Evaluation of mangrove rehabilitation project at Carey Island coast, Peninsular Malaysia based on long-term geochemical changes

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Abstract. A project for mangrove rehabilitation purpose has been carried out at intertidal area of Carey Island, Peninsular Malaysia in early 2009. As part of the project, a detached low-crested breakwater has been constructed near the bare degraded mangrove area to reduce wave energy and storm surges forcing the site. The breakwater is also expected to trap the sediment behind its structure as well as soil nutrients needed for mangrove seedling. This study attempts to evaluate the changes of seabed elevation and geochemical in soil around the degraded mangrove area after 6 years implementation of the breakwater’s structure. Seabed elevations at degraded mangrove area (rehabilitated area) and concentration of soil nutrients at three locations (rehabilitated area, non-rehabilitated area and natural forest area) were monitored on October 2015. The seabed elevations on October 2015 are compared to the seabed elevation in January 2009 to determine the seabed level changes. In addition, the values of soil nutrients at rehabilitated area were compared to soil nutrients at non-rehabilitated area and natural mangrove forest to evaluate the geochemical condition of soil at mangrove degradation area for preparation of mangrove seedling planting. The results present that there is an increment of seabed elevations at the degraded mangrove area after 6 years construction of the breakwater (approximately 32 cm in average). The results also show a significant increase in the amount of soil nutrients on the top soil (approximately 0 to 20 cm depth) especially carbon, nitrogen and potassium at degraded mangrove area with almost similar to soil nutrients in natural mangrove forest. It demonstrate that the condition of degraded mangrove area after 6 year implementation of the breakwater is conducive for replanting the mangrove seedlings to restore the endangered mangroves at intertidal area of Carey Island, Peninsular Malaysia.

1. Introduction

Mangroves forests are the most important ecosystem in the tropical and subtropical coasts that naturally protect the coastline from ocean impact [1]. For example, mangrove roots have capability in
absorbing the energy of waves and therefore could stabilize shoreline erosion [2-3]. Besides, the existences of mangroves are crucial not only from the perspective of the environment, but also in terms of their economic value [4-5]. Mangroves could provide a suitable environment for breeding and serve as a nursery ground for marine species such as shrimps, crabs, fishes and terrestrial vertebrates and terrestrial vertebrates [6-7].

Over the past decades, rapid development has taken place in Malaysian coastal states. These development activities have diminished mangrove forest though clear-cutting the mangrove along the coastline [8-10]. The bare coastal area (without mangrove) exposed to tidal inundation and wave actions causing erosion problems. The magnitude of nearshore forces such as wave energy and tidal currents influence the survival of the mangrove while human activities such as clear cutting the mangrove leads the issue of mangrove degradation [4]. Therefore, coastal zones need proper protection from these threats. For this case, a technique in shoreline protection needs to carry out in order to prevent the coastal damage and restore the erosion by trapping sediments [11].

The mangrove degradation and erosion problems faced at the intertidal area of Carey Island require mangrove rehabilitation projects to carry out for coastal protection. According to Lewis [12], calm hydrodynamic conditions, normal tidal regime and rich sediment nutrients are the most important factors in mangrove rehabilitation projects. In January 2009, a low-crested breakwater has been constructed at intertidal zone of Carey Island coast around the mangrove degradation area. The breakwater structure is expected to reduce wave-height, currents velocity and restore erosion by trapping the sediment as well as soil nutrients behind its structure to provide a suitable environment required for mangrove replantation purpose. Recently, low-crested breakwaters are being popular for coastal protection and mangrove rehabilitation project on cohesive shore. It is because of their low construction costs and they were effective in reducing the problem of coastal erosion with less environmental impacts [13-15].

