CORAL FORMS, CORAL BIODIVERSITY AND PHYSICAL FACTORS AT RACHA YAI ISLANDS, PHUKET

KITTISAK JITKUE

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN COMPUTATIONAL SCIENCE
SCHOOL OF SCIENCE
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Dissertation Title	Coral forms, Coral biodiversity and Physical factors at Racha Yai Islands, Phuket
Author	Kittisak Jitkue
Program	Computational Science

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ชื่อวิทยานิพนธ์ รูปแบบการเจริญเติบโตของปะการัง ค่าดัชนีความหลากหลายทางชีวภาพและปัจจัยทางกายภาพ ที่เกาะราชาใหญ่ จังหวัดภูเก็ต
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ปีการศึกษา 2550

บทคัดย่อ

งานวิจัยนี้เป็นการศึกษารูปแบบการเจริญเติบโตของปะการัง ค่าดัชนีความหลากหลายทางชีวภาพ และปัจจัยทางกายภาพ ที่เกาะราชาใหญ่ จังหวัดภูเก็ต โดยการศึกษานี้ใช้เทคนิควิธีการแบบสุ่ม ซึ่งอาศัยข้อมูลภาพปะการังจากการถ่ายรูปใต้น้ำ รวมถึงข้อมูลอุณหภูมิและความเข้มของแสงอาทิตย์ที่ทำการทดสอบถูกนำมาเปรียบเทียบภาพถ่ายดาวเทียม ที่ใช้ในการศึกษาอยู่ระหว่างวันที่ 1 กรกฎาคม 2550 – 29 กุมภาพันธ์ 2551 ในการศึกษานี้รูปแบบของปะการังจะจัดแบ่งออกเป็น 7 รูปแบบ โดยรวมทั้งการศึกษาจากสถานที่ศึกษาและศึกษาจากรายงานผลการสำรวจของสถาบันวิจัยและพัฒนาทรัพยากรทางทะเล จังหวัดภูเก็ต นอกจากนี้ยังศึกษาเปรียบเทียบระหว่างเกาะราชาใหญ่กับเกรทแบริเออร์รีฟ ประเทศออสเตรเลีย เพื่อวิเคราะห์ปัจจัยด้านอุณหภูมิและปัจจัยอื่นๆ ที่มีผลต่อปะการัง

จากการศึกษาพบว่า ดัชนีความหลากหลายทางชีวภาพที่เกาะราชาใหญ่ตั้งแต่ปี 2534-2549 มีค่าเฉลี่ยที่ลดลง โดยรูปแบบการเจริญเติบโตของปะการังที่พบมากที่สุดคือ ปะการังแบบก้อน รองลงมาคือ ปะการังแบบกิ่ง ขณะที่การเจริญเติบโตปะการังแบบทรงกระบอก ลดลงอย่างต่อเนื่อง นอกจากนี้ยังพบเศษหรือชิ้นส่วนของปะการังที่แตกหักบนพื้นทราย โดยเกิดจากความแรงของคลื่น จากเศษขยะ สิ่งปฏิกูล และพบสาหร่ายปุยเขียว ในปริมาณที่เพิ่มมากขึ้น

สำหรับผลจากการศึกษาเกี่ยวกับอุณหภูมิของน้ำทะเล จากอุปกรณ์ตรวจวัดเมื่อเทียบกับ*ข้อมูลจากภาพถ่ายดาวเทียว พบว่ามีค่าที่ใกล้เคียงกัน ขณะที่เมื่อเทียบกับข้อมูลเกรทแบริเออร์รีฟ* ประเทศออสเตรเลีย พบว่าอุณหภูมิแตกต่างกัน ทั้งนี้เป็นเพราะสภาพทางภูมิศาสตร์ต่างกัน และ

เมื่อพิจารณาในด้านอื่นๆ ทั้ง 2 แห่ง พบว่า มีภาวะระดับความร้อนและภาวะของปรากฏการณ์ปะการังฟอกขาว ที่เกรทแบริเออร์รีฟ เกิดขึ้นมากกว่าที่เกาะราชาใหญ่ ซึ่งส่งผลกระทบโดยตรงต่อปะการัง ขณะที่ปัจจัยด้านดังกล่าว มีผลกระทบเพียงเล็กน้อยกับเกาะราชาใหญ่ จังหวัดภูเก็ต

Thesis Title	Coral forms, Coral biodiversity and Physical factors at Racha Yai Islands, Phuket
Author	Mr. Kittisak Jitkue
Major Program	Computational Science
Academic Year	2007

Abstract

This study aims at estimating coral growth forms at Racha Islands, Phuket. We use random sampling techniques. We took coral photographs with a digital camera and underwater casing. The temperature and light intensity examined by the HOBO sensors compared with satellite data on sea surface temperature form the NOAA website from 1 July 2007 – 29 February 2008. Coral images were classified into one of seven coral forms and used these percentages to calculate coral biodiversity indices. Included data from at study site and the reported from Phuket Marine Biological Center and compared with data from Great Barrier Reef, Australia to analysis factor of temperature and the other effect to coral.

Our results showed that Shannon-Wiener Index (SWI) at Racha Yai Islands since 1991 to 2006. was decreased. The most common growth form was the Massive form. The second common coral growth form was the branching form. Coral reef at Racha Yai Islands had a high amount of the dead coral fragment scattering on sand floor resulting from being hit by the waves, and from crashing and banging of various types of vessels and waste, and debris of damaged/collapsed natural materials The

filamentous alga called turtle weed (*Chlorodesmis fastigiata*) was found at coral reef at Racha Yai Islands.

Our results showed that SST from the NOAA website was similar to SST measured by the HOBO data loggers. (When compared data with Great Barrier Reef, Australia, we found that temperature was different because that the locations were different). Degree Heating Weeks (DHW) and coral bleaching hotspot (HotSpot) data at Great Barrier Reef were higher than Racha Yai Islands.

ACKNOWLEDGEMENTS

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Finally, thanks are due to my father, my mother, my sister and my friends for for their loving support.

Kittisak Jitkue

DISCLAIMER

I certify that the material contained in this dissertation is my own work and does not contain significant portions of unreferenced or unacknowledged material. I also warrant that the above statement applied to the implementation of the project and all associated documentation.

In the case of electronically submitted work, I also consent to this work being stored electronically and copied for assessment purposes, including the department's use of plagiarism detection systems in order to check the integrity of assessed work.

Signature

20 April 2008.

Date

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List of Abbreviations

ANOVA = Analysis of Variance

CSRIO = Commonwealth Scientific and Research Organization

CX-KURUE = Complex System Key University Research Unit of Excellent

DHW = Degree Heating Week

ENSO = El Niño-Southern Oscillation

GBR = Great Barrier Reef, Australia

HOTSPOT = Coral bleaching Hotspot

MMM = Maximum Monthly Mean

NOAA = National Oceanic and Atmospheric Administration

PLOS = Public Library Of Science

PMBC = Phuket Marine Biological Center

SD = Standard Deviation

SST = Sea Surface Temperature

SSTa = Sea Surface Temperature Anomaly

SWI = Shannon-Wiener Index

CHAPTER 1

INTRODUCTION

Coral reefs are the most sensitive of all ecosystems to global warming, pollution, and new diseases. They will be the first to go as a result of climate change. As the most important resources for fisheries, tourism, shore protection, and marine biodiversity for more than a hundred countries, this will be a huge disaster. Almost all reefs have already been heated above their maximum temperature thresholds. Many have already lost most of their corals, and temperature rise in most places gives only a few years before most corals die from heatstroke.

According to a report by the PLoS Biology, found that climate change may increase the incidence of disease in Great Barrier Reef corals. Ominously, the research also shows that healthy reefs, with the highest density of corals, are hit the hardest by disease.

In 1998, coral reefs around the world experienced the most extensive and severe bleaching in recorded history (ISRS, 1998; Wilkinson et al., 1999). Coral bleaching was reported in 60 countries and island nations at sites in the Pacific Ocean, Indian Ocean, Red Sea, Persian Gulf, Mediterranean and Caribbean. Indian Ocean corals were particularly severely impacted, with greater than 70 percent mortality reported in the Maldives, Andaman, Lakshadweep Islands, and in Seychelles Marine Park System. Unlike most previous bleaching events in which severe impacts were limited to less than 15 m water depth the 1998 bleaching affected corals at up to 50 m water depth. This mass bleaching followed similar but less severe events in 1987 and

1990. Prior to the early to mid 1980s, bleaching tended to be rare and localized, and corals generally recovered.

Year 1998, mass bleaching was coincident with anomalously high sea surface temperatures. That year was the warmest of this century (NOAA, 1999), and tropical sea surface temperatures were the highest in the modern record (Strong et al., 1998). For many parts of the Pacific, the 1997-1998 mass bleaching has been linked to the strong El Niño-induced seawater warming. The relationship between El Niño and coral bleaching is less clear, however, for the Indian Ocean, Arabian Gulf, and some parts of the Pacific (ISRS, 1998; Wilkinson, 1999). The geographic extent, regional severity, and increasing frequency of recent mass bleaching events point to an underlying global cause namely a trend of increasing sea surface temperatures in some of the tropical oceans, driven by global warming (US Department of State, 1999).

Global mean sea-surface temperatures are projected to increase by about 1-2 °C in the next century (Kattenberg et al., 1996). If the overall warming is accompanied by more frequent periods of sustained high temperatures, mass bleaching events will become more frequent and widespread. Increasing human stresses such as pollution, overfishing, soil erosion, and physical damage from boats and other recreational activities will also weaken corals, limiting their ability to adapt to climate change (Nurse et al., 1998; Hodgson, 1999). Furthermore, as ocean warming coincides with sea-level rise and perhaps more frequent tropical storms and El Niños (e.g., Timmerman et al., 1999), reefs are likely to experience greater coastal erosion, sedimentation, and turbidity, which would add to their demise.

In the case of Thailand, Phuket province is the biggest island which located in the Andaman Sea of Southern Thailand. One of the most popular diving and snorkelling near Phuket province is Racha Yai Islands which is about 12 km from Phuket. Racha Yai Islands lies directly south of Phuket. It is well known for clear waters and colorful reef, however this study site is selected to monitor because NOAA data are available for comparisons.

Racha Island consists of Racha Yai and Racha Noi islands located south of Phuket. Racha Yai Islands has an enchanting beach located on the west between the valleys that resembles horseshoes. The area is known as Ao Bungalow which is famous for its white powdery beach and crystal clear water. Visitors can marvel at the delightful panoramic view of the whole island from the vantage point at the peak of the mountain located south of the bay. Racha Yai Islands is the ultimate place to explore the wonders of the underwater world, especially at Ao Siam, Ao Tue and Khon Kae. Racha Noi Islands is located just 10 km. from Racha Yai Island. Originating from the accumulation of coral stones, the island has more rocky hills than beaches, thus the island is more suitable for fishing. To get there, visitors can charter long-tailed or speed boats from Chalong Pier.

