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Effect of artificial structures on shoreline profile of Selingan Island, Sandakan, Sabah, Malaysia

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Abstract

Selingan Island off Sandakan, Sabah is a famous turtle nesting ground and a part of the Turtle Islands Park (TIP) within the Coral Triangle region of Malaysia. This small island faces the serious problem of beach erosion that is reducing the turtle nesting area. Sabah Parks deployed stone revetments in 2005, followed by placement of reef balls at the southern part of the Selingan Island in 2007 for protecting the shoreline. The objective of this study was to determine the effectiveness of these measures for shoreline protection. Shoreline changes were determined from satellite images, beach profiling and field observations. Satellite images from 2010 to 2016 were obtained from Google Earth Pro analyzed to examine the changes in the shape and size of the island with QGIS software. Beach profiling was performed in December 2017 at three sites and compared with the condition in 2011. The findings indicated that the shape of the island was squeezed towards the east where the reef balls were located. The size of the island has not changed much in 9 years after the deployment of the reef balls, but a high volume of sediments accumulated at the south due to the presence of shoreline protection. Generally, the man-made structures in Selingan Island are effective in trapping the sediment and providing more nesting area for turtles. It is recommended that the shoreline dynamics of the island should be regularly monitored for better understanding of the changes and taking appropriate actions.

Keywords: Shoreline changes, Man-made structures, Selingan Island, Coral Triangle area

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Introduction

Sabah is surrounded by more than 280 small islands (EPD, 2013). Some of the islands have been gazetted as marine protected areas (MPA) for conservation, regulating human activities and ensuring sustainable development (Sabah Parks, 2018). Sabah has six MPAs under the jurisdiction of Sabah Parks, and Turtle Islands Park (TIP) is one of them. Beach erosion is one of the most conspicuous of the natural phenomena occurring on the islands. It involves scraping and removal of sediments from the beaches and dunes along the shoreline and is considered a major global problem affecting more than 70% of the beaches around the world (Bird and Schwartz, 1985).

The TIP consists of three islands located in the Sulu Sea, part of Coral Triangle region. These islands are well-known for their pristine beaches which attract tourists to Sabah every year. Selingan is the largest island compared to Bakkungan Kecil and Gulisaan Island (Saleh, 2017) in this park. It offers turtle nesting experience to tourists. Sabah Parks management allows 50 tourists to stay overnight at one time on this protected island. Size and shape of islands in TIP are changing throughout the year due to the impacts of monsoon seasons, extreme events and local coastal processes.

The erosional problem has caused loss of both habitat and infrastructure on the Selingan Island. Jetty, public toilet and part of Sabah Park's office were damaged due to beach erosion. As a solution, Sabah Parks and Reef Ball Foundation collaborated to install about 290 sets of reef balls (Goliath balls) (Figure 1) as shoreline protection at the southern part of the island in 2007, which was severely affected by the erosion. This is an extension of the stone revetment installed parallel to the shoreline in 2005. The reef balls were deployed by arranging into three rows to increase the stability. Those reef balls serve as submerged breakwaters to protect the shoreline of Selingan Island.

Figure 1. Reef Balls at Selingan Island.

Reef balls help in stabilizing the shoreline through wave attenuation and refraction. Deployment can take the form of three segmented breakwater sections by three rows of Reef Ball ™ units for each segment (Harris, 2003). Reef balls imitate natural system which has holes of varying size. The holes in the interior cavity are smaller than the exterior to create a whirlpool effect to nourish marine life attached to the reef. All surfaces can be enhanced with air entrainment admixture to produce small pockets in the concrete which allow tiny marine organisms a place to attach themselves (Reef Ball Foundation, 2017). Reef balls have been deployed in many countries including Israel, Egypt and USA to protect their coastal areas (Harris, 2009).

This study was designed to assess the performance of reef balls in Selingan Island. The objective was to determine the shoreline changes after the instalment of reef balls in 2007 and its effectiveness in shoreline protection in Selingan Island.