Mangrove seeding can take root in the area with relatively calm and the geotechnical stratum is well elevated with respect to mean sea level (MSL) with enough soil nutrients [16]. Assessment of the soil nutrients is an important aspect of mangrove rehabilitation and conservation activities [17]. Therefore, in this paper, we investigate the condition of seabed elevation and determine the values of soil nutrients such as Carbon (C), Nitrogen (N), Phosphorus (P) and Potassium (K) at degraded mangrove area after 6 years implementation of the breakwater in mangrove rehabilitation site. The values of seabed elevations on Oct 2015 were compared to initial bed elevation on January 2009 to determine the seabed level changes. Besides, soil nutrients at rehabilitated area were further compared to the soil nutrients at natural mangrove forest and non-rehabilitated areas to evaluate the geochemical condition of soil at mangrove degradation area. Finally, the results are used to assess the readiness of the study site at Carey Island coastline to support the successful of replanting mangrove seedling to restore the lost mangrove at degraded area.

2. Materials and Methods
2.1. Study area description
This study was carried out at the coastline of Carey Island, west coast of Peninsular Malaysia with long: 02°49′26″N to 02°49′29″N and lat: 101°20′22″E to 101°20′27″E (figure 1). The coastline of Carey Island is one of the mangrove forest reserves in the Strait of Malacca. Mangrove forest grows in the intertidal zone areas approximately 80 m width, with specific bed elevations, which result the specific tidal regime for mangrove survival. Figure 1(b) illustrates the geographic position of the study site before the breakwater system was constructed on January 2009.
The climate at Carey Island, Malaysia is primarily subjected to two seasons during the year that are the Northeast (NE) season and the Southwest (SW) season. The strongest winds are blown from northwest direction with dominant wind speed between 7.5 and 10 m/s occurred during the Northeast season.
season. The Carey Island coast is a mangrove forest reserve, with a semi-diurnal tidal system that receives daily tidal inundations (maximum 2.96 m MSL of neap rise and 4.33 m MSL of spring rise). For the most part, the Carey Island coast is covered by cohesive sediment. Based on soil sample analyses, the median grain diameter ($D_{50}$) of the cohesive sediments in the intertidal area of Carey Island at a depth less than 40 cm was approximately 0.018 mm, while the sub-soil was consisted of stiff clay.

2.2. Mangrove rehabilitation project

The critical condition of Carey Island coastline in term of erosion and mangroves degradation attracted the attention of local engineers. The problem of mangrove degradation is a more severe threat to the coastline (see Figure 1). In this respect, a greater effort is needed to rehabilitate the mangroves by replanting mangrove seedlings at mangrove degradation area. The successful of mangrove seedling plantation in the site is always supported by the calm hydrodynamic condition, enough bed elevation and soil nutrients. Due to these purposes, a low-crested breakwater was constructed with 85 m length on the intertidal zone of Carey Island coast on January 2009 in order to create the calm hydrodynamic condition, restore erosion imbalances and increase the sediment deposition as well as soil nutrients behind the structure (mangrove degradation area). Figure 2 depicts the geological position of breakwater system after construction was completed.

![Figure 2. Schematic view of study site after construction of breakwater on January 2009](image)

Detached breakwater was placed in the bare area of intertidal zone approximately in the vicinity of the degraded mangrove area which has been previously occupied by fringing mangroves (Figure 1). The breakwater is a homogenous rubble mound built with a combination of quarried rock/stone ($D_{50} = 17$ cm) and an unique armoring unit named as $L$-Block [14]. The breakwater was emerged during low tide exposure and was submerged during high tide exposure. The first head of the breakwater is positioned nearly perpendicular to the shoreline and the last head is placed parallel, 40 m away from the shoreline. Fitri et al., [14] reported that the breakwater was designed with two parts (main segment and gap segment) with the crest height and width of breakwater are 1.8 m and 2.5 m (main segment) and 1.4 m and 2.0 m (gap segment) above Mean Sea Level (MSL).