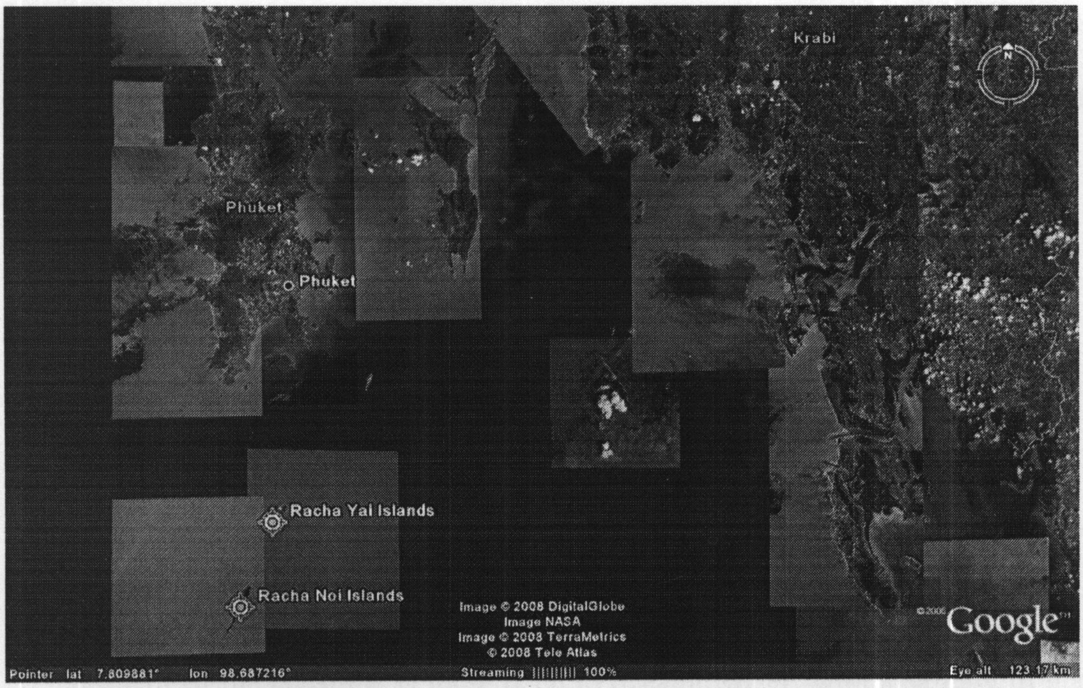

Figure 1. A map of Phuket, Racha Yai and Racha Noi Islands, Thailand

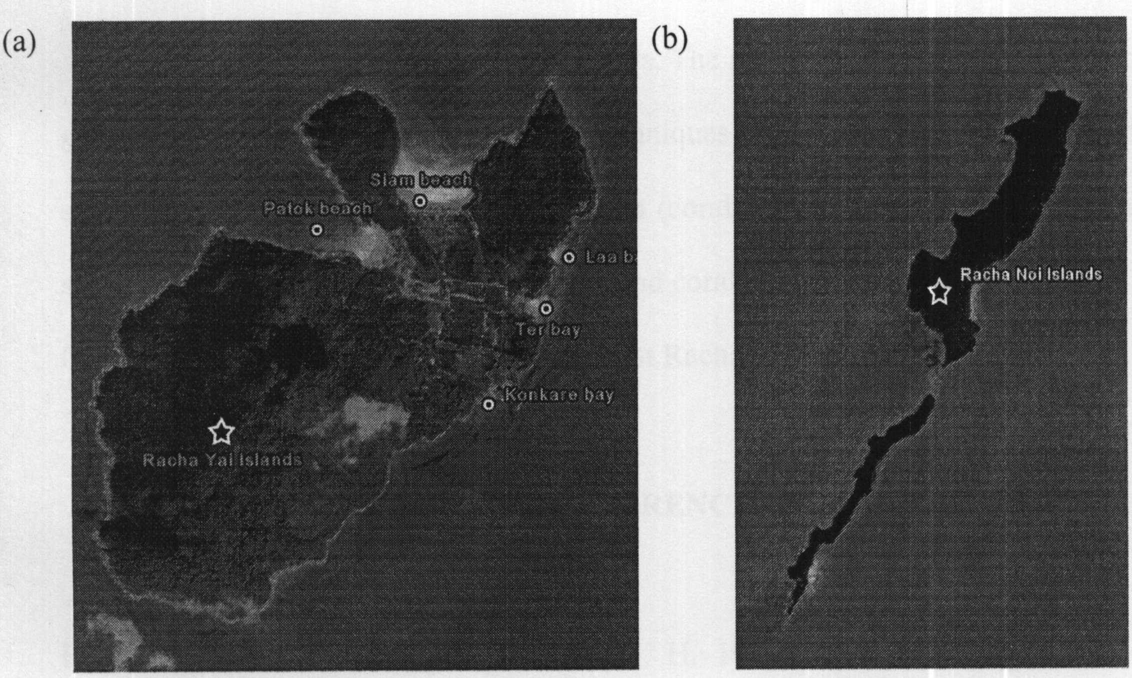

Figure 2. A map of (a) Racha Yai Islands and (b) Racha Noi Islands

Coral reefs are one of the most productive marine systems in Thai waters. Reef status had been monitored under a coral reef resource management programme during 1995-1999 by Phuket Marine Biological Center (PMBC) and Fisheries Development Centers, Department of Fisheries. Maps, with detailed description of almost all coral reefs in Thailand, were published (Chansang et al., 1999).

The length of the Andaman Sea coastline is approximately 700 km. The width of the continental shelf varies from 27 km to 130 km. The sea is strongly influenced by the southwest monsoon during May-October. The coastline is subjected to a semi-diurnal tide, with the maximum tidal range of 2.8-3.0 m during spring tides. The northern half of the coastline is more open to oceanic water, with a salinity of about 32-33 ppt, while the southern half is more influenced by run-off from the mainland. Salinity of southern coastal waters is about 29-32 ppt (Limpasaichol et al., 1991).

This study was divided into three parts. The first part aimed at estimating coral growth forms by using random sampling techniques at Racha Yai Island, Phuket. The second part aimed at using multi-source data (coral diversity, sensors based data and satellite data) to monitor coral biodiversity and coral bleaching at the same sites as the first part. The third part is about coral status at Racha Yai Islands.

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CHAPTER 2

CORAL GROWTH FORMS, BIODIVERSITY INDEX AND PHYSICAL FACTORS AT RACHA YAI ISLANDS, PHUKET

Jitkue, K., Yaiprasert, C., Surabun, S., Wongkoon, S., Jaroensutasinee, M. and Jaroensutasinee, K. 2007. 33rd Congress on Science and Technology of Thailand. Nakhon Si Thammarat, Thailand. 18th-20th October, B6_B0082, p.127.

ABSTRACT

This study aimed at estimating coral growth forms at Racha Yai Islands, Phuket. We used random sampling techniques. We took coral photographs with a digital camera and underwater casing. Coral images were classified into one of seven coral forms and used these percentages to calculate coral biodiversity indices (i.e. Shannon-Wiener index and Simpson index). The percentage of coral growth forms was different. The most common growth form was the foliaceous form. The second common coral growth form was the encrusting form. There were few columnar and free living growth forms at Racha Yai Islands. There were very high biodiversity indices at Racha Yai Islands estimating from coral growth forms. This study suggests that coral reef at Racha Yai Islands is still in prime condition.

Keywords: Coral, Sea surface temperature, Biodiversity index, Shannon-Wiener index, Simpson index.

INTRODUCTION

Coral reef ecosystems are highly valued as biological, ecological, cultural, and economic resources. In the past few decades, competing demands on coral reef ecosystems and increasing threats from both natural and anthropogenic stressors have contributed to a significant decline in coral reef health worldwide (Simpson, 1949; Veron, 2000). This study aimed at studying coral growth forms, biodiversity index, the amount of light intensity and water temperature at coral reef habitat at Racha Yai Islands, Phuket. We estimated seven coral reef growth forms using random sampling techniques. These percentages of coral growth forms were used to estimate coral biodiversity indices.

MATERIALS AND METHODS

This study was undertaken at Racha Yai Islands, Phuket province, Thailand (Figure 1). Coral reefs in this area were 1-5 m depth. We used a random sampling technique to estimate coral growth forms. We took coral photographs with digital cameras, Canon Power Shot A620 and Olympus uD600/S600 with underwater casings. We used the digital cameras, swam in straight lines and took 100 coral photographs. Coral photographs were classified into seven coral growth forms: massive, encrusting, branching, foliaceous, laminar, free-living, and columnar (Knowton, 2001) (Figure 4 a-g). We randomly selected 40 out of 100 coral photographs/study site for a random sampling technique to estimate % coral growth form photography. We used %coral growth forms to calculate Shannon-Wiener index and Simpson index. We selected a 1 m^2 empty area located within coral reef with sandy bottom. We deployed four HOBO Pendant temperature and light data loggers model UA-002-64 to measure water temperature and light intensity at Racha Yai Islands (latitude 7.60488 °N, Longitude 98.37660 °E) on 29 June 2007. We placed 1.5 kg weight at 1 m^2 empty area and tied these four data loggers to the weight in four diagonal corners. This allowed each data logger to receive an accurate and maximum light intensity. We used a shuttle to upload the water temperature and light intensity data from data loggers.

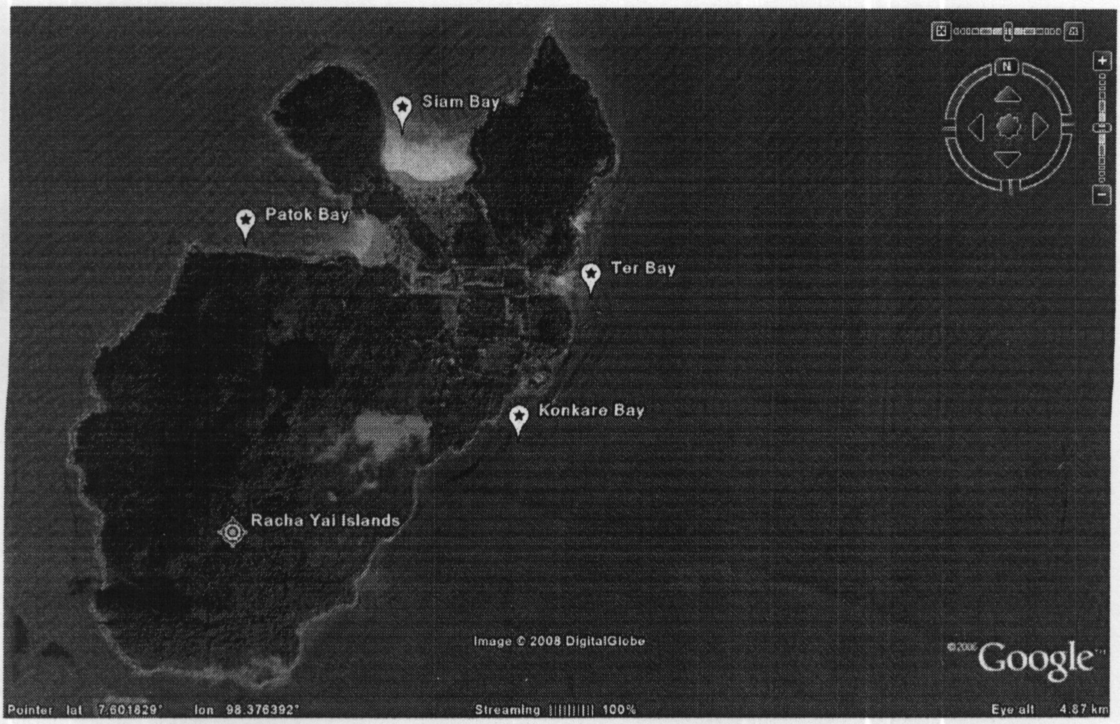
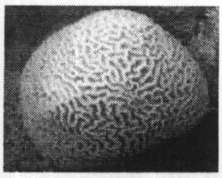
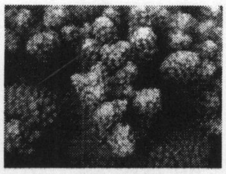


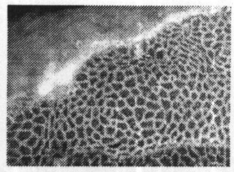
Figure 3. Study site at Racha Yai Islands, Phuket, Thailand



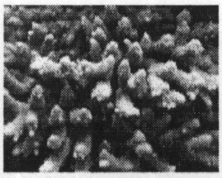
(a)Massive



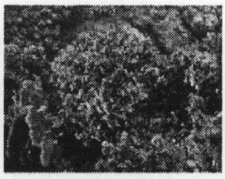
(b) Columnar



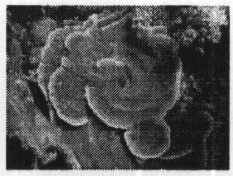
(c) Encrusting



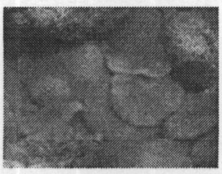
(d) Branching



(e) Foliaceous



(f) Laminar



(g) Free-living

Figure 4. Seven coral growth forms. (a) Massive, (b) Columnar, (c) Encrusting, (d) Branching, (e) Foliaceous, (f) Laminar and (g) Free-Living

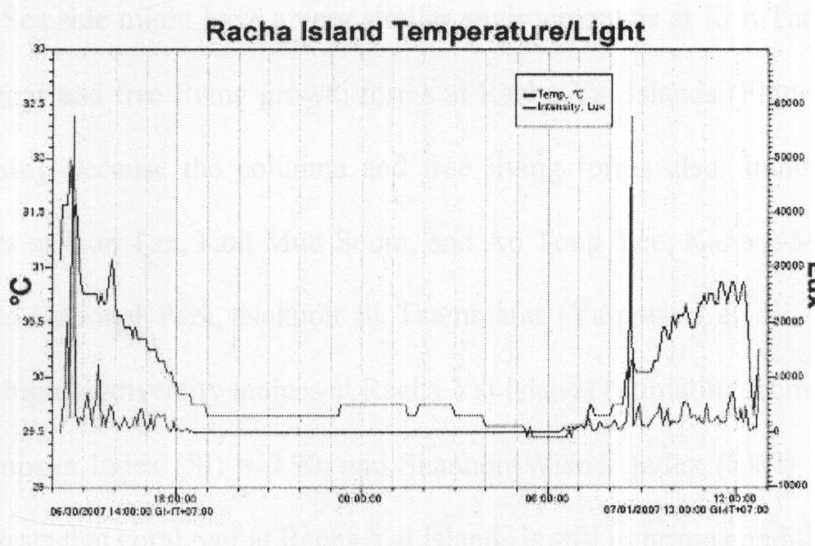


Figure 5 Sea surface temperature and light intensity at Racha Yai Islands on 30 June 2007

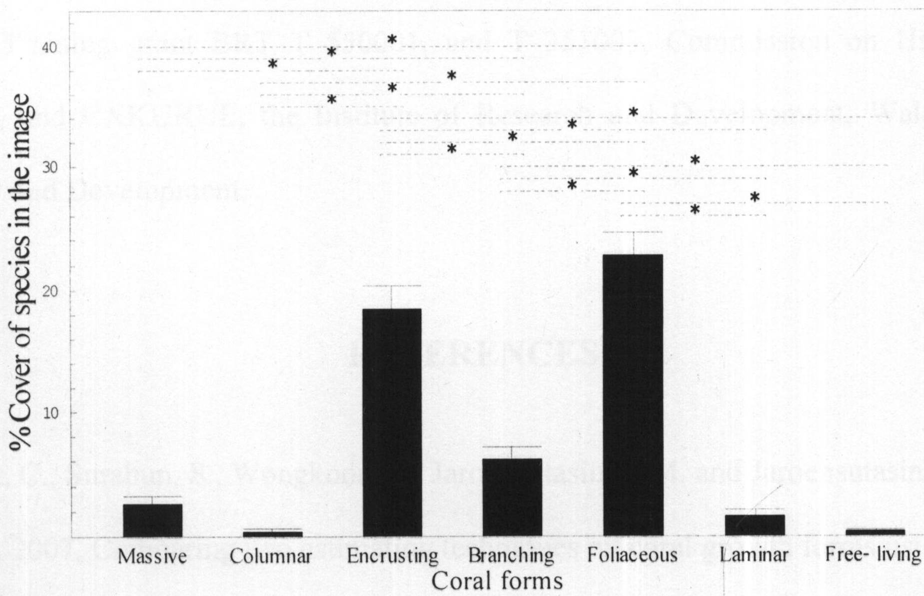
RESULTS AND DISCUSSION

Sea surface temperature at Racha Yai Islands on 30 June 2007 had an averaged of 31.25 °C (Figure 5). The amount of light intensity had an average of 380 lumen per ft^2 (Figure 5). Temperature seems to be very high due to several reasons, such as the circulation in the ocean, wind surface, and high solar radiation. Temperature decreased from 32.4 °C during the day to 29.5 °C at night. However, the sea surface temperature did not fluctuate much between day and night (Figure 5).