Methodology

Study sites

The Selingan Island consists of sandy beaches except rocky shore at the north. Sandy beach is one of the most important features in TIP, as it provides substrate for turtles to lay their eggs. Loss of the sandy beaches due to beach erosion has reduced turtle nesting area. The shape of the Selingan Island in the 70s is shown in Figure 2a. Severe beach erosion occurs in the south of the island. Stone revetment and placement of reef balls in 2005 and 2007, respectively were the measures undertaken to address this problem.

a

b

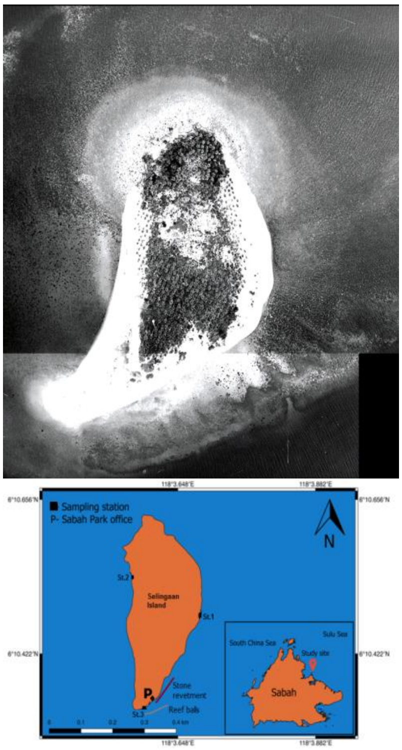


Figure 2 (a). Aerial photo of Selingan Island in 1970. **(b).** Location of Selingan Island and sampling stations.

Analysis of Selingan Island's satellite images

Shoreline changes in the Selingan Island were detected by analyzing the satellite images, beach profiling and field observation after the instalment of reef ball in 2007. The satellite images were obtained from Google Earth Pro from 2010 to 2016 at an interval of 2 years (Figure 3). The Coordinate Reference System (CRS) was changed to WGS 84 with the security code of EPSG:4326 to match the satellite images obtained from Google Earth Pro. This step was required to obtain constant scale and accurate coordinates for the maps. The shoreline of Selingan Island in each satellite images was traced and overlaid using QGIS software. The overlaid maps were then used to determine the change in the Island's shape and size.

Beach profiling

Sampling stations for beach profiling were detected by the GPS coordinates. Beach profile data recorded included transect orientation, time, height of auto level from the ground and width of the beach. Three sampling sites (St) were selected. St 1 and St 2 were located at the east and west side for the Selingan Island, respectively (Figure 2b). St. 3 was located at the south, next to the Sabah Parks Office. Field trip was carried out on 27 December 2017. The width of the beach was measured from the supratidal area (vegetation line) as a reference point to the low tidal area where the lowest water level was reached during low tide. The beach profiling data were arranged and plotted in the Microsoft Excel. The profiling data in 2017 were also compared with the previous study conducted on 18th February 2011 by the Sabah Parks and Universiti Malaysia Sabah (2014). The results of the beach profiling were used to characterize the shoreline changes based on the foreshore slope change.

