Collaborative research in the Malacca straits to understand the process and factors leading to bleaching and recovery of corals, and thereby contribute to collaborative coral reef conservation in a changing climate.
FINAL REPORT
BAY OF BENGAL LARGE MARINE ECOSYSTEM PROJECT

Collaborative research in the Malacca straits to understand the process and factors leading to bleaching and recovery of corals and thereby contribute to collaborative coral reef conservation in a changing climate

Project No.: 304/PB/650617/F110

ASSOC. PROF. DR. AILEEN TAN SHAU HWAI

School of Biological Sciences
Universiti Sains Malaysia

2014
## CONTENT

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACKGROUND</td>
<td>3</td>
</tr>
<tr>
<td>RESEARCH PROJECT</td>
<td>4</td>
</tr>
<tr>
<td>A1 Introduction</td>
<td>4</td>
</tr>
<tr>
<td>A2 Materials and Method</td>
<td>5</td>
</tr>
<tr>
<td>A3 Results</td>
<td>9</td>
</tr>
<tr>
<td>A4 Outputs</td>
<td>12</td>
</tr>
<tr>
<td>B WORKSHOP ON CORAL REEF RESTORATION IN</td>
<td>13</td>
</tr>
<tr>
<td>BAY OF BENGAL LARGE MARINE ECOSYSTEM</td>
<td></td>
</tr>
<tr>
<td>ANNEX 1</td>
<td>15</td>
</tr>
</tbody>
</table>
BACKGROUND

The mass coral bleaching event in the Southern Hemisphere, which happened in 1997-98 is considered as the most severe on record (NOAA, 1998), related to a strong El Niño-Southern Oscillation (ENSO) disturbance. Bleaching was reported across South-east Asia in May 1998. Bleaching causes corals, which otherwise may live for well over 100 years, to die (Hoegh- Guldberg, 1999). With the 2009-2010 El-Niño, most of the Southeast Asia region experienced intensive thermal stress. Significant bleaching was reported in the Maldives, both sides of the Thai Peninsula (Andaman Sea and Gulf of Thailand), Malaysia, Singapore, Cambodia, parts of Indonesia and the Anilao region of the Philippines.

In order to manage and conserve coral reef systems, detailed understanding of the climatic and other physical-chemical threats and their impacts, using established monitoring processes is important. The Northern Malacca Straits provides excellent opportunities for a tri-national collaborative effort in this regard.

University Sains Malaysia (USM) is engaged in research on coral reefs and studies the bleaching of corals and their recovery and effects of sedimentation, temperature and light on the systems. USM carried out studies on these aspects in the Malaysia and Indonesia side of the Northern Malacca Straight and organized a workshop to share results from this and other studies, with funding from BOBLME Project. The studies are discussed in Section A and the workshop under Section B-Proceedings.
A. RESEARCH PROJECT

A.1 Introduction

Malaysia experienced widespread coral bleaching in 1998, 2004 and 2010. Coral bleaching in Peninsular Malaysia was reported from mid-April to June 2010, whereas bleaching was reported from East Malaysia mid-May to early June 2010. Rapid environmental changes and increasing anthropogenic threats increase the frequency of coral bleaching. Reef Check Malaysia\(^1\) (2012) has predicted that coral bleaching will occur annually in the coming decades. While bleaching cannot easily be prevented or stopped, steps can be taken to promote coral recovery after a bleaching event.

Many Malaysian coral reefs are found in the South China Sea and Sulawesi Seas, around various island groups off the coasts of Terengganu and Southeast Johor, and around the Semporna group in Sabah and Labuan islands. Some reefs are also found in the Straits of Malacca, around Pulau Langkawi and Pulau Pangkor. Smaller reefs occur around Tanjung Tuan in Melaka. These reefs were affected by the coral bleaching event. However, no proper documentation on the bleaching and recovery was made. Therefore, it was important to conduct a thorough study on the coral bleaching effect and its recovery and correlation with sedimentation, temperature and light intensity. The study site was the reefs in Pulau Langkawi, located at the Straits of Malacca. For comparison, a reef located in Pulau Weh, Aceh, Indonesia, was also studied.

A.2 Objectives

The objectives of this project were:

i. To determine the status of coral bleaching and recovery to the generic level at the reefs of Pulau Langkawi

ii. To determine the influence of sedimentation, temperature and light intensity to the coral recovery to different generic levels at the reefs of Pulau Langkawi

iii. Recommendations on measures in coral reef conservation and management in a changing climate

\(^1\) Reef Check Malaysia (RCM) is a non-profit organisation that was registered in 2007 to engage with the local community to raise awareness for the importance of, and threats to, coral reefs.
A.3  

**Materials and Method**

The project was conducted at two islands namely Pulau Langkawi (Kedah, Malaysia) and Pulau Weh (Aceh, Indonesia). Both are located along the Straits of Malacca. Pulau Langkawi lies on the northern part of the Straits of Malacca about 30km off the north-western coast of Peninsular Malaysia. Teluk Nyior is located at the northwest of Pulau Langkawi at the latitude of 6°26’N and the longitude of 99°45’E as shown in Figure 1. The study site was chosen due to its richness of coral distribution. Coral surveys were carried out on the upper and lower reefs to determine the status of coral recovery between the reefs at the study site.