The percentage of coral growth forms was different among seven coral growth forms (one-way ANOVA: $F_{6,1078} = 68.255$, $P < 0.001$, Figure 6a). The most common coral growth form was the foliaceous form (Figure 6a). The second common coral growth form was the encrusting form (Figure 6a). This kind of % coral growth forms was similar to Koh Tan, Kanom-Mo Koh Talae Tai Marine National Park, Nakhon Si Thammarat (Yaiprasert et al., 2007). This indicates that Racha Yai Islands on the Andaman Sea side might have a very similar environment as at Koh Tan. There were few columnar and free living growth forms at Racha Yai Islands (Figure 6a). This is not surprising because the columna and free living forms also found at very low percentages at Koh Tan, Koh Mud Soom, and Ao Tong Yee, Kanom-Mo Koh Talae Tai Marine National Park, Nakhon Si Thammarat (Yaiprasert et al., 2007). There were very high biodiversity indices at Racha Yai Islands estimating from coral growth forms (Simpson Index (SI) = 0.90, and Shannon-Wiener Index (SWI) = 1.46). This study suggests that coral reef at Racha Yai Islands is still in prime condition.

When we plotted the accumulation curve of biodiversity indices with the number of coral photographs (Figure 6b), we found that the graph was reaching plateau at 20 coral photographs. This suggests that for the future study, researchers who are interested in working on coral diversity at Racha Yai Islands should take at least 20 photographs in order to get the correct estimation of biodiversity indices.

(a)



(b)

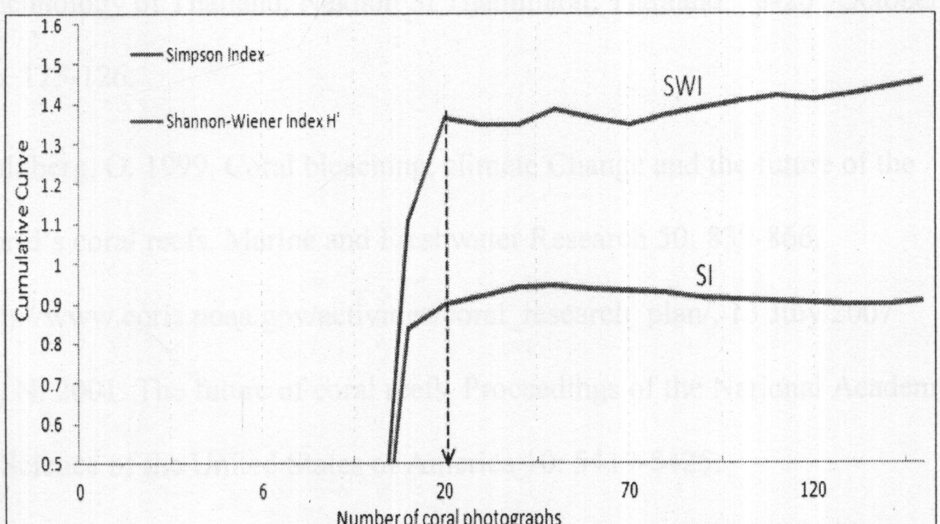


Figure 6. Results of (a) Mean and Standard error of % coral form at Racha Yai Islands and (b) accumulation curve of SI and SWI with the number of coral photographs. The red and blue lines represent SWI and SI, respectively. * $P<0.001$

ACKNOWLEDGEMENTS

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CHAPTER 3

INTEGRATION OF MULTI-SOURCE DATA TO MONITOR CORAL BIODIVERSITY

Jitkue, K., Yaiprasert, C., Srisang, W., Jaroensutasinee, M. and Jaroensutasinee, K. 2007. *International Journal of Mathematical, Physical and Engineering Service, 1(4):* 238-242.

ABSTRACT

This study aims at using multi-source data to monitor coral biodiversity and coral bleaching. We used coral reef at Racha Yai Islands, Phuket as a study area. There were three sources of data: coral diversity, sensor based data and satellite data. The percentage of coral growth forms differed among seven coral growth forms. The most common growth form was the foliaceous form. The second most common coral growth form was the encrusting form. This kind of % coral growth forms was similar to Koh Tan, Khanom-Mo Koh Talae Tai Marine National Park, Nakhon Si Thammarat. There were very high biodiversity indices at Racha Yai Islands estimating from coral growth forms: Species Richness equaled seven growth forms, Simpson Index (SI) = 0.90, and Shannon-Wiener Index (SWI) = 1.46. Water temperature at Racha Yai Islands on 30 June – 28 August 2007 had a mean ± SD of 29.11± 0.66 °C. Light intensity at Racha Yai Islands on 30 June – 28 August 2007 had a mean ± SD of 2131.60 ± 3006.15 Lux.

Keywords: Coral reefs, Remote sensing, Sea surface temperature, Satellite imagery

INTRODUCTION

Coral reefs are the most sensitive of all ecosystems to global warming, pollution, and new diseases. Coral reef ecosystems are sensitive to natural, anthropogenic, and climatic pressures. Assessments as to late 2000 are that 27% of the world's reefs have been effectively lost, with the largest single cause being the massive climate-related coral bleaching event of 1998. This destroyed about 16% of the world's coral reefs in only 9 months, during the largest El Niño and La Niña climate mode ever recorded. While there is a good chance that many of the 16% of damaged reefs will, with time, recover, it is estimated that half of these decimated reefs will never recover to full health. These losses will add to the 11% of the world's reefs already lost to human impacts such as sediment and nutrient pollution, overexploitation and mining of sand and rock, blast fishing, and development on and reclamation of coral reefs.

In 1998, coral reefs around the world experienced the most extensive and severe bleaching in recorded history (ISRS, 1998; Wilkinson et al., 1999). Coral bleaching was reported in 60 countries and island nations at sites in the Pacific Ocean, Indian Ocean, Red Sea, Persian Gulf, Mediterranean and Caribbean. Indian Ocean corals were particularly severely impacted, with greater than 70 percent mortality reported in the Maldives, Andaman, Lakshadweep Islands, and in Seychelles Marine Park System. Unlike most previous bleaching events in which severe impacts were limited to less than 15 m water depth the 1998 bleaching affected corals at up to 50 m water depth.

This mass bleaching followed similar but less severe events in 1987 and 1990. Prior to the early to mid 1980s, bleaching tended to be rare and localized, and corals generally recovered. Year 1998, mass bleaching was coincident with anomalously high sea surface temperatures. That year was the warmest of this century (NOAA, 1999) and tropical sea surface temperatures were the highest in the modern record (Strong et al., 1998). The geographic extent, regional severity, and increasing frequency of recent mass bleaching events point to an underlying global cause namely a trend of increasing sea surface temperatures in some of the tropical oceans, driven by global warming (US Department of State, 1999).

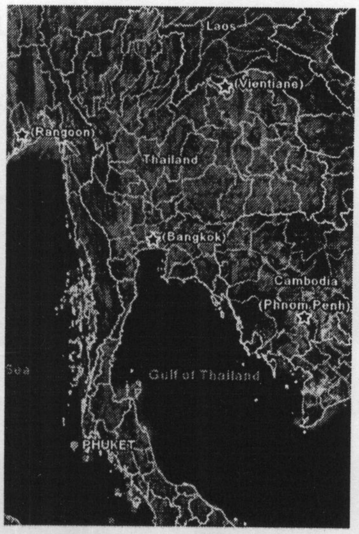
This study aims at using multi-source data to monitor coral biodiversity and coral bleaching at Racha Yai Islands, Phuket, Thailand. There were three sources of data: coral form biodiversity, sensor based data and satellite imagery. For coral form biodiversity, we estimated the percentage of seven coral growth forms at Racha Yai Islands, Phuket. For sensor based data, we deployed HOBO pendent sensors to measure sea temperature and light intensity at coral study site. For satellite data, we got satellite data on sea surface temperature from the National Oceanic & Atmospheric Administration (NOAA) website.

MATERIALS AND METHODS

SITE DESCRIPTION

Phuket province is the biggest island which is located on the Andaman sea, southern Thailand. One of the most popular diving and snorkelling near Phuket province is Racha Yai Islands which is about 12 km from Phuket. Racha Yai Islands lies directly south of Phuket known for clear waters and colorful reef. We selected Racha Yai Islands as our coral study site because sea surface temperature of Racha Yai Islands could be downloaded from the NOAA website (Figure 7 a,b).

(a)



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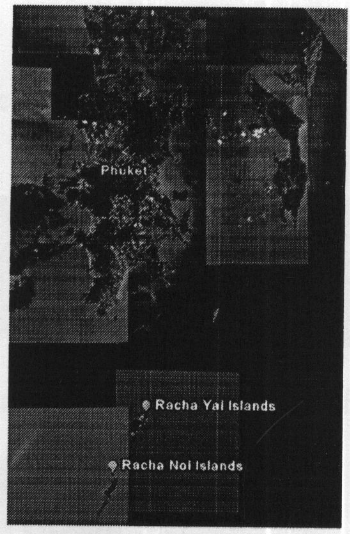
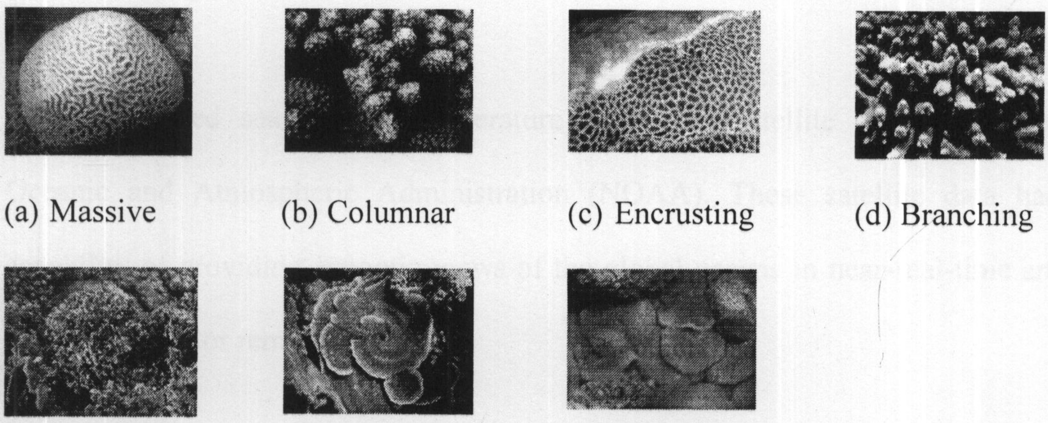


Figure 7. (a) The map of Thailand, (b) Phuket, Racha Yai, and Racha Noi Islands

CORAL FORM BIODIVERSITY

This study was undertaken at Racha Yai Islands, Phuket province, Thailand (Figure 7a). Coral reefs in this area were 1-5 m depth. We used a random sampling technique to estimate coral growth forms. We took coral photographs with digital cameras, Canon Power Shot A620 and Olympus uD600/S600 with underwater casings. We used digital cameras, swam in straight lines and took 100 coral photographs. Coral photographs were classified into seven coral growth forms: massive, columnar, encrusting, branching, foliaceous, laminar, and free-living (Veron, 2000) (Figure 8a-g). We randomly selected 40 out of 100 coral photographs/study site for a random sampling technique to estimate % coral growth form photography. We used %coral growth forms to calculate species richness, Shannon-Wiener index and Simpson index (Strong et al., 1998; US Department of State, 1999). All variables were tested for normality by using descriptive statistics. Parametric statistics were used when underlying assumptions were met, otherwise non-parametric tests were used. One-way ANOVA tests were used to test for differences in the percentage of seven coral growth forms. All significant tests were two-tailed.



(a) Massive (b) Columnar (c) Encrusting (d) Branching

(e) Foliaceous (f) Laminar (g) Free-living

Figure 8. Seven coral growth forms. (a) Massive, (b) Columnar, (c) Encrusting, (d) Branching, (e) Foliaceous, (f) Laminar, and (g) Free living

SENSOR BASED DATA

We selected a 1 m^2 empty area located within coral reef with sandy bottom at Racha Yai Islands (Latitude 7.60488 °N, Longitude 98.37660 °E). We deployed four HOBO Pendant temperature and light data loggers model UA-002-64 to measure water temperature and light intensity on 30 June 2007. These loggers were programmed to record water temperature every 5 minutes continuously for six to 12 months. We placed 1.5 kg weight at 1 m^2 empty area and tied these four data loggers to the 1.5 kg weight in four diagonal corners. This allowed each data logger to receive an accurate and maximum light intensity. We used a shuttle to upload the water temperature and light intensity data from data loggers every two months. This HOBO data logger was used for comparison with the sea surface temperature from NOAA satellite data.

