

Possible Effects of Temperature and Precipitation on Ba/Ca of *Porites lutea* : A Case Study in Chonburi

ผลกระทบของอุณหภูมิและปริมาณน้ำฝนต่อ Ba / Ca ของ *Porites lutea* : กรณีศึกษาในชลบุรี

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ABSTRACT

Ba/Ca ratio in corals has been considered as a useful geochemical proxy for climate change, upwelling, river flood and other oceanic processes. In this study, Ba/Ca ratios of *Porites lutea* collected from Sak Island in Chonburi Province, the Gulf of Thailand were used to study the relationship with environmental factors including temperature and precipitation. There are 37 sets of bands total indicating that the corals represent the ages from 1977 – 2014 AD. The results demonstrate that Ba/Ca ratios and temperature show the highest correlation ($R=0.3579$) probably due to being under the stresses of high temperatures while precipitation does not correlate with Ba/Ca ratios. Apart from climatic factor, it is possible that Ba/Ca ratio peaks of coral could be resulted from anthropogenic activities such as recent land use changes occurring within Chonburi.

บทคัดย่อ

อัตราส่วนแบเรียมแคลเซียม (Ba/Ca ratio) ในแนวปะการังได้นำมาพิจารณาใช้เป็นบันทึก (proxy) ทางธรณีเคมีที่มีประโยชน์สำหรับการเปลี่ยนแปลงสภาพภูมิอากาศ กระบวนการน้ำพุค (upwelling) น้ำท่วมและกระบวนการทางมหาสมุทร ในการศึกษาที่เก็บตัวอย่างปะการัง *Porites lutea* จากเกาะซาก จังหวัดชลบุรีในทะเลอ่าวไทยเพื่อใช้ในการหาความสัมพันธ์ระหว่างอัตราส่วนแบเรียมแคลเซียมกับปัจจัยทางสิ่งแวดล้อมได้แก่ อุณหภูมิและปริมาณน้ำฝน โดยเปรียบเทียบย้อนหลัง 37 ปี ตั้งแต่ปี ค.ศ. 1977-2014 ผลการศึกษาพบว่าอัตราส่วนแบเรียมแคลเซียมในปะการังมีความสัมพันธ์สูงสุดกับอุณหภูมิ ($R=0.3579$) โดยคาดว่าอัตราส่วนแบเรียมแคลเซียมในปะการังที่มีแนวโน้มเพิ่มขึ้นอาจมาจากปะการังหดหายได้ความเครียดของอุณหภูมิที่สูงขึ้น ในขณะที่อัตราส่วนแบเรียมแคลเซียมในปะการังไม่มีความสัมพันธ์กับปริมาณน้ำฝน นอกจากปัจจัยภูมิอากาศการเพิ่มขึ้นของอัตราส่วนแบเรียมแคลเซียมในปะการังอาจเป็นผลมาจากกิจกรรมของมนุษย์ เช่น การเปลี่ยนแปลงการใช้ประโยชน์ที่ดินที่เกิดขึ้นในเขตพื้นที่จังหวัดชลบุรี

Keywords: Temperature, Precipitation, land use change

คำสำคัญ: อุณหภูมิ ปริมาณน้ำฝน การเปลี่ยนแปลงการใช้ที่ดิน

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Introduction

Increased CO₂ results in global warming. The average temperature increased about 2.6 to 4.8 ° C in the last century (Jiao et al., 2015). Change in temperature of the Earth's atmosphere and recent anthropogenic activities can affect the environment and climate change associated with a variety of terrestrial, aquatic and marine ecosystems of the world. Ocean covers more than 70% of the Earth's surface and has important functions in regulating climate by storing and distribution of materials, energy and heat (Le Quéré et al., 2015).

Coral reef is one of the most important ecosystems as they are extremely important for biodiversity and provides a home to more than 25% of marine life. In addition, they are also important for people and economy (WWF, n.d.). However, coral can be used to reconstruct past environment and climate conditions in the ocean (Khongchai et al., 2003). Long-term coral reef records can distinguish coral responses to both natural and anthropogenic disturbance (Jupiter et al., 2008).