*Figure 1. Base map of the study site in Teluk Nyior, Pulau Langkawi.*
Similar sampling activities were conducted in Pulau Weh, Indonesia. This site was chosen based on the corals, which had just recovered from the 2004 Tsunami event that hit Banda Aceh, Indonesia.

**Figure 2:** Study sites in Pulau Weh, Aceh (Indonesia) (modified from Campbell *et al.*, 2007; Agustan *et al.*, 2009)
The methodology applied in this project for both sampling sites (Pulau Langkawi and Pulau Weh) is shown in Figure 3. The details of the sampling methods are presented in Annex 1.

1. To determine coral bleaching and the status of coral recovery to the generic level

- **PhotoQuadrat Method**
  - Photographs of 1x1m quadrat from four 25m permanent transects will be taken at the upper and lower reef zone.
  - Estimate the percentage of coral categories in each quadrat by using grid method.
  - Identify the normal, bleached and recovering corals in different genera.

2. To determine the influence of sedimentation, temperature and light intensity to the coral recovery to different level

- **Sedimentation Analysis** (modified from Stoddart and Johannes 1978)
  - Collect the sediments from four sediment traps (two from lower reef and two from upper reef).
  - Wash the sediment samples with freshwater and leave it to settle.
  - Sieve the sediments by using sieves of sizes 1mm, 430µm, 500µm, 250µm, 125µm and 63µm.
  - Place the sediment samples in Petri dishes and oven dried at 105° for 24 hours.
  - Weigh the sediment sample.
  - Calculate the sedimentate.

- **Temperature/Light**
  - Data recorded using HOBO Logger and will be replaced every two months.
  - Temperature and light intensity graph will be plotted.

**Figure 3. Flow chart summarizing the sampling method used in this study.**

The analysis of coral coverage was done in the laboratory to determine the percentage of coral recovery in the study sites after the recent bleaching event. Data from the loggers and sediment traps were used to determine the influence of temperature, light intensity and sedimentation on the coral recovery.

The photographs of the transect line were analyzed two-dimensionally. The components for the coral coverage analysis were estimated in the photographs by using 10x10 grids as shown in Figure 4. The total coral coverage was calculated manually. The classification of the biotic and abiotic components for the coral coverage analysis was based on the classification method by English et al. (1994) (Figure 5).
Figure 4. Coral coverage analysis was done using 10x10 grids on a photographed image.

Figure 5. Classification of the biotic and abiotic components (modified from English et al., 1994).
Sedimentation analysis was done using the wet sieving method modified from Stoddart and Johannes (1978). The details of the method are presented in the scientific paper in Annex 1.

The temperature and light intensity data were retrieved from the HOBO logger using HOBO software. Monthly mean graphs of temperature and light intensity were plotted. This is to determine the influence of temperature and light intensity on the coral recovery.

### A.4 Results

**Pulau Langkawi**

The overall coral coverage of biotic and abiotic components on the shallow and deep reef at Pulau Langkawi, Malaysia from year 2010 to 2013 is shown in Figure 6.

![Figure 6: The overall area coverage of the biotic and abiotic components on the shallow and deep reefs at Pulau Langkawi, Malaysia from year 2010 to 2013.](image)

*Shallow reef*

After the mass bleaching event, corals in Pulau Langkawi underwent a recovery process, and recovering corals were recorded in year 2010, 2011 and 2012, with values of 5.12%, 7.26% and 6.76%, respectively. The results showed that dead coral was the major coverage component at the shallow reef in year 2010 (59.22%) and
2011 (61.34%). Macroalgae only recorded in year 2012 (20.58%) and rapidly increased in year 2013 (48.22%).

The increase of the dead coral coverage has been contributed by the death of bleached corals and corals that were unable to recover. The dead coral and live coral in this site was replaced by macroalgae and sediment in year 2012 and 2013. The coverage of live and dead corals was affected by the sediment and macroalgae.

Deep reef

About 12.14% coverage of normal coral was observed in year 2010. The coverage increased in year 2011 (17.24%) but decreased again in 2012 (10.98%). However, the coral coverage increased slightly from 2012 to 2013 (18.04%). The area covered by bleached coral was only about 0.38% in year 2010, and bleached corals were not detected in the deep reef in year 2011 and 2012. However, in year 2013 the area covered by bleached corals was 0.10. Recovering corals at the deep reef was decreasing from year 2010 to 2013 where, 5.52% in 2010, followed by 1.50% in 2011, 0.42% in 2012 and 0.36% in year 2013. Dead coral was the major component observed on the deep reef in the years 2010 and 2011. The results showed that the area coverage of dead coral had slightly decreased from 2010 to 2011. However, the dead coral was not the major component in the deep reef in year 2012 and 2013, where it was replaced by macroalgae and coral rubble.

Pulau Weh

The overall coral coverage of biotic and abiotic components on the shallow and deep reef at Gapang and Lhok Weng in Pulau Weh, Indonesia in year 2013 is shown in Figure 7.