SATELLITE IMAGERY

We used sea surface temperature data from satellite data from National Oceanic and Atmospheric Administration (NOAA). These satellite data had the capability of providing synoptic views of the global oceans in near-real-time and the ability to monitor remote reef areas.

NETWORK OF BIODIVERSITY DATABASE SYSTEM (NBIDS-BRT)

NBIDS-BRT was a web database system designed with four main features: database, data analysis tool, data visualization tools, and GIS tools. NBIDS developed by Walailak University team and funded by Biodiversity Research Training Program (BRT). Data analysis tools for NBIDS-BRT comprised statistical analysis tools and computational modules for each research project. Examples of computation modules' outputs were biodiversity index, mosquito house index, coral data and fish morphometric data. This tool was an interaction tool for visualizing graph with *Mathematica* software. We developed web-based tools for data entry at study site.

Google Earth KML was used as tools for map visualization. Web*Mathematica* was used for advanced data analysis and visualization, e.g., spatial interpolation, and statistical analysis.

RESULTS AND DISCUSSION

CORAL FORM BIODIVERSITY

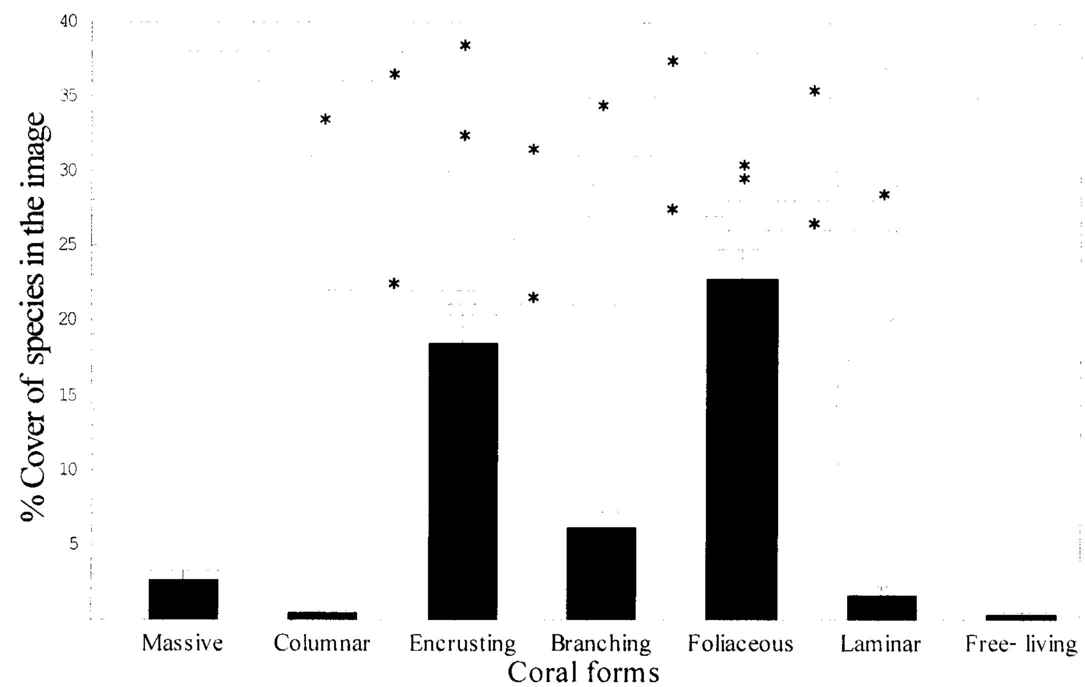


Figure 9. Mean and standard error of % coral form at Racha Yai Islands, Phuket, Thailand

The percentage of coral growth forms differed among seven coral growth forms (one-way ANOVA: $F_{6,1078} = 68.255$, $P < 0.001$, Figure 9). The most common growth form was the foliaceous form (Figure 9). The second most common coral growth form was the encrusting form (Figure 9). This kind of % coral growth forms was similar to Koh Tan, Khanom-Mo Koh Talae Tai Marine National Park, Nakhon Si Thammarat (Jitkue et al., 2007). This indicates that Racha Yai Islands on the

Andaman Sea side might have a very similar environment as at Koh Tan. There were few columnar and free living growth forms at Racha Yai Islands. The columna and free living forms also found at very low percentages at Koh Tan, Koh Mud Soom, and Ao Tong Yee, Khanom-Mo Koh Talae Tai Marine National Park, Nakhon Si Thammarat, Thailand (Jitkue et al., 2007).

There were very high biodiversity indices at Racha Yai Islands estimating from coral growth forms: Species Richness equaled seven growth forms, Simpson Index (SI) = 0.90, and Shannon-Wiener Index (SWI) = 1.46. This study suggests that coral reef at Racha Yai Islands is still in prime condition. When we plotted the accumulation curve of coral form biodiversity indices with the number of coral photographs. We found that the graph was reaching plateau and steady state at 50 coral photographs. This suggests that for the future study, researchers who are interested in working on coral diversity at Racha Yai Islands should take at least 50 photographs in order to get a good estimation of biodiversity indices.

SENSOR BASED DATA

Water temperature at Racha Yai Islands on 30 June – 28 August 2007 had a mean ± SD of 29.11± 0.66 °C (Figure 11). Light intensity at Racha Yai Islands on 30 June – 28 August 2007 had a mean ± SD of 2131.60 ± 3006.15 Lux. Water temperature seems to be very high due to several reasons such as the circulation in the ocean, wind surface, and high solar radiation. Temperature decreased from 30.5 °C during the day to 28.5 °C at night (Figure 11). However, the temperature did not fluctuate much during the day. This study helps us gain a better understanding of coral forms, coral species diversity, coral species richness, and some physical factors at Racha Yai Island.

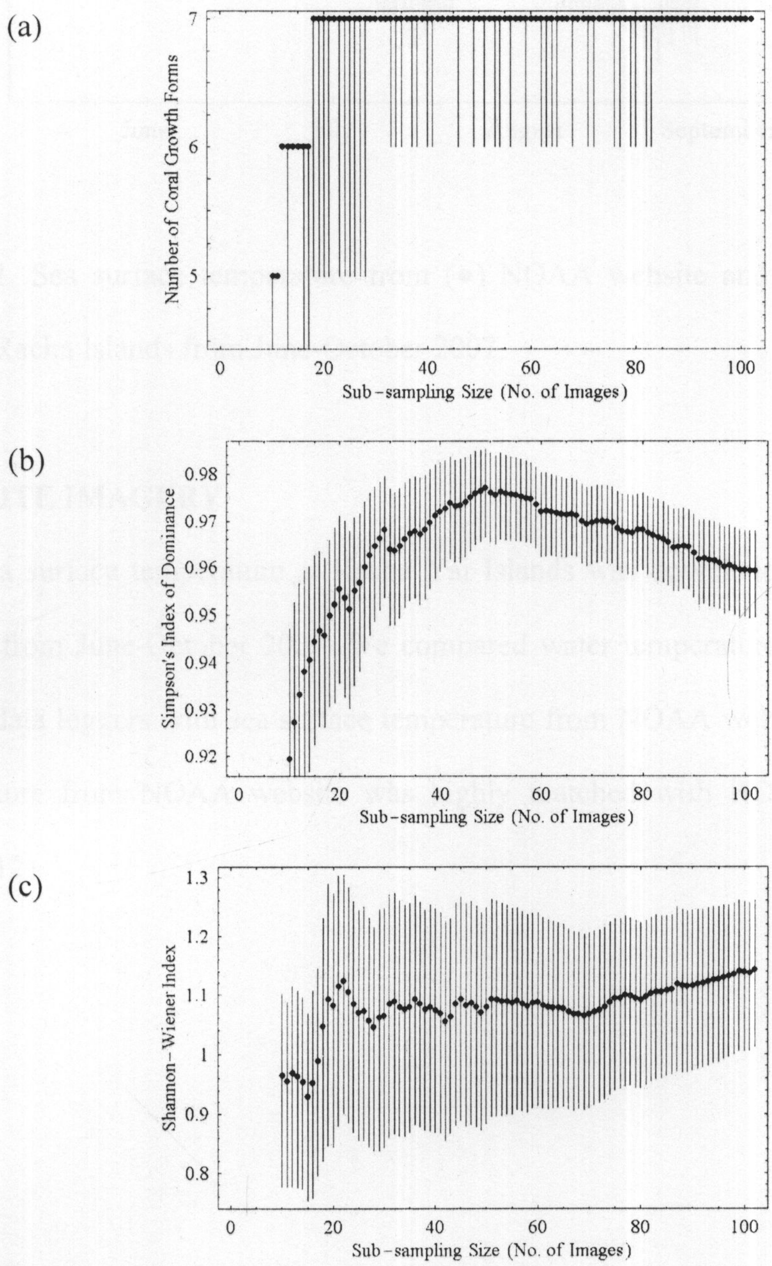


Figure 10. Accumulative curve of coral biodiversity indices and the sub-sampling size (No. of images). (a) Number of coral growth forms, (b) Simpsom's index and (c) Shannon-Wiener Index. (-) represents maximum and minimum indices, and (•) represents the mean of indices.

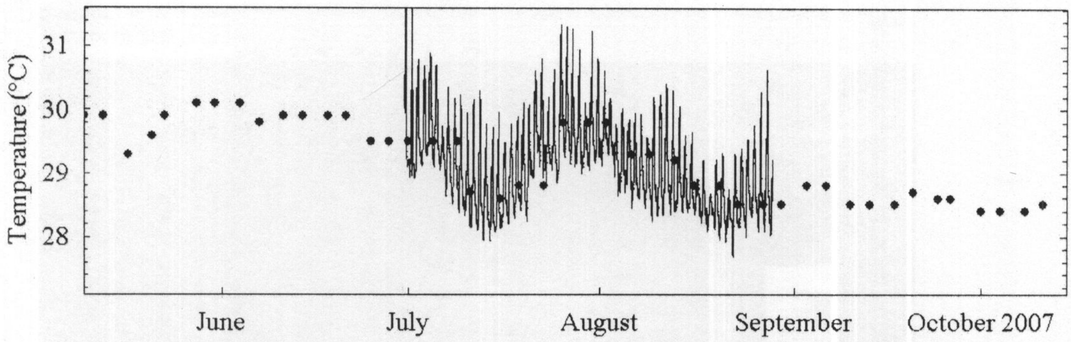
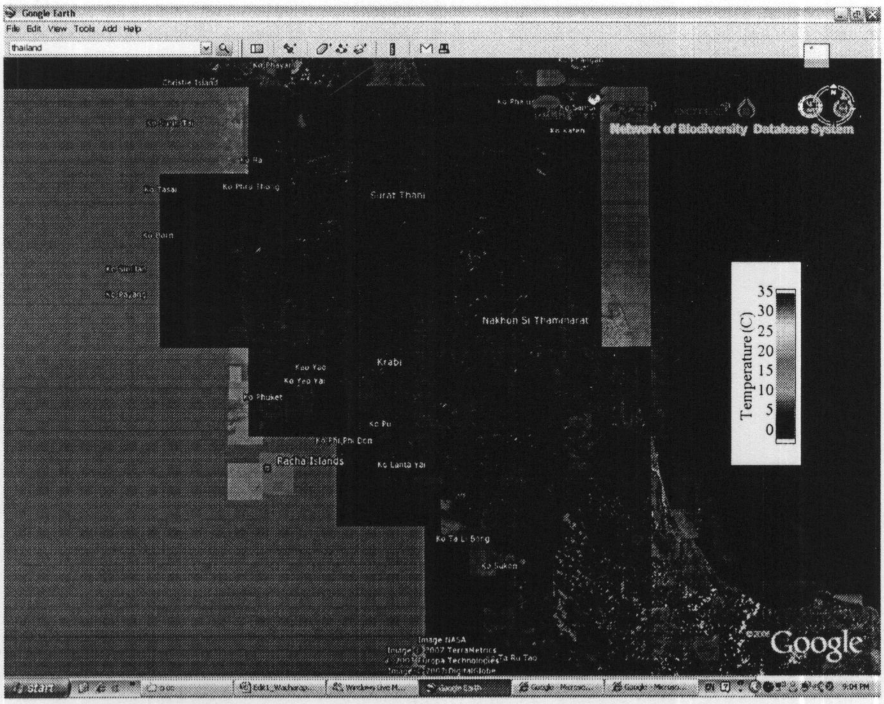


Figure 11. Sea surface temperature from (●) NOAA website and (-) HOBO data logger at Racha Islands from June-October 2007.

SATELLITE IMAGERY

Sea surface temperature at Racha Yai Islands was downloaded from NOAA website from June-October 2007. We compared water temperature measured from HOBO data loggers with sea surface temperature from NOAA website. Sea surface temperature from NOAA website was highly matched with HOBO data logger (Figure 12).