Geochemical record of coral is a great climate proxy that is reliable and widely used. It is important especially in areas where meteorological information is not available. Coralline ratio of barium to calcium (Ba/Ca) is one of the proxies that has been commonly used for paleoclimatic reconstruction (Horta-Puga, Carriquiry, 2012). Barium is a very important element for studying about coral skeletons because the variance of Ba/Ca ratios in coral skeletons is large and demonstrates a complex range of behavior in the marine environment (Sinclair, McCulloch, 2005). Also, Ba²⁺ forms an isostructural carbonate and its structure is similar to the substitutes for Ca²⁺ in coralline aragonite. As a result, the focusing on skeletons can record Ba²⁺ in the ambient ocean (Sinclair, 2005). Peaks in Ba/Ca ratios coincide with episodic release of sediments discharged to the near shore environment by flood events from large and dry catchments (McCulloch et al., 2003).

Generally corals are found in the tropics, including Thailand. Thailand has coral reef area about 96,357 hectares (154.17 square kilometers) which is about 45,545 hectares (72.9 square kilometers) located in the Gulf of Thailand in water depths in excess of 50 m. It reflects an interaction between sediment water runoff and erosion activity of the present-day bottom currents (Puchala, 2014).

Chonburi is situated in the eastern coast of the Gulf of Thailand. Chonburi is Thailand's largest and primary seaport including Industrial Estate areas. It has a thriving migrant and population migration. Chonburi also has a largest tourist oriented city known as Pattaya and some islands containing coral habitats (Tourism Authority of Thailand, 2015). For this reason, Chonburi was selected as a representative to reconstruct past climate and environmental changes by using Ba/Ca of coral from the Gulf of Thailand. This information could help to understand how environment and climate changed in this area in the past and it may be useful for future planning regarding the protection and development of the economic, environmental and land use.

Objective of the study

To study the relationship between Ba/Ca ratios in *Porites lutea* and climatic factors including temperature and precipitation in the Gulf of Thailand.

Materials and methods

Study site and coral sample

A coral reef in Sak Island, Chonburi Province, the Gulf of Thailand was selected (Figure 1). A living and healthy colony of the hermatypic coral *Porites lutea* was cored using a submersible hydraulic drill in March of 2015 on the outer Sak Island ($12^{\circ} 56' 41.7''$ N $100^{\circ} 47' 31.7''$ E). It is 600 m away from the north of Larn Island and 7 km from the west of Pattaya Beach in Chonburi Province.

