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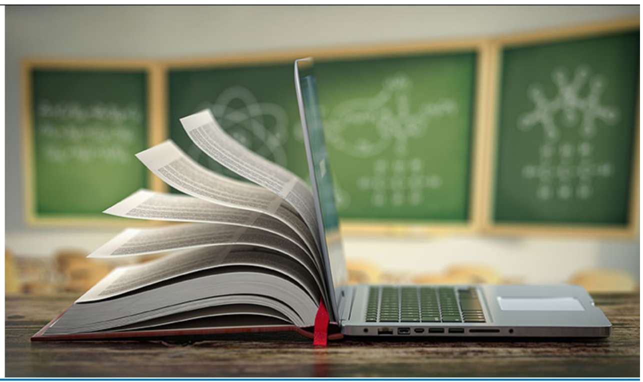

The effectiveness of breakwaters decreasing the peat shoreline change in Bengkalis Island

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Abstract. The preserve presence of peatland in Indonesia is not only endangered by direct anthropogenic force (e.g., peat fires, logging, land-use change, and canalisation). In the last three decades, coastal peat erosion upon northern Bengkalis Island threatens the peat ecosystem's subsistence. Climate change, rising global sea levels, and high tides across the Malacca strait are potential threats to the Island's existence. This paper will emphasise analysing the current coastal breakwaters' effectiveness and their effect on the shoreline change rates from 2014-2020. The result indicates that the compounding Mangrove and breakwaters conserved the coastal area and decreased erosion rates for the last five years in Bantan districts.

1. Introduction

The increasingly damaged and degraded peatlands due to peat swamp forest logging, canalisation, fires, and peatland conversion lead to significant carbon release, loss of biodiversity, and decreased quality of peat ecosystems [1]. The shoreline changes, the peat bog burst [2], and the hydro-climatological factors [3] should be considered the driving causes of peat abrasion and deterioration. Bengkalis Island is one of the largest archipelagic peat ecosystems in Riau Province, with extreme wave runoff that escalates the peat vulnerability with Malacca Strait as the direct border. Peat erosion in Bengkalis Island occurs on the north coast because the peatland on the north is lower than one in the south [4]. Bengkalis Island shoreline has been changing dynamically due to the very high coastal erosion rate [5].

Peat erosion is a natural occurrence due to water-wind transfer resulting in shoreline recession, and minor modification forced by individual actions can also accelerate peat depletion [6]. The peatland structures are generally prone to destructive currents, and waves contribute significantly to the eroded peat material and lowlands backlog in coastal areas. The shoreline changes in Bengkalis Island from 1998 to 2014 were 32.7 m/year, and the total land loss was 1,097.53 hectares. The shoreline changes rate multiplied drastically after 2004, palm oil land-use conversion from 2004 to 2013 corresponds to the high rate in the north-west section of the Island [5].

The natural conditions without protection installment worsen the peat loss and the most affected area is the settlement and communities. If the natural conditions without instalment worsen the peat depletion, coastal protection through the breakwaters or revetment is assigned priority-based [7]. The development of breakwaters has been spreading along with the coastal peat ecosystems in several locations on Bengkalis Island. In total, 73 kilometers of shoreline affected by erosion [8], only 10% have been protected by breakwaters or revetment. The combination of breakwaters and Mangroves can be utilised as the utmost protection from the wave and current and traps the sediments behind the structure [9]. The mangrove plantation can reduce the energy intensity from the waves [10]. Although mangroves cannot stop coastal erosion, mangroves' existence can decrease the rate of erosion and protect the coastal areas [11,12]. Other studies have shown that a combination of structural construction and Mangrove planting approaches has successfully reduced the rate of erosion [13].