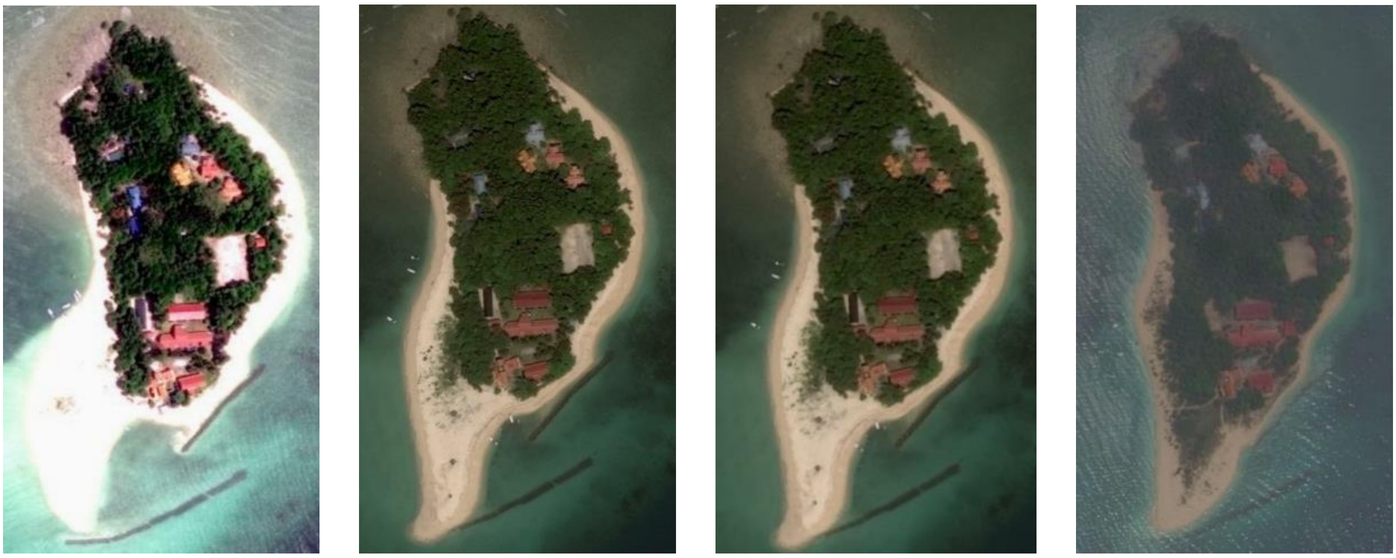
Field observations

Field observation and photographs of the shoreline were taken on 18th February 2011 and 27 December 2017. The selected photographs were compared and discussed to support the shoreline changes assessment of the Selingan Island.

Results

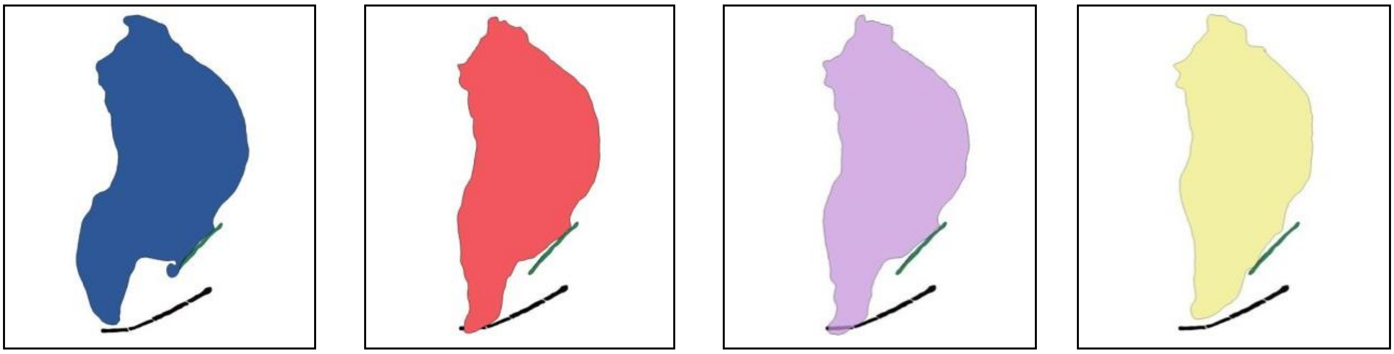
Based on the traced shorelines of Selingan Island from the satellite images the changes were evident. In 2010, the shape of the shoreline was slightly curved in the eastern side of the island but it changed to a nearly straight form in 2016 (Figure 4).

The southern tip of Selingan Island has inconsistent changes in shape (Figure 4). The sand at the south-west area of the Island was shifted towards the east where the Sabah Park office is located (Figure 2b). The southern tip of the island was also connected to the reef balls from 2012 to 2014, but there were no clear changes in the Island's shape. However, more sand was shifted towards the south west in 2016 and the Island was separated from the reef balls. The east and west mid-sides of the Island were further eroded (loss of beach sediment) while southern tip experienced sand deposition between the reef balls and stone revetment.



2010 **2012** **2014** **2016**

Figure 3. Satellite images of Selingan Island from 2010 to 2016 (Source: Google Earth Pro).



2010 **2012** **2014** **2016**

Figure 4. The shape of Selingan Island from 2010 to 2016.