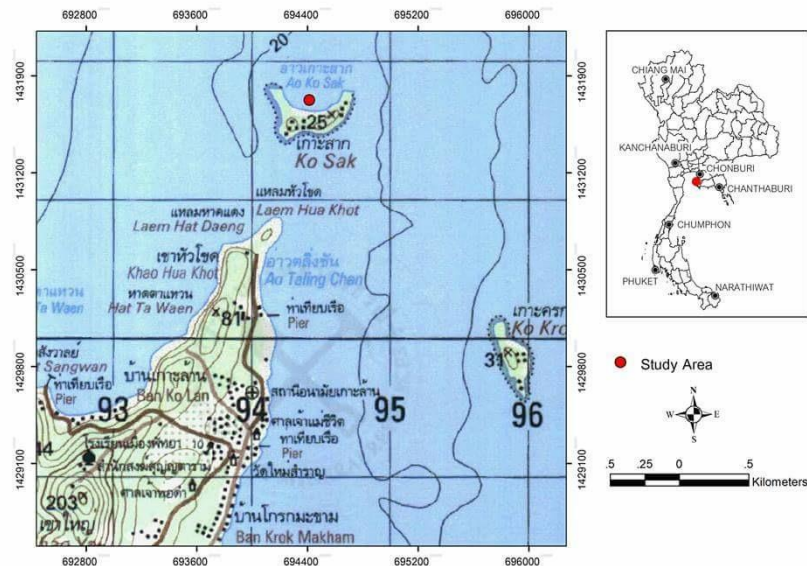


Figure 1 Map showing coral sampling Sak Island in Chonburi

Coral Preparation and Annual banding study

Coral cores were cleaned with water and left to dry. Cores were then cut vertically by a marble saw with the thickness of about 1 cm. Samples are taken to X-ray in order to study band lines from coral the annual density banding pattern of skeletal growth. The position of annual density bands (low and high) were determined using the X-ray images in order to reconstruct annual model of the coral by assigning years to each band couplet when counting backwards from the band/year of coral.

Coral Sampling for Ba/Ca study

Coral samples were cut by a rotary tool equipped a diamond-cutting wheel from each annual band. Each coral sample piece was dusted to get rid of particles. Samples were cleaned with Deionized water (DI water) and put in ultrasonicator for 10 minutes. After that, each sample was dried in a laminar flow hood for 48 hours, or until completely dry and was crushed with an acid cleaned agate mortar and pestle. Fragments were sieved between 297 and 550 μ m polypropylene sieves to produce size fraction between 297 and 550 μ m. The sieves and mesh screens were dusted out thoroughly in between samples. After that, each sample was thoroughly cleaned in oxidizing reagent (1:1 mixture of % H_2O_2 :0.2 N NaOH) and 0.15 N HNO_3 for removing contamination from organic in the sample.

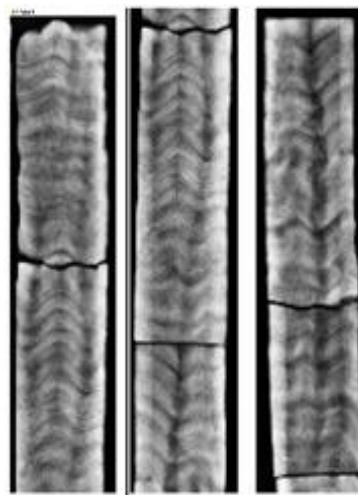


Figure 2 X-radiography prints for *P. lutea* cores from Sak Island in Chonburi Province, The Gulf of Thailand.

Instrumental analysis

The Ba/Ca molar ratios were measured using an axial-viewed Agilent 710 Inductively Coupled Plasma Optimal Emission Spectrometer (ICP-OES) (Figure 2) facility at the Center for Environmental Monitoring and Modelling of the National University of Singapore (SMART). Instrumental drift during the ICP run was corrected using a synthetic coral standard with known concentrations of Ba and Ca following a method outlined by Schrag (1999). 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 $\mu\text{mol/mol}$. A natural standard (JcP-1) and blanks was used to identify inter-run difference. The analytical precision of Ba/Ca measurement is $\pm 4.95\%$.

Data analysis

The relationships between Ba/Ca ratio and past climate data of Chonburi Province collected from Meteorological Department of Thailand were analysed using Pearson Correlation function by Microsoft Excel Software 2013. The relationships between coral and climate data were examined using linear regression by Microsoft Excel Software 2013 and graph.

Results and Discussions

Banding Pattern

Coral growth throughout a year appears as an alternation between high density and low density banding. From this study, the visibly dark band was high density (HD) band while the visibly white band was considered as low density (LD) band (Figure 2). Normally the HD band is a result of coral growth during the wet season period when precipitation and suspended solid is high. Low density bands were deposited during the dry season with low precipitation and sediment (Supriharyono, 2004). There are 37 sets of bands total, indicating that the corals from this study represents the age from 1977 – 2014 AD.