(a)


Google Earth
File Edit View Tools Add Help
Network of Biodiversity Database System
Surat Thani
Nakhon Si Thammarat
Krabi
Ko Phuket
Racha Islands
Ko Lanta Yai
Temperature (C)
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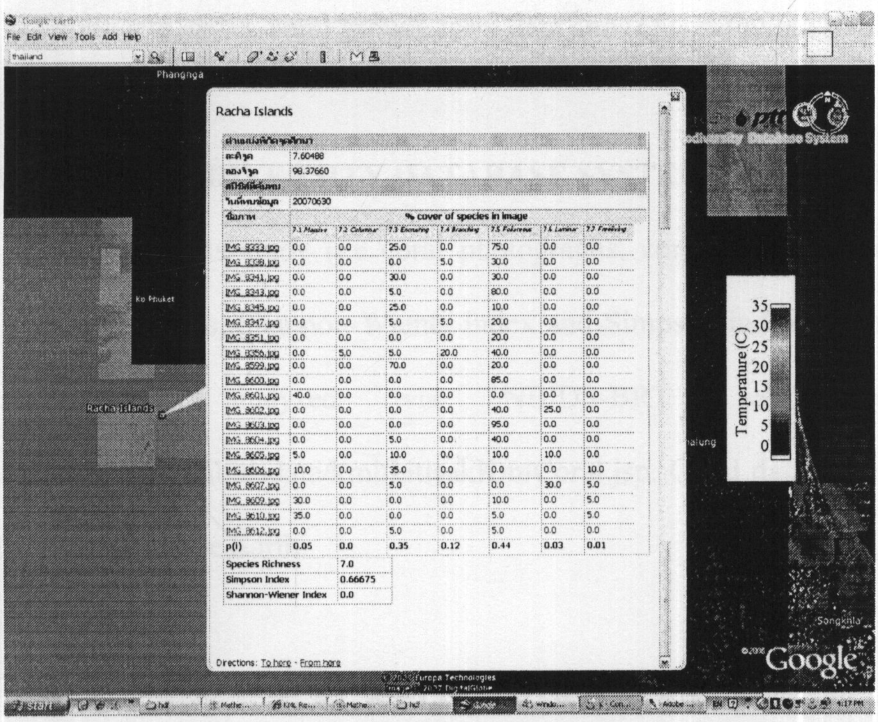
(b)


Google Earth
File Edit View Tools Add Help
Phangnga
Racha Islands
Ko Phuket
% cover of species in image
Species Richness 7.0
Simpson Index 0.66675
Shannon-Wiener Index 0.0
Directions: To here - From here
Temperature (C)
35
30
25
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15
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Songkhla
Google

(c)

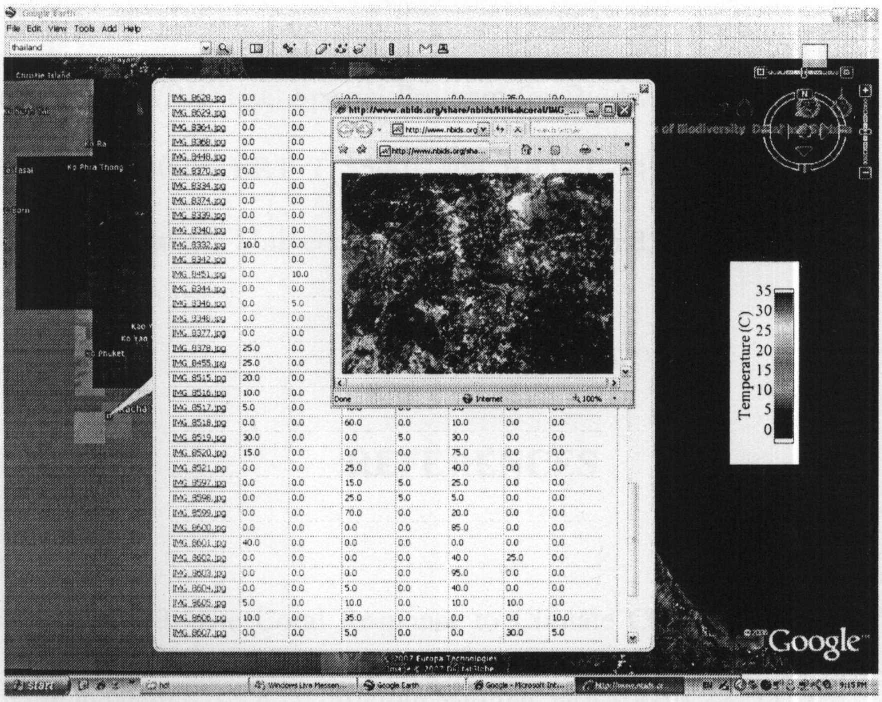

Figure 12. NBIDS-BRT database visualization tools on Google Earth.

(a) study site, (b) % coral growth form data and (c) coral photograph

NETWORK OF BIODIVERSITY DATABASE SYSTEM (NBIDS-BRT)

Data from this study (i.e coral photographs, coral growth forms, % coral cover, Species richness, Shannon-Wiener index and Simpson index) were submitted, visualized, and analyzed via NBIDS-BRT web service at http://www.nbids.org/nbidsdata/kml/kitisakKmlCoral.jsp. Coral data were overlaid in KML format on Google Earth.

ACKNOWLEDGEMENTS

We thank Network of Biodiversity Database Systems (NBIDS-BRT) team for data visualization in this manuscript. This work was supported in part by Banraya

Racha Islands, PTT Pubic Company Limited, TOTAL Foundation and TOTAL E&P Thailand, the TRF/BIOTEC Special Program for Biodiversity Research and Training grant BRT T_351003, BRT T_55001 and BRT T_549002, DPST to W. Srisang, CXKURUE, Walailak University, GLOBE Thailand, GLOBE STN, and IPST Thailand.

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CHAPTER 4

CORAL STATUS AT RACHA YAI ISLANDS, THAILAND

Jitkue, K., Srisang, W., Jaroensutasinee, M. and Jaroensutasinee, K. 2008. (in preparation)

ABSTRACT

This study aimed to study coral status at Racha Yai Islands, Phuket. Shannon-Wiener Index (SWI) at Racha Yai Islands has been declined since 1991. Massive growth form increased rapidly but encrusting, branching and free living forms decreased. Columnar growth form decreased from 1991 to 1992 and disappeared from Racha Yai Islands since the year 2003. The amount of light density at Racha Islands from 1 July 2007- 29 February 2008 was varied between 0-20,000 Lux. The amount of light intensity was lower in August and November 2007 but higher in December - January. SST at Racha Yai Islands was normally distributed but SST at the Great Barrier Reef was a bi-normal curve. DHW at Racha Islands had the highest DHW of 2.5 °C-weeks but at the Great Barrier Reef had 40 DHF that had a value greater than 2.5 °C-weeks. There were more coral bleaching hotspot at the Great Barrier Reef than at Racha Islands. Racha Islands did not have hot spots since 2006; however, the Great Barrier Reef still continued to have hot spots.

Keywords: Coral, Coral growth forms, NOAA SST, Shannon-Weiner Index

INTRODUCTION

Coral reefs have declined over the course of human history, culminating in the dramatic increase in coral mortality and reef degradation of the past 20-50 years (Pandolfi et al., 2003). This "coral reef crisis" is well-documented and has stimulated numerous publications on the future of coral reefs (e.g., Hoegh-Guldberg, 1999; Knowlton, 2001; McClanahan, 2002) and their vulnerability to environmental change (e.g., Bryant et al., 1998; Hughes et al., 2003). The causes of this crisis are a complex mixture of direct human-imposed and climate-related stresses, and include factors such as outbreaks of disease, which have suspected but unproven connections to both human activities and climate factors. By 1998, an estimated 11 percent of the world's reefs had been destroyed by human activity, and an additional 16 percent were extensively damaged in 1997–98 by coral beaching (Wilkinson, 2000, 2002). Widespread coral bleaching, unknown before the 1980s, has brought recognition that reefs are threatened by global-scale climate factors as well as by more localized threats, and that different types of stress may interact in complex ways.

The atmosphere and the ocean have warmed since the end of the 19^{th} century and will continue to warm into the foreseeable future, largely as a result of increasing greenhouse gas concentrations (Houghton et al., 2001; Levitus et al., 2000, 2001). El Niño-Southern Oscillation (ENSO) events have increased in frequency and intensity over the last few decades. This combination (warming and intense El Niño events) has resulted in a dramatic increase in coral bleaching (Glynn, 1993; Brown, 1997a; Wilkinson, 2000).

The severe bleaching event in 1998 has added further weight to the argument that elevated temperature is the primary variable triggering coral bleaching. Not only were most incidents of bleaching in 1998 associated with reports of warmer-than-normal conditions, but the Hotspot program (Goreau and Hayes, 1994) run by the US National Oceanic and Atmospheric Administration (NOAA) predicted (days or weeks in advance) bleaching for most geographic regions where bleaching occurred during 1998.

The temperature threshold for bleaching is not an absolute value, but is relative to other environmental variables (especially light) and to the duration and severity of the departure from the normal temperature conditions of a reef (Liu et al., 2003). Bleaching due to thermal stress is not, therefore, limited to areas of normally high water temperature. However, regions where higher temperatures are the norm seem likely to be more vulnerable to increased physiological bleaching (Fitt et al., 2001). CSRIO, (1999) estimated temperature at which coral bleach (also called thermal threshold) at Phuket to be equaled to 30.2 °C. Roeckner et al., (1996) simulated sea surface temperature data by using the coupled atmosphere ocean ice model at Phuket. Their model predicted that sea surface temperature at Phuket would be hotter than thermal threshold (i.e. 30.2 °C) in 2030.

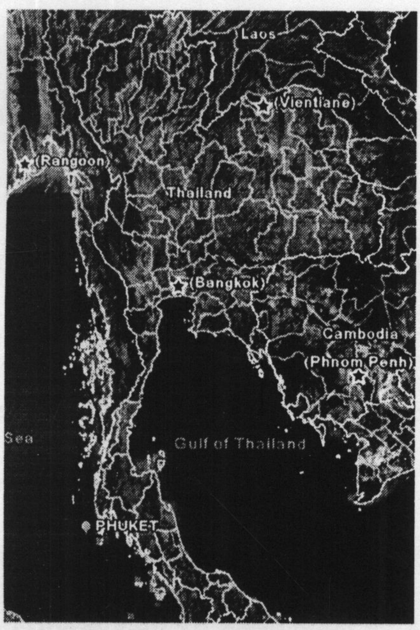
This study aimed at (1) classifying coral growth forms, coral diversity, (2) comparing temperature and light intensity data between NOAA satellite data and HOBO data loggers during 1 July 2007 – 29 February 2008, (3) comparing NOAA Sea surface temperature (SST), sea surface temperature anomaly (SSTa), Degree Heating Weeks (DHW) and Coral bleaching Hotspot between Racha Yai Islands and the Great Barrier Reef, Australia.

METHODOLOGY

Study site

Racha Islands is one of the most popular diving and snorkeling places near Phuket province (Figure 13a,b). There were four hotels on Racha Yai Islands: The Racha, Ban Raya resort and spa, Bungalow Raya Resort and Raya Sea view (Figure 13c). Racha Islands was selected as a study site to monitor coral diversity and sea surface temperature because at this site, there were NOAA data on sea surface temperature available for comparisons.

(a)



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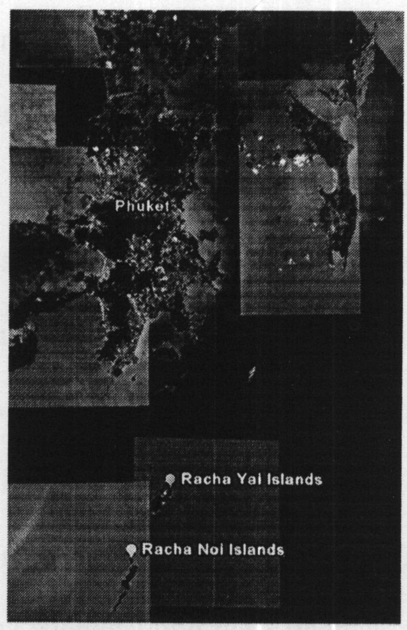