Shallow reef

The major components found in Lhok Weng shallow reef were rock, coral rubble and sand. The coverage of rock, coral rubble and sand in Lhok Weng shallow reef was 74.63%, 14.73% and 5.75%, respectively. Bleached coral, recovering coral, macroalgae and sediment was not recorded in Lhok Weng shallow reef. The coverage of dead coral in that area was also relatively low (0.05%).
Figure 7: The overall percentage of abiotic and biotic coverage in Gapang and Lhok Weng at shallow reef and deep reef. (GPS: Gapang shallow reef; LWS: Lhok Weng shallow reef; GPD: Gapang deep reef; LWD: Lhok Weng deep reef).

Deep reef

Abiotic components (rock and coral rubble) dominated both Gapang and Lhok Weng deep reefs. The coverage of rock at Gapang and Lhok Weng was 39.93% and 66.88%, respectively. Coral rubble at Gapang deep reef (47.30%) was higher than Lhok Weng deep reef (16.90%). In Gapang, the normal coral coverage (1.88%) was low compared to Lhok Weng (15.58%). The biotic components from both locations were the normal corals. There was no bleached coral, recovering coral and macroalgae recorded from ns (Gapang and Lhok Weng).
A.5 Outputs

Coral reefs in Pulau Langkawi

Based on the overall coverage of abiotic and biotic components, dead coral coverage had slightly increased from 2010 to 2011 and gradually decreased in 2012 and 2013. Corals on the shallow reef had been affected more by the bleaching events because of the longer exposure duration during low tides compared to the deep reef area. The deep reef area had lower percentage of dead corals compared to the shallow reef area. Following that, the bleached coral on the shallow reef of Pulau Langkawi needed more time for the recovery process. The shallow reef in Pulau Langkawi was not only exposed longer to sunlight and dryness, this shallow reef also experienced a higher sedimentation rate. Sedimentation, temperature and light intensity played an important role in influencing the recovery rate of the coral reefs in Pulau Langkawi.

Coral reefs in Pulau Weh, Indonesia

The reefs in Pulau Weh are located at the subtidal area, and the reefs are submerged all the time. The reefs are subjected to storm and strong waves occasionally. The deep reef in Pulau Weh showed higher percentage of coral cover compared to the shallow reef. The shallow reef experienced stronger and more wave action in any normal day and also during storms.

Recommendations on measures in coral reef conservation

In order to ensure the success of coral reef conservation, the site selected for the coral reef restoration has to be specific, depending on the environmental factors such as sedimentation rate, light intensity and sea surface temperature. Based on the study conducted in this project, the deeper reefs seem to be preferred because these reefs are less influenced by sedimentation and temperature.

The details of the results are presented in the scientific paper in Annex 1.
B. WORKSHOP ON CORAL REEF RESTORATION IN BAY OF BENGAL LARGE MARINE ECOSYSTEM

A workshop entitled “Coral Reef Restoration in Bay of Bengal Large Marine Ecosystem” was held in Penang on 17-18 February 2014. The objectives of the workshop were:

- To share and exchange experiences tries on the status of coral reefs in BOBLME
- To discuss efforts done by other countries and scientists on the rehabilitation and restoration of coral reefs
- To create an opportunity for networking between scientists from countries surrounding BOBLME

Fifteen participants, ten from Malaysia, three from Thailand and two from Indonesia attended the two-days’ workshop. Nine papers were presented. The full papers and presentations are in a separate proceedings.

Invited speakers of the workshop (from left: Zulfikar, Aileen Tan, Mahadi Mohamed, James True, Thamasak Yeemin, Susetiono, Zulfigar Yasin, Suchana Chavanich, Norhanis Razalli and Nithiyaa Nilamani)
Conclusions:

- Recruitment of corals are dependent on seasons and disturbances imposed on the coral reefs, as well as the coral species involved
- Importance of prevention and mitigation of coral reef degradation
- Importance of mitigation measures to cope with additional anthropogenic stressors
- Relatively cheap and simple restoration techniques can be used
- The local government and communities need to be sensitized on the conservation and environment issues
- Involvement and commitment of local communities and agencies are important

Following to the workshop, the international networking between Malaysia, Indonesia and Thailand will be continued especially in the effort to restore the reefs around these countries.

The proceedings are brought out separately” Workshop on Coral Restoration in Bay of Bengal Large Marine Ecosystems, February 17-8, 2014, Universiti Sains Malaysia, Penang Malaysia.
ANNEX 1

RESEARCH PROJECT

Coral Bleaching and Recovery: Effect of Sedimentation on the Corals of the Northern Straits of Malacca
# Table of Content