Ba/Ca ratios in comparison with environmental factors

In this study, the ratios of Ba/Ca were analyzed to compare the two types of environmental factors, including temperature and precipitation. Ba/Ca ratios in this core vary from 2–10 $\mu\text{mol/mol}$ (Figure 3, 5). The Ba/Ca ratios of white band is usually lower than the dark band with average values of $3.84 \pm 1.67 \mu\text{mol/mol}$ and $4.87 \pm 1.68 \mu\text{mol/mol}$. In this study, the highest correlation is found between Ba/Ca ratios in both dark and white bands and temperature. White bands correlate with temperature in dry season (Nov-Apr). The correlation between Ba/Ca ratios in white band with average three year-temperature in dry season is at $R = 0.3579$. While dark bands correlate with temperature in rainy season (May-Oct) and with average three year-temperature in rainy season with $R = 0.1734$ (Figure 4, 6). Overall, Ba/Ca ratios of band dark and white have positive correlation with temperature. At higher temperature, Ba/Ca ratios were higher as well. It is probably because higher temperatures could cause more stress in coral leading mechanisms to prevent the loss of rare elements. This is similar to other studies showing that Ba/Ca peaks could be during the incorporation of Ba-rich particles when coral tissue retracts. Temporary tissue retraction may occur when corals are exposed to stressful condition such as a sudden drop in sea surface temperature (SST) in temperate zone (Brown et al., 1991). They concluded that Ba/Ca ratios in relatively high-latitude corals can be a potential proxy for tracing the low temperature stress (11.5°C). Another study also found that coral uptakes more Ba/Ca under being under stress (Chen et al., 2011). For this study, is possible that the relationship between temperature and Ba/Ca is quite linear between 26.5°C - 30°C . The relationship is shown as an equation of $\text{Ba/Ca} = 0.3035 \text{ Temperature} + 25.93$ ($R^2 = 0.3579$). Thus, the stress may be accumulative rather than abrupt. We did not see a specific temperature threshold that starts to cause higher accumulation of Ba/Ca. Further study on the relationship between temperature and growth band from this coral samples will help to identify how much the temperature affect growth rate and stress level. As Thailand where is located near the equator with high temperatures, the high temperature will affect the growth of coral and formation of the elements of coral.

Precipitation does not correlate well with Ba/Ca ratios of white band in dry season (Nov-Apr). However, precipitation has an inverse correlation with Ba/Ca ratios of dark band and temperature in rainy season (May-Oct). When Ba/Ca ratios and temperature in rainy season are higher, precipitation decreases. In comparison to other studies, coralline Ba/Ca is usually a good proxy for precipitation and temperature. Coralline Ba/Ca ratio also represents a powerful proxy for seasonal upwelling (Lea et al., 1989) or riverine discharge and sediment transport in flood events associated with intense rainfall during the wet season (McCulloch et al., 2003). This study area is the island that receives contribution from several rivers from central plain of Thailand and it has a long rainy season (five months). Thus, it may result in dilution of sediment which may result in lower Ba in water leading to lower Ba accumulation in corals.