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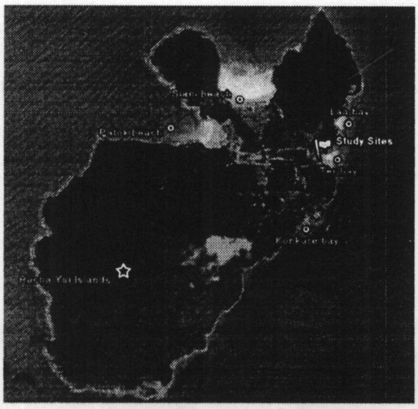
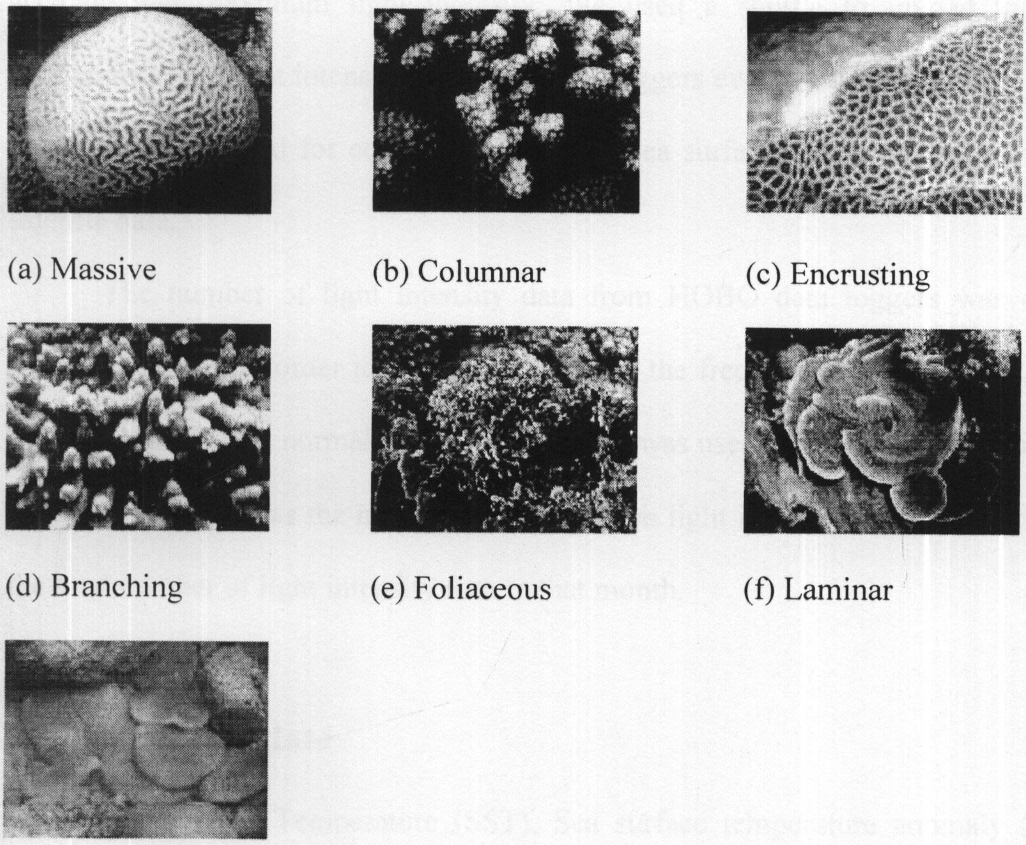


Figure 13. (a) The map of Thailand, (b) Racha Islands and (c) Study sites.

Coral diversity

Phuket Marine Biological Center (PMBC) have been conducted a coral reef monitoring program in the Andaman Sea in order to determine the long term change in coral and reef fish communities since 1981. The quadrat–photographic method was used for coral assessment. In the early period, the effect of off-shore tin mining to the reef and the outbreak of crown of-thorns starfish were studied by the manta–tow technique. During 1988-1991, the ASEAN–Australia Co-operative Program was carried out. Since then, the line transect method was used to study coral communities. Since the ASEAN–Australia Project ended, the Department of Fisheries' long-term monitoring of reefs under the Coral Reef Management Program has been done. There are approximately 80 permanent study sites on the islands along the Andaman coast. From the results of manta-tow surveys, the coral reef map book with detailed descriptions of the status of the reefs was published (Chansang et al., 1999, 2000).

We used coral diversity, and a percent coral cover from PMBC's report (i.e. the year 1991, 1992, 2003 and 2006) at Racha Yai Islands (see Appendix A for raw data). We reclassified coral growth forms into seven coral growth forms: Massive, Columnar, Encrusting, Branching, Foliaceous, Laminar and Free living (Figure 14a-g). The percentage of area cover in each growth form was used to calculate Shannon-Wiener index.



(a) Massive (b) Columnar (c) Encrusting

(d) Branching (e) Foliaceous (f) Laminar

(g) Free-living

Figure 14. Seven coral growth forms. (a) Massive, (b) Columnar, (c) Encrusting, (d) Branching, (e) Branching, (f) Laminar and (g) Free-Living

SENSOR BASED DATA

We selected a 1 m^2 empty area located within coral reef with sandy bottom at Racha Yai Islands (Latitude 7.60488 °N, Longitude 98.37660 °E). We deployed four HOBO Pendant temperature and light data loggers model UA-002-64 to measure water temperature and light intensity during 1 July 2007 to 29 February 2008. These loggers were programmed to record water temperature every 5 minutes continuously. We placed 1.5 kg weight at 1 m^2 empty area and tied these four data loggers to the 1.5 kg weight in four diagonal corners. This allowed each data logger to receive an accurate and maximum light intensity. We used a shuttle to upload the water temperature and light intensity data from data loggers every two months. This HOBO data logger was used for comparison with the sea surface temperature from NOAA satellite data.

The number of light intensity data from HOBO data loggers was differed between months. In order to be able to compare the frequency of light intensity data between months, the normalized number of data was used. The normalized number of data was calculated as the number of data in each light intensity intervals divided by the total number of light intensity data in that month.

NOAA Satellite data

Sea Surface Temperature (SST), Sea surface temperature anomaly (SSTa), Degree heating week (DHW) and Coral bleaching Hot Spots data of Racha Yai Islands (Latitude 7.60488 °N, Longitude 98.37660 °E) were downloaded from the NOAA website. These NOAA satellite data were capable of providing synoptic views of the global oceans in near-real-time and the ability to monitor remote reef areas. These NOAA data were compared with the field data from HOBO Pendant Temperature and Light loggers at two sites: Racha Yai Islands, Phuket, Thailand and Great Barrier Reef, Australia.

SST is affected by local weather, currents, and seasonal changes. The temperature anomaly used to track changes in SST defined as the difference between the expected temperature and the actual one. The expected temperature was the average temperature for that day of the year, based on data from the last several decades. The SST anomaly is the difference between coral reef watch's nighttime SST and the SST climatology for the corresponding period. The base period for the climatology was 1950-1979.

Whenever positive SST anomalies occur during the warmest months of the year, often a 1°C elevation above the monthly mean maximum accompanies bleaching. To take advantage of this finding, an experimental SST chart has been developed for the Tropics that compares presently observed SST to the warmest monthly mean SST at each location. These special anomalies, that show SST in excess of the highest monthly values, denote potential bleaching activity is most likely underway wherever a +1°C elevation above the monthly mean maximum exists.

$$\text{SST anomaly} = \text{SST analysis} - \text{SST interpolated climatology} \quad (1)$$

$$\text{SST interpolated climatology} = \text{day fraction}^* (b_2 - b_1) + b_1 \quad (2)$$

Where, SST analysis is the 50 km nighttime only SST analysis,

b_1 is the first month's climatology data.

b_2 is the second month's climatology data.

The day fraction is the ratio of the current number of days away from the 15th of the 1st month to the number of days between the two closest climatology files.

DHW is a cumulative measurement of the intensity and duration of thermal stress, and is expressed in the units of °C-weeks. A DHW of 2 is equivalent to two weeks of Hot Spot at 1 °C or one week of Hot Spot at 2 °C. DHW over 4 has been shown to cause significant bleaching, and values over 8 can cause widespread bleaching and some mortality.

Coral bleaching Hot Spots highlight SST anomalies that are 1 °C greater than the SST Maximum Monthly Mean (MMM). The climatology was then interpolated to 50 km resolution and serves as the input threshold for the Coral Bleaching Hot Spot charts.

Hot Spots = SST analysis – SST interpolated MMM (3)

In the Hot Spot charts, only regions where the SST is 1 °C greater than the maximum expected summer time temperature are highlighted. A color table is used which highlights anomalies greater than 1.0 °C in yellow to red, with anomalies between 0.25 to 1.0 °C in purple to blue. The yellow to red colors usually indicate potential coral bleaching.

RESULTS

Shannon-Wiener Index (SWI) at Racha Yai Islands was declined from the year 1991, 1992, 2003 to 2006, respectively (Figure 15). There were seven coral growth forms at Racha Yai Islands during 1991-2006 (Figure 16). Massive growth form increased rapidly but encrusting, branching and free living forms decreased (Figure 16). Columnar growth form decreased from 1991 to 1992 and disappeared from Racha Yai Islands since the year 2003.

SST from the NOAA website was similar to SST measured by the HOBO data loggers during 1 July 2007 – 29 February 2008 (Figure 17). The amount of light density at Racha Islands from 1 July 2007- 29 February 2008 was varied between 0-

20,000 Lux (Figure 18a-f). The amount of light intensity was lower in August and November 2007 but higher in December -January.

The average (±SD) SST at Racha Yai Islands, Thailand was 29.23±0.70 °C with a range of 27.20 to 31.40 °C and the average (±SD) SST at the Great Barrier Reef, Australia was 25.48 ± 2.03 °C with a range of 21.70 to 29.90°C (Figure 19a, 20a). The average (±SD) SSTa at Racha Yai Islands, Thailand was 0.32 ± 0.45 °C with a range of (-1.16) to 1.50°C and the average (±SD) SSTa at the Great Barrier Reef, Australia was 0.08 ± 0.51 °C with a range of (-1.70) to 2.30 °C (Figure 19b, 20b). SST at Racha Yai Islands was normally distributed (bell curve distribution) but SST at the Great Barrier Reef was a bi-normal curve (Figure 20a).

DHW at Great Barrier Reef occurred on three years (i.e. 2002, 2004, 2006) with a total DHW of 94 °C-weeks out of 755 °C-weeks but DHW at Racha Islands occurred on only one year in 2005 with a total DHW of 27 °C-weeks out of 755 °C-weeks (Figure 19c, 20e,f). DHW at the Great Barrier Reef in the year 2002 was 5 °C-weeks (Figure 19c). DHW at Racha Islands had the highest DHW of 2.5 °C-weeks but at the Great Barrier Reef had 40 DHF that had a value greater than 2.5 °C-weeks (Figure 20f).

There were more coral bleaching hotspot at the Great Barrier Reef than at Racha Islands (Figure 19d, 20g,h). Racha Islands did not have hot spots since 2006; however, the Great Barrier Reef still continued to have hot spots.

At Racha Islands, there was the filamentous alga called turtle weed (*Chlorodesmis fastigiata*) present (Figure 21a). This turtle weed can cause coral polyp retraction but had little other noticeable effect on coral tissue.

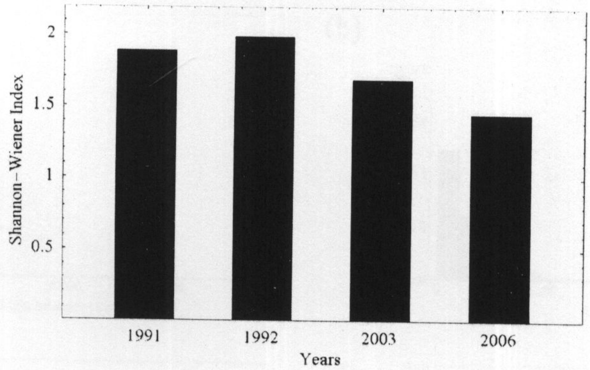


Figure 15. Shannon-Weiner Index of coral diversity at Racha Yai Islands, Phuket on 1991, 1992, 2003 and 2006.

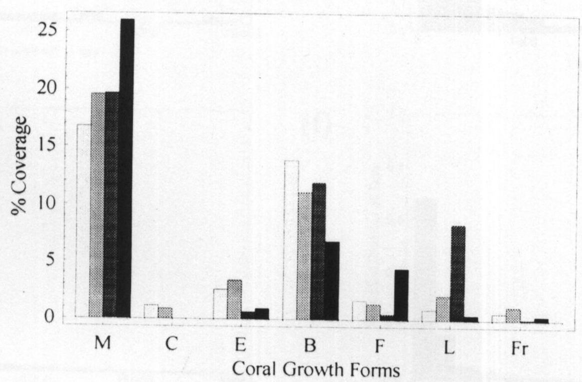


Figure 16. The percent Coral Cover at Racha Yai Islands in (▫) 1991, (▫) 1992, (●) 2003 and (●) 2006. M, C, E, B, F, L and Fr represent massive, columnar, encrusting, branching, foliaceous, laminar and free living growth form.

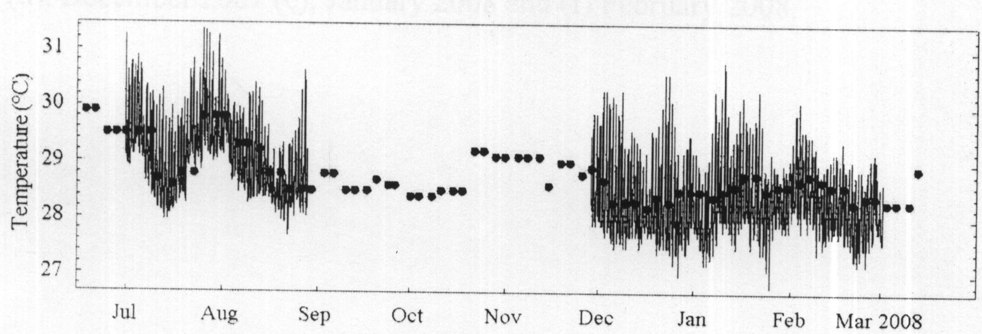


Figure 17. Sea surface temperature (SST) from (●) NOAA and (-) HOBO data logger at Racha Yai Islands during 1 July 2007 – 29 February 2008.