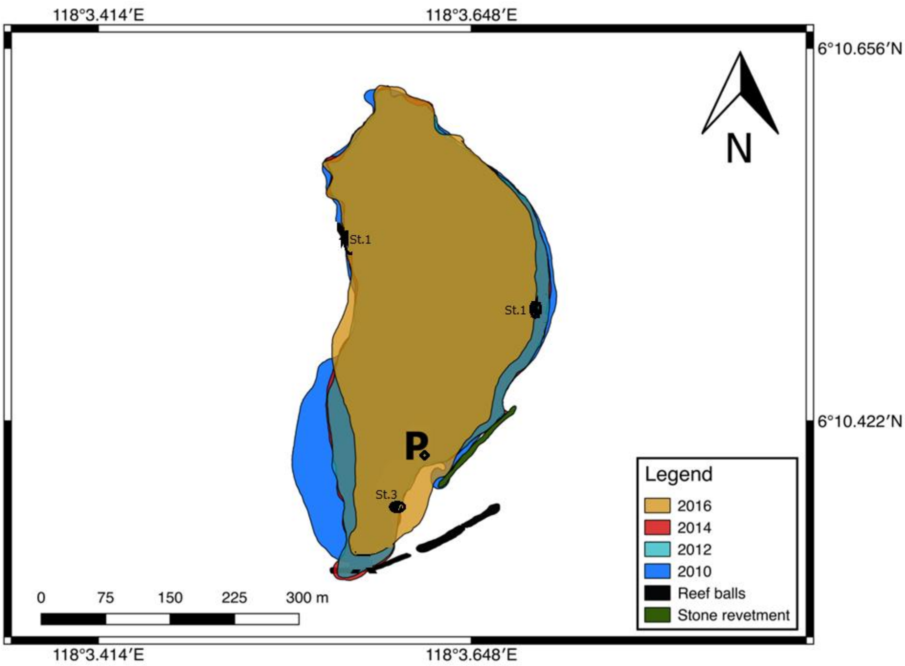


Figure 5. Overlaid satellite images of Selingan Island from 2010 to 2016.

Overlaid satellite images indicated that the shape of Selingan Island consistently varied both in its eastern and western sides (Figure 5). Little change occurred at the northern part of the Island as the shoreline consisted of rocky beach and the supratidal area was covered by vegetation. Small changes were not captured by the satellites as the shoreline was shaded by the vegetation. Most dynamic part of the Island was its south. There was sediment loss at the eastern side of the Island while the accumulated sand in the south was shifted to the southeast.

Selingan Island size decreased from 9.56 hectares to 8.95 hectares over a period of 2 years from 2010 to 2012. Detailed analysis of the satellite images indicated that the greatest decrease (~ 0.61 hectare) in the size occurred during 2010 to 2012 (Table 1). Selingan Island's size slightly increased to 9.00 hectares in 2014 but reduced again to 8.56 hectares in 2016.

Table 1. Shape and size of Selingan Island from 2010 to 2016.

Year	Size (Hectare)	Description of the island's shape and size
2010	9.56	The largest island size detected but shape of the southern end shifted towards its western side.
2012	8.95	Island's size decreased and the shape change shifted to the center. The Island is connected to the reef balls.
2014	9.00	Not much change of the Island's shape occurred but there was a slight increase compared to 2010.
2016	8.56	Island is detached from reef balls and the sand accumulated between the two shoreline protections.

Beach profiling

Beach profiles at St. 1 showed high beach elevation in 2017 compared to 2011, from the reference point to the low tide. However, there was no change in the width of the beach (~ 23 m) (Figure 6a). There was not much change at high tide (St 2) area but elevation was high in 2017 compared to 2011 at mid to low tides area (Figure 6b). Both beach profiles for St. 3 showed slight changes in elevation from 5 m to 10 m distances from the reference point (Figure 6c). Steep gradient was seen at 10 m in both years. The beach has a higher elevation in 2011 compared to the beach profile in 2017.