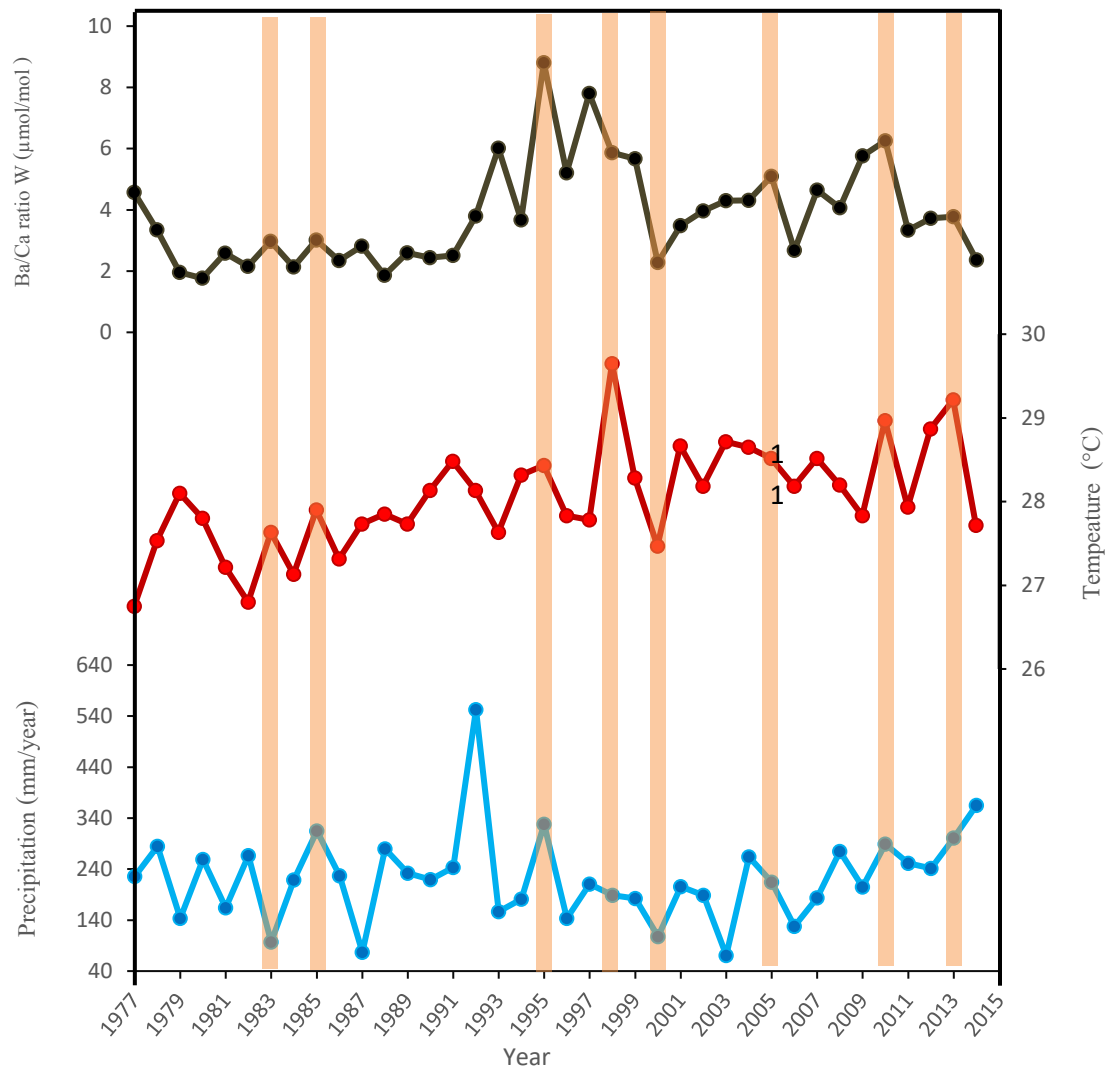


Figure 3 Time series for coral Ba/Ca (white band) against temperature and precipitation in Dry season (Nov-Dec) from 1977 to 2014

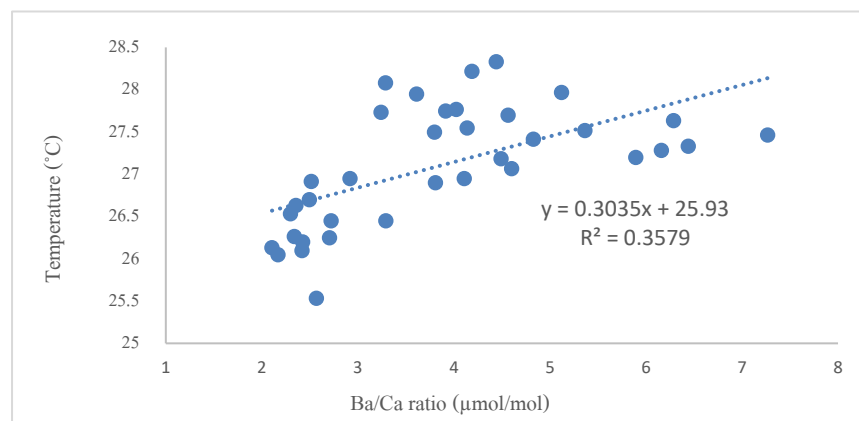


Figure 4 Plot of Ba/Ca in *Porites lutea* (White band) versus the temperature in Dry season (Nov-Dec) from 1997 to 2014.