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>Research objectives</td>
<td>2</td>
</tr>
<tr>
<td>2.0</td>
<td>Materials and Methods</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Research sites</td>
<td>3</td>
</tr>
<tr>
<td>2.2</td>
<td>Coral coverage (Photo-quadrat method)</td>
<td>5</td>
</tr>
<tr>
<td>2.3</td>
<td>Sediment measurement</td>
<td>7</td>
</tr>
<tr>
<td>2.4</td>
<td>Temperature and light intensity</td>
<td>8</td>
</tr>
<tr>
<td>3.0</td>
<td>Results</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Coral coverage in Pulau Langkawi (Malaysia)</td>
<td>9</td>
</tr>
<tr>
<td>3.1.1</td>
<td>Coral coverage at shallow reef</td>
<td>9</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Coral coverage at deep reef</td>
<td>10</td>
</tr>
<tr>
<td>3.1.3</td>
<td>Sediment analysis</td>
<td>12</td>
</tr>
<tr>
<td>3.1.4</td>
<td>Temperature analysis</td>
<td>14</td>
</tr>
<tr>
<td>3.1.5</td>
<td>Light intensity analysis</td>
<td>15</td>
</tr>
<tr>
<td>3.2</td>
<td>Coral coverage in Pulau Weh, Aceh (Indonesia)</td>
<td>16</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Coral coverage at shallow reef</td>
<td>16</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Coral coverage at deep reef</td>
<td>16</td>
</tr>
<tr>
<td>4.0</td>
<td>Discussion</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Coral coverage at Pulau Langkawi, Malaysia</td>
<td>19</td>
</tr>
<tr>
<td>4.2</td>
<td>Status of coral recovery on reef at Pulau Langkawi</td>
<td>20</td>
</tr>
<tr>
<td>4.3</td>
<td>Factors affecting coral recovery at Pulau Langkawi</td>
<td>21</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Sedimentation</td>
<td>21</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Temperature and light intensity</td>
<td>24</td>
</tr>
<tr>
<td>4.4</td>
<td>Comparison of coral coverage at Pulau Langkawi (Malaysia) and Pulau Weh, Aceh (Indonesia)</td>
<td>25</td>
</tr>
<tr>
<td>5.0</td>
<td>Conclusion</td>
<td>27</td>
</tr>
<tr>
<td>6.0</td>
<td>References</td>
<td>28</td>
</tr>
</tbody>
</table>
1 Introduction

1.1 Background

Coral reefs are one of the most diverse, highly dynamic and productive ecosystems (English et al., 1994; Alquezar and Boyd, 2007). They play vital ecological roles in the marine environment by providing refuge, habitat, breeding and nursery grounds for a vast number of marine organisms including molluscs, fishes, and other organisms (Hoegh-Guldberg et al., 2007). Unfortunately, coral reef ecosystems are degrading because of multiple disturbances, which are becoming more frequent and severe. The coral reefs will be lost in the next 30 years if current degradation continues unabated (Wilkinson, 2000). The major threats that contribute to the decline of coral reef coverage are sedimentation caused by coastal development and shipping activities, overfishing, tourism activities and also increased sea water temperature (climate change) which subsequently causes bleaching and diseases (Rogers, 1990; Birkeland, 1997; Talbot and Wilkinson, 2001; Burke et al., 2011).

Malaysia and Indonesia are the countries in the Southeast Asia which are richest in coral reef biodiversity. Both countries and Thailand fall in the coral reef triangle. However, coastal development, climate change and siltation problems caused by the sediment discharge threaten the coral reefs in both of these countries. Expulsion of zooxanthellae from coral tissues causes whitening of the corals when under temperature shock. Severe coral bleaching and slow recovery has resulted in the decline of live hard coral cover on many reefs throughout the world (Loya et al., 2001). The widespread bleaching events in year 1998, 2004 and 2010 had big impacts to the coral reefs worldwide. El Niño
caused the sea surface temperature to rise above the tolerance levels. According to Wilkinson (1998), the worst episode of mass coral bleaching events in the world happened in year 1997 to 1998.

Studies on coral status has been conducted worldwide, including reefs in South Asia and other countries. Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand are working together through the Bay of Bengal of Large Marine Ecosystem (BOBLME) project which is designed to improve the lives of the coastal populations through the improved regional management of fisheries. Universiti Sains Malaysia (USM) is engaged in research on coral reefs in northern part of the Straits of Malacca (Langkawi, Malaysia) and also covering the coral reefs around Pulau Weh (Aceh, Indonesia). The research focuses on coral bleaching, effects of sedimentation, lights and seawater temperature on recovery.

This project was funded by the Bay of Bengal Large Marine Ecosystem. We wish to thank the students and staff from Universiti Sains Malaysia for the tremendous support with data collection.

1.2 Research objectives

This research is a combination of coral coverage, sedimentation, light and temperature effects on the coral reefs in northern Straits of Malacca, Pulau Langkawi (Kedah, Malaysia) and Pulau Weh (Aceh, Indonesia) with the objective to

- determine the status of coral bleaching and recovery at the reefs of Northern Straits of Malacca.
- investigate the influence of sedimentation, temperature and light intensity to the coral recovery of Northern Straits of Malacca.
2. Materials and Methods

2.1 Research sites

The research was carried out at two different islands which are located at the northern Straits of Malacca, Pulau Langkawi (Kedah, Malaysia) (Figure 1) and Pulau Weh (Aceh, Indonesia) (Figure 2). At the Langkawi reef, located at Teluk Nyior, monitoring was carried out during the spring low tide when the reef was fully or partially exposed. In Langkawi the shallow reef (25 m from shore) and deep reef (50 m from shore) were monitored. In Pulau Weh, the monitoring project was carried out at the coral reef in Gapang and Lhok Weng. The reef in Gapang and Lohkweng was always submerged in the water. The monitoring in Pulau Weh was conducted at two different depths: 4m (shallow reef) and 8m (deep reef).
Figure 1: Base map of study sites in Pulau Langkawi, Malaysia (modified from Samsudin, 2010)

Figure 2: Study sites in Pulau Weh, Aceh (Indonesia) (modified from Campbell et al., 2007; Agustan et al., 2009)
2.2 Coral coverage (Photo-quadrat method)

The status of the bleaching of the corals was studied using the photo quadrates method. Photographs of 1 x 1 m quadrant were taken from a 25 m transect. Transect lines were placed at shallow reef (25 m from the shore) and at the deep reef (50 m from the shore) (Figure 3 and Figure 4). The sampling was carried out every 6 months. In Gapang and Lokh Weng, scuba diving was needed to place underwater photoquadrates and underwater photographs was taken.