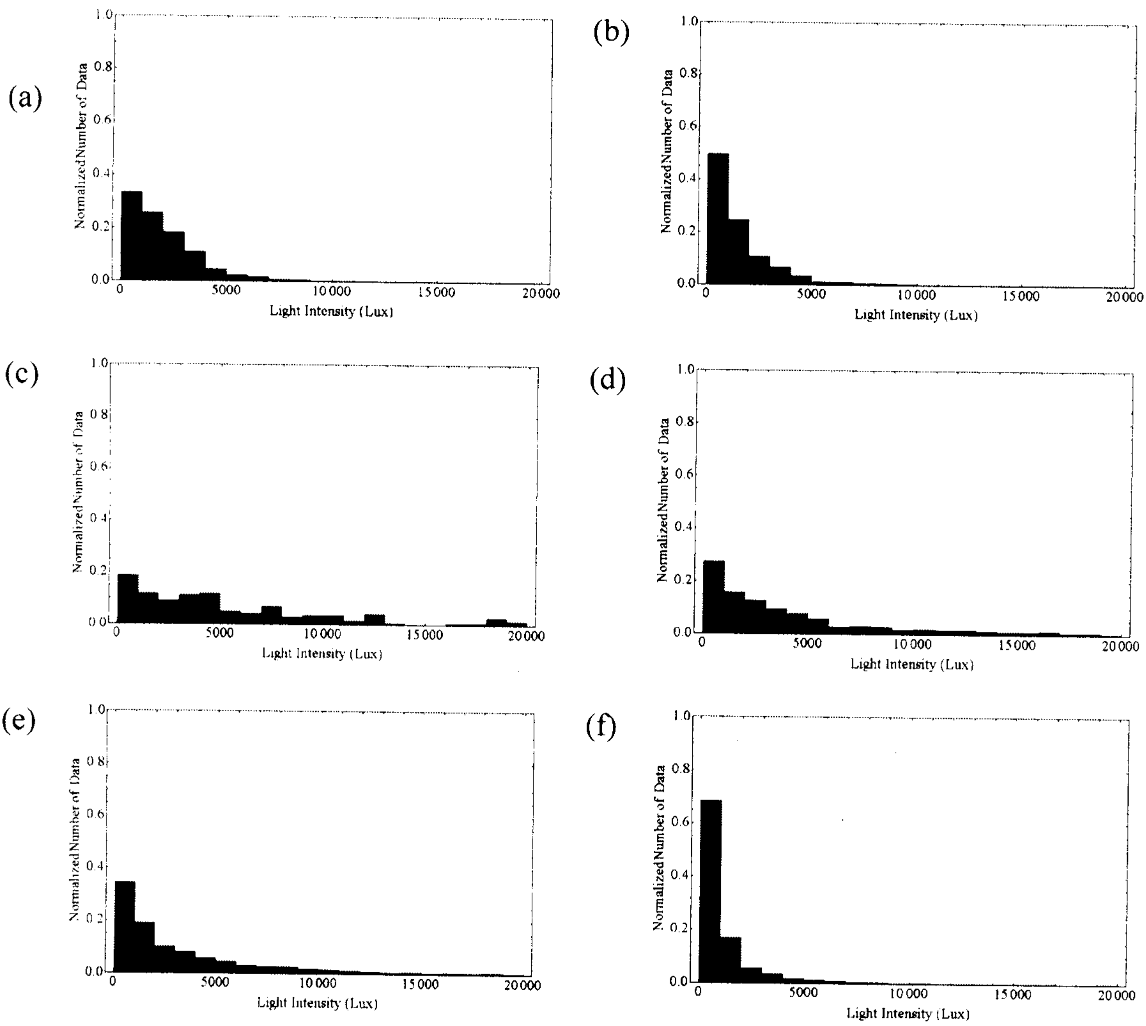


Figure 18. The amount of light intensity (Lux) at (■) Racha Islands from 1 July 2007-29 February 2008, Phuket, Thailand. (a) July 2007, (b), August 2007 (c), November 2007 (d), December 2007 (e), January 2008 and (f) February 2008.

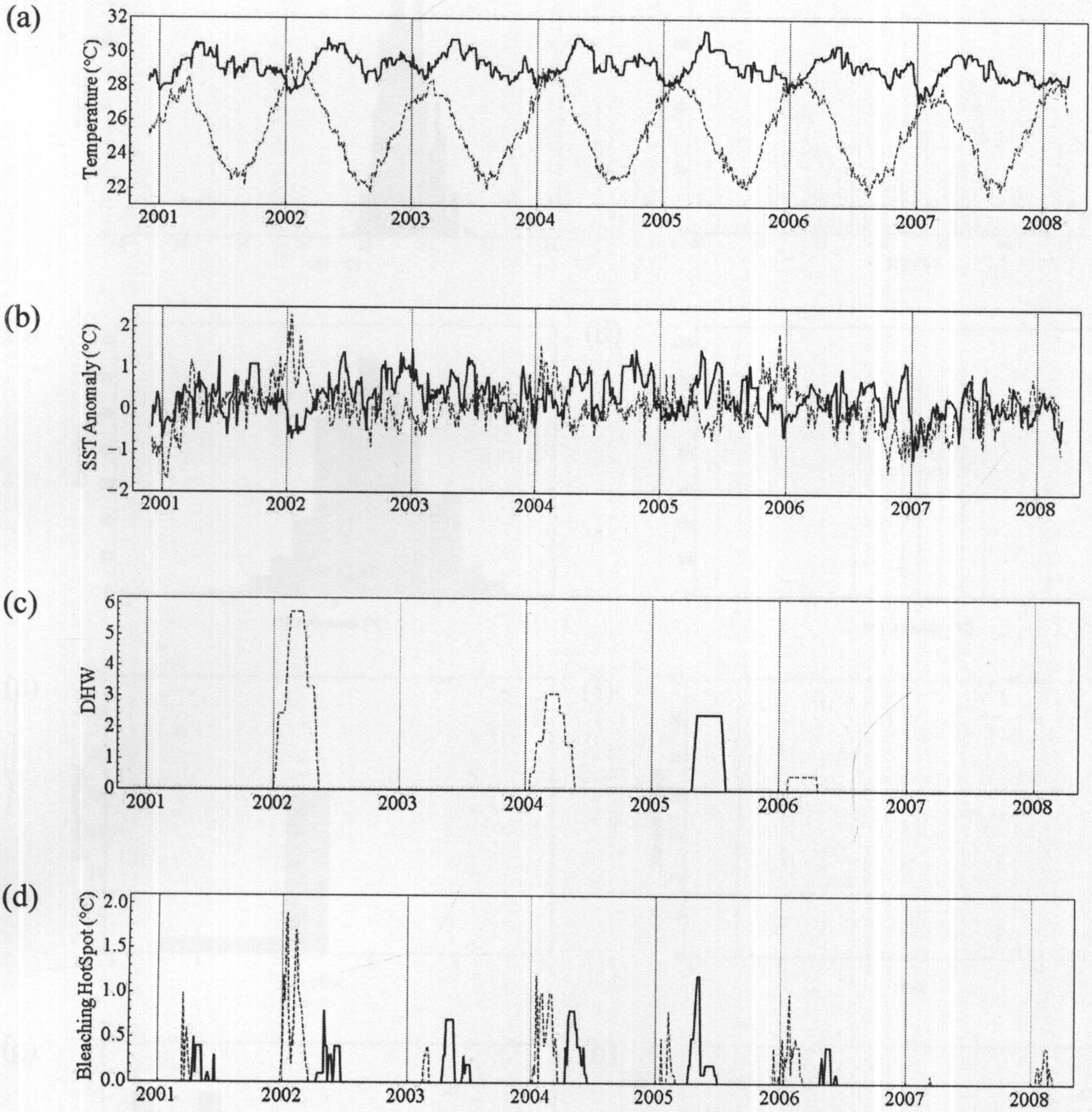


Figure 19. (a) Sea surface temperature (SST), (b) SST Anomaly, (c) Degree Heating Weeks (DHW) and (d) Coral Bleaching Hotspot (HotSpot) at (solid line) Racha Yai Islands, Thailand and (dashed line) the Great Barrier Reef, Australia during 2 December 2000- 2 March 2008.

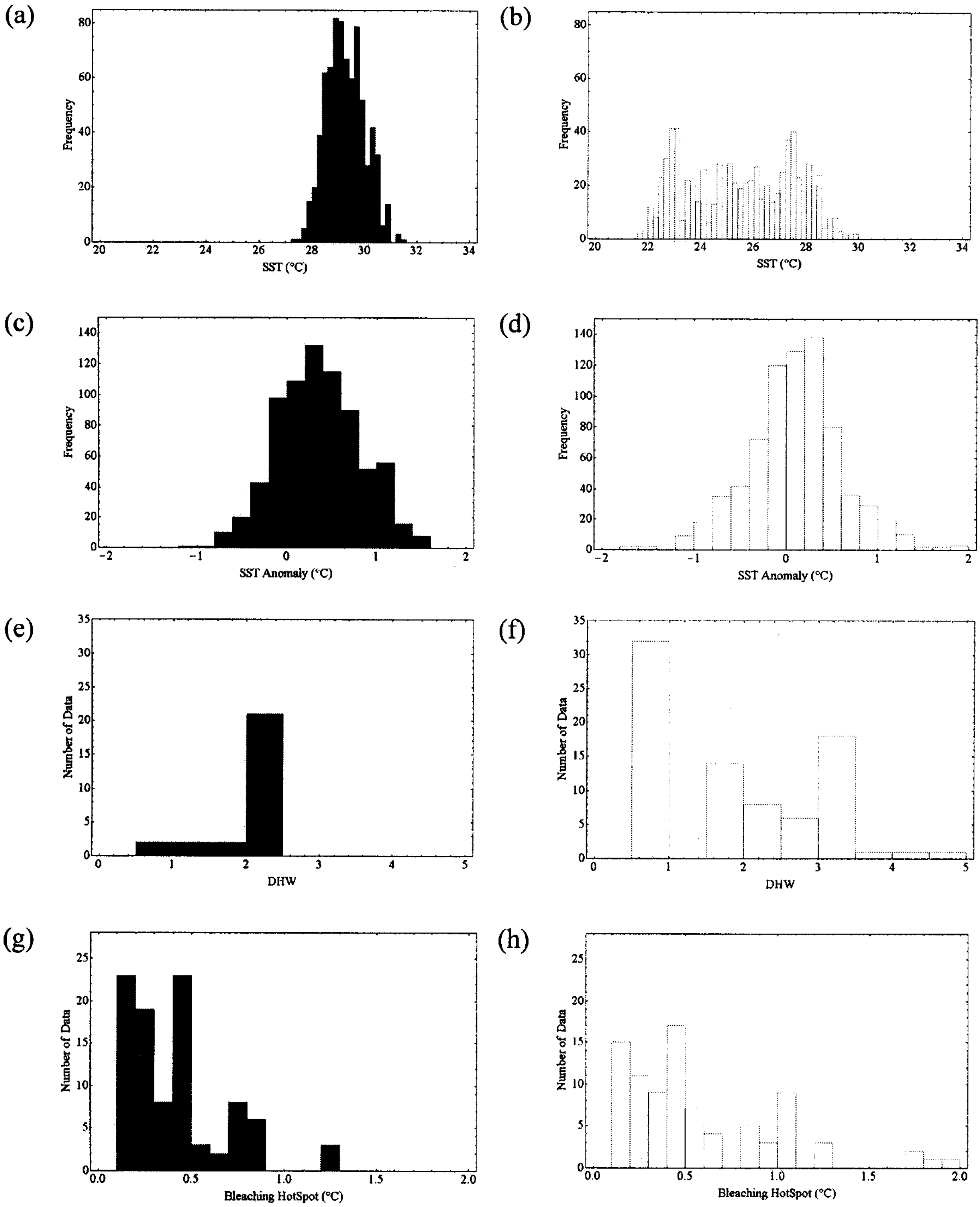


Figure 20. Number of data of (a) and (b) Sea surface temperature (SST), (c) and (d) SST Anomaly, (e) and (f) Degree Heating Weeks (DHW) and (g) and (f) Coral Bleaching Hotspot (HotSpot) at (■) Racha Yai Islands, Thailand and (□) the Great Barrier Reef, Australia during 2 December 2000- 2 March 2008.

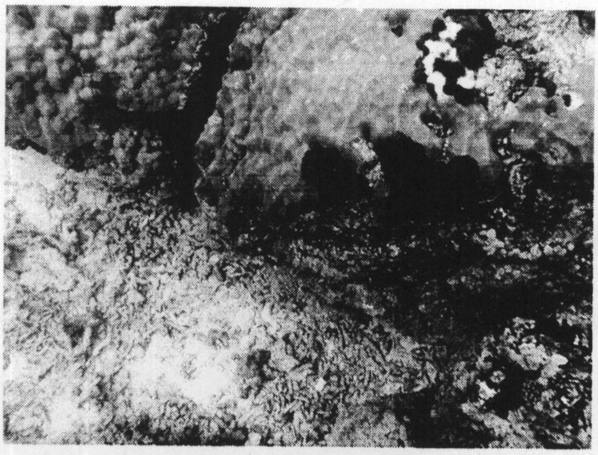
(a)  (b) 

Figure 21. (a) Dead coral fragment scattering on sand floor and Turtle weed (*Chlorodesmis* spp.) and (b) new coral recruitment at Racha Yai Islands, Phuket.

DISCUSSION

Our results showed that Shannon-Wiener Index (SWI) at Racha Yai Islands were declined from the year 1991to 2006. Massive growth form increased rapidly but encrusting, branching and free living forms decreased. Columnar growth form decreased from 1991 to 1992 and disappeared from Racha Yai Islands since the year 2003. This could be because coral with branching growth form tends to be more sensitive to bleaching than massive corals. Massive growth form tends to be less sensitive and could recover from disturbance due to lower growth rate, and thick tissue (Hughes et al., 2003).