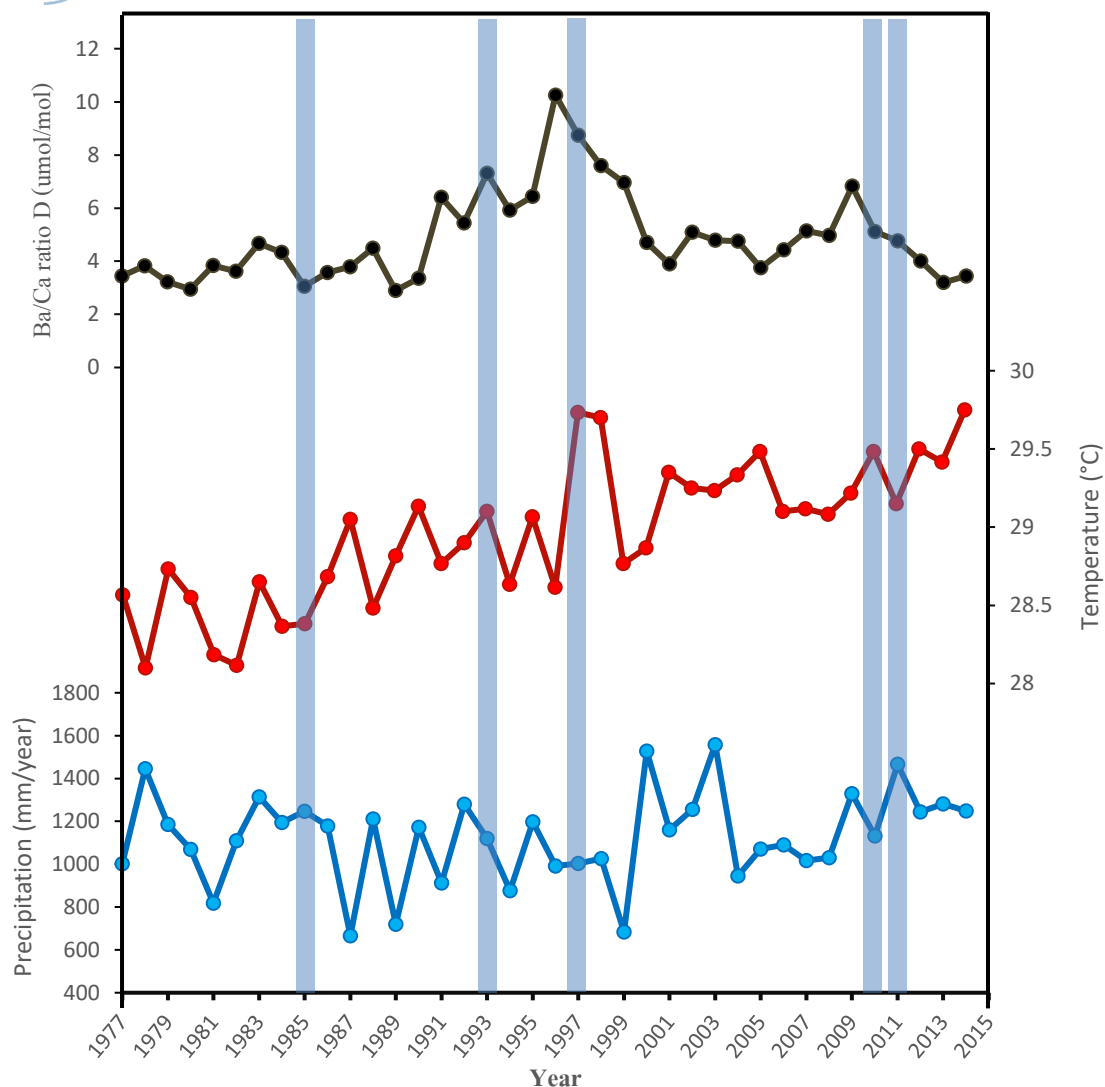


Figure 5 Time series for coral Ba/Ca (Black band) against temperature and precipitation in rainy season (May-Oct) from 1977 to 2014.