2.3. Monitoring seabed elevations

The seabed levels at the intertidal area of cohesive shore of Carey Island were monitored using a bed profiler on January 2009 and October 2015. The instrument used in this study was a high-end TOPCON total station. The survey program was conducted along 5 profile lines (P1-P5) which were nearly perpendicular to the shoreline (figure 3) and crossed the main segments and gap segments of the breakwater. The measurements were then carried out during low tide
exposure referred to datum B 5345 and B 63083 provided by Department of Survey and Mapping, Malaysia around the study site area.

**Figure 3.** Location of the field measurement

2.4. **Geotechnical assessment**

Soil nutrients such as carbon (C), nitrogen (N), phosphorus (P), and potassium (K) are crucial for mangrove plants, especially during the early stages of a seedling’s development [17]. Carbon and Nitrogen is necessary for fertile soil that promotes plant growth [18]. Nitrogen (N) is an essential element in the plants growth and photosynthesis. Excessive or deficiency of nitrogen will result in various consequences such as soil infertility and retarded growth of plants [19]. Phosphorus is also required in large amounts by plants to help them reach optimal growth. Potassium is another important soil nutrient for mangroves which is needed in large amounts for energy transfer within the plant, especially for photosynthesis [16]. Potassium has also been used in fertilizer to increase soil fertility and acts as an indicator of healthy plants [20]. The lack of K value in soil could lead to unhealthy plant growth. Together, concentration of C, N, P, K in soils play a strong role in supplying sufficient nutrients to the plants for a healthy growth [18,21].

The nutrients distribution patterns in mangroves were varies depending on the location, plant type and environmental conditions [22]. Here, we carried out a study on the geochemical properties of soil samples collected in the area around Carey Island’s coastal zone. We totally collected 15 soil samples in the site for three different areas (area A, area B and area C). Area A denote rehabilitated area, area B denote non-rehabilitated area and area C denote area of existing mangroves (natural habitat). The soil samples were collected for one m depth and were taken during low tide using an Eijkelkamp multi-sampler. Then, the soil divided into three segments according to vertical depth (0-20, 20-40, 40-80) cm. The natural habitat can be considered as the control site and the rehabilitated area can be considered as the experimental site. The nutrient concentrations such as C, N, P and K in the soil samples were measured for every segment from the samples. The locations of collected soil samples were depicted in Fig. 3.

Walkley and Black analysis was used to analyse the content of organic Carbon [23]. Kjedahl method was used to determine the total nitrogen through the process of distillation [24]. Deniege method was used to determine the available phosphorus in the soil [25]. In order to analyse the potassium (K), exchangeable K was determined through distillation method [26].
3. Results and Discussion

Palm cultivation along the coastline of Carey Island used fertilizers which area rich with nutrient. Further, the surface water runoff bring fertilizer fragments into the rehabilitation site because the site is at the edge of the palm cultivation areas. Nutrients are important chemical components needed for plant growth and life-cycle completion. Nutrient-rich sediments quicken the growth of mangrove seedlings (Duarte et al., 1998). In this section, we quantitatively assess nutrients of C, N, P, K in the soil samples.

Table 1, 2, 3 and 4 present the concentrations of soil nutrients including carbon, nitrogen, phosphorous and potassium measured from soil samples collected in the site from three different areas (area A, area B, area C) after 6 years implementaiton of detached breakwater. In addition, figure 4 and 5 present the comparison of seabed elevations in degraded mangrove area before and 6 years after construction of the breakwater (on January 2009 and October 2015) for profile line 3 (crossing the main segment of the breakwater) and profile line 4 (crossing the gap segment of the breakwater).

