the temperature in rainy season (May-June) since 1952 to 2009.

Conclusion

The Ba/Ca ratio in the aragonite skeleton of *Porites lutea* collected from Racha Island, Phuket, the Andaman Sea were analyzed. The Ba/Ca ratio curve showed an upward trend, with the average 3.03 ±0.62 µmol/mol, within the range 1.46-4.54 µmol/mol. This 58 years coral record spans the period from 1952-2009. X-ray radiography helps to identify the alternating white band and dark band. White band and dark band from during summer season and rainy season respectively.

The relationships between both bands have positive correlation with temperature during its own growing season. Comparing to other study, we hypothesize that Ba/Ca accumulation during high temperature might be due to stress from high heat. High temperature may be affect coral growth rate and accumulation of trace element in coral. The relationships between both bands have negative correlation with precipitation because southern Thailand always has heavy rain almost year round. In rainy season with higher precipitation, it may cause dilution of the sediment which may result in lower Ba in water, and thus lower Ba accumulation in corals in some cases. High erosion during drought may increase the amount of sediment in dry years.

However, in recently Ba/Ca ratio has obviously increased after 1981, which may be caused by multiple factors such as land use change or population increase. These factors may have effects on the accumulation Ba^{2+} in coral. Since Phuket is highly populated with a lot of tourism activities, such environmental change may have occurred. We would need to further analyze historical data and perform further experiment to a better understanding of the process that affect coral's Ba/Ca in Thai Andaman Sea.

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