2. Methodology

2.1 Study area

This research study area was located in Bengkalis Island, which peripheries directly to the Malacca Strait. This research was carried out on the northeast coast of the Island in Bantan Timur, Muntai, Muntai Barat, and Pambang Pesisir Village, Bantan District, Bengkalis Regency, Riau Province, shown in figure 1. The nearby northern coastal landscape is dreadfully vulnerable to erosion due to its offshore frontages and peat coastal. Bengkalis Island is one of the largest archipelagic peat ecosystems in Riau Province. It has a peatland shoreline that depths reach 10 meters with fibric-hemic peat maturation to hemic-sapric [4]. Peat thickness in Riau Province ranges from more than 10 meters, and it is estimated that there are 16.4 Gigatons of stored carbon or nearly half of Indonesia's total carbon [14]. Based on the history of human habitation on the island hundreds of years ago, peat swamp forests and mangroves on the east coast of Sumatra are well known for their harsh environments and avoided by most hunters or indigenous people [15]. Because the climate of tropical peat swamp forests is quite challenging to inhabit or for cultivation, these forest areas have indeed been left undisturbed, except for lesser native communities [16].

2.2 Data source

The historical shoreline position is generated from the shoreline delineation on SPOT and Sentinel satellite imagery from 2014 to 2020, as shown in table 1. The particular features, such as the lowest average water situation and the highest ordinary water situation, must be considered in the digitisation process [17]. For this reason, identifying the average position of water can be utilised by image stacking the short-wave infrared (SWIR) and green band. It facilitates identifying and distinguishing open water features, vegetation, and built areas associated with water bodies or other indices [18].

Table 1. List satellite data used for this study

Acquisition Date	Satellite Imagery	Resolution (m)
14/02/2014	SPOT 6	6
12/02/2017	Sentinel 2	10
31/01/2018	Sentinel 2	10
06/10/2019	SPOT 7	6
25/02/2020	Sentinel 2	10

Source: Data compilation, 2020

2.3 Shoreline Change

The shoreline changes acquaintance and appraisal have demonstrated an essential comprehension of coastal dynamics and morphodynamic change configuration [19]. By using Digital Shoreline Change (DSAS) within ArcGIS, the utilisation of historical trend analysis will embark on i) the historical configuration of shoreline position mapping over the period based on available aerial photographs or satellite imagery data, ii) the historical changes and pattern evaluation dependent on the specific transects, iii) the analysis of shoreline geometry, and iv) to foretell shoreline behavior patterns using a historical derivation change of rate [20]. The shoreline change rate processed by DSAS is dependable to shoreline position. To enhance the statistical reliableness of the rate of the change, the measurement, and an overall verification assessment must be conducted [21]. Shoreline position and geometry are the essential guides to estimate coastal regions change and peat volume loss. Digital Shoreline Analysis System (DSAS) calculates the End Point Rate (EPR) and Linear Regression Rate

(LRR). Both approaches statistically estimate the regression value and estimate the distance of movement or historical shoreline position. The EPR is determined by dividing the shoreline movement gap by the lapse of time among the last and recent shoreline, while LRR is defined by fitting a least-squares regression line to all shoreline points of a transect [19]. The advantage of using linear regression is that all data can have a change in trend or accuracy, computing-based, at ease to use, and statistical models tested [5].

3. Results and discussion

3.1 Identification of breakwaters

The breakwaters were inventoried first by using remotely sensed data from 2019 SPOT imagery. The field verification was conducted in December 2020. There was one breakwater in Bantan Timur; three breakwaters and 200 m long revetment in Muntai; two breakwaters in Muntai Barat; and four breakwaters and 700 m long revetment in Pambang Pesisir with breakage in several points. The breakwaters were built from 2015-2017 and financed by the national state budget fund. Whether for the revetments build in 2010 and 2014, the local government initiated the project as a trial project to test which coastal protection structure befit the whereabouts. The detailed list of breakwaters and revetment is shown in table 2.

Table 2. Breakwaters and revetment inventory.