Coral reef at Racha Yai Islands had a high amount of the dead coral fragment scattering on sand floor, the most common damage patterns included flipping, inclination, overturning, breaking and fragmentation of coral parts or branches, resulting from being hit by the waves, and from crashing and banging of various types of vessels and waste, and debris of damaged/collapsed natural materials and man–made items that were carried along the water. The filamentous alga called turtle weed (*Chlorodesmis fastigiata*) was found at coral reef at Racha Yai Islands. This turtle weed could cause coral polyp retraction but would have little other noticeable effect on coral tissue.

According to a report coral reefs status of the west coast of Thailand by PMBC (Phongsuwan and Brown, 2007) found that were minimally affected by the Indian Ocean tsunami of December 26, 2004. The results of rapid assessment survey prior to the present study revealed that only 13% of 174 sites visited along the west coast of Thailand were severely damaged with 60% of sites showing little or no damage and overall damages was extremely localized affecting only small sectors of reef which were exposed to the full force of the tsunami waves and Racha Yai Islands, were least affected and diving and tourist activities went on as usual.

Fringe reefs and barrier reefs also help in preventing coastal erosion caused by the impact of waves and tides, and in mitigating the impacts of strong winds. During the monsoon season, coastal areas with damaged coral reefs are normally severely hit by strong winds and waves. The colorful and fascinating beauty of coral reefs, along with the diversity of marine organisms that inhabit the reefs, clear water and other unique physical features, make coastal areas very popular recreational areas and tourist spots that attract millions of tourists from all over the world. They come to enjoy the scenery and to engage in deep sea diving and underwater photography.

Our results showed SST from the NOAA website was similar to SST measured by the HOBO data loggers. This suggests that we could use SST of Racha Yai Islands from the NOAA website. Our results showed that the amount of light intensity at Racha Yai Islands was lower in August and November 2007 but higher in December -January. This indicates that during December to January, there were fewer clouds and rainfalls at Racha Yai Islands, therefore, there were lots of light intensity on the coral reef. The coral reef at Racha Yai Islands would receive different amounts of light intensity throughout the year.

Our results showed that Racha Yai Islands had higher SST than the Great Barrier Reef, Australia. This could be because Racha Yai Islands was located near epicenter zone and dominated by ocean current whereas the Great Barrier Reef was in temporate zone and affected by seasonality. Our results showed that the SST at Racha Yai Islands had an opposite trend to the Great Barrier Reef. When SST at Racha Yai Islands had the lowest temperature, SST at the Great Barrier Reef had the highest temperature. Coral reef at the Great Barrier Reef would experience higher temperature fluctuation than at Racha Yai Islands due to higher in standard deviation of SST and SSTa.

This study showed that DHW at Great Barrier Reef occurred on three years (i.e. 2002, 2004, 2006) with a total DHW of 94 °C-weeks out of 755 °C-weeks but DHW at Racha Yai Islands occurred on only one year in 2005 with a total DHW of 27 °C-weeks out of 755 °C-weeks. This indicated that coral reef at Racha Yai Islands would have a lower chance of coral bleaching than at the Great Barrier Reef. DHW at the Great Barrier Reef in the year 2002 was 5 °C-weeks (Figure 19c). NOAA reported that when DHW was over 4 °C-weeks, coral reef would show significant bleaching.

DHW at Racha Yai Islands had the highest DHW of 2.5 °C-weeks but at the Great Barrier Reef had 40 DHW that had a value greater than 2.5 °C-weeks.

There were more coral bleaching hotspot at the Great Barrier Reef than at Racha Yai Islands. These hot spots indicated that areas where SST was 1 °C greater than the maximum expected summer time temperature. Racha Yai Islands did not have hot spots since 2006; however, the Great Barrier Reef still continued to have hot spots.

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APPENDIX

From annual report during 1989-1991 and 1991-1992, Living Coastal Resources, the ASEAN–Australia Co-operative Program on marine sc and from coral status monitoring report for 2003 and 2006 at Racha Yai Islands in Phuket province

Years			1991		1992		2003		2006	
Items	Genus Name	Growth forms	Number of Colony	% of Cover	Number of Colony	% of Cover	Number of Colony	% of Cover	Number of Colony	% of Cover
1	*Acropora* -branching	Branching	6.00	2.22	0.00	0.00	0.00	0.00	0.00	0.00
2	*Acropora* -corymbose	Branching	3.00	0.90	3.00	0.51	0.00	0.00	0.00	0.00
3	*Acropora austera*	Branching	1.00	0.07	1.00	0.22	0.00	0.00	0.00	0.00
4	*Acropora clatrata*	Laminar	1.00	0.77	2.00	2.11	0.00	0.00	0.00	0.00
5	*Acropora divaricata*	Branching	3.00	0.48	1.00	0.14	0.00	0.00	0.00	0.00
6	*Acropora formasa*	Branching	7.00	2.34	8.00	2.32	0.00	0.00	0.00	0.00
7	*Acropora florida*	Branching	2.00	1.22	1.00	1.10	0.00	0.00	0.00	0.00
8	*Acropora humilis*	Columnar	4.00	0.60	3.00	0.50	0.00	0.00	0.00	0.00
9	*Acropora nasuata*	Branching	2.00	0.68	2.00	0.53	0.00	0.00	0.00	0.00
10	*Acropora nobilis*	Branching	3.00	1.20	5.00	0.93	0.00	0.00	0.00	0.00
11	*Alveopora* sp.	Massive	1.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
12	*Astreopora* sp.	Massive	0.00	0.00	0.00	0.00	1.00	0.09	1.00	0.03
13	*Coeloseris* sp.	Massive	17.00	4.22	16.00	6.15	12.00	3.04	15.00	4.01
14	*Cyphastrea* sp.	Massive	1.00	0.05	1.00	0.03	0.00	0.00	3.00	0.45
15	*Diploastrea* sp.	Massive	1.00	0.28	1.00	0.34	0.00	0.00	1.00	0.05
16	*Fungia* sp.	Free-living	3.00	0.27	7.00	0.62	0.00	0.00	0.00	0.00
17	*Fungia echinata* sp.	Free-living	1.00	0.14	3.00	0.53	0.00	0.00	0.00	0.00
18	*Favia* sp.	Columnar	1.00	0.25	1.00	0.03	0.00	0.00	0.00	0.00
19	*Favites abdita*	Massive	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.05

20	*Favites pentagona*	Massive	0.00	0.00	0.00	0.00	1.00	0.05	0.00	0.00
21	*Fungia echinata*	Free-Living	0.00	0.00	0.00	0.00	1.00	0.10	1.00	0.03
22	*Fungia fungites*	Free-Living	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.34
23	*Favia amicorum*	Massive	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.10
24	*Goniastrea pectinata*	Massive	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.02
25	*Goniastrea* sp.	Massive	1.00	0.15	1.00	0.18	0.00	0.00	0.00	0.00
26	*Goniopora* sp.	Massive	2.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00
27	*Galaxea fascicularis*	Massive	0.00	0.00	0.00	0.00	2.00	0.07	0.00	0.00
28	*Leptastrea transversa*	Encrusting	0.00	0.00	0.00	0.00	0.00	0.00	6.00	0.34
29	*Leptastrea*	Massive	1.00	0.04	1.00	0.02	5.00	0.19	0.00	0.00
30	*Leptoria*	Massive	0.00	0.00	1.00	0.04	0.00	0.00	0.00	0.00
31	*Montipora aequituberculata*	Laminar	0.00	0.00	0.00	0.00	33.00	8.38	13.00	3.82
32	*Montipora angulata*	Branching	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.63
33	*Montipora digitata*	Branching	0.00	0.00	0.00	0.00	35.00	11.86	17.00	6.23
34	*Montipora hispida*	Laminar	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.43
35	*Montipora efflorescens*	Encrusting	0.00	0.00	0.00	0.00	2.00	0.16	0.00	0.00
36	*Montipora tuberculata*	Encrusting	0.00	0.00	0.00	0.00	3.00	0.45	2.00	0.09
37	*Montipora cf. caliculata*	Massive	0.00	0.00	0.00	0.00	5.00	1.55	0.00	0.00
38	*Montipora-mix*	Foliaceous	0.00	0.00	1.00	0.23	0.00	0.00	0.00	0.00
39	*Millepora tenella*	Branching	0.00	0.00	0.00	0.00	1.00	0.10	0.00	0.00
40	*Montipora* sp.	Encrusting	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.33
41	*Millepora* -branching	Branching	1.00	0.20	1.00	0.23	0.00	0.00	0.00	0.00
42	*Millepora* -encrusting-CME	Encrusting	1.00	0.05	1.00	0.12	0.00	0.00	0.00	0.00
43	*Millepora* -plate	Laminar	1.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
44	*Millepora* -encrusting-CE	Encrusting	8.00	0.97	5.00	0.74	0.00	0.00	0.00	0.00
45	*Millepora* -foliaceous	Foliaceous	9.00	1.67	8.00	1.16	0.00	0.00	0.00	0.00

46	*Montipora* -massive	Massive	2.00	0.47	1.00	0.08	0.00	0.00	0.00	0.00
47	*Millepora* -massive	Massive	0.00	0.00	3.00	0.45	0.00	0.00	0.00	0.00
48	*Millepora* -platyphylla	Foliaceous	0.00	0.00	4.00	1.28	0.00	0.00	1.00	0.10
49	*Porites lutea*	Massive	39.00	10.48	35.00	11.22	43.00	10.94	51.00	15.57
50	*Porites massive*	Massive	2.00	0.27	1.00	0.13	0.00	0.00	0.00	0.00
51	*Porites lobata*	Massive	0.00	0.00	0.00	0.00	4.00	3.38	6.00	5.29
52	*Porites stephensoni*	Massive	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.24
53	*Porites (Synaraea) rus*	Massive	0.00	0.00	0.00	0.00	3.00	0.15	1.00	0.15
54	*Porites (Synaraea) rus* – encrust type	Encrusting	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.08
55	*Porites annae*	Branching	3.00	0.16	5.00	0.47	0.00	0.00	0.00	0.00
56	*Porites cylindrica*	Branching	1.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00
57	*Porites lobata*	Encrusting	4.00	1.22	4.00	1.21	0.00	0.00	0.00	0.00
58	*Porites nigrescens*	Branching	4.00	0.82	6.00	0.82	0.00	0.00	0.00	0.00
59	*Pachyseris*	Free-living	1.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
60	*Platygyra*	Massive	3.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
61	*Pocillopora damicornis*	Branching	2.00	0.01	5.00	0.84	0.00	0.00	0.00	0.00
62	*Porites verrucosa*	Branching	8.00	2.45	2.00	0.11	0.00	0.00	0.00	0.00
63	*Psammocora contigua*	Foliaceous	17.00	1.72	12.00	1.32	2.00	0.49	5.00	0.54
64	*Pavona decussate*	Massive	0.00	0.00	0.00	0.00	1.00	0.08	0.00	0.00
65	*Psammocora digitata*	Branching	2.00	0.22	1.00	0.12	0.00	0.00	0.00	0.00
66	*Pavona explanulata*	Massive	2.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
67	*Pavona variens*	Encrusting	5.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
68	*Synaraea rus-branching*	Branching	5.00	1.25	6.00	1.44	0.00	0.00	0.00	0.00
69	*Scapophyllia cylindrica*	Massive	0.00	0.00	0.00	0.00	1.00	0.20	1.00	0.08
70	*Scapophyllia rus-columnar*	Columnar	1.00	0.28	1.00	0.20	0.00	0.00	0.00	0.00
71	*Oulophyllia*	Massive	0.00	0.00	1.00	0.06	0.00	0.00	0.00	0.00

72	*Platygyra* sp.	Massive	0.00	0.00	3.00	0.27	0.00	0.00	0.00	0.00
73	*Platygyra eydouxi*	Columnar	0.00	0.00	1.00	0.16	0.00	0.00	0.00	0.00
74	*Pavona variens*	Encrusting	0.00	0.00	4.00	0.35	2.00	0.03	1.00	0.08
75	*Pavona venosa*	Massive	0.00	0.00	3.00	0.23	0.00	0.00	0.00	0.00
76	Coralimorph	Orthers	4.00	0.64	6.00	1.57	1.00	0.20	1.00	0.10
77	*Chlorodesmis* sp.	Orthers	1.00	0.14	3.00	0.09	6.00	0.34	8.00	0.55
78	Soanthid	Others	0.00	0.00	1.00	0.07	0.00	0.00	0.00	0.00
79	Halimeda	Others	0.00	0.00	1.00	0.24	0.00	0.00	0.00	0.00
80	Sand	Others	45.00	35.51	46.00	44.87	13.00	9.30	10.00	5.85
81	Dead Coral	Others	0.00	24.00	0.00	13.62	0.00	41.96	0.00	44.72

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List of Publications

Jitkue, K., Yaiprasert, C., Surabun, S., Wongkoon, S., Jaroensutasinee, M. & Jaroensutasinee, K. 2007. Coral growth forms, biodiversity index and physical factors at Racha Yai Islands, Phuket. 33rd Congress on Science and Technology of Thailand. Nakhon Si Thammarat, Thailand. 18th-20th October, p..

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