![Figure 3: Arrangement of the permanent transect lines.](image)

![Figure 4: Arrangement of 1m x 1m quadrant placed on the transect line which was marked every 1m along the 25m transect line without overlapping.](image)
The percentage of coral categories in each quadrant was estimated based on the photographs, which were analyzed based on the biotic and abiotic components. The biotic component consists of live coral, dead coral and macro-algae whereas the abiotic components are sediments, coral rubble and sand. The categories and description of biotic and abiotic components used for the analysis were modified from English et al. (1994) (Table 1). The photographs of the quadrants were analyzed in two dimensions. The components for the coral coverage analysis were estimated by using 10 x 10 grids as shown in Figure 5. The total coral coverage was calculated manually.

**Table 1:** Description of the biotic and abiotic components (modified from English et al., 1994).

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live Coral</td>
<td></td>
</tr>
<tr>
<td>Normal coral</td>
<td>Living coral colonies has uniform colour.</td>
</tr>
<tr>
<td>Bleached coral</td>
<td>Living coral colonies in white colour.</td>
</tr>
<tr>
<td>Recovering coral</td>
<td>Living coral colonies with mixed colour of white and brown.</td>
</tr>
<tr>
<td>Dead coral</td>
<td>Coral covered with algae or sediment, still standing and only skeleton is remain and corallites still recognizable.</td>
</tr>
<tr>
<td>Macroalgae</td>
<td>All types of macroalgae attached or living with the substrate.</td>
</tr>
<tr>
<td>Sediment</td>
<td>Gravel size less than 0.1cm.</td>
</tr>
<tr>
<td>Coral rubble</td>
<td>Unconsolidated coral fragments of broken finger-like form diameter between 0.5 and 15cm.</td>
</tr>
<tr>
<td>Sand</td>
<td>Gravel size less than 0.5cm.</td>
</tr>
</tbody>
</table>
Figure 5: An example of the coral coverage analysis using 10 x 10 grids on a photographed image.

2.3 Sediment measurement

Sedimentation rate was determined using two sediments traps (Figure 6), one in the shallow and the other in the deep reef. The sediment samples were collected every 6 months. The sediment analysis was carried out following standard practices of sediment rate determination.

Figure 6: The setup of the sediment trap in the field.
2.4 Temperature and light intensity

Figure 7 shows the HOBO pendant Temperature/Light Logger UA-002-08 with built in light sensor, which was used in this study. The logger was used to record temperature and light intensity that coral experienced at Teluk Nyior, Langkawi and Pulau Weh. These loggers were replaced with new ones every two months. The data were downloaded before the logger was re-launched at the study site.

Figure 7: HOBO Pendant temperature and light logger.
3. Results

3.1 Coral coverage in Pulau Langkawi (Malaysia)

The research site in Pulau Langkawi (Teluk Nyior) covers a large area of coral reef and can be accessed through walking during the lowest spring tide. Development on the island had progressed rapidly especially the tourism industry. The number of tourists increased from 1.9 million to 2.3 million between year 2004 to 2008 (Samat, 2010). The corals at this study site were distributed in patches. Most of the corals near the shoreline area were exposed to sedimentation. The overall coral coverage of biotic and abiotic components on the shallow and deep reef at Pulau Langkawi, Malaysia from year 2010 to 2013 is shown in Figure 8.

3.1.1 Coral coverage at shallow reef

Normal coral increased from 2010 (5.72%) to 2011 (18.26%), decreased sharply in 2012 (1.3%) and increased steeply in 2013 (10.9%). In 2010, there was a mass coral bleaching event, bleaching was also reported from Teluk Nyior. Bleached coral was recorded in 2010 (7.28%). After the bleaching event, some corals underwent a recovering process. From the observations, bleached coral changed from white back to light brown. Recovering corals were recorded in 2010, 2011 and 2012 with the percentage 5.12%, 7.26% and 6.76% respectively in Teluk Nyior. The dead coral was the major coverage component at the shallow reef in year 2010 (59.22%) and 2011 (61.34%). Macroalgae was recorded in year 2012 (20.58%) and rapidly increased in year 2013 (48.22%).

Based on the shallow reef coverage of biotic and abiotic components, dead coral showed a gradual increased from year 2010 to 2011 during the post-bleaching event.
The increase in dead coral might be the result of the death of bleached and the recovering coral was unable to recover. The dead coral and live coral in this site was replaced by macroalgae and sediment in year 2012 and 2013. According to Jonsson (2002), the 60% of the dead coral in this area were covered by sediment. This explained that the high number of the sedimentation and macroalgae cover on the dead coral. Area coverage of normal coral varied due to the effect of sedimentation. Sediments did not permanently settle on corals because it was re-suspended by wave action (Phongsuwan, 1991). Therefore, coverage of live and dead coral could be affected by covering and exposing of sediment and macroalgae.