Village	Breakwaters			Revetment		
	Code	Length (m)	Year installment	Code	Length (m)	Year installment
Bantan Timur	BA1	100	2016			
Muntai Barat	MB1	160	2017			
	MB2	200	2016			
Muntai	MT1	60	2016	MTR1	100	2014
	MT2	150	2016			
	MT3	145	2015			
Pambang Pesisir	PB1	200	2016	PBR1	700	2010
	PB2	100	2015			
	PB3	170	2016			
	PB4	100	2016			

3.2 Identification of shoreline change rate

The shoreline change rate was calculated using EPR and LRR method, counting shoreline datasets (2014, 2017, 2018, 2019, and 2020) with 405 transects and a 40-meter interval of 16.25 km in the northeast coast of the Bantan district. Figure 1 shows that the LRR shoreline change rate result shows that the positive value reflects accretion (deposition sediment) and negatively reflects erosion/abrasion accordingly. The average shoreline changes rate during 2014-2020 is -4.89 m/year (EPR) and -3.29 m/year (LRR). The mean of all erosional rates is -5.82 m/year (EPR) and -4.68 (LRR) m/year, with a maximum erosion value of 13.7 m. The surrounding area with erosion value increased significantly in Muntai Village is not protected with breakwaters and Mangrove plantation shown in figure 2.

Moreover, Muntai Village's area with breakwaters installment in 2016 and 2017 has the highest accretion value up to 16.17 m. The average of all accretional rates in the Bantan district is 5.55 m/year. Based on this finding, breakwaters' existence protects the coastal ecosystem from severe erosion and formed peat sediment deposition onshore due to the wave's movement, tides, and longshore current of the peat bog burst. The peat accretion phenomena will generate organic carbon transport through peat debris discouragement. It will affect the loss of biogeochemical near the coast and has long-term consequences of destroying the peat ecosystem, coastal and coral communities.

Figure 1. Rate of shoreline change using LRR method in Bantan District.

Figure 2. The highest erosion in Muntai Village.

3.3 Correlation of breakwaters and shoreline change

Refer to the coastal protection structure and the shoreline change in Muntai Barat village of Bantan district shown in figure 3. The area with and without breakwaters is observable. The severe erosion area indicates the red line, and the erosion rate is around 5-12.8 m/year. The public facilities, i.e., port, road, and Navy base in Muntai Barat, became protected and safer, while the area without breakwaters is rapidly shrinking and endangers the inhabitant's area. In 10 years onward, the settlement and main road in Muntai Barat village probably should be relocated far from the coastline area.

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Meanwhile, in Muntai village, the breakwater installment aims to protect the community rubber plantation, navigation tower, and the river downstream as the main channel for fisher seagoing vessels to anchor, load, and unload. The accretion area in MTR1 and MT3 environs shown in figure 4 detected erosion rate is the highest among other villages, with a shoreline change rate of 7.5-12.8 m/year. The strong waves and high tide in Malacca strait during the north monsoon season from November to March eroding the peatland ecosystem rigorously. The fisher community in Muntai Village also put an effort to stick the coconut trunks along the river estuary to protect the vessel leaning.

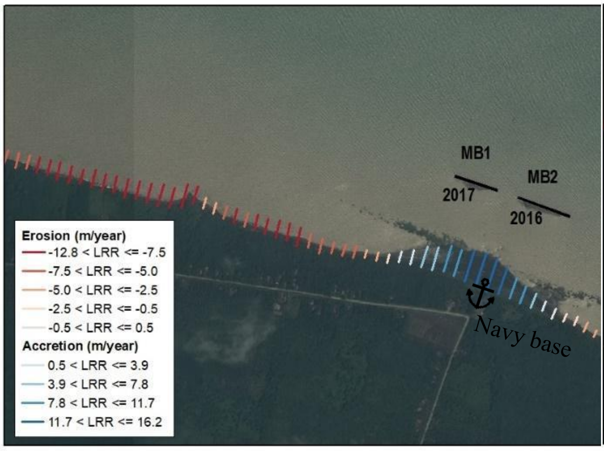

Figure 3. Rate of shoreline change Muntai Barat Village.