| Depth (cm) | Table 1. Percentages of Carbon in three different areas at different soil depth |
|-----------|--------------------------------------------------------------------------------|
|           | Natural | Rehabilitation | Non-rehabilitation |
| 0-20      | 1.28±0.34 | 1.55±0.30 | 1.11±0.28 |
| 20-40     | 1.88±0.77 | 1.41±0.25 | 0.96±0.15 |
| 40-100    | 2.39-2.54 | 0.79-0.99 | 0.51-0.77 |

| Depth (cm) | Table 2. Percentages of Nitrogen in three different areas at different soil depth |
|-----------|--------------------------------------------------------------------------------|
|           | Natural | Rehabilitation | Non-rehabilitation |
| 0-20      | 0.05±0.01 | 0.05±0.02 | 0.04±0.02 |
| 20-40     | 0.07±0.01 | 0.04±0.01 | 0.02±0.01 |
| 40-100    | 0.06-0.08 | 0.02-0.03 | 0.01-0.02 |

| Depth (cm) | Table 3. Phosphorus concentration in three different areas at different soil depth |
|-----------|--------------------------------------------------------------------------------|
|           | Natural | Rehabilitation | Non-rehabilitation |
| 0-20      | 49.05±16.26 | 38.27±6.06 | 26.37±4.77 |
| 20-40     | 48.15±7.97 | 36.02±7.86 | 29.02±6.19 |
| 40-100    | 50.84-59.86 | 32.15-28.25 | 25.24-26.12 |

| Depth (cm) | Table 4. Potassium concentration in three different areas at different soil depth |
|-----------|--------------------------------------------------------------------------------|
|           | Natural | Rehabilitation | Non-rehabilitation |
| 0-20      | 1.27±0.74 | 1.22±0.45 | 0.58±0.51 |
| 20-40     | 1.67±0.85 | 1.12±0.57 | 0.37±0.44 |
| 40-100    | 1.48-1.55 | 0.63-0.54 | 0.23-0.40 |
Based on Table 1, percentages of carbon in rehabilitated area after 6 years construction of the breakwater were found to be higher compared to both non-rehabilitated and natural habitat areas at the soil vertical depth 0-20 cm with value of 1.55 ± 0.30%. Besides, based on Table 2, the percentages of nitrogen at the rehabilitated area on October 2015 at the soil vertical depth 0-20 cm were approximately 0.05 ± 0.02%. It means that the percentages of nitrogen at degraded mangrove area were found to be at the same range with the nitrogen percentages at natural mangrove habitat.

A part of that, the concentration of phosphorus in the rehabilitated area after 6 years implementation of the breakwater were approximately 38.27±6.06 ppm that is much less than amount of phosphorus at natural habitat of mangrove that is approximately 49.05±16.26 ppm. But, since the standard amount of phosphorus required in soil for mangrove plantation must be more than 30 ppm, therefore, the amount of phosphorus in rehabilitated area was enough for mangrove seedling plantation. In addition, the sufficient amount of potassium in the soil could help seedlings growth and survival, with a minimum and maximum of 0.63 ± 0.25 cmol/kg and 1.67±0.85. On October 2015, it was found that the concentrations of potassium were about 1.22 ± 0.45 cmol/kg at the mangrove

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**Figure 4.** Seabed level changes along profile line 3 (P3)

**Figure 5.** Seabed level changes along profile line 4 (P4)
degraded area for the depth 0-20cm. The results showed that degraded mangrove area has enough soil nutrients need for mangrove seedling after 6 years implementation of the breakwater in the study site.

Based on figure 4 and 5, the existence of the breakwater has restored slightly erosion imbalance at degraded mangrove area caused by human activity in the coastal zone by increasing slightly sediment accumulation at that area. The average increments of seabed elevations are approximately 28 cm and 32 cm at degraded mangrove area for the line crossing the gap segment (P4) and main segment (P3), respectively.

4. Conclusion
The major purpose of a mangrove rehabilitation project is to provide a suitable area which has proper conditions for mangrove establishment. Based on results, it demonstrated that the rehabilitated area has enough carbon, nitrogen, phosphorus and potassium for mangrove establishment. We can conclude that the condition of degraded mangrove area after 6 year implementation of the breakwater is conducive for replanting the mangrove seedlings to restore the endangered mangroves at intertidal area of Carey Island, Peninsular Malaysia.

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