3.1.2 Coral coverage at deep reef

Normal coral area coverage varied from year 2010 to 2013. About 12.14% was covered with normal coral in 2010. The coverage increased in 2011 (17.24%), but decreased in 2012 (10.98%). However, the normal coverage again increased slightly from 2012 to 2013 (18.04%). The area covered by bleached coral was only about 0.38% in year 2010 and bleached coral was not detected in deep reef in year 2011 and 2012. However, in year 2013 0.10% was covered by bleached coral. Recovering coral at the deep reef was decreasing since year 2010 to year 2013; 5.52% in 2010, followed by 2011 (1.50%), 2012 (0.42%) and 2013 (0.36%). Dead coral in year 2010 and 2011 was the major component in the deep reef. The results showed that the area covered by dead coral slightly decreased from 2010 (39.44%) to 2011 (38.92%). However, dead coral was not the major component in the deep reef in year 2012 and 2013. It was replaced by macroalgae and coral rubble.
Figure 8: The overall area coverage of the biotic and abiotic components on the shallow and deep reefs at Teluk Nyior, Pulau Langkawi, Malaysia from year 2010 to 2013.
3.1.3 Sediment analysis

Sediments analysis was only conducted in Teluk Nyior, Pulau Langkawi, Malaysia... Detailed investigation of different particle size was done with the samples from the four sediments traps. Four classes of particle sizes were observed and measured. Sediment particles 500 to 1000 µm were the biggest, followed by 250 to 500 µm (medium sand), 63 to 250 µm (fine sand) and the smallest particle size was <63 µm (silt). The trend for the distribution of the particle size at shallow reef was similar in the shallow and deep reefs. The biggest particles, coarse sand were decreasing from 2010 to 2011, increased in 2012 and decreased again in year 2013. For occurrence of particle size 250 to 500 µm (medium sand) was low in 2010 and 2011. However, there was a rapid increase in 2012 to 2013. Fine sand (63 to 250 µm) showed not much of fluctuation from 2010 to 2013 at both shallow and deep reef. The highest percentage of silt (<63 µm) was recorded in year 2011 both on the shallow and the deep reef. There was a sharp decrease in 2012 and slight increase in 2013. Figure 9 shows the percentage of the distribution of the particle sizes in both shallow and deep reefs in Teluk Nyior, Pulau Langkawi, Malaysia from year 2010 to 2013.
Figure 9: The total mean of percentage of sedimentation according to different particle sizes on the shallow and deep reef at Teluk Nyior, Pulau Langkawi, Malaysia from year 2010 to 2013.
3.1.4 Temperature analysis

The monthly mean temperature for the shallow and deep reef at Teluk Nyior, Pulau Langkawi was plotted. The maximum temperature was recorded in November 2012 in the shallow and deep reefs (32.11°C and 32.21°C respectively), denoted with (*) in Figure 10. The lowest temperature was recorded in the Jan 2011 in shallow reef (28.91°C) and deep reef (28.81°C). The temperature in Teluk Nyior showed no significant different between shallow and deep reefs.

![Figure 10: The mean temperature (°C) experienced by corals on the shallow and deep reef at Teluk Nyior, Pulau Langkawi from October 2010 to March 2013.](image-url)
3.1.5 Light intensity analysis

The mean light intensity on the shallow and deep reef at Teluk Nyior, Pulau Langkawi from October 2010 to March 2013 is shown in Figure 11. The shallow reef at Teluk Nyior received more light than the deep reef. The maximum mean light intensity in February 2011 was higher in the shallow reef (18353.45 ± 3980.64 LUX) than the deep reef (12440.27 ± 1198.87 LUX).

A t-test was conducted to compare the monthly mean light intensity from the shallow reef and deep reef at Teluk Nyior, Pulau Langkawi. Results of unpaired t-test showed that only the light intensity from February 2011 to April 2011 between the shallow reef and deep reef were significant different (P<0.05).

Figure 11: The mean light intensity (LUX) that the corals experienced on the shallow and deep reefs at Teluk Nyior, Pulau Langkawi from October 2010 to March 2013.
3.2 Coral coverage in Pulau Weh, Aceh (Indonesia)

The coverage of the biotic and abiotic components varied among two locations in Pulau Weh, Aceh (Gapang (GP) and Lhok Weng (LW)) at shallow and deep reef in year 2013 (Figure 12). Both shallow and deep reef in Pulau Weh, Aceh were submerged in the water. SCUBA diving was needed to take photos underwater. Gapang and Lhok Weng are located at the northwestern part of Pulau Weh. Both locations experience monsoonal season, where the Northeast (NE) monsoon season occurs from December to March, and the Southwest (SW) monsoon occurs from May to September (Whitten et al., 2000).