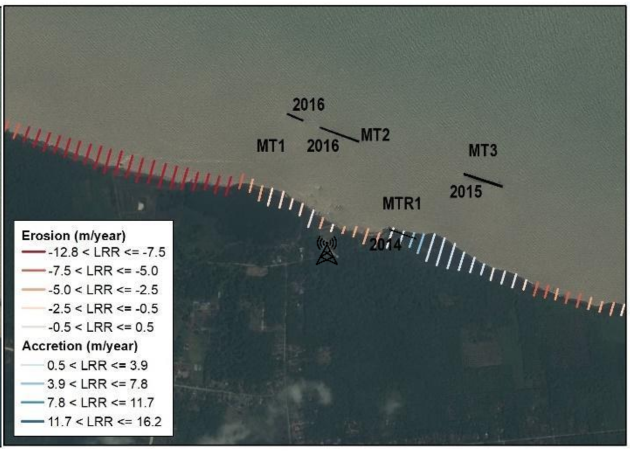

Figure 4. Rate of shoreline change Muntai Village.

For Pambang Pesisir village, as shown in figure 5, both revetment and breakwaters protect the settlements within 100 meters of the shoreline for about 1.5 km long with a total coastline of ± 4 km. Both revetment that was built in 2010 and the breakwater successfully decreased the erosion. The breakwater's installment formed the accretion zone, and the fisher could utilise the structure as their vessel's seaport. While in Bantan Timur, the erosion is at 0.5 m/year up to 5 m/year, categorised as moderate change rate as shown in figure 6. Bantan Timur coastline is protected with Mangrove plantation species *Avicennia alba* known as *api api hitam,* planted in 2008, an adaptive nature plant in the intertidal zone. This plantation shows potentially lessening coastal degradation by reducing the wave energy and height in Malacca Strait.

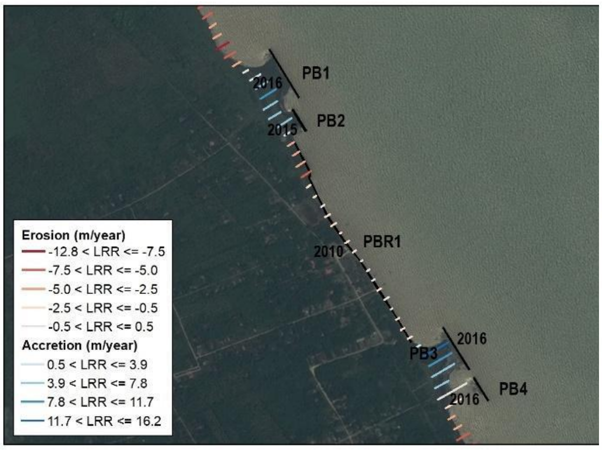

Figure 5. Rate of shoreline change Pambang Pesisir Village.

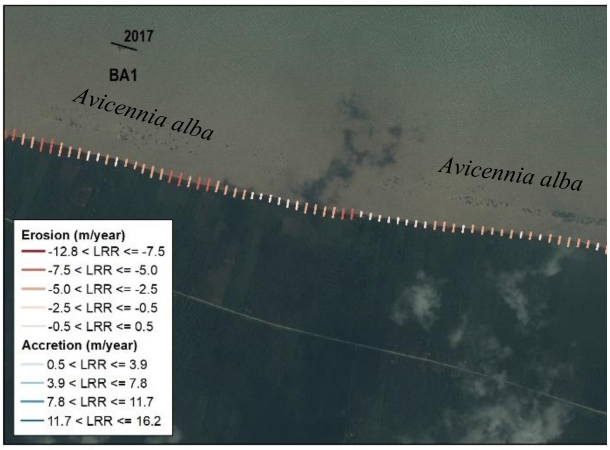

Figure 6. Rate of shoreline change Bantan Air Village.

4 Conclusion

The study results show that breakwaters preserve the coastal area significantly, decrease the erosion rate, and form peat sediment deposition. The shoreline changes rate in Bengkalis Island from 2014-2020 is 4.89 m/year based on the EPR method and 3.29 m/year for the LRR method. The Mangrove plantation (*Avicennia alba*) is an adaptive nature plant, and it shows potentially lowering the erosion rate by reducing the extreme wave energy during monsoon season in Malacca Strait. By implementing both interventions, the breakwaters and Mangrove planting, the way to suppress the peat erosion and depletion will continuously show the significant improvement in managing the sustainable peat coastal ecosystem.

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