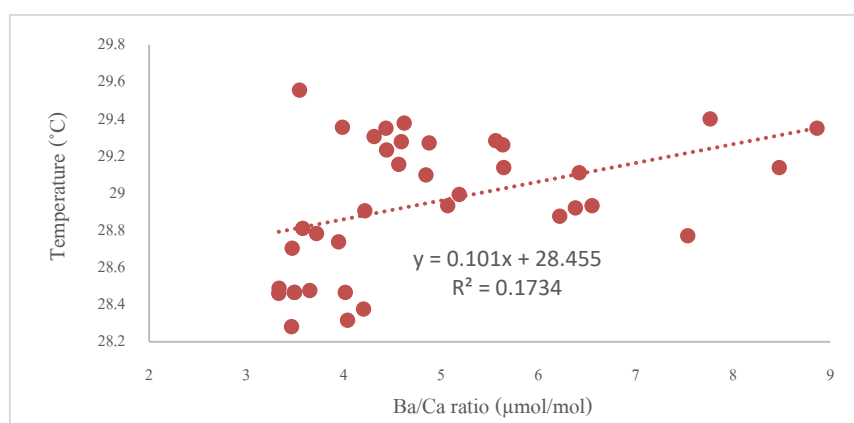


Figure 6 Plot of Ba/Ca in *Porites lutea* (White band) versus the temperature in rainy season (May-Oct) from 1997 to 2014.

Apart from climatic factor, it is possible that Ba/Ca ratio peaks of coral could be resulted from recent anthropogenic activities such as land use changes in Chonburi because Ba/Ca ratio is significantly higher during the period between 1991 and 2000. Industrial Estate was established in four areas in Chonburi in 1982-2006 with the total areas of 2717.6 hectares (Industrial Estate Authority of Thailand, 2016). Land use changes have been reported as another factor that affect the accumulation Ba/Ca in coral (McCulch et al., 2003). The researchers analysed Ba/Ca ratios in long-lived *Porites lutea* coral site in the inner Great Barrier Reef that is influenced by flood plumes from the Burdekin river to establish a record of sediment fluxes from about 1750 to 1998. They concluded that land use changes led to major degradation of the sediment resulting in substantially increased sediment loads entering the inner Great Barrier Reef and led Ba/Ca ratios to increase.

Conclusion

Ba/Ca ratios of corals collected from Sak Island, Chonburi Province, the upper Gulf of Thailand were analyzed. The Ba/Ca ratios within the range of 2–10 $\mu\text{mol/mol}$. The Ba/Ca ratios of white band are usually lower than the dark band with average values of 3.84 $\mu\text{mol/mol}$ and 4.87 $\mu\text{mol/mol}$, respectively. The correlation between Ba/Ca ratios in white band with average three year-temperature in dry season is at $R = 0.3579$. While dark bands are correlated with temperature in rainy season (May-Oct) and are correlated with average three year-temperature in rainy season ($R = 0.1734$).

The study also found Ba/Ca ratios of dark band and white band are higher at higher temperature in both wet and dry seasons. It may be that higher temperatures cause corals to be under stress and accumulate less Ba/Ca. However, precipitation does not correlate with Ba/Ca ratios of dark band and white band but probably correlate with land use change. It is difficult to identify all past environmental changes as it is possible that the other environmental factors or the impact of human during the period of human occupation can affect the accumulation of Ba/Ca ratios incorporation. Further study or experiment is required to identify those other factors.

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