3.2.1 Coral coverage at shallow reef

There is no data available for the Gapang shallow reef due to tidal restrictions. The major components found in Lhok Weng shallow reef were from abiotic components namely rock, coral rubble and sand covering 74.63%, 14.73% and 5.75%, respectively. Bleached coral, recovering coral, macroalgae and sediment were not recorded in Lhok Weng shallow reef. The coverage of dead coral in that area was also relatively low (0.05%).

3.2.2 Coral coverage at deep reef

Abiotic components dominated both Gapang and Lhok Weng deep reef. The coverage of rock at Gapang and Lhok Weng were 39.93% and 66.88%, respectively. Coral rubble at Gapang deep reef (47.30%) was higher compared to Lhok Weng deep reef (16.90%). In Gapang, the normal coral coverage was low compared to Lhok Weng where Gapang had
only 1.88% of normal coral and Lhok Weng normal coral coverage was 15.58%. From the results, the biotic components from both locations were normal coral. There was no bleached coral, recovering coral and macroalgae recorded from those locations (Gapang and Lhok Weng).

Sedimentation, temperature and light intensity data were not available in Pulau Weh's shallow and deep reef as the sediment traps were swept away and missing data logger due to strong wave action.
Figure 12: The overall percentage of abiotic and biotic coverage in Gapang and Lhok Weng at shallow reef and deep reef. (GPS: Gapang Shallow; LWS: Lhok Weng Shallow; GPD: Gapang Deep; LWD: Lhok Weng Deep). * indicates no data available.
4. Discussion

4.1 Coral coverage at Pulau Langkawi, Malaysia

The reef location at Teluk Nyior in Pulau Langkawi is in the intertidal reef zone where the whole reef is exposed during the spring tidal period. From the field observation, the shallow reef had many hemispherical shaped colonies while the deep reef was a slightly rough area with larger colonies. Dead coral coverage increased slightly from 2010 to 2011 and then gradually decreased in 2012 and 2013. In the study of Jonsson (2002), more than 60% of the dead coral was covered by heavy sedimentation. The observations showed that the deep reef had lower percentage of dead coral compared to the shallow reef. According to Brown et al. (1996), coral mortality is lower at greater depth. Based on research by Phongsuwan (1991), coverage of sediments was re-suspended by wave action, where the sediments did not permanently settle on the coral. Therefore, coverage of the normal coral, dead coral or coral rubble could be affected by the cover and exposure of sediments. Corals on the shallow reef were the most affected by the bleaching events due to longer exposure than in the deep reef. Therefore, the bleached coral on the shallow reef needed a longer period to recover. The shallow reef not only had longer exposure but also experienced higher sedimentation rate (Phongsuwan, 1991). Some corals recovered faster and some slower depending on the supply of larvae from the unaffected reef (Brown and Suharsono, 1990). The ability of corals to recover their zooxanthellae after bleaching also is species-specific and related to their susceptibility to increase in water temperature and recovery period (Burke et al., 2004).
Since the shallow reef in Teluk Nyior is flat, it might not accumulate coral rubble easily where the coral rubbles were easily carried along with the wave and water current from shallow reef to deeper reef. Therefore, the deeper reef, which has the rough condition could have caused more space between colonies to accumulate coral rubbles.

4.2 Status of coral recovery on reef at Pulau Langkawi

After the mass bleaching event in year 2010, some bleached and recovering corals at Teluk Nyior, Pulau Langkawi were able to recover and survive while some corals died. Loya et al. (2001) stated that thicker tissues corals were relatively abundant in the intertidal zone where they are exposed to the air, high irradiance and desiccation during summer midday low tides. The colony growth form and thickness of coral tissues affected vulnerability to bleaching and coral mortality. Massive and encrusting colonies such as some species of faviids and poritids are more resistant to bleach. They take longer to bleach and survived after the bleaching event. Results showed that the cover of coral genera varied monthly as some corals were covered by sediments (Figure 13). Some bleached corals were not able to recover when they were covered by sediment. Jonsson (2002) stated that Pulau Langkawi experiences high sedimentation level and bad water turbidity.
4.3 Factors affecting coral recovery at Pulau Langkawi

In this study, only sedimentation, temperature and light intensity were taken into consideration to assess the coral recovery at Teluk Nyior, Pulau Langkawi.

4.3.1 Sedimentation

Comparison of the sediments recorded from the photo quadrants and sedimentation from the sediment trap was shown in Figure 14. The sedimentation measured from the samples had the same trend in coverage as observed and calculated from photos. Sedimentation was inversely proportional to the percentage of corals in Teluk Nyior, Pulau Langkawi. The photoquadrate samples were analysed in two dimensions, the coral covered by sediment was categorised as sediment. Hence, the coral coverage...
decreased while the sedimentation was high. During the tidal changes and high amount of rainfall the runoff from the shores will increase (Lee and Mohamed, 2011). This might cause sediments to be brought to the shallow reef. According to Abdullah et al. (2011), a large amount of fine particle (< 200 µm) was observed on the reef flat in Teluk Nyior, due to the shallowness of the reef flats and their full exposure to air during low water. Nasir (2005) stated that the freshwater runoff from Lenggara River could influence the seawater quality and later affect the coral distribution and growth. In addition, high input of sediments during heavy rainfall from Lenggara River and the forest near the coral reef community could be one of the possibilities. As shown in Figure 15, larger sediment particles were deposited within a few kilometers from the river mouth while finer sediment may be transported over a longer distances. Based on the study of Lee and Mohamed (2011), Pulau Langkawi has extremely high settling of particles in their corals. If the wave energy is low, the suspended sediment will settle out of water column and deposit on the seafloor (Phillip and Fabricius, 2003). The coral is still able to recover if the sediment does not settle or cover the corallites of the corals for long periods.
Figure 14: Comparison the percentage coverage of sediment from photo quadrans and sedimentation rate from sediment traps.
4.3.2 Temperature and light intensity