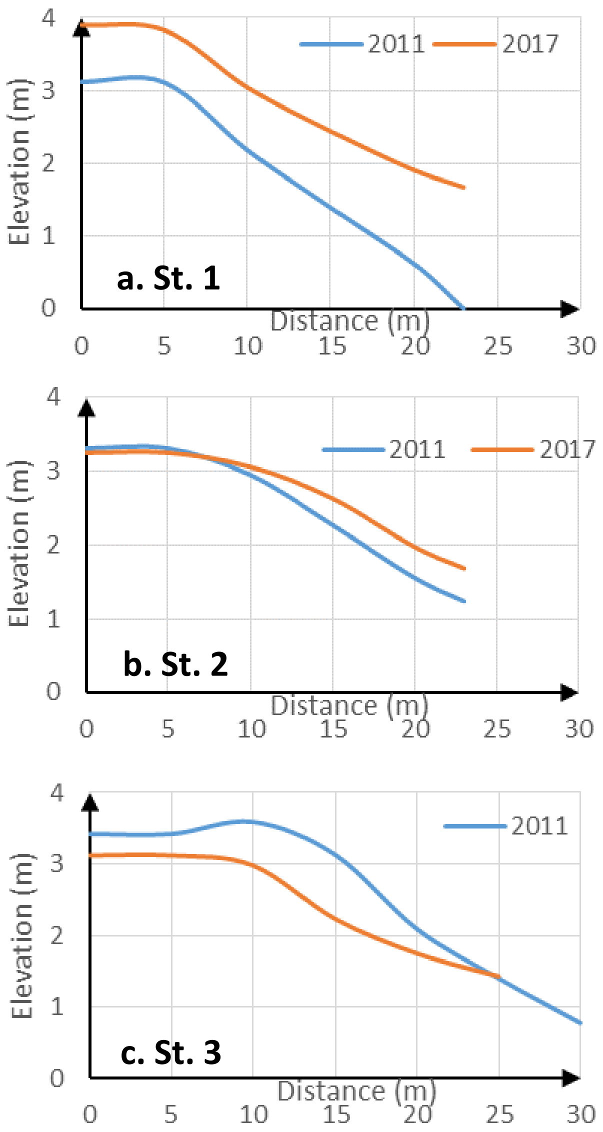


Figure 6. Comparison of beach profiles at three different stations (Stations 1, 2 and 3) in Selingan Island from 2011 and 2017.

Field observation of Selingan Island

A comparison of the field observations of the Selingan Island's shoreline in 2011 and 2017 (Figure 7) yielded interesting information. The sand accumulated at the southern end was seen to have shifted and covered part of the reef balls in 2011 (Figure 7a). The satellite images showed that reef balls were also connected to the Island between 2012 and 2014 (Figures 3-4). Part of the Sabah Parks office structures was damaged by strong waves in 2005 and can still be seen in 2011 (Figure 7b). There is also an accumulation of sand between the stone revetment and Island. Creeping vegetation and coconuts threes planted by the Sabah Parks staff were growing parallel to the stone revetments (Figure 7c). The vegetable looked healthy.

Photos were taken in 2011

a. Some reef balls were covered by sand.

b. Exposed beach and part of the Sabah Parks office. Some damage to the building by strong waves was noticeable.

c. Healthy vegetation and coconuts tree growing parallel to the stone revetments.

Photos were taken in 2017

d. All reef balls are exposed during low tide.

e. More trees and creeping vegetation surrounding the Sabah Parks office.

f. Turtle nesting activities have reduced the vegetation cover.

Figure 7. Field observations in 2011 (a-c) and 2017 (d-f).

All the reef balls covered by sand in 2011 were exposed in 2017 (Figure 7d). The sand in this area shifted further to the southeastern side between the reef balls and the Island. Sand was also deposited next to the Sabah Parks office (Figure 7e). Creeping vegetation was also growing on the sand with marking of turtle nesting activity. The sand next to the coconuts tree showed signs of turtle activities which caused reduction of the vegetation coverage (Figure 7f).

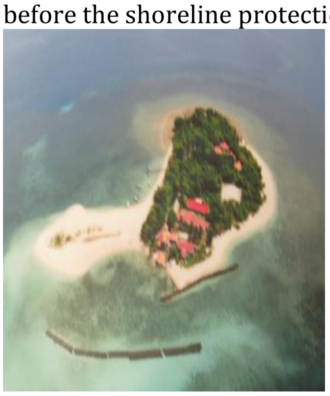
Discussion

Shoreline changes after the deployment of reef balls

There was not much shoreline change at the northern part of Selingan Island but the changes were notable on the southern part (Figure 5). This finding is similar to the observations made by Saleh et al. (2013). The Island Selingan appeared squeezed towards its middle and southern areas in 2016. The shorelines of both east and west sides of the Selingan Island were eroded and sediment tended to accumulate at its southern tip. Active beach changes have been seen on the eastern part of the island by the Sabah Parks staff. To overcome this problem, stone revetment was installed in 2005 but the formation of 'tombolo' in the south-west region of Selingan Island occurred and probably caused beach erosion on the southern part of the Island. Tombolo completely cut off the flow of the sediment to the south. This process resulted in the sediment transport outside the breakwater (Reef Ball Foundation, 2006). As a consequence, the Selingan Island area decreased one hectare from 2010 to 2016.

Before the shoreline protection measures were taken, the southern part of Selingan Island suffered from severe beach erosion and part of the Sabah Parks office building was damaged by strong waves (Figure 7b and Figure 8a) as explained earlier. Therefore, installation of reef balls as additional shoreline protection in 2007 was approved by the State Government (Figure 8b). The situation of the shoreline has improved over the years. There is no formation of tombolo on the eastern side of the Island and more sediments are deposited on the southern tip of Selingan in 2016 (Figure 8c). During the field observation in 2017, the upper part of this beach was covered by coastal vegetation (Figure 7e) and the area is used by the turtles as the nesting ground. This indicates that the reef balls have successfully increased the sand deposition processes in the south of the Selingan Island. The success of reef balls in shoreline protection as seen in Selingan Island has also been reported elsewhere (Iskander, 2010; Harris, 2006; Harris, 2007 and Arnouil, 2008).

a. Formation of spilt at the southern part of Selingan Island before the shoreline protection.



b. Two shorelines protection measures were taken to reduce beach erosion in 2006.

c. Spilt has disappeared and sand accumulated at the southern end between the shoreline protection and the Island.

Figure 8. Selingan Island before (a) and after (b-c) the shoreline protection measures.

The sand deposition process in Selingan Island may relate to the attenuation of waves and reduction of local current speed around it. The waves break up upon coming into contact with the reef balls and this reduces the wave energy as the water approaches the shore which in turn curtails the erosional influence of water strike (Harris, 2009). When waves hit the reef balls and enter into shallow water, the wave angles are refracted and tend to become parallel to the shoreline. According to Mead and Black (2002), the waters that travel across the shallow submerged breakwater are wide enough to reduce magnitude of longshore currents and wave transport which then reduce the erosion of an area. The presence of reef balls helps in stabilizing the coast by wave attenuation and wave refraction.

Changes in foreshore slope

The beach elevation at the east side of the Selingan Island (St. 1) is higher and created a steep profile in 2017 (Figure 6a). Based on the satellite images (Figure 5), the land area around St 1 decreased from 2011 to 2017. The beach profiling was conducted during the northeast monsoon period when the wind blows easterly or northeasterly, and this might result in moving the sediments from offshore and its deposition on the beach towards the eastern side of the island. The beach elevation in 2017 is higher and steeper but may reduce at the end of this season.

Seasonal monsoon promotes sand deposition at low tide area in St 2 (Figure 6b). During the field trip in 2011, it was also observed that around 80 units of reef balls from the west to the middle of these structures were covered with sand (Figure 7a). The performance of the reef balls in shoreline protection depends on the incoming wave energy. If the wave energy is low, reef balls might slow down the waves and allow sand to be deposited on these structured or nearby (Harris, 2001). This might explain the condition of the shoreline in 2012, 2014 and field observation in 2011.

The beach elevation in St 3 is higher in 2011 compared to 2017 (Figure 5c). This station had the steepest slope compared to the other two stations. Presence of large coral reef area in front of St 3 serves as a natural shoreline protection and is able to attenuate incoming wave energy and reduce the rate of erosion (Elliff and Silva, 2017 and Maza *et al*., 2016).

A high resolution of the satellite images will give better results of beach dynamics, more importantly the beach changes. Hydrodynamic assessment and identification of beach erosion factors and beach changes in Selingan Island are important for the management of the TIP. Type and shape of coastline are results of various processes such as wind, wave seasonal change, climate, erosion and accretion. Therefore, sizes and shapes of islands are not static but strongly influenced by coastal hydrodynamics since the islands are constantly surrounded by water.

Conclusion

The size and shape of Selingan Island as deduced from the satellite images varied from 2010 to 2016. The installation of reef balls as a measure for shoreline protection of Selingan has increased the sandy beach area at the southern tip of the island. The increment of the land size area at the southern tip is observable through overlaying of satellite images from 2010 to 2016. However, no clear increment of the island land area from 2010 to 2016 was seen on the western and southern sides due to continued beach erosion. The presence of the reef balls as shoreline protection has improved the beach condition at the southern part of the island. Preservation of TIP beaches is necessary for protection of turtle nesting sites.

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