Temperature between shallow and deep reef showed no significant difference from October 2010 to March 2013. Jonsson (2002) reported that the Teluk Nyior area has a normal range of seawater temperature from 27.3°C to 28.5°C. However, based on the data collection, the temperature in Teluk Nyior, Pulau Langkawi has increased. This might due to the global warming and also the Southwest Monsoon, which caused most of the areas in Peninsular Malaysia to receive high solar radiation and temperature. After the mass bleaching event in 2010, corals in Teluk Nyior, Pulau Langkawi are more tolerant to higher temperatures. According to Vivekanandan et al. (2008), coral reefs of Andaman Sea has a thermal threshold of 31.4°C, if sea surface temperature exceeds that threshold it will trigger bleaching. The mean temperature at Teluk Nyior from year 2010 to 2013 was about 30.2 ± 0.6°C which did not exceeded the thermal threshold. There was no bleaching recorded after the mass bleaching event in year 2010.

Light intensity of the shallow reef was higher compared to the deep reef throughout the whole study. This is due to the fact that shallow reef was exposed longer than the deep reef in Teluk Nyior, Pulau Langkawi. The deep reef experienced low
light intensity probably due to high water turbidity and sedimentation transported by the wave action.

4.4 Comparison of Coral coverage at Pulau Langakwi (Malaysia) and Pulau Weh, Aceh (Indonesia), 2013

The coral reefs in Pulau Weh were always submerged unlike the reef flat in Pulau Langkawi, Malaysia. Figure 16 shows the comparison of the percentage coverage of abiotic and biotic components at the three locations in year 2013. The highest percentage of normal coral coverage was recorded in Pulau Langkawi at both shallow and deep reefs. In Gapang and Lhok Weng, due to the monsoonal season, the wave action was the major reason for coral mortality (Whitten et al., 2000). The main factor affecting coral coverage in Teluk Nyior, Pulau Langkawi was sedimentation, where the reef was located at intertidal area and sediment brought by wave was settled on coral (exposed to air longer period). In contrast, Pulau Weh reefs were located at subtidal area and storm event occurred frequently in Pulau Weh, Indonesia. The lower coral coverage at shallower reef could be due to the stronger wave action. From the recorded data, abiotic components (rock, coral rubble and sand) in Gapang and Lhok Weng were higher. The high wave energy during the storm might have washed away some of the coral and caused some to die. Some dead coral might be broken into coral bubbles due to the high wave energy during the storm.
Figure 16: Comparison of the percentage of coverage of abiotic and biotic components at three locations which are Pulau Langkawi (Malaysia), Pulau Weh (Indonesia) in year 2013. PLS: Pulau Langkawi Shallow; GPS: Gapang Shallow; LWS: Lhok Weng Shallow; PLD: Pulau Langkawi Deep; GPD: Gapang Deep; LWD: Lhok Weng Deep.
5.0 Conclusion

The mass bleaching event in year 2010 had a severe impact on coral reefs in Malaysia. Recovery of coral in deeper reefs was faster compared to shallower reefs. Sedimentation was one of the major problems faced by both Pulau Langkawi (Malaysia) and Pulau Weh (Indonesia). High sedimentation in the reef covered the surface of the coral and the corallites of the coral and zooxanthallae could not settle in the corallites and symbiont with coral. Coral removed the sandy grain size and nutrient poor sediments more easily than silt and nutrient-rich sediments. Sedimentation tolerances vary greatly among coral species. Sediment rates from about 1000 to 11000 mg/cm²/d or 100mg/cm² for a few days might reduce the photosynthesis and kill the coral tissue. Development of tourism had restricted the long term study on the coral status and coverage and coral reef at Teluk Nyior in Pulau Langkawi cannot be accessed since 2013 due to the development. This study contributed useful information for government and non government institution for future research on coral reef status, sedimentation level and historical events at the research areas.
6.0 References


Nasir, M. 2005. Studies of coral Porites lutea (LINK, 1807) growth as indicators of environmental and climate changes at Teluk Nyior reef, Pulau Langkawi, Malaysia. Master theses. *Universiti Sains Malaysia, Malaysia*


Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand are working together through the Bay of Bengal Large Marine Ecosystem (BOBLME) Project to lay the foundations for a coordinated programme of action designed to better the lives of the coastal populations through improved regional management of the Bay of Bengal environment and its fisheries.

The Food and Agriculture Organization (FAO) is the implementing agency for the BOBLME Project.

The Project is funded principally by the Global Environment Facility (GEF), Norway, the Swedish International Development Cooperation Agency, the FAO, and the National Oceanic and Atmospheric Administration of the USA.

For more information, please visit www